MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MAY 2017

VOLUME 1

PROGRESS REPORT

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Montreal Protocol
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Foreword

The May 2017 TEAP Report

The May 2017 TEAP Report consists of four volumes:

***Volume 1**: Progress Report:*

- *TOC Progress Reports*
- *TEAP Essential Use Nominations Report May 2017*
- *Decision XXVIII/8 Report on issues related to the phase-out of HCFCs*
- *TEAP administrative issues and list of TEAP and TOC members at May 2017*
- *Matrix of Expertise*

***Volume 2**: May 2017 TEAP Critical Use Nominations Report*

***Volume 3**: Decision XXVIII/4 Task Force Report on Safety Standards Relevant for Low-GWP Alternatives*

***Volume 4**: Decision XXVIII/5 Task Force Report: Assessment of the Funding Requirement for the Replenishment of the Multilateral Fund for the Period 2018-2020*

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1 Introduction

This is volume 1 of 4 of the May 2017 TEAP Report and contains Progress Reports from the five Technical Options Committees (TOCs) composing the TEAP: the Flexible and Rigid Foams TOC (FTOC), the Halons TOC (HTOC), the Methyl Bromide TOC (MBTOC), the Medical and Chemicals TOC (MCTOC) and the Refrigeration and Air Conditioning and Heat Pumps TOC (RTOC).

Also included in this volume is an evaluation of Essential Use Nominations within MCTOC's Progress Report in Chapter 5. A response to Decision XXVIII/8 – *Phaseout of hydrofluorocarbons* is presented in Chapter 7 of this report with submissions by parties included in Annex 3 (pdf file separate to this report).

The TEAP and TOC membership lists, as at 31st May 2017, which includes each member's terms for re-appointment and a matrix of needed expertise on the TEAP and its TOCs appear in annexes at the end of this document. Specific issues relating to each TOC are also discussed in Chapter 8 and in the annexes.

1.1. Key TEAP messages

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

1.1.1. FTOC

In non-A5 parties, fluorinated gas regulations now indicate precise dates for the phase-out of certain high global warming potential (GWP) hydrofluorocarbons (HFCs) in foam manufacture.

Article 5 parties face common challenges in phasing out remaining HCFCs while phasing down high-GWP HFC blowing agents.

High-GWP HFCs and hyrdrofluoro-olefins/hydrochlorofluoro-olefins (HFOs/HCFOs) are currently around 3 times as expensive as HCFCs. HFO/HCFO blown foams remain more expensive than high-GWP HFC foams due to the pricing of the blowing agent and required additives.

Decisions on transition may be delayed because the final formulations to optimise performance and cost are still not clear for all applications and geographies, and because of the currently limited availability of some lowGWP blowing agents in some regions. Effective transitions will require continued communication between regulators, producers and users to facilitate capacity planning.

1.1.2. HTOC

The Decision XXVI/7 *Availability of recovered, recycled or reclaimed halons* working group conclusion remains that it is nearly indisputable that the world's supply of halon 1301 will be exhausted well before civil aviation completes the transition to an alternative. Also given the lack of further progress by civil aviation to implement alternatives in the remaining halon 1301 applications, it becomes imperative to quantify more accurately the rate of increase of installed amounts and the resulting emissions from civil aviation.

While the Decision XXVI/7 working group estimated this shortage to be in the 2035 timeframe, there are many unknowns that could change this date significantly, such as the rate of implementation of alternatives, the increase of installed amounts of halon as the global aircraft fleet increases, and the emissions from civil aviation.

Therefore, the parties may wish to consider continuing their efforts to work with the International Civil Aviation Organization (ICAO), and to request ICAO form a working group or similar body in conjunction with the HTOC to better estimate current and future civil aviation installed base and emissions and report back at the 31st Meeting of the Parties.

At the ICAO 39th Assembly in October 2016, Resolution 39-13 was approved that sets a date for the replacement of halons in the cargo compartments of newly designed aircraft in the 2024 timeframe. Owing to a delay in the commercialisation of 2-bromo-3,3,3-trifluoropropene (2-BTP) as an agent for use in hand-held extinguishers, an amendment was approved to Annex 6 of the Chicago Convention delaying the requirement for halon replacement in hand-held extinguishers on new production aircraft until 31 December 2018.

A low-GWP chemical being commercialised for solvent, foam-blowing and refrigerant applications, HCFO-1233zd(E), was submitted by the manufacturer and has received US Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) program listing as acceptable for fire protection in total flooding applications in 2016. However, the manufacturer has subsequently decided not to proceed further with its listing as a total flooding agent in the International Organization for Standardisation (ISO) and the National Fire Protection Association standards, which would have been required prior to its use in this application in countries (e.g., Australia, EU, South Africa, US, etc.) that adopt such standards.

1.1.3. MBTOC

Article 7 data indicate that 99% of controlled uses have been phased out, and Critical Use Nomination (CUN) amounts of MB requested in 2017 have decreased to about 300 tonnes. However, MBTOC has identified a discrepancy of around 15,000 tonnes between top-down and bottom-up comparisons of emissions and production/consumption. Parties may wish to consider investigating this apparent discrepancy.

Some parties have expressed concerns over difficulties in interpreting the categories of MB uses between controlled and exempt uses. Parties may wish to consider requesting MBTOC to provide clear examples of the allocation of MB between controlled and exempt uses under the provisions of the Montreal Protocol. Subsequently parties may wish to consider providing assistance.

MBTOC is concerned that the official reporting of stocks under the present Decisions is only a requirement for those parties that submit CUNs and thus an unknown amount of stocks may be held and/or used by parties who do not submit a CUN. MBTOC is further concerned that the continuous granting of exemptions over many years for strawberry runners may, in and of itself, become a potential barrier for the adoption of technically and economically feasible alternatives.

Nearly all the MB used for quarantine and pre-shipment (QPS) is emitted to the atmosphere as recapture systems are either impractical or not being used. This is offsetting the benefit gained by the phasing out of controlled uses. Parties may wish to consider controlling the use of MB for those uses of QPS for which proven alternatives are available.

1.1.4. MCTOC

The global transition away from chlorofluorocarbon (CFC) metered dose inhalers (MDIs) is almost completed.

Based on the information reported by parties on the use of controlled substances under exemptions as process agents, parties may wish to consider changes to Tables A and B of Decision XXII/7, and that additional information be provided by parties.

In 2015, total production of ODS for feedstock uses was 1,084,101 tonnes, representing a total of 375,488 ODP tonnes. The range of ODS emissions from feedstock uses is estimated as 5,421 to 21,682 tonnes, or 1,877 to 7,510 ODP tonnes for 2015.

Parties may wish to consider providing MCTOC with production data for *n*-propyl bromide in order that global production quantities could be collated and reported.

There is a wide range of alternatives available for methyl bromide when used as a methylating agent, and an insignificant volume of methyl bromide used in this and other laboratory and analytical applications. TEAP plans to report further on this topic if and when parties make available new and different information.

Parties may wish to consider nominating experts to MCTOC, in particular for destruction technologies and laboratory and analytical uses. In addition, parties may wish to consider providing any relevant new information on destruction technologies.

1.1.5. RTOC

Research and development to improve the performance of refrigeration and air conditioning (RAC) equipment containing low-GWP and zero-ozone depletion potential (ODP) refrigerants continues to make strong progress.

The charge limit of flammable refrigerants in the US has increased from 57 to 150 g. Use of HC-600a for new domestic appliances continues to grow.

Transcritical carbon dioxide (CO_2) systems using technical improvements such as ejector, sub-cooling and parallel compression have started to be installed in supermarkets to increase energy efficiency.

The production of HFC-32 air-to-air conditioners continues in Japan, Southeast Asia and Australia and is beginning in Europe. In India, production of HC-290 split air conditioners continues, and in China production lines are being converted to HC-290.

HFO-1234yf has been identified as main HFC-134a replacement for mobile air conditioning systems. R-744 is also an alternative, which is under evaluation for heat pumps on pure electric vehicles.

Considering not-in-kind (NIK) technologies, units using magnetocaloric refrigeration are in beta testing at three sites.

2 Flexible and Rigid Foams TOC (FTOC) Progress Report

Executive Summary

Total global production of polymeric foams continues to grow by 4.1 % per year, from an estimated 22.9 million tonnes in 2015 to 28.0 million tonnes by 2020. Production of foams used for insulation is expected to grow in line with global construction and continued development of refrigerated food processing, transportation and storage (cold chain).

Article 5 parties face common challenges in phasing out HCFC and phasing down high-GWP HFC blowing agents.

- In general, HCFCs are ~30% of the cost of high-GWP HFCs and HFO/HCFOs. HFO/HCFO blown foams remains more expensive than HFC foams due to the pricing of the blowing agent and required additives.
- The timing of regulations for HFCs in non-A5 parties is enabling the planning of HFO/HCFO manufacturing capacity to meet demand. Many A5 parties will need small quantities of HFOs/HCFOs, so coordination could be helpful to manage capacity and ensure that supply will be available for transitions.
- There are high initial investment costs to address safety concerns for the use of hydrocarbons by many Small and Medium Enterprises (SMEs).
- In some A5 parties, import of HCFC-141b itself is restricted or under license, but polyols containing HCFC-141b can be imported without restriction. Some A5 parties are contemplating regulations that would ban or restrict import of HCFC-containing polyol systems.
- Transition decisions may be delayed for some foam applications, while formulations that optimise performance and cost are developed, and because of the currently limited availability of some low GWP blowing agents in some regions.

Capacity planning for alternatives will require continued communication between regulators, producers and users to ensure smooth transitions.

The FTOC had a successful meeting in Manchester UK on March 1-3 2017, attended by 17 members, including new co-chair Paulo Altoe.

2.1. Global drivers of foam production

The global production of major types of polymeric foams produced using a blowing agent is estimated to grow by 22 % between 2015 and 2020. The majority of flexible polyurethane foam uses water and carbon dioxide as blowing agents, along with some limited use of methylene chloride. Rigid polyurethane, EPS, XPS, and other types of foam use a variety of blowing agents including; HCFCs, HFCs, HFO/HCFOs, water, DME, ethanol, carbon dioxide, methyl formate, and hydrocarbons. These foam types are used in construction and throughout the cold chain in hot and cold climates. They substantially reduce energy consumption and carbon dioxide emissions due to their thermal insulation properties.

Table 2.1 Estimated global polymer foam production

	2015	**2020**	**Compound Annual Growth Rate**
Polyurethane	Tonnes	Tonnes	
Rigid	5,836,000	7,322,230	4.6%
Flexible	5,865,670	7,101,070	3.9%
Total PU Foam Production	**11,701,670**	**14,423,300**	**4.3%**
Polystyrene			
EPS	8,151,000	10,050,000	4.3%
XPS	1,750,000	1,950,000	2.2%
Total PS Foam Production	**9,901,000**	**12,000,000**	**3.9%**
Others			
Phenolics,Polyolefins, EVA, ENR			
Total Others	1,366,200	1,600,000	3.2%
Total Foams	**22,968,870**	**28,023,300**	**4.1%**
Source: IAL Consultants & Smithers RAPRA, LRM, and various market reports			

2.2. Regulations and codes

For Article 5 (A5) parties, market and regulatory pressure continue for foam producers to transition to zero-ODP blowing agents. In some countries, use of HCFCs is limited to applications where hydrocarbons are not suitable, such as spray foam. In others, HCFCs are still widely used. Globally, the controlled availability and the increasing price of HCFCs may drive faster transition.

HCFC transition and Kigali Amendment

The FTOC has discussed and will monitor the interaction of the Kigali Amendment with the HCFC-141b phase out. There are a number of variables, which may influence the rate of transition out of HCFC-141b into low-GWP and zero-ODP blowing agents directly, or as a second conversion via high-GWP HFCs. These variables include: the cost and availability of HFOs and the cost and availability of high GWP HFCs (e.g., HFC-245fa, HFC-365mfc/HFC-227ea).

Under HCFC Phase-out Management Plans (HPMPs), projects that transition from HCFC-141b used in polyurethane foam to low-GWP alternatives have been funded and many have been completed or are in progress. However, unfunded companies (e.g., companies that were established after September 2007, multi-national companies and companies in unfunded countries) operating in Article 5 countries may convert from HCFCs to high-GWP HFCs to meet HCFC phase-out deadlines rather than converting directly to low-GWP alternatives.

Article 5 parties face common challenges in phasing out HCFC and phasing down high GWP HFC blowing agents. In general, HCFCs are currently ~30% of the cost of high-GWP HFCs. HFO and HCFO blown foams may be slightly more costly than HFC foams due to pricing of the blowing agent and additives needed. Transition decisions may be delayed for some foam applications while formulations that optimise performance and cost are developed, and because of limited availability of low-GWP blowing agents in some regions.

Some Southeast Asian countries with funded HPMPs have proposed to establish or amend regulations to phase out HCFC-141b in polyurethane foam through a quota system, with a permit for the import of bulk HCFC-141b. Additional regulations under consideration in these countries include a restriction on the import of HCFCs and polyols containing HCFC-141b after conversion projects are completed and a prohibition of the expansion of existing HCFC-based manufacturing capacities or building new facilities. HCFC-141b in spray foam is still allowed because of technical concerns about replacement products.

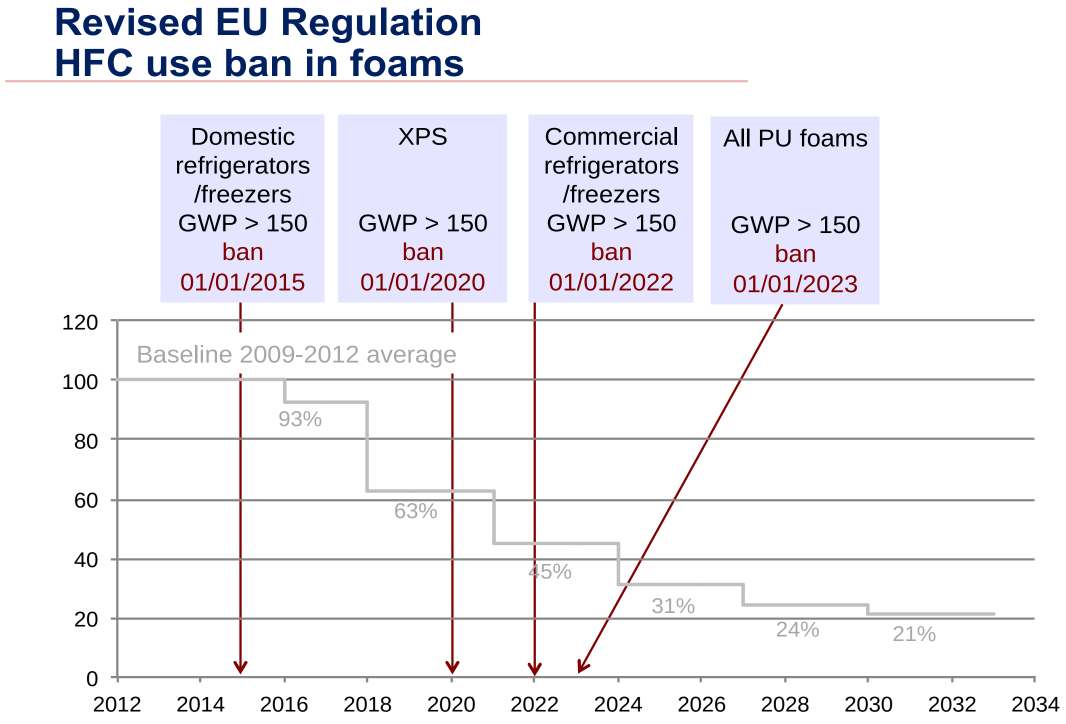
In China, the new national fire code standard GB50016 came into force in May 2015 and has changed the landscape for insulation materials in the construction sector. The extremely stringent fire performance criteria set out in the standard limits the use of organic foam materials such as rigid polyurethane and polystyrene foams in thermal insulation. This may make it more difficult to achieve China's energy efficiency goals.

In India, labelling of pre-blended polyols and insulation boards containing HFCs has been required as of 1 January 2015 and "included in descriptions used for advertising" of finished goods. In addition, there is an annual reporting obligation on manufacturers of pre-blended polyol containing HFCs (covering imports and exports).

In the **US**, the SNAP program implemented by the EPA has made significant changes in the list of acceptable foam blowing agents. The SNAP program lists alternatives to ozone-depleting substances (ODS) as acceptable or unacceptable, depending on the comparative overall health and environmental impacts of available alternatives. In 2015 and 2016, the EPA SNAP program published two new regulations changing the status from acceptable to unacceptable for HFC-134a, HFC-245fa and HFC-365mfc and other higher GWP HFCs for use in polyurethane, phenolic, polypropylene and polystyrene foams between 2017 and 2021. There are extended timelines in both rules for military, space and aeronautics related applications. The 2016 rule also includes a change of status to unacceptable for methylene chloride for use in flexible foams, integral skins, and polyolefins. Finally, a provision was added in the 2016 rule prohibiting the use of closed cell foam products and products that contain closed cell foam manufactured with an unacceptable foam blowing agent: 1) one year after publication of final rule, or 2) the date when the foam blowing agent is unacceptable

In the **European Union (EU) or European Economic Area (EEA),** high-GWP fluorinated gases are being phased down, according to F-gas regulations. In 2015, all HFCs with GWP greater than 150 were banned for foam use in domestic appliances. Labelling is obligatory on foams and polyol-blends, and the presence of HFC has to be mentioned in the technical documentation and marketing brochures for spray polyurethane foams (SPF) used in building insulation, refrigerated containers and trucks. By 1 January 2023 all HFCs with GWP greater than 150 will cease being used in all foam manufacturing **(See Fig2.1).**

Fig. 2.1. HFC phase down according to F-Gas Regulations in EEA



The F-Gas Regulation operates on the supply side through a quota system, which will likely mean that supply of blowing agents to the foam sector could become restricted well before the phase-out dates noted above. This is especially likely because the bulk of the demand is in the RAC sector. A recent European Partnership for Energy and the Environment Study (presented at a side event at MOP-27) indicated that the RAC sector will have difficulty in meeting its phase-down targets, leading to an inevitable increase in price as demand exceeds supply.

In Japan, a voluntary target on HFC phase down program was set based on “the Act on Rational Use and Proper Management of Fluorocarbons”, put in force in April 2015. HFCs must be replaced with low-GWP blowing agents in 2020 for polyurethane spray foam used in residential buildings. As the result of its ratification of the Paris Agreement, Japan requires additional voluntary targets on HFC phase out program for all applications of rigid polyurethane foam. HCFOs have been used commercially for various rigid foam applications since mid-2015.

In **Canada**, regulations have been proposed that will require the elimination of the use of high-GWP blowing agents in Canada. It seems that **Australia** will implement an overall phase-down of HFCs rather than taking a sector-specific approach.

Regulations impacting extruded polystyrene

Regulations affecting the use of blowing agents in extruded polystyrene (XPS) will drive the point of sale replacement of HFC-134a foams by low GWP alternatives in the EU (1 January 2020) and the US (1 January 2021). Manufacturing conversion will have to be completed in early 2019 to remove higher GWP HFCs from the supply chain in Europe. HFO-1234ze (E) is only available from a single supplier, and may have significantly higher costs when used as a direct replacement for HFC-134a. Blends are being tested and have been commercialized by some companies as a lower cost option with similar performance characteristics compared to foams containing HFC-134a.

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

Some A5 XPS producers have already converted to zero ODP alternatives. Other A5 XPS producers continue testing zero-ODP alternatives and/or low GWP alternatives to prepare for transition away from HCFCs. In China HCFC-142b/22 blends are still used because of price and availability. These could transition directly to low GWP alternatives, including HFC-152a, CO_2, hydrocarbons (HCs), dimethyl ether (DME), alcohols etc. However, building codes for fire protection will limit HCs as an alternative. Even though HFC-134a has low solubility in foam systems, it is often used as the main blowing agent in XPS foams to achieve lower thermal conductivity. It is used in blends with the aforementioned alternatives to better balance XPS foam performance. HFO/HCFO’s are being evaluated either individually or in blends as a replacement for HFC-134a.

2.3. Status of blowing agents in current use

In some Article 5 parties, HCFC-141b is still a widely used blowing agent for rigid foams. In some cases, import of HCFC-141b itself is restricted or under license, but polyols containing HCFC-141b can be imported without restriction, creating a difficulty for verification of HPMP compliance. Some countries are contemplating regulations that would prevent the import of polyol systems containing HCFCs, transition away from HCFCs is occurring, and it may be possible for some remaining foam manufacturers to transition directly to a low-GWP alternative.

In India and many parts of Asia, SMEs form the largest number of HCFC-141b consumers, and HFO/HCFOs may be the best technical option for phase-out of HCFCs because they are non-flammable, but they are more expensive than HCFCs and HFCs in many cases. Demonstration projects are needed to develop methods to reduce loading and costs, and there may be a delay in transition until these are completed.

HCFC-142b in combination with HCFC-22 is predominant in XPS production in thousands of small and medium-sized enterprises (SMEs) in Asian countries. China has proposed a direct phase out of HCFCs to CO_2 based formulations. There are technical difficulties associated with the implementation of this technology including poor processability of these formulations, limited machine design, and the inherent challenge of using high levels of external recycle content from multiple different sources. The implementation of this technology will be a significant challenge for such a diverse installed base within the phase down deadlines.

High-GWP HFCs (e.g. HFC-134a) are still widely used in non-A5 parties, mainly for production of extruded polystyrene and specific PU products such as PU Spray Foam. HFC-134a is often blended with HFC-152a to enhance product properties as an alternative to HCFC-142b/HCFC-22 blends. HFC-152a enhances physical characteristics foams and has high solubility in XPS foam, enabling the molecules to diffuse out of the foam matrix very quickly. HFC-134a has lower solubility in XPS foams and a lower diffusion rate, which means that it provides consistent, long-term thermal performance. Finding an economically viable alternative to HFC-134a for use in polystyrene foam remains a challenge. HFCs are due to be phased out in many non-A5 parties by 2022. In addition, producers in non-A5 parties may need to transition to these chemicals, or to blends containing these chemicals, in order to meet HCFC phase-out targets.

HCs are one of the most widely used blowing agents for a number of types of insulating foams globally and will continue to be a major replacement for HCFCs in the future. Large and medium-sized foam producers, in many countries worldwide, have installed safety equipment and are consequently able to safely handle flammable materials. In some countries and regions, local regulations limit the use of hydrocarbons or require additional safety and emission abatement equipment both because they are flammable, and are also volatile organic compounds with the potential to create ground level ozone or smog. Currently, pentanes are considered to offer a low variable cost alternative to HFCs and HCFCs in polyurethane foams. However, converting SMEs (often located in urban areas) over to HCs, will require additional capital costs for safety equipment and training

Methyl formate use as a low-GWP blowing agent is slowly increasing around the world in pour-in-place applications (such as discontinuous panels and commercial refrigeration). It has been noted that methyl formate has been used in integral skin and spray foam in some A5 parties. A project is ongoing in Mexico evaluating methyl formate and methyl formate blends for spray foam and analysing flammability of pre-blended polyols containing methyl formate.

Depending on its concentration in blends with polyol and or isocyanate, appropriate precautions should be taken during transportation, handling and processing to address potential flammability issues of methyl formate or systems containing high levels of methyl formate. As with all chemicals, compatibility of metals, plastics and other materials should be considered when selecting processing equipment that will be in contact with methyl formate.

CO_2 (Water) blown foam is a feasible option for applications where insulation requirements per thickness unit are less critical. Examples include some spray foams, pipe insulation and water heater insulation.

CO_2 is used as a blowing agent in the manufacture of some grades of extruded polystyrene either neat or blended with other blowing agents. It is also used in the production of flexible polyurethane foams used for comfort applications in furniture, bedding and automotive seating.

HFOs/HCFOs provide an alternative to HCs, which can eliminate the flammability issue in polyurethane foam production and therefore, the capital investment required to address safety when using HCs as a blowing agent. The transition to HFOs/HCFOs amongst PU foam SMEs is currently slowed by both their greater expense and limited supply of some HFO/HCFOs in A5 parties. Strategies are being developed to lower the cost by using less HFO/HCFOs in blends.

Manufacturers of HFO/HCFOs, have current capacity and have also announced plans to increase manufacturing capacity to meet the demand for low GWP blowing agents that is expected to result from the implementation of low GWP regulations. A new HFO/HCFO plant costs approximately US $100-200 million and can take 18 months to several years to achieve business planning consent, construct and reach full production rates.

The timing of regulations for HFCs in non-A5 parties has enabled the planning of HFO/HCFO manufacturing capacity to meet demand. Many A5 parties will need small quantities of HFOs/HCFOs, so coordination could be helpful to manage capacity and ensure that adequate supply will be available for transitions.

The demand for HFOs/HCFOs will be influenced by the formulations that are developed. Significant work is ongoing by system houses to reduce HFO/HCFO loading in final foam products. Optimized foam formulations using HFO/HCFOs or blends of HFO/HCFOs with other blowing agents (such as HC and methyl formate) will require product approval and qualification/certification testing, not only for the blowing agent itself, but also for the foam products where the blowing agent is used. This foam formulation development, qualification and gaining of code approvals can take also from 18 months to several years, but is often done in parallel with the construction of the HFO/HCFO manufacturing facility using product from existing facilities.

Another aspect of the change to HFO/HCFOs, is the continuing development by additive suppliers of catalysts and surfactants which help optimize various performance parameters of HFO/HCFOs, such as thermal and mechanical properties and shelf stability of polyol blends.

DME, ethanol and butanes are used in extruded polystyrene. DME is also used in some one-component polyurethane foams that are dispensed from an aerosol can.

Methylene chloride is still used as a blowing agent in the production of flexible foams in A5 Parties. The US EPA’s SNAP program has changed the status of methylene chloride to “unacceptable” for use in foams, although foam produced from methylene chloride in A5 Parties can be exported to the US provided the foam is open-celled.

Methylal is used as a co-blowing agent in low-resistance, high-density (“memory”) foams and in very low concentrations in combination with water in rigid foams. Flammability of the polyol blend is a limiting factor when used as a sole blowing agent.

Trans-1,2 dichloroethylene (1,2-DCE) is also used as a co-blowing agent with HFCs and is approved for use in the US and Europe. Flammability of the polyol blend is a limiting factor when used as a sole blowing agent.

In the PU hydrocarbon-blown sector, FTOC had previously become aware of two Perfluorocarbon foam additives **(FA-188 and PF-5056**), both from the same manufacturer), which are being used to optimise cell formation in order to gain maximum thermal performance. FA-188 is a perfluorinated olefin, which is used in very small quantities and has a GWP of only around 100, but there are concerns about its potential breakdown products, which currently remain uncertain. PF-5056 has high GWP. FTOC plans to continue to investigate these and other new additives for their potential environmental, health and safety impact in order to ensure that Parties are appropriately informed. At present, the FTOC is working with the Science Assessment Panel to agree on next steps.

2.4. Conclusion

The foam industry is working to provide suitable polyols and foam blowing agents that optimise costs and performance parameters determined by national and regional agencies concerned with improving energy efficiency. Capacity planning for alternatives will require continued communication between regulators, producers and users to ensure smooth transitions.

3 Halons TOC (HTOC) Progress Report

The HTOC met from the 5th to 7th April, 2017 in Seoul, South Korea. Attending members were from Australia, Brazil, Canada, France, India, Kuwait, Japan, Russia, South Korea, Sweden, the United Kingdom, and the United States of America.

Executive Summary

The parties may wish to consider continuing to work with the ICAO by requesting ICAO to form a working group or similar body in conjunction with the HTOC to better estimate current and future civil aviation installed base and emissions and to report back at the 31st Meeting of the Parties. This is based on the following:

1. The conclusion of the Decision XXVI/7 *Availability of recovered, recycled or reclaimed halons* working group that it remains nearly indisputable that the world's supply of halon 1301 will be exhausted (currently estimated to be in the 2035 timeframe) well before civil aviation completes the transition to an alternative.
2. While the Decision XXVI/7 working group estimated this shortage to be in the 2035 timeframe, there are many unknowns that could change this date significantly, such as the rate of implementation of alternatives, the increase of installed amounts of halon as the global aircraft fleet increases, and the emissions from civil aviation.

3.1. New agents in development

There are now three potential new agents reported in various stages of development in the US and four in the Russian Federation for the halon sector. It has not been reported whether these are intended as total flooding or streaming agents.

A low-GWP chemical being commercialised for solvent, foam-blowing and refrigerant applications, HCFO-1233zd(E), was submitted by the manufacturer and has been listed acceptable by EPA's SNAP program for fire protection in total flooding applications in 2016. However, the manufacturer has subsequently decided not to proceed further with its listing as a total flooding agent in the ISO and the NFPA standards which would have been required prior to its use in this application in countries (e.g., South Africa, Australia, EU, US, etc.) that adopt such standards.

3.2. Military

In general, available information indicates militaries from non-A5 parties continue to manage their usage of halons responsibly and have begun to consider the issues related to the long-term availability of HFCs. Many militaries have adopted HFCs as halon replacements and low-level research regarding HFC replacement agents is being conducted to assess the feasibility of emerging low GWP candidate extinguishing agents for a range of vehicle and aviation applications.

In contrast, available information suggests that the militaries of some A5 parties do not appear to be managing their halons well:

1) There has been a high turnover of people involved in halon phaseout over the past 10 years and owing to lost knowledge there is a need for reviews of the history and state of affairs in the halon phaseout,
2) Many A5 military and (other affected A5 users) are unaware and thus unprepared for any possible future halon shortages and unfamiliar with alternative protection options

3) Many A5 militaries/users have a need to be well informed on the alternatives with high atmospheric lifetimes and global warming (*and issues surrounding them*) to make the optimum decisions on use and management – due to misunderstandings some countries have begun discussions on mandatory removal of alternatives already in use.

Parties may wish to consider providing workshops to address these issues.

The U.S. Army hosted a 2-day military fire protection workshop in May 2017 with other military services, industry, academia, and Allied military partners to exchange information regarding issues of mutual concern. Parties may wish to consider encouraging their militaries to participate in future collaborations such as this.

3.3. Civil aviation update

3.3.1. International Civil Aviation Organization (ICAO)

At the ICAO 39th Assembly in October 2016, Resolution 39-13 was approved that sets a date for the replacement of halons in the cargo compartments of newly designed aircraft in the 2024 timeframe.

Owing to a delay in the commercialisation of 2-BTP as an agent for use in hand-held extinguishers, an amendment was approved to Annex 6 of the Chicago Convention delaying the requirement for halon replacement in hand-held extinguishers on new production aircraft until 31 December 2018. This change was implemented even though several countries had already adopted the earlier date (2016) in their national regulations.

3.3.2. Aircraft engine nacelle protection

Although ICAO has set 2014 as the date after which new design aircraft will need to use a halon alternative in engine nacelle and auxiliary power unit (APU) fire protection, there isno approved design available as of now. This is in spite of the fact that HFC-125 has been proven and installed for this purpose in military aviation for many years. Civil aviation appears to continue to be reluctant to switch over to high-GWP agents in this application.

The Halon Alternatives for Aircraft Propulsion Systems (HAAPS) consortium continue its efforts to develop a single, common alternative to halon 1301 for engines/APUs in aircraft and is still developing a joint collaboration agreement so that work on research and development can commence.

3.3.3. Portable extinguishers

The agent 2-BTP has received EPA’s SNAP listing, and is in the process of being commercialised for use in civil aviation.

The European Aviation Safety Agency (EASA) is proceeding with rulemaking task RMT.0560 “Halon: Update of Part-26 to comply with ICAO Standards”. The proposed rule is setting dates from which in-production “large” aircraft (aeroplanes and rotorcraft) shall not use halon as an extinguishing agent in lavatories and portable fire extinguishers. The final rule should be published by the EC prior to the end of 2017.

3.3.4. Cargo compartments

The current EU requirement for use of halon alternatives in cargo bays of new designs, remains in 2018 in lieu of the ICAO adopted date of 2024. Two companies are working on halon-free cargo compartment fire protection systems, one using water mist and inert gas, the other using inert gas alone.

3.4. Global supplies and banking

The demand for halon 1211 has decreased over the past few years. The current usage demand is being satisfied by decommissioning and reclamation. Some banks are no longer adding additional halon 1211 to their banking inventory.

The current demand for halon 1301 usage and banking is being satisfied to date through decommissioning of systems and reclamation. Additional sourcing of halon 1301 is becoming challenging because of a lack of knowledge of current halon holders, the critical need for this agent, individual country regulations regarding exportation (for example, some countries regard its importation shuld be carried out under the Basel Convention whereas others do not), and the extensive documentation requirements for importation, which can be difficult to navigate and burdensome. The UNEP Halon Trader, an e-market place, could be restarted to facilitate halon movement.

Halon Bank owners need to continue to monitor, maintain, and carefully manage their stocks to prevent leakage in order to sustain supply. Depending on what is being prescribed by the end user, halon 1211, halon 1301, halon 2402 must meet the relevant ASTM, ISO, GOST or military specifications. For the quality of the gas to remain stable during banking and to ensure its efficacy for fire protection purposes, the halon needs to be filled into containers that are fit for purpose, clean, dry and have been tested. Testing should be conducted as per applicable purity standards after the halon is filled into the storage container to assure the quality of the banked gas.

3.5. Regional updates

3.5.1. Russian Federation update

The market continues to be in balance with no surplus available for outside markets. More than 25 tonnes (t) / year of halon 2402 was available as a free agent ready for purchase in the period from 2013 to 2016. Table 1 provides information on the Russian installed base, recycling, and emissions from 2007 to 2016.

Table 3.1. Changes in Russian bank of halon 2402 (tonnes, t)

	2007	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016[1]**
Recycled amount, t	80.0	120.0	21.0	23.0	23.0	25.0	30.0	40.0	50.0
Annual offer of free agent, t	10.0	20.0	24.0	25.0	25.0	28.0	30.0	28.0	38.0
Emissions, t	8.0	10.0	1.6	3.0	2.2	2.0	3.0	3.8	3.5
Total bank, t	947.0	941.0	939.4	936.4	934.2	932.2	929.2	925.4	921.9

Note 1: Data obtained by January 2017

There is a new foam fire suppression system with extremely high intensity of discharge (1200 dm^3/sec) in Russia that is being developed and tested on fuel tanks up to 20,000 cubic meters, which has been approved for some former halon 2402 applications. It is intended for open spaces such as refineries and transport tunnels. It was tested in high wind and met performance requirements.

3.5.2. China update

An agreement has been reached between the Foreign Economic Cooperation Office (FECO) and the Ministry of Public Security (MPS) to establish a halon management center (HMC) as part of the MPS Fire Safety Division. The MPS is responsible for Fire Safety and Fire Fighting in China. The HMC will operate as a clearinghouse and plans to develop a database with information on halon 1301 and 1211 stocks and halon fire extinguishing systems in China. It may also track trading of halons. The operational details of the HMC will be developed in cooperation with FECO. Surveys on remaining halons in two Provinces have been completed. It is expected that the identified stocks of obsolete halons will be collected under the guidance of the new HMC at the MPS facilities. The halon 1211 stock at Dongyang has been moved to a new location as part of the relocation of the company. When the HMC starts operating, the stock and future sale of halon 1211 from the stock will be reported by the new HMC.

A contract has been signed with Lantian SinoChem for setting up a halon 1301 recycling facility at their location in Hangzhou. The recycling facility will be the only recycling facility for halon 1301 in China. The HTOC believes that Lantian SinoChem is the only halon 1301 producer in China (for feedstock use in the manufacture of the pesticide fipronil). The World Bank plans to discuss with FECO how to avoid “leakage” from this production of halon 1301.

The halon 1211 recycling center at Shenjie Fire Equipment Company in Guangdong is still on hold. The company is committed to continue the project, but is still waiting for a solution regarding classification as a hazardous waste. Shenjie was bought by a company in a non-A5 party in 2009 and maintains a majority ownership in the facility.

3.5.3. India update

A national halon bank was initially set up in 2004, with the MLF assistance, followed by an awareness campaign until 2006 that included training and numerous workshops. From 2004–2007 only small quantities of halon, approximately 1 MT was reclaimed through the national halon banking facility. The facility has remained non-functional since then, but an effort to revive the banking facility now is underway.

India in the past has reported limited recovery of halon 2402 and halon 1301 received from shipbreaking in the port of Alang. The updated quantities are under assessment. It was also reported that the recovered halon was being disposed as scrap in the Indian market and being reused by some civilian users; however, the whereabouts of these reported uses are unknown.

The following is a summary of some of the halon alternatives in use:

1) Floating roof tanks are being equipped with foam systems in place of halon 2402;
2) More than 50% of the portable halon extinguishers have been replaced with dry chemical powder extinguishants, where about 20% are now using carbon dioxide, and less than 20% are utilizing HFCs; and
3) Some existing fixed systems had been replaced with HCFCs and inert gas systems.

Now no new halon systems are being installed in the civil sector, however, dry powders and clean agents such as HFC and CO_2 are being reported in both portables and fixed systems. The use of HCFC and its blends has been decreasing drastically and is now less than 5% of the installations. Additionally, a regulation was passed in 2014 banning the import of HCFCs and limiting their use in many applications.

It is reported that the armed forces utilize halon 1211 and halon 1301 for their mission critical uses and have procured the reclaimed quantities needed to support their remaining applications. The military does not currently use dry powder systems, water mist systems, or halon 2402 for armoured vehicles; they still require halon 1301 and halon 1211 and are in the process of developing and commissioning banking to support this application as it is expected to be a medium to long-term requirement. The Navy is considering replacing their halon systems with HFC 227ea and/or water mist systems for shipboard applications.

India has an HPMP in place to address the phase-out of HCFCs. Multilateral Fund support is being provided to assist India in moving forward the phase-out dates for HCFCs from 2040 to 2025.

4 Methyl Bromide TOC (MBTOC) Progress Report

Executive Summary

The 2017 MBTOC Progress Report provides an update on the production, consumption and emissions of methyl bromide (MB). It also provides an update on recent developments with alternatives to MB focusing on specific sectors for which critical uses are still requested or where additional information on alternatives is useful for further phase out of MB. Consumption and production of MB for both controlled and exempted (QPS) uses are provided and a section on remaining challenges, including possible illegal trade and unreported/ erroneously reported MB is also presented.

Despite successful reduction of MB for controlled uses under the Montreal Protocol, emission studies show that about 31% of the baseline emissions are still being measured in the atmosphere. As discussed in this and recent reports, it appears that this annual anthropogenic emission of methyl bromide corresponds to a global consumption of approximately 22,000 tonnes. Uses reported for quarantine and pre-shipment (QPS, about 8,00 - 10,000 tonnes annually) contribute to less than half of the MB emitted, and the remaining amount is most likely due to unreported consumption and partly due to changes in the natural baseline emissions due to climate effects (e.g. El Niño). This unreported amount dwarfs present consumption for critical uses (around 500 tonnes) and is offsetting the benefit gained by progress in phasing out methyl bromide for Critical Use Exemption (CUE) uses. Parties may wish to address this issue. For example, by implementing methods to report on amounts distributed by manufacturers/distributors of MB, supporting ways to improve reporting/management of unreported and/or illegal uses that may be occurring in certain countries or regions and others.

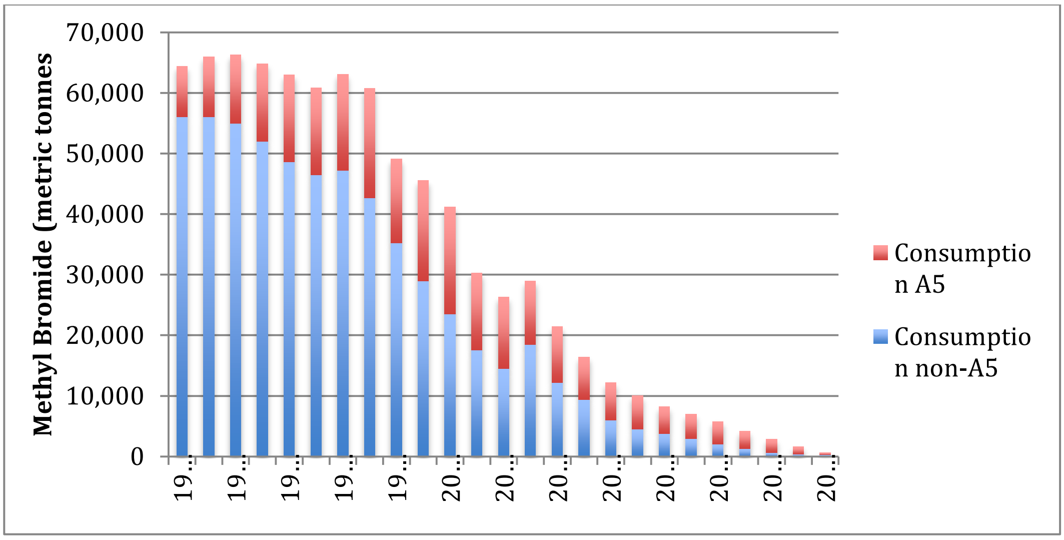
Phase-out of controlled uses of MB has continued progressing under the Critical Use Exemption, in both A5 and non-A5 parties. In 2015, controlled uses amounted to less than 1% of the global baseline, (about 56,000 tonnes for non-A5 and 16,000 for A5 parties) showing successful development and adoption of alternatives in the vast majority of sectors where MB was once used, both as a soil fumigant and a postharvest or structural treatment. MBTOC notes however that progress in phasing out certain critical uses, such as for strawberry runners produced as planting stock, seems to have stalled. In some countries, alternatives have not been developed that are acceptable to government agencies tasked with certifying planting stock or environmental issues. Some nominations thus continue, under the same conditions and often the same amounts, after 12 years in non-A5 parties. MBTOC considers that continuous recommendation of these CUEs may be acting as an almost certain guarantee of MB supply to users involved – and could be becoming in itself a barrier to technological change and adoption of alternatives. In other instances, MB used for production of certified plant stock has been reclassified as exempt under QPS and therefore the MB use has not actually been phased out as a controlled use. MBTOC thus urges the Parties to review regulations and other hurdles to the adoption of alternatives, to help move the MB phase out process forward.

4.1. Global MB production and consumption

By the end of 2015, over 99 % of the global consumption baseline for pre-plant and postharvest uses, excluding QPS and feedstock uses, had reportedly been replaced with alternatives (or re-categorised to QPS). Reported consumption as of the end of 2015 for controlled uses in A5 and non- A5 parties is now almost equivalent, at 333 and 281 metric tonnes respectively.

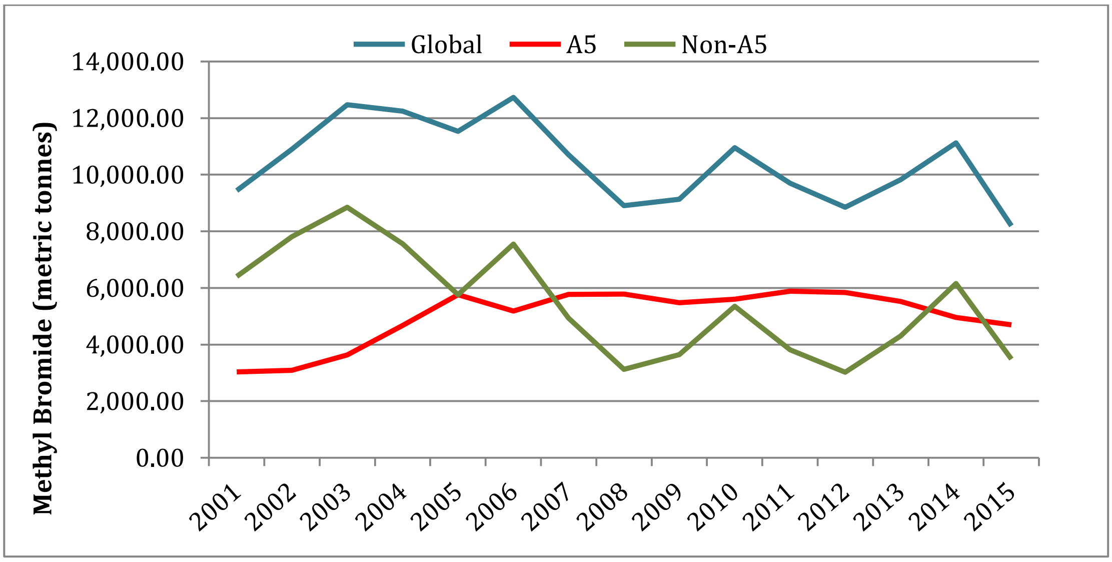
Figures 4.1 and 4.2 below illustrate MB global consumption for controlled and exempted (QPS) uses up to 2015, the last year for which full Article 7 data is available at the Ozone Secretariat's Data Access Centre (http://ozone.unep.org/en/data-reporting/data-centre). Note that the non-A5 consumption baseline was about 56,000 metric tonnes (consumption in 1991) and the A5 baseline about 16,000 metric tonnes (average consumption 1995 – 1998). The phaseout deadline for controlled uses for non-A5 Parties was 1 January 2005, whilst that for A5 Parties was 1 January 2015. Fig. 4.3 refers to MB production for exempted uses (QPS).

Figure 4.1. Global consumption of MB for controlled uses



Source: Ozone Secretariat Data Access Centre, 2017

Figure 4.2. Global and regional consumption of MB for QPS purposes

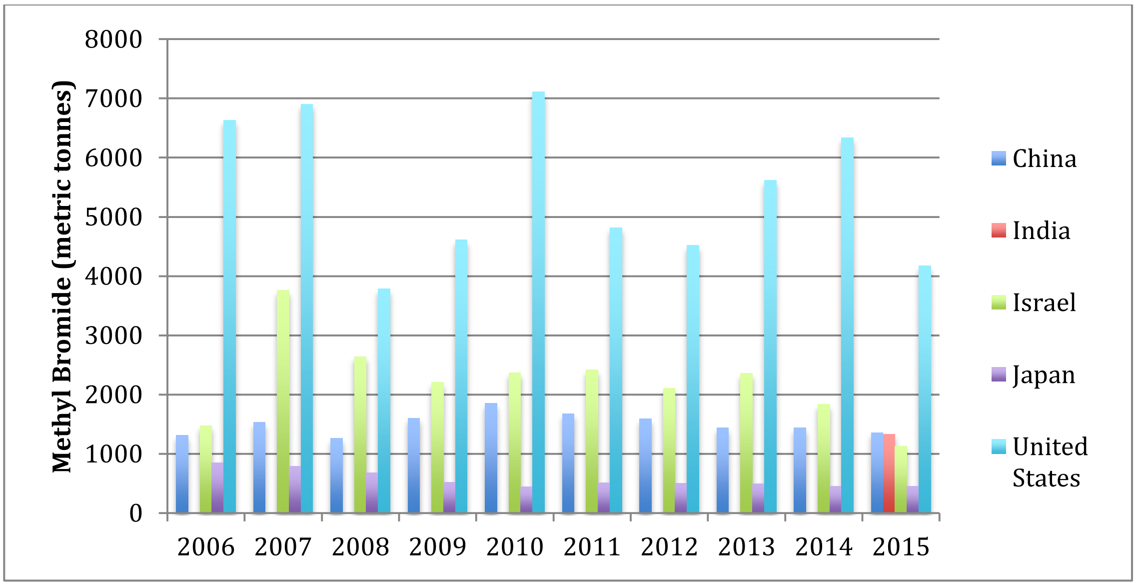


Source: Ozone Secretariat Data Access Centre, 2017

MB consumption for QPS uses typically shows variations from year to year but appears to continue at an average of around 10,000 metric tonnes per year. In 2015 there appeared to be a fall from this long-term trend, with total reported QPS consumption of about 8,300 tonnes (in A5 Parties amounted to about 4,700 metric tonnes, whilst that of non-A5 Parties was 3,500 metric tonnes).

Information on global production of MB for QPS purposes has become more complete as of 2015, with India now reporting production of 1,333 metric tonnes of MB in that year. It is the first time India reports any production of MB since 2002. Total world production of MB for QPS amounted to about 8,450 metric tonnes in 2015. Five parties, two A5 (China, India) and three non-A5s (US, Israel and Japan) presently produce MB for QPS, as seen in Fig. 4 below.

Figure 4.3. Global MB production for QPS purposes



Source: Ozone Secretariat Data Access Centre, 2017

4.2. Update on alternatives for remaining critical uses

Technically and economically feasible chemical and non-chemical alternatives to MB have been found for virtually all soils, structural and commodity applications for which MB was used in the past with comprehensive information available for these uses (MBTOC, 2015).

4.2.1. Alternatives for remaining CUNs in the soil sector

4.2.1.1 False rootknot nematode of tomato

Control of the false root-knot nematode is proving difficult in protected cultivation (i.e. in plastic greenhouses) in Argentina. The false rootknot nematode, *Nacobbus aberrans*, has a very wide host range, the most significant being tomatoes and potatoes, but also including brassica crops, peppers, carrots, cucumbers, lettuce, sugar beet and various weeds. Several pathotypes of *Nacobbus* have been reported (Lax *et al*., 2011). It is one of the top 10 nematodes based on economic importance (Jones *et al*., 2013) and is mainly particularly prevalent in Mexico, Argentina, Bolivia, Chile, Ecuador and Peru (Sher, 1970, Canto-Sáenz *et al* 1996). It is of quarantine importance in some countries (EPPO, 2009). In Argentina, *N. aberrans* has been reported from several provinces (Chaves and Sisler, 1980; Costilla and Ojeda, 1985; Del Toro *et al*., 2004; Doucet and Lax, 2005), causing particularly high damage in greenhouse crops.

Control of *Nacobbus* is complex due to its wide host range and variable behaviour between populations (Costilla, 1990; Doucet and Gardenal 1992, Boluarte and Jatala 1999; Lax *et al*., 2011). This led to frequent treatments with methyl bromide in the past and research has been conducted on both non-chemical and chemical alternatives.

MB use for several other pathogens of tomatoes in the past was avoided by use of resistant cultivars, but no commercial tomato cultivars resistant to *N. aberrans* are yet available. Cultivars and rootstocks with specific resistance to this nematode have been sought for many years for tomato, pepper and potato (Sisler and Pelicano de Casaurang, 1983, Manzanilla-Lopez *et al*., 2002, Thies and Ariss, 2009, Djian-Caporalino *et al*., 2009)., Although past research evaluating tomato cultivars and wild tomato species was not successful for identifying resistance genes that can help reduce yield losses in tomatoes attacked by this nematode (see for example, Veremis *et al.*, 1997), current research has yielded encouraging results (Lax *et al.,* 2016).

An Integrated Management program to control *Naccobus* was developed by Cristobal-Alejo *et al.,* (2006) in Mexico, comprising fertilization, nematicide applications (ethoprop) and biofumigation with chicken manure. This resulted in significant increases of plant height, foliage dry weight, stem diameter and crop yield. *N.aberrans* is controlled on greenhouse pepper in Mexico with various chemical (carbofuran) and non-chemical control methods such as biofumigation, biological control with *Pochonia chlamydospora* (Pérez-Rodríguez *et al.,* 2010).

Recently, Hidalgo *et al.,* (2015) reported significant reduction of population density, reproduction rate, and root galling of *N. aberrans* in tomato crops with fluensulfone (Nimitz®) a contact nematicide. Results were similar to those obtained with 1,3-D/Pic, and **t**hey concluded that fluensulfone, which poses less risk to human health and the environment than fumigants, could be considered a good alternative to MB for tomato and cucumber crops affected by *N. aberrans*. Fluensulfone has also been identified as an effective alternative to MB for nematode control on different crops including tomato (Castillo *et al* 2016). When this product was combined with Pic-Clor 60 a combination of chloropicrin and 1,3-Dichloropropene (Pic + 1,3-D) showed lower galling index was shown as compared to Pic-Clor 60 alone (Castillo *et al.,* 2016).

4.2.1.2. Alternatives for strawberry runner production

Many strawberry runner nurseries around the world relied on methyl bromide soil fumigation to produce disease-free transplants in the past, but most have phased-out MB and successfully implemented alternatives (García-Sinovas *et al*., 2014; López-Aranda, 2016). Several countries still use MB, but continue to seek alternatives under the critical use process (e.g. Australia, Canada) and another (US) has the use classified under the Quarantine and Preshipment exemption.

MBTOC is concerned that MB may be being used for this sector in other countries, but that this use is not being reported. Pre 2015 stocks may also be being used for this purpose in non-A5 parties, but this MB is still required to be reported.

In come countries, policies exist (e.g. certification) which makes it mor difficult to implement alternatives, but parties are encouraged to expediate consideration of any alternative so these policies do not become a barrier to adoption of the alternatives.

Lopez Aranda *et al* (2016) recently conducted a comprehensive survey of 41 European and other strawberry industries (fruit and nursery). With respect to strawberry nurseries (more than 5,755 ha identified, with different soil and climate situations), the survey showed that 32% were fumigated with metham sodium (spading), 31% used crop rotation with cereals, grasses, oilseed crops, legumes, and other crops i.e. green manures like oil radish, mustards, winter rye, and buckwheat and/or change of location; 19.3% were fumigated with 1,3D and/or 1,3D+Chloropicrin; 8.6% relied on non-chemical methods (cover/catch crops, soil solarisation, and ASD), 7.2% was fumigated with dazomet (Mix-Tiller), and the remaining 1.9% used other chemical options. None of the nurseries in the sample used MB.

Further, production in substrates has been adopted at various locations. Strawberry transplants may be bare root or plugs. Bare root transplants are obtained from runners rooted in the soil, while plug transplants are rooted in containers or trays filled with substrate (Durner *et al*, 2002, Giménez *et al*., 2008). Plugs have the root system embodied by the substrate and have advantages in relation to crop stand, earliness, and disease and pest management.

4.2.1.3. Barrier films

For many years MBTOC has indicated the benefits of using barrier films when using soil fumigants, as these provide a way of reducing emissions and increasing effectiveness of fumigants, allowing for much lower dosages that without such films. Decisions condsider the practices which minimise emissions of MB as an essential criteria, and research for many years has show the benefit of barrier films to reduce MB dosage rates needed to control pathogens and weeds. Barrier films are also now mandatory or at the very least strongly encouraged for use with all fumigants in various countries (TEAP, 2016).

A recent trial conducted by Thalavaisundaram *et al* (2015) showed that sealing soil with VIF improved the efficacy of ethylenedinitrile (EDN) for soil disinfestation and runner production, compared with LDPE. VIF also significantly increased weed control and runner yields compared with LDPE.

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

Only one Party (Republic of South Africa, RSA) is still requesting a CUE for further use of MB for pest control in structures and/or postharvest commodities, namely for disinfestations of empty grain mills and wood houses (dwellings). The main chemical alternatives for the nominated uses, (e.g. sulfuryl fluoride, SF, ethylene dinitrile, EDN) are in use or considered promising in many countries, but not yet available in South Africa, mainly due to lack of registration. This process has been delayed due to difficulties encountered by the fumigating companies in sourcing the required information to complete registration, however this is being addressed.

Heat, an additional alternative widely in use around the world under comparable situations is not presently used in RSA. The import of heating machines (burners or electrical heaters) is costly and the technique is not in regular use for pest control in this country. Local sourcing or manufacturing of suitable machines and optimising their use will need time. As a consequence, a rapid phase out of MB with economically feasible and equally effective measures is being delayed. MBTOC submitted information on heat control (Hammond, 2015) to the relevant sector representatives and will continue to supply information on this technique, including sourcing of suitable equipment that may be imported at lower prices, in order to speed up adoption where suitable.

The following sections present more detailed updated information on these and other alternatives, which according to particular circumstances within the CUNs may be appropriate for the uses described above. Further and much more detailed information is available in MBTOC's past reports, particularly Assessment Reports.

4.2.2.1 Sulfuryl fluoride

As stated previously, sulfuryl fluoride (SF) is a key alternative to MB for structures (including mills and dwellings). It is registered for use on dwellings in many countries (e.g. Australia (APVMA 2017)) and, as Vikane, took over from methyl bromide fumigation of houses against drywood termites and woodborers in US many years ago. It is becoming clear that exposure periods may need to be prolonged (>24h) where the SF-tolerant egg stage of pests needs to be eliminated, with the maximum labelled ct-product of 1500 g h m-3 achieved over 48h or more. Extended exposure is however not required for controlling drywood termites, which are a key pest of the RSA nomination.

SF is also used as an alternative to MB for controlling pests of stored grain and other foodstuffs. Buckman *et al*. (2013) have dealt over several years with control of the red flour beetle (*Tribolium castaneum)*, which is challenging as this pest can come back after fumigation of rice mills with SF. An interesting correlation between capture of beetles inside and outside the mills was shown. A metaanalysis involving 111 treatments in 39 objects comparing control of the two *Tribolium* species - *T. castaneum* and *T. confusum* - in grain processing factories revealed fairly comparable results as those obtained with methyl bromide or sulfuryl fluoride or application of heat (Campbell *et al*., 2015).

Treatment of antique buildings and artefacts is another instance where replacing MB has been difficult. Recently, Ferizli and Emekci (2016) have described a successful treatment of a large antique heritage wooden structure, the Aynali Kavak pavilion in Istanbul, Turkey with SF. This provides a good example of effective treatment under technically demanding conditions of a very valuable building; treatment was possible with antique furnishings and furniture left in situ during the process.

4.2.2.2. Hydrogen cyanide

Hydrogen cyanide (HCN) is a potential fumigant alternative for treatment of logs and timber, which is also currently under consideration as an alternative treatment to MB for the ISPM 15 standard for wood packaging material in international trade. Where registered, it is a long-established alternative to methyl bromide for full site disinfestations of flourmills and similar premises.

Douda *et al.,* (2015) treating wood with HCN at dosage rates between 12.3 to 24.12 g/m³ for between 2-20 h gave total mortality of for control of the pine wood nematode (*Bursaphelenchus xylophilus*). Overall, despite results showing good efficiency of the HCN treatment against the nematode, research on naturally infested wood would be desirable, as well as a wood sorption analysis in wood with higher moisture content.

Stejskal *et al*. (2014) showed that the highest tested HCN dose (20 g/m³) led to 100% mortality of the Asian long horned beetle *(Anoplophora glabripennis)* and European house borer (*Hylotrupes bajulus)* larvae after less than 1 h of exposure. Hydrogen cyanide doses of 10 g/m³ and 20 g/m³ led to full control of *B. xylophilus* within 40 and 18 h, respectively. For *B. xylophilus*, the ct product was < 424 g h/m³ at 20 C and 10 g/m³ and < 349.51 g h/m³ at 25 C and 20 g/m³.

Malkova *et al*. (2016) describe studies with Bluefume, a formulation of EDN + HCN, measuring the concentration-time (Ct) of product achieved during the fumigation in order to examine the efficacy of fumigation on some wood boring pests With an initial HCN initial dosage of 20 g/m^3, the ct-products giving 100% mortality of larvae of *H. bajulus* and of *A. glabripennis* were <18.66 g h m^{-3} and <17.67 g h m^{-3}, respectively.

Stejskal et al. (2016) conducted a commercial scale demonstration of a flourmill, with bioassays of several species of stored-product insects included to demonstrate effectiveness. In this demonstration, complete mortality of adults of *T. castaneum*, *T. confusum* (confused flour beetle), *Cryptolestes turcicus* (flourmill beetle), *Sitophilus oryzae* (rice weevil) and *Rhyzopertha dominica* (lesser grain borer) was shown on Petri dishes and of adults and larvae of *T. confusum* in flour at measured ct-products ranging from 54 to 100 g h m/^{3}.

4.2.2.3. EDN

Information on EDN continues to become available. McConville (2016), for example, has presented an overview on the various areas of applications of ethanedinitrile (EDN) for pest control.

Malkova *et al*. (2016) published on the effectiveness of EDN and HCN against some wood pests. The ct-product for EDN giving 100% mortality (initial dosage 50 g m^{-3}) were 105.62 g h m^{-3} and 311.57 g h m^{-3} for larvae of European house borers (*H. bajulus)* and pinewood nematodes (*B. xylophilus)* respectively.

Hall *et al.* (2016) reported effective results of field trials with 50 g/m³ of EDN for 10 h (measured ct products at about 333 g h/m³) and concentration measurements including emission determination for 5 h up to 50 m around treated stacks in New Zealand.

4.2.2.4. Heat

As stated previously, heat is in use around the world for treating structures, stored commodities (e.g. grain) and other items. Hammond (2015) has published a comprehensive and useful book (manual) on heat treatment for pest control. Tang *et al*. (2007) reviewed heat treatment for postharvest pest control (durables, perishables, structures) with detailed descriptions of the theory, practice and biological effects of the process.

Phomphai *et al*. (2017) have recently reported on infrared heating as a disinfestation method against the rice weevil (*S. oryzae)* and its effect on the texture and cooking properties of milled rice. Minimal changes in rice quality before and after storage were observed under optimum temperature and an exposure time of 53.6 C and 1.2 min.

4.2.2.5. Termite control

Termites are often found infesting wood in many kinds of structures and can be a difficult pest to deal with. Dry wood termites such as *Cryptotermes* spp. develop without need for contact with the soil and are thus less amenable to the commonly used baiting techniques used with most other species. They are effectively controlled with fumigation or heat treatment. In South African conditions, infestations of the exotic but long-established drywood termite, *Cryptotermes brevis* may be fumigated periodically to achieve continued protection of wooden structures made with untreated timber, such as older dwellings, shops and warehouses, in face of continued reinfestation pressure.

Recent research on termite control includes studies by Bhatta and Henderson (2016) and Bhatta *et al*. (2016) using the bioinsecticides Spinosad and Spinetoram (based on chemical compounds produced by the bacterium *Saccharopolyspora spinosa*) for controlling various species of termites.

In addition, Choi *et al*. (2014) investigated the efficacy of phosphine against the Japanese termite, *Reticulitermes speratus.* Fumigant toxicities of phosphine, PH_3 (LD50 values) towards the termites were 0.735 mg h/l and 0.744 mg h/l at 20°C. Phosphine adsorbed weakly onto wood, indicating that the gas, as a fumigant, might be useful for controlling termite infestations even in quarantine situations.

4.2.3. Economic issues related to MB phaseout

Three recent publications add considerably to our knowledge of economic issues involved in assessing the efficacy of alternatives to methyl bromide. These deal with pre-plant soil fumigation and are briefly discussed below, in alphabetical order.

First, Guthman (2016) discusses the regulatory battle around the withdrawal of methyl iodide, originally regarded as an alternative to methyl bromide for soil fumigation in strawberry systems. In this analysis, she points out, based on interviews with growers, *"... that growers' decisions not to use it were primarily related to public disapproval, although the continued availability of methyl bromide and other fumigants played a contributing role by making adoption less urgent. The study results suggest that policies in place during the methyl bromide phaseout did not strongly encourage the development and extension of less toxic alternatives, which undermined the strawberry industry's position."*

Second, Hammond (2015) has provided the first publication that looks at the economic aspects of the use of heat as an alternative method of insect control in mills. After providing data on the cost of different materials and processes of heating vs. treatment with methyl bromide, he concludes that, all arguments considered, heat treatment should cost around half of the methyl bromide treatment in the UK.

Third, most of the literature on the economic aspects of the methyl bromide phaseout consists of a partial budget comparison between methyl bromide and its next best alternative. In this regard, Wu *et al.* (2016) show how external factors (rainfall, weed pressure and soil temperature) affected fumigant efficacy. However, they take the analysis further: because they consider the long term cost-effectiveness of alternatives, they model the risks to the producer of using each of these alternatives given weather variability using the well-known Monte Carlo simulation. The result: alternative treatments of tomatoes in Florida can be ranked as 1,3-D:Pic: Metam>Midas>methyl bromide>1,3-D:Pic>DMDS: Pic when used over the long term (from higher to lower cost effectiveness).

4.3. QPS sector

4.3.1. Irradiation

E-beam (electron beam) irradiation systems have progressed to the point that they might make irradiation more available for phytosanitary uses in the near future. Essentially, x-rays are generated electronically, and therefore, the radiation source can be turned on and off at will, a fact that makes e-beam technology safer than cobalt-60, and require less oversight and regulation. This technology has been available since the late 1990's, but is finally moving into the early implementation stages for phytosanitation in the United States. However, phytosanitary regulatory agencies sometimes require rates that are damaging to the goods, and more research is needed to improve technical data on the minimal rates actually required for adequate phytosanitation (Hallman 2016). Although radiation has been around a long time, its use was somewhat limited in the United States, partly due to low consumer acceptance of irradiated goods, and economic cost. Whether the new e-beam technology will have higher acceptance and economic feasibility is not yet clear.

4.3.2. Ethyl formate

Ethyl formate (EF) is a Generally Recognised As Safe (GRAS) plant volatile compound. It has been used in trials to reduce incidence of external pests on apples to acceptable rates for export markets. Mealybugs, scale insects, thrips and apple leaf curling midge (ALCM) on packed New Zealand apples are a concern for export markets. A treatment of 0.3% EF +CO_2

for 1 h controlled 99% of onion thrips and latania scale, and 0.81% EF + CO_2 for 1 h controlled obscure mealybug. Jamieson *et al*. (2014) found treatment concentrations and times required to control ALCM (4.94% EF for 4 h) were beyond the apple quality tolerance level.

Yang *et al*. (2016) conducted a study to compare the effects of EF and phosphine (PH_3) as individual treatments, and of EF mixed with PH_3 as alternatives to MB for controlling citrus mealybug (*Planococcus citri)* adults, nymphs, and eggs. The combined treatment was significantly more effective; it was observed that the eggs were more tolerant than the nymphs and adults. In pineapples, a mixed treatment of EF + PH_3 achieved complete control of eggs at concentrations of 25.1/1.0 (EF/PH_3) mg/liter at 8C with a 4 h exposure time. This combined treatment could offer shorter exposure times and less damage to perishable commodities at low temperatures, and could potentially be extended to controlling other quarantine pests of fruit and vegetables for which MB is currently used.

Chhagan (2013) exposed New Zealand flower thrips (NZFT), *Thrips obscuratus* to a range of EF and pyrethrum-based postharvest treatments on apricots. The trials showed that EF+CO_2 or EF+N_2 were effective treatments against NZFT and caused negligible damage to apricot fruit quality. However, pyrethrum dipping did not effectively control NZFT and caused significant internal damage to apricot fruit.

Codling moth (CM, *Cydia pomonella*) is a pest of quarantine concern on apple exports to Asian markets. Apples exported to Japan must be fumigated with MB and then cold stored. Jamieson *et al*. (2016) investigated EF as an alternative to MB, to control an internal pest such as CM by determining the responses of key insect stages without fruit and inside apples. Trials without fruit in a 2 h fumigation showed that late-stage CM eggs and third instar CM larvae were the most tolerant life stages, requiring a mean concentration of 1.34–1.94% EF to achieve 99% mortality, but 100% mortality of 4th/5th instar CM larvae. Trials with CM in fruit in a 2 h fumigation showed that 1.13% EF resulted in 53.4% mortality of 4th/5th CM larvae inside apples. Increasing the mean concentration to 2.4% EF increased the mortality of 4th/5th larvae inside apples to 85.2%.

Jamieson (2015) examined the tolerances of different life stages of tomato potato psyllid (TPP) to EF, finding that eggs were considerably more tolerant than adults and nymphs. Complete elimination of egg hatch was achieved after a 1-h exposure to 1.19% EF. In contrast, all nymphs and adults were killed after a 1-h exposure to 0.12% and 0.06% EF, respectively. Assessment of egg mortality was altered to better reflect the post-hatch treatment effects on nymph survival. In a subsequent egg age tolerance trial, mean lethal concentrations for 99% mortality ranged from ca 1% EF for young and older eggs to ca 1.5% EF for mid-aged eggs.

Export of Pink Lady apples from Australia has been significantly affected by infestations of adult eucalyptus weevils (*Gonipterus platensis* Marelli). These weevils cling tenaciously to the pedicel of apple fruit when selecting overwintering sites. As a result, apples infested with live *G. platensis* adults are rejected for export. Agarwal *et al*. (2015) conducted laboratory experiments using a wide range of concentrations of ethyl formate. Complete control (100% mortality) was achieved at 25–30 mg/liter of ethyl formate at 22–24°C for 24-h exposure without apples. However, with 90–95% of the volume full of apples, complete control was achieved at 40 mg/liter of ethyl formate at 22–24°C for 24-h exposure. No phytotoxicity was observed and after aerating for one day, residue of ethyl formate declined to natural levels (0.05–0.2 mg/kg). Five ethyl formate field trials were conducted in cool storages and 100% kill of eucalyptus weevils were achieved at 50–55 mg/liter at 7–10°C for 24 h.

Vapormate was also evaluated in South Africa. Grout and Stoltz (2016) reported that South African fruit is sometimes rejected for export due to the presence of live arthropods that are not considered pests of the fruit concerned. They fumigated *Macchiademus diplopterus* at a dosage of Vapormate 250 g/m3 for 4hrs resulting in no survivors out of >35,000 *M. diplopterus* fumigated. A small-scale trial using the same ethyl formate treatment also killed the arboreal mite *Siculobata sicula*. The treatment conditions did not appear to have phytotoxic effects on pears or oranges, unless they had prior mechanical injuries that were accentuated.

Bessi *et al*. (2016) reported results of fumigating dates of the Deglet Nour variety with EF. A laboratory scale test revealed that the most efficient combination was 143 g/m3 of EF for 2 h, which led to 98.12% mortality of the most resistant larvae stage of the carob moth (*Ectomyelois ceratoniae*). In a semi-industrial scale treatment with Vapormate, the mortality rate was further improved, reaching 100%. No changes in fruit quality were observed after fumigation.

Ethyl formate vapour is highly flammable with a lower flammability limit of 2.8% in air. While this is above typical fumigation concentrations, it needs dilution in practice to below the flammability limit from its liquid or concentrated form. This may be done by dilution with CO_2 as in the Vapormate formulation or in a stream of CO_2 as described by Navarro and Navarro (2016) in their full scale trials with ethyl formate on grain. Alternatively the ethyl formate may be volatilised in a stream of nitrogen gas, as per Yang *et al*. (2016), who describe this technique as used for disinfestation of oranges imported into South Korea.

4.3.3. Ethanedinitrile (EDN)

The sorption characteristics of EDN (syn. cyanogen, EDN Fumigas®) were quantified by Hall *et al*. (2015) for recently harvested pine logs, and a proposed EDN sorption model developed for sawn timber was tested, showing a high sorption rate as compared to other fumigants such as MB. A proportional drop in headspace concentration over time was consistent for the two doses evaluated (20 and 50 g/m3), confirming that EDN sorption is influenced by the dose applied. Bark cover did not significantly influence EDN sorption.

Pranamornkith *et al.* (2014) studied EDN at doses of 20 g/m3 or 50 g/m3, timber moisture content (green or kiln dried sawn timber), end-grain sealing (sealed or unsealed timber end-grain) and load factor (11% or 44%) on sorption of EDN by sawn timber at 15°C. This was quantified using headspace samples taken from 28-litre fumigation chambers. Chamber loading significantly influenced sorption, with higher loading resulting in greater sorption. Changes in the dose of EDN did not affect the sorption pattern. Increased moisture content and end-grain sealing both reduced sorption, but these effects were relatively small and the differences in sorption patterns caused by moisture content or end-grain sealing decreased over time.

These same researchers tested the efficacy of ethanedinitrile for controlling burnt pine longhorn beetle adults (*Arhopalus ferus*) using a range of EDN concentrations. The LD99 for adults after a 3 h exposure at 15°C was 12.6 g/m3. The results demonstrate that EDN is a potential phytosanitary alternative to methyl bromide for disinfesting burnt pine longhorn adults from sawn timber exported from New Zealand.

In Japan the pinewood nematode *B. xylophilus* is a quarantine pest often associated with beetles of the genus *Monochamus* (pine sawyers) particularly *Monochamus alternatus*, which can disperse the nematodes to long distances causing widespread losses in pine forests. Park *et al*. (2014) conducted two fumigation trials on logs naturally infested with *M. alternatus* and *B. xylophilus*. The logs were treated with EDN at low temperature (-7-25.7°C and -3.7-23.1°C) for 3 days in winter and early spring. Results suggest that 97 g/m^3 of EDN gives complete control of *M. alternatus* in pine wood and that dosages above 158 g/m^3 are required for eradication of *B. xylophilus* at low temperature fumigation.

Bong-Su *et al*. (2015) verified the efficacy of EDN under different temperature conditions (5, 5-15, >15℃) and monitored its TLV (Threshold limited value) post-fumigation for worker safety. Fumigation doses of 30, 40 and 50 g/m^3 for 24hr for controlling ordinary pests of wood such as Japanese termite (*Reticulitermes speratus*) and bark beetle (*Cryphalus fulvus*), showed >99% efficacy at 5, 5-15 and >15℃, respectively. Doses of 100, 120 and 150 g/m^3 for 24 hr were also successful in achieving the required efficacy at 5, 5-15, >15℃, respectively, meeting quarantine guidelines for wood related pests such as the Japanese pine sawyer (*Monochamus alternatus*) and the pine wood nematode (*B. xylophilus*). Recommended ventilation times with atmospheric conditions at ports were > 1 and > 2 hr under fully uncovered and partially uncovered tent conditions, respectively.

4.3.4. Other issues

4.3.4.1. Progress in reducing MB consumption for QPS in Japan

Japan is a large importer of grain (e.g. wheat, maize, soybean), edible oil and foodstuffs from many countries. Whenever live specimens of granary weevil (*Sitophilus granarius)* are detected, consignments are fumigated with MB as this is the only fumigant specified for such events in Japanese import plant quarantine regulations. Fumigation with phosphine is not permitted, as its efficacy against pupal stages of *Sitophilus* spp is low (Mori and Kawamoto, 1966). Research aimed at reducing MB use for this QPS application is described below.

Ishige *et al*. (2017) have worked on a phosphine fumigation standard to kill *S. granariu,s* which considers treatment conditions, sorption onto stored grains and preliminary mortality tests, in order to establish a treatment schedule. Mortality tests showed complete kill of *S. granarius* at a dose of 2.0 mg/l with a loading factor of 0.5 kg/l or below for 24 days at 10–15C, for 16 days at 15–20C, for 7 days at 20–25C and for 5 days at 25–35C. Negative effects were stringently assessed but not found.

Nishizaki *et al*. (2016) studied the survival of *S. granarius* on grain and beans when using phosphine. Twelve different products were examined (corncob meal, corn gluten feed, cotton-seed, flax-seed, rapeseed, rapeseed meal, safflower seed, sesame seed, sorghum, soybean, soybean meal and wheat-bran pellets) and it was found that a new generation of adults occurred in wheat-bran pellets and sorghum, but not in the other materials. The pest also survived in impurities from corncob meal, flax seed and safflower seed. The study further showed that in a single generation, adult *S. granarius* survived more than 40 days on wheat-bran pellets and sorghum, but only 20 days or less on the 10 remaining grains or foodstuffs.

4.3.4.2. Changes in fumigation regulations for imported goods

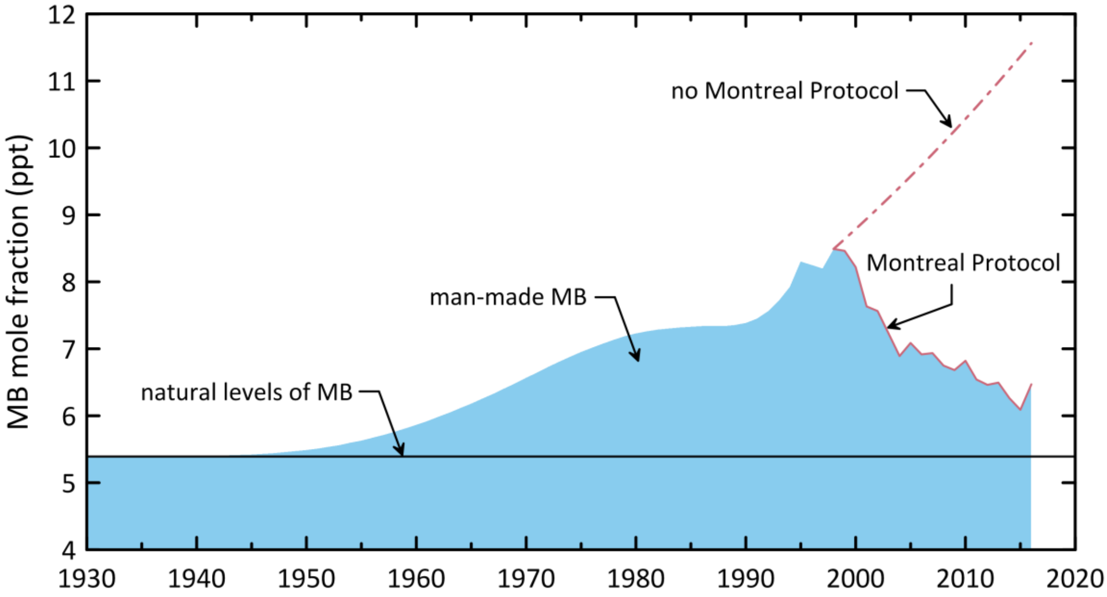
India used to fumigate imported goods with methyl bromide on arrival but is now imposing a rule whereby these will need to be treated at origin, before export. This rule is impacting for example teak log exports from Latin American countries, or exports of pulses from Canada, where MB use is minimal or no longer exists, even for QPS (see for example https://www.fcc-fac.ca/en/ag-knowledge/marketing/tricky-trade-situation-with-india-averted-for-now.html).

Ecuador has come to a bilateral agreement with India whereby Indian authorities have accepted pre-shipment fumigation of teak logs with 3g/m^3 of phosphine gas (aluminium phosphide/ magnesium phosphide of 56% or more, 3 tablets/ m^3) for 7 days. Ecuadorian fumigators conducting the treatment must be accredited by the Indian NPPO, which takes place through a direct technical visit (India Min of Agric. 2017).

4.4. Update on MB emissions

Despite the successful reduction of methyl bromide applied for controlled uses under the Montreal Protocol, measurements of MB concentrations in the atmosphere show that 32% of the equivalent level of baseline emissions are still present (Fig 4.4). This concentration corresponds to a global MB consumption of approximately 22,000 tonnes. Of this amount, QPS uses account for about 8,000-10,000 tonnes annually reported by parties and the remaining emissions are most likely due to unreported consumption or partly due to variation in natural emissions. Recently in 2016, the downward trend in MB concentration in the atmosphere appeared to stop and MB concentrations in the atmosphere increased. This may have been due to unusual climatic factors, including a strong El Niño, but could also be due partly to increased consumption. The present concentration of MB over the last few years is of concern because there is still a gap being shown over several years between reported production/consumption and the concentration of MB in the atmosphere. MBTOC is concerned that this data has identified a potential large source of unreported production/consumption of up to 15,000 tonnes. This unreported amount dwarfs present consumption for critical uses (around 300 tonnes in 2015) and is offsetting the benefit gained by progress in phasing out MB for CUN uses.

Fig 4.4. Global emissions of MB showing the estimated natural baseline and natural levels of MB and the increased levels caused by anthropogenic activity.



Source: (AGAGE/NOAA data from Cape Grim - Fraser, Krummel, Derek, Montzka and Porter)..

The 10th Ozone Research Managers Meeting, held recently in Geneva (28-30th March, 2017) included the following amongst its research recommendations:

> *" There continues to be an imbalance in the global budget of methyl bromide suggesting that there may be larger amounts of emissions than expected or our understanding of methyl bromide removal is somewhat incomplete. Further research into the methyl bromide budget and loss processes are warranted" (ORM, 2017)*

MBTOC is aware of some large unreported uses for preplant soil fumigation and commodity treatments, which could represent thousands of tonnes (MBTOC, 2015, TEAP, 2009).

Additionally there are some other reported uses, which have not been included in previous emission models (MBTOC, 2015). For example MB is produced by the breakdown of bromide-based catalysts in the production of terephthallic acid (TPA) and dimethyl terephthallate (DMT), intermediates used in the manufacture of polyesters such as PET (polyethylene terephthallate). In the past, emissions from these processes were calculated at several thousand tonnes (MBTOC, 1995), however they appear to be largely contained at present (e.g. Anguil, 2017). Smaller amounts are reported from other processes for example baking wheat products (approx. 200 tonnes, Thornton *et al*, 2016).

Parties may wish to consider ways to improve the reporting and management of these unreported and/or illegal uses in order to reduce these emissions. A monitoring and evaluation process (possibly under the MLF program of work) could provide the basis for undertaking further action.

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5 Medical and Chemicals TOC (MCTOC) Progress Report (including Recommendations for Essential Use Nominations)

Executive Summary

The global transition away from chlorofluorocarbon (CFC) metered dose inhalers (MDIs) is almost complete. In the last remaining countries, CFC MDIs were manufactured entirely from CFC stockpiles in 2015 and 2016 in China and Russia. Information indicates that hydrochlorofluorocarbon (HCFC) use in medical aerosols in China could be about 2,500 tonnes, using HCFC-22 and HCFC-141b.

China nominated 65 tonnes of carbon tetrachloride (CTC) for laboratory and analytical uses for the testing of oil, grease and total petroleum hydrocarbons in water as an essential use exemption (EUE) for 2018. MCTOC recommends that parties authorise an essential use exemption, and requests that China provides specific additional information on progress in the development of its alternative method and its studies of the purification of tetrachloroethylene, available sources of higher purity tetrachloroethylene, further evaluations of alternative international and other national methods, and timelines for the phase-out of CTC in laboratory and analytical uses, with anticipated steps and the end date in that process.

MCTOC reviewed the information submitted by parties under Decision XVII/6 on the use of controlled substances under exemptions as process agents, and the make-up and emissions for those uses. Based on the information reported, parties may wish to consider changes to Tables A and B of Decision XXII/7. Furthermore, parties may wish to consider requesting information be provided by parties in order to understand better the remaining eleven process agent uses.

MCTOC has analysed data on parties' production, import and export of ozone depleting substances (ODS) used as feedstock for the year 2015. These data include quantities used as process agents. In 2015, total production for these uses was 1,084,101 tonnes, representing a total of 375,488 ODP tonnes. Emissions from ODS feedstock use are not reported by parties. Using emissions factors from the SPARC Report on the Mystery of Carbon Tetrachloride, the range of ODS emissions from feedstock uses can be estimated as 5,421 to 21,682 tonnes, or 1,877 to 7,510 ODP tonnes for 2015. MCTOC also presents historic data on controlled substances used as feedstock from 2002 to 2015.

Parties may wish to consider providing MCTOC with production data for *n*-propyl bromide in order that global production quantities could be collated and reported.

The current laboratory and analytical usage of methyl bromide as a reference or standard, in laboratory toxicological studies, and for comparison of methyl bromide and its alternatives inside a laboratory, is likely to be minor, possibly in the kilograms range globally. Furthermore, the use of methyl bromide in laboratories as a methylating agent, in chemical reactions to deliver a methyl group to a chemical substrate, is also considered to be very minor. There are many alternatives available that are nearly always used in preference to methyl bromide. TEAP plans to report further on this topic if and when parties make available new and different information.

MCTOC wishes to bring to the attention of parties that it is seeking new members who are experts in destruction technology and laboratory and analytical uses. Parties may wish to consider nominating experts to MCTOC. In addition, in preparation for its future work, parties may wish to consider providing any relevant new information on destruction technologies to MCTOC.

5.1. Medical

5.1.1 Progress in the phase-out of ODS in MDIs

The global transition away from chlorofluorocarbon (CFC) metered-dose inhalers (MDIs) is almost complete. In 2015, the total quantity of CFCs used globally to manufacture MDIs was 210 tonnes. Quantities were not available for 2016 because accounting frameworks were not reported, although quantities would be expected to be less than 200 tonnes. This compares with 1997 when global annual CFC use for MDI manufacture peaked at about 10,000 tonnes, and also with about 11,250 tonnes of hydrofluorocarbons (HFCs) used to manufacture MDIs in 2016[1].

Manufacturing transition is moving towards completion in the last remaining countries, China and Russia. No CFCs have been produced for MDI manufacture since 2014. For both China and Russia, CFC MDIs were manufactured entirely from CFC stockpiles in 2015 and 2016.

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

Alternate propellants with lower GWP than HFC-134a and -227ea are being considered for MDIs. Research and development for any new therapeutic inhalational product is a lengthy and resource-intensive process, especially when this involves a propellant not previously used in an inhalational medicine.

One chemical company has recently reported research and development to investigate HFC-152a as a possible MDI propellant with lower global warming potential than HFC-134a (~5-6% of HFC-134a). HFC-152a is a colourless and odourless gas that is already manufactured in large volumes and widely used in a number of non-medical applications, and shows some promising MDI formulation benefits in initial research. HFC-152a is flammable and therefore its adoption would require MDI manufacturing to address safety. Inhalation safety and toxicology studies are underway and, until these are completed, its potential is uncertain.

Another chemical company has also started research and development to investigate HFO-1234ze as a possible propellant for use in MDIs with lower global warming potential than HFC-134a (<1% of HFC-134a). HFO-1234ze is a colourless and odourless gas that is commercially available and used in a number of non-medical applications. HFO-1234ze is designated as a Class 2.2 non-flammable liquefied gas. Although classified as non-flammable under standard tests, HFO-1234ze has a flammable range of 8.0-8.5 volume per cent in air at one atmosphere under certain conditions[2], and, like HFC-152a, its adoption would require MDI manufacturing to address safety. This propellant is being investigated as to its suitability as an alternate propellant in MDIs, and, as with HFC-152a, will require toxicology and inhalational safety studies.

More information on both of these alternate propellants can be reported if or when it becomes available.

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[1] Estimates of HFC consumption for MDI manufacture in 2016 are thought to show higher than normal demand due to market anomalies.

[2] https://www.honeywell-solstice-propellants.com/ResourceCenter/Whitepapers/Solstice®1234ze,%20HFO-1234ze,%201234ze%20Flammability%20Assessment.pdf, accessed May 2017.

5.1.2 Status of CFCs produced under essential use exemptions for the manufacture of MDIs

This section provides available information on CFCs produced for the manufacture of MDIs under previously authorised essential use exemptions. This information was gathered through informal MCTOC consultations, not through reporting accounting frameworks.

5.1.2.1 Argentina

Argentina's essential use exemption was authorised by parties for 2012. Argentina's accounting framework for 2012 showed CFC stocks on hand at the end of 2012 of about 5 tonnes.

All the companies except one in Argentina opted for technologies using HFC-134a as the excipient in their MDIs. Laboratorio Pablo Cassará initially converted its salbutamol MDI production to HFCs, but has been implementing an MLF project to use iso-butane as the propellant. MCTOC reported previously that Laboratorio Pablo Cassará planned to launch its first salbutamol isobutane MDI in 2016. According to information obtained from the Secretary of Industry, Laboratorio Pablo Cassará completed research in 2015 and submitted the results to the national regulatory agency (ANMAT) in order to get approval of that new formulation; at the present time, there is no news about any final decisions, or the date when, if approved, this product would be launched into the market.

5.1.2.2 China

Parties authorised an essential use exemption of 182.61 tonnes of CFCs for the manufacture of MDIs in China for 2015. According to China's accounting framework for 2015, China did not produce any CFCs under its exemption that year, and used 124.04 tonnes CFCs for MDI manufacture supplied from its stockpile, with 391.86 tonnes remaining in stockpile at the end of 2015. Consumption in 2014 and 2015 continued a consistent downward trend, and less in both years than the CFC quantity authorized by parties for China for 2015 (182.62 tonnes).

China stated in its phase-out strategy that 2015 would be the last year in which salbutamol CFC MDIs would be manufactured, with the intent of providing sufficient product to allow salbutamol HFC and CFC MDIs to co-exist over a subsequent transition period of one year, and a complete phase-out of salbutamol CFC MDIs by December 31, 2016. Nevertheless, China continued to use CFCs to manufacture salbutamol MDIs in 2016. Among 12 manufacturers, 2 or 3 have been approved licenses to manufacture non-CFC MDIs, while others are waiting for approval. Salbutamol CFC MDIs make up the large majority of CFC demand in China (about 85 per cent of the 2015 nomination). Beclomethasone and other active ingredients make up the remainder of CFC demand for MDI manufacture. For beclomethasone and other active ingredients, China has stated in its phase-out strategy that 2016 would be the last year to manufacture CFC MDIs, with complete phase-out by 31 December 2017.

China used 120.65 tonnes CFCs for the manufacture of CFC MDIs in 2016, which implies through arithmetic that remaining CFC stockpile is 271.21 tonnes (assuming no destruction), although remaining stockpile is thought to be about 136 tonnes. Given recent consumption trends, China's estimated CFC stockpile at the end of 2016 could be equivalent to another 1-2 years supply (2017-2018). The quantity of CFCs in the stockpile may lead to:

- CFC MDIs being manufactured and supplied for longer than is projected by China's phase-out strategy or in quantities that might disrupt smooth transition; and/or

- The need for destruction of CFCs.

China has stated that its CFC manufacturer has made a commitment that all CFCs produced under the quota issued by the authorities will be used for MDI purposes only, and any remaining substances, if not used in MDI applications will be treated in an environmentally harmless way.

5.1.2.3 Russian Federation

Parties authorised an essential use exemption of 212 tonnes of CFCs to the Russian Federation for the manufacture of MDIs for 2014. The Russian Federation has not submitted any further nominations, in line with the announcement that its nomination for 2014 would be its last. An accounting framework was provided for 2015. At the end of 2015, 88.76 tonnes of CFCs were remaining in stockpile.

Russia is in the final stages of manufacturing conversion to HFC MDIs. Both Russian MDI manufacturers have developed and started sales of salbutamol HFC MDIs, but continue also to produce in parallel salbutamol CFC MDIs. CFC-based production was rather small in 2016, with some CFC inventory remaining at the end of 2016 to be used in salbutamol production in 2017. Both companies will use all of the remaining available CFCs for their MDI production.

5.1.3 Developments in the phase-out of ODS in medical aerosols, and sterilants

Available information indicates that hydrochlorofluorocarbon (HCFC) use in medical aerosols in China could be about 2,500 tonnes, using HCFC-22 and HCFC-141b. The complete phase-out of HCFCs in sterilization uses to meet the Montreal Protocol schedule is readily achievable.

5.2. Chemicals

5.2.1 Essential use nomination of CTC for laboratory and analytical uses ("testing of oil, grease and total petroleum hydrocarbons in water") by China for 2017

Quantities are expressed in metric tonnes.

Year	Controlled Substance	Quantity nominated
2018	CTC	65 tonnes

Specific Use: Laboratory and analytical uses for the testing of oil, grease and total petroleum hydrocarbons in water (hereinafter referred to as "oil in water").

Recommendation: Recommend

5.2.1.1 Introduction and background

China is requesting continued use of carbon tetrachloride (CTC) for laboratory and analytical uses for the testing of oil in water. Decision XXIII/6 specifies that after 31 December 2014, the use of CTC for the testing of oil in water would only be allowed under an essential use exemption. In accordance with this Decision, parties authorised essential use exemptions for China for 80 tonnes, 70 tonnes, and 65 tonnes of CTC for 2015, 2016, and 2017 respectively. China has nominated 65 tonnes of CTC for the testing of oil in water for 2018, a reduction of almost 20% from 2015.

Role in Society

The oil in water test that is a fundamental requirement in monitoring water quality in China observes the national standard *"HJ 637-2012 Water quality- Determination of petroleum oil, animal and vegetable oils- Infrared photometric method"*, in which CTC is used as the extracting agent to extract oil substances which are then determined with the infrared oil monitoring instrument. This method is capable of testing petroleum oil, animal and vegetable oils and total petroleum hydrocarbons, including long chain petroleum hydrocarbons, fatty acids, and aromatic hydrocarbons. The required detection limit for this method is 0.04mg/L.

Alternatives and alternative technologies options

The Ministry of Environmental Protection of China (MEP) has invited experts to conduct thorough research and assessment on the international oil in water test methods. In consideration of oil testing scope and detection limit, there is yet no alternative method to replace HJ 637-2012 standard in China.

Given the fact that this standard is so widely applied, it might be the best technical route to replace CTC with non-ODS substance as the extracting agent, and maintain the same infrared photometric method, keeping its testing scope and detection limit. Over two years of tests, research and analyses, the technical route to replace CTC with tetrachloroethylene (PCE) has been eventually determined, which requires the revision of the standard HJ 637-2012.

However, great challenges lie ahead in terms of reaching the detection limit of 0.04mg/L required by the standard HJ 637-2012. The method using PCE as the extracting agent has a detection limit of 0.1 mg/L.

China has also been promoting other non-ODS standards. *"Water quality- Determination of petroleum oil- Molecular fluorescence spectrometry (SL 366-2006)"* was released by the Ministry of Water Resources, which uses n-hexane as the extracting agent. *"The specification for marine monitoring Part 4: Seawater analysis (GB/T 17378.4-2007)"* was implemented in 2008, which is used to measure oil pollution in marine, offshore and estuary waters. The standard uses spectrofluorimetry, UV spectrophotometry and gravimetric method, and the extracting agents are petroleum ether and cyclohexane. The revision of two related standards on monitoring methods, *"Water quality- Determination of volatile petroleum hydrocarbons- Purge and Trap/Gas chromatography (C6-C9)*" and *"Water quality- Determination of extractable petroleum hydrocarbons- liquid-liquid extraction/Gas chromatography (C11-C40)*" started in April 2014. The above-mentioned standards were released for public consultation in March 2017 and are expected to be issued in 2017. China has encouraged different industries or departments to apply specific standards for water quality monitoring based on actual needs and to test the use of alternative substances, to reduce the use of the standard HJ 637-2012 and CTC emissions.

Steps to Minimize Use and Emissions

The described steps to minimize CTC usage and emissions look adequate, and the amount of recycled CTC increased recently from 20% to 30%.

5.2.1.2 Comments

MCTOC has reviewed the nomination for 65 tonnes of CTC for an essential use exemption for China for laboratory and analytical uses. MCTOC thanks China for its responses to the additional questions requested for clarification.

MCTOC also acknowledges that China has surveyed the international standards that are used globally for the measurement of varying levels of oil in water and do not use CTC.

MCTOC has reviewed the proposed alternative method of using purified tetrachloroethylene as a solvent for the analysis of oil in water. China is still in the process of establishing a method for the purification of tetrachloroethylene. Currently, China predicts that a revised new standard could be published in 2018, which is now one year later than the completion year proposed in 2016.

The need to remove stabilizers and other chlorinated impurities, that otherwise would interfere with the analysis, could result in the need to generate purified tetrachloroethylene to a specific standard prior to every analysis. MCTOC is concerned that this could lead to a double process with the potential to cause errors. One option, if efforts to purify tetrachloroethylene prove to be unsuccessful, could be for China to consider using tetrachloroethylene from other sources that are free from impurities. If requested, MCTOC can assist with advice on possible supply options. Another option could be for the chemical companies supplying tetrachloroethlyene to purify the bulk chemical prior to supplying it to laboratories, rather than the purification step being required by many laboratory end users. There could be cost considerations in installing the necessary distillation columns for the relatively small quantities required for analytical purposes.

The MCTOC further acknowledges that another ministry, that is the Ministry of Water Resources, has been promoting other non-ODS standards for water quality monitoring, some of which are under revision and due to be issued in 2017. MCTOC would like to ask MEP in China if these standards could be applied to the monitoring of oil in water, which is the subject of this nomination.

The MCTOC suggests that China continues to evaluate the possible use of currently available international or other national methods for the analysis of oil in water.

5.2.1.3 Conclusions

China is to be commended for its on-going efforts to find a non-ODS method for the analysis of oil in water.

MCTOC recommends that parties authorise an essential use exemption for China for 2018, and requests that China, provides information on:

1. **Progress in the development of its method, including the purification of tetrachloroethylene;**
2. **Progress with its studies of the purification of tetrachloroethylene and the associated required reagent stability (in September 2017);**
3. **Evaluation of available alternative sources of higher purity tetrachloroethylene;**
4. **Any further evaluations regarding the use of international or other national analytical methods;**
5. **Timelines for the phase-out of CTC in laboratory and analytical uses, indicating the anticipated steps and end date in that process.**

5.2.2 Status of CFC-113 produced under EUE for use as a solvent in aerospace applications

The Russian Federation was authorised an essential use exemption of 75 tonnes of CFC-113 for 2015 for solvents used in aerospace applications. In its reporting accounting framework, Russia reported that aerospace applications used 85 tonnes of CFC-113 in 2015, and 75 tonnes of CFC-113 remained at the end of that year. The Russian Federation reported previously it would phase out the use of CFC-113 used as a cleaning solvent in aerospace applications at the end of 2016. The Russian Federation will continue to use CFC-113 from its stockpile until depleted. In these applications, CFC-113 is recovered and recycled. The Russian Federation enterprises do not anticipate requesting future essential use production for this application, and will move to alternatives as its stockpile is depleted.

The Russian Federation has eliminated most of the uses of CFC-113 by using a variety of alternative solvents and cleaning agents in its aerospace applications, including aqueous detergents, organic solvents, chlorinated solvents, and HCFCs. MCTOC understands that alternatives to HCFCs, including HFCs, are also currently being considered and tested for aerospace applications. MCTOC does not know whether HCFCs will be required in the Russian Federation after the 2020 HCFC phase out date in non-Article 5 parties. Any HCFC production for these uses after 2020 would need to satisfy the essential use criteria established in Decision IV/25, and be duly authorised by parties.

5.2.3 Decisions XVII/6(6) and XXII/8(5): Review of information submitted by parties on the use of controlled substances as process agents

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

"That all Parties should:

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

"To request Parties with process-agent uses to submit data to the TEAP by 31 December 2007 and 31 December of each subsequent year on opportunities to reduce emissions listed in table B and for the TEAP to review in 2008, and every other year thereafter, emissions in table B of decision X/14, taking into account information and data reported by the Parties in accordance with that decision, and to recommend any reductions to the make-up and maximum emission on the basis of that review. On the basis of these recommendations, the Parties shall decide on reductions to the make-up and maximum emissions with respect to table B."

China, the European Union, Israel, and the United States submitted information about their process agent uses in accordance with the above decisions. MCTOC has reviewed this information submitted by these parties on their use of controlled substances as process agents, quantities produced or imported for process agent applications, on make-up, levels of emissions, and containment technologies to minimise emissions for those uses.

Tables A and B summarise the data submitted. It is noted that several parties are no longer reporting data for certain process agent uses, indicative that these processes are no longer in use in these parties (see Table A below).

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

Table A: List of uses of controlled substances as process agents[3]

No.	Process agent application Decision XXVII/7	Substance	Permitted Parties Decision XXIII/7	Parties that reported data for 2015	Parties no longer reporting for that use
1	Elimination of NCl_3 in chlor-alkali production	CTC	European Union, Israel, United States of America	European Union, Israel, United States of America	
2	Chlorine recovery by tail gas absorption in chlor- alkali production	CTC	European Union, United States of America	European Union, United States of America	
3	Production of chlorinated rubber	CTC	European Union	European Union	
4	Production of chlorosulfonated polyolefin (CSM)	CTC	China, United States of America	China	United States of America
5	Production of aramid polymer (PPTA)	CTC	European Union	European Union	
6	Production of synthetic fibre sheet	CFC-11	United States of America	United States of America	
7	Photochemical synthesis of perfluoropolyetherpolyperoxide precursors of Z-perfluoropolyethers and difunctional derivatives	CFC-12	European Union	European Union	
8	Preparation of perfluoropolyether diols with high functionality	CFC-113	European Union	European Union	
9	Production of cyclodime	CTC	European Union	European Union	
10	Production of chlorinated polypropene	CTC	China		China
11	Production of chlorinated ethylene vinyl acetate (CEVA)	CTC	China		China
12	Production of methyl isocyanate derivatives	CTC	China, Israel		China, Israel
13	Bromination of a styrenic polymer	BCM	United States of America	United States of America	
14	Production of high modulus polyethylene fibre	CFC-113	United States of America	United States of America	

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[3] Table A was last updated in 2011 with Decision XXIII/7: Use of controlled substances as process agents. The table shows Dec. XXIII/7 Tables A alongside the reported information received from parties for the year 2015.

Table B: Limits for process agent uses (all figures are in metric tonnes per year)[4]

Party	**Make-up or consumption Decision XXIII/7**	**Maximum emissions Decision XXIII/7**	**Reported make-up or consumption for 2015**	**Reported emissions for 2015**
China	1,103	313	179.84	106.46
European Union	1,083	17	283.313	6.414
Israel	3.5	0	1.8	0.0617
United States of America	2,300	181	Not reported	33.2
Total	4,489.5	511	*[464.953]**	146.1357

*Nominal totals for 2015, which exclude data not reported.

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[4] Table B was last updated in 2011 with Decision XXIII/7: Use of controlled substances as process agents. The table shows Dec. XXIII/7 Tables B alongside the reported information received from parties for the year 2015.

Table 5.1 Historic data reported by parties on process agent applications on associated make-up or consumption and emissions

Party	**Reported make-up or consumption**						
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Brazil	0	-	-	-	-	-	-
China	313	179.3	179.92	179.24	88.92	178.44	179.84
Colombia	-	0.64	-	-	-	-	-
European Union	669	1116.231	954.42	547.178	622.101	508.741	283.313
Israel	2.4	2.4	-	3.6	2.4	2.4	1.8
Mexico	-	40.9954	-	-	-	-	-
United States of America	-	-	-	-	-	-	-
Total	*984.4**	*1339.5664**	*1134.34**	*730.018**	*713.421**	*689.581**	*464.953**

*Nominal totals, which exclude data not reported.

Party	**Reported emissions**						
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Brazil	0	-	-	-	-	-	-
China	-	179.3	179.2	179.24	52.64	105.63	106.46
Colombia	-	-	-	-	-	-	-
European Union	1.6	1.287	116.428	27.192	15.808	7.338	6.414
Israel	0	-	-	-	0.000038	0.1794	0.0617
Mexico	-	40.9954	-	-	-	-	-
United States of America	47.1	59.79	44.35	34.63	34.5	34.1	33.2
Total	48.7	281.3724	339.978	241.062	102.9480	147.2474	146.1357

5.2.3.1 Progress made in reducing emissions from process agent uses

The information reported in Table 5.1 demonstrates that the quantities of ozone depleting substances emitted from the reported processes have stabilised over the past two years and are significantly less than the maximum quantity of emissions contained in Decision XXIII/7 (511 tonnes). This downward trend can be a result of a reduction in the number of processes using ozone-depleting substances as process agents or implementation of improvements in the processes to further reduce emissions.

5.2.3.2 Associated make-up quantity of controlled substances

The information reported in Table 5.1 demonstrates that the total reported make-up or consumption quantities of ozone depleting substances used for the reported processes decreased from 2014 to 2015. This excludes information on make-up or consumption in the United States, which is not reported for these years. For the parties reporting (China, the EU and Israel), the quantities of make-up/consumption of controlled substances reported for 2015 (464.953 tonnes) are significantly less than the maximum quantity of make-up/consumption contained in Decision XXIII/7 for those parties (2,189.5 tonnes). This downward trend can be a result of a reduction in the number of processes using ozone-depleting substances as process agents or implementation of improvements in the processes.

5.2.3.3 Implementation and development of emissions-reduction techniques

For the process of removing NCl_3 from chlorine, Israel has noted in its submission that it uses compression and purification systems obtained from Krebs Swiss and has continuous chlorine analysers that activate the safety interlockers system when the chlorine concentration in the air is 0.5 ppmv. China has noted that it uses a CTC/chloroform mixture in its CSM process. MCTOC notes that under certain conditions this procedure can also generate CTC *in situ*. The United States has provided a list of technologies used to control emissions of ODS[1]. No information has yet been received from the European Union on the implementation of emissions-reduction technologies in 2015.

5.2.3.4 Alternative processes and products not using ozone-depleting substances

No information has been received from the reporting parties on the implementation of alternative processes and products not using ozone-depleting substances. MCTOC is not aware of any new information and would welcome further input from parties if available. For example, for those parties no longer reporting the use of a controlled substance as a process agent, MCTOC would welcome information on how this was accomplished in those specific cases.

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

5.2.3.5 Recommendations on Process Agents

In response to the following decisions, the TEAP has prepared the following recommendations.

Decision XVII/6(6) requests,

> *"...the TEAP and the Executive Committee to report to the Open-ended Working Group at its twenty-seventh meeting in 2007, and every other year thereafter, unless the Parties decide otherwise, on the progress made in reducing emissions of controlled substances from process-agent uses; the associated make-up quantity of controlled substances; on the implementation and development of emissions-reduction techniques and alternative processes and products not using ozone-depleting substances*;" and

Decision XXII/8(5) requests,

> *"...the TEAP, beyond the reporting and assessment in respect of process agent uses requested for 2011, to review in 2013, and every second year thereafter, progress made in reducing process agent uses and to make any additional recommendations to parties on further actions to reduce uses and emissions of process agents;"*

Recommendations:

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

1. **Removing the following process agent uses from Table A of Decision XXII/7:**
    - **Production of chlorinated polypropene**
    - **Production of chlorinated ethylene vinyl acetate (CEVA)**
    - **Production methyl isocyanate derivatives**
2. **Updating and removing previously permitted uses of controlled substances as process agents in certain Parties from Table A of Decision XXVII/7, as indicated by information no longer reported for 2014 and 2015:**
    - **United States of America for production of chlorosulfonated polyolefin (CSM)**
3. **Reducing the quantities of make-up/consumption and maximum emissions levels contained in Table B of Decision XXIII/7 to take into account the currently reported process agent uses and emissions, noting that the United States of America has not reported make-up/consumption.**

Furthermore, in order to understand better the remaining eleven process agent applications, Parties may wish to consider revisiting and updating their information on the use of controlled substances as process agents and by the end of 2017, in time for MCTOC to report next under Decision XVII/6 in early 2018, provide the Secretariat with information on:

- **Current technology used**
- **Technology used for reducing emissions**
- **Actual emissions**
- **Alternatives available for replacing controlled substances in these processes.**

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

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

No applications were submitted under this decision for TEAP assessment.

5.2.5 Use of controlled substances for chemical feedstock

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

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

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

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

5.2.5.1 How the ODS feedstock is used

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

Table 5.2 shows common feedstock applications, although the list is not exhaustive. Parties report amounts of ODS used as feedstock to the Secretariat but not how they are used. Processes are proprietary and there is no official source to define the manufacturing routes followed and their efficacy. The table provides some examples and is the product of the collective experience and knowledge of MCTOC members. Products included are both intermediates as well as final products, including fluoropolymers.

The original fluorochemicals used for refrigerants, aerosols and blowing agents were CFC-11 and CFC-12. It is of great significance to note that production of these CFCs from CTC is now zero, reflecting the success of Montreal Protocol efforts in the total phase-out of their production. The fluorochemical industry is now producing a fourth generation of products as they transitioned from CFCs to HCFCs to HFCs, and now to hydrofluoroolefins (HFOs). Some HFOs utilise CTC as a starting material: these new products are short-lived (days of atmospheric lifetimes rather than decades or centuries), have zero ODP, and GWPs in single digits.

Table 5.2 Common feedstock applications of ozone-depleting substances (this list is not exhaustive)

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

5.2.5.2 Trends in feedstock uses of ozone-depleting substances

Parties report the use of ODS as feedstock to the Ozone Secretariat. Data have been provided to the MCTOC by the Ozone Secretariat on production, import and export of ODS used as feedstock for the year 2015. These also include quantities used as process agents because parties are required to report such consumption in a manner consistent to that for feedstock. Detailed information can be found in Table 5.3, as provided by UNEP.

For 2015, a total of 17 parties reported use of ODS as feedstock, while 14 of these parties were also producers of ODS for these uses. In 2014, 14 parties reported use of ODS as feedstock.

In 2015, total production for feedstock uses was 1,084,101 tonnes, representing a total of 375,488 ODP tonnes. Overall use of ODS as feedstock decreased by 10.3% (81,578 metric tonnes) compared with 2014, with a corresponding decrease of 17.2% in ODP tonnes.

The largest feedstock uses are HCFC-22 (48.0% of the total quantity), CTC (19.7%), and HCFC-142b (11.0%). The feedstock use of HCFC-22 has decreased by 3.2% from 2014. The majority of HCFC-22 feedstock use is for the production of tetrafluoroethylene (TFE), which can be both homo- and co-polymerized to make stable, chemically resistant fluoropolymers with a myriad of end uses. TFE can also be used as raw material for producing HFC-125, especially in China. With HFC-125 production moving to the perchloroethylene process, which is more competitive than the TFE process, TFE use for this feedstock has decreased and this then would also lead to a decrease in feedstock use of HCFC-22. CTC used as feedstock decreased by 0.1%, where CTC is used to build intermediates, which are in turn used for HFCs and HFO production.

Production of CFC-113 decreased by a significant 53.4%, which would, in the absence of other information, suggest a possible decrease in polymer production, feedstock use of CFC-113a as an intermediate for trifluoroacetic acid and pesticide production, and HFC production, assuming that reporting is complete. When the data was queried, it was learnt that one producer, which is also a user, chose not to produce CFC-113 during 2015 but instead to operate by reducing in-house inventories. It is likely that data for CFC-113 from earlier years were suggesting higher annual usage than was actually used for feedstock, when instead inventory was increased. The total consumption (production plus import minus export) for 2015 now likely understates actual usage for that year. These annual mismatches even out over longer time periods.

Other significant ODS feedstock also experienced reductions over the previous year. While the total use of ODS as feedstock decreased by 10%, the corresponding ODP tonnes decreased by 17.2% because the mix of ODS contributors tended toward lower ODP values.

Table 5.3 Amount of ODS used as feedstock in 2015

Substance	**ODP**	**Tonnes**	**ODP Tonnes**
CFC-11	1	0	0
CFC-12	1	0	0
CFC-113	0.8	62,196	49,756
CFC-114	1	25,141	25,141
Carbon Tetrachloride	1.1	213,893	235,282
Methyl Chloroform	0.1	85,122	8,512
Halon-1211	3	0	0
Halon-1301	10	871	8,710
HBFC-21B2	1	6	6
HBFC-31B1	0.73	5	3.7
HBF-22B1	0.74	1	0.7
Methyl Bromide	0.6	4,072	2,443
Bromochloromethane	0.12	1,414	170
HCFC-22	0.055	519,891	28,594
HCFC-123	0.02	5,396	324
HCFC-124	0.022	32,756	7,206
HCFC-141b	0.11	12,388	1,363
HCFC-142b	0.065	119,084	7,741
HCFC-31	0.02	0	0
Total		1,084,101	375,488

Figure 5.1 shows quantities of controlled substances imported or produced for feedstock uses from 2002 to 2015 based on Article 7 data reporting by parties. These data indicate a general upward trend in feedstock uses of controlled substances in the last decade, with production/importation of Annex CI substances increasing, and a slight decreasing trend in Annex AI substances. Figure 5.2 shows the number of parties reporting this data for each year, which indicates a general downward trend over the period. The Ozone Secretariat is credited for providing the data presented in these figures.

Figure 5.1 Quantities of controlled substances produced or imported for feedstock uses[6]

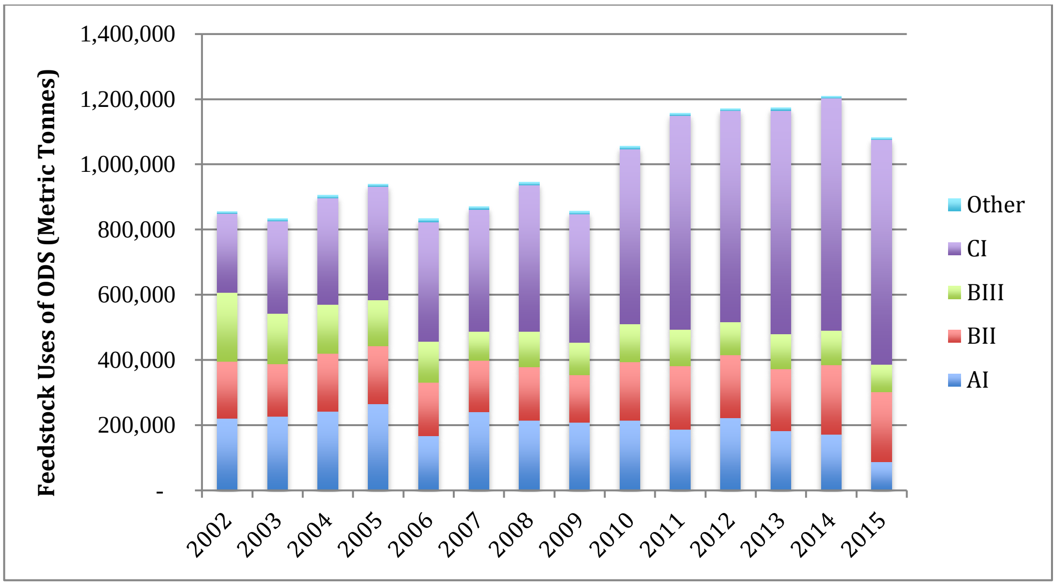
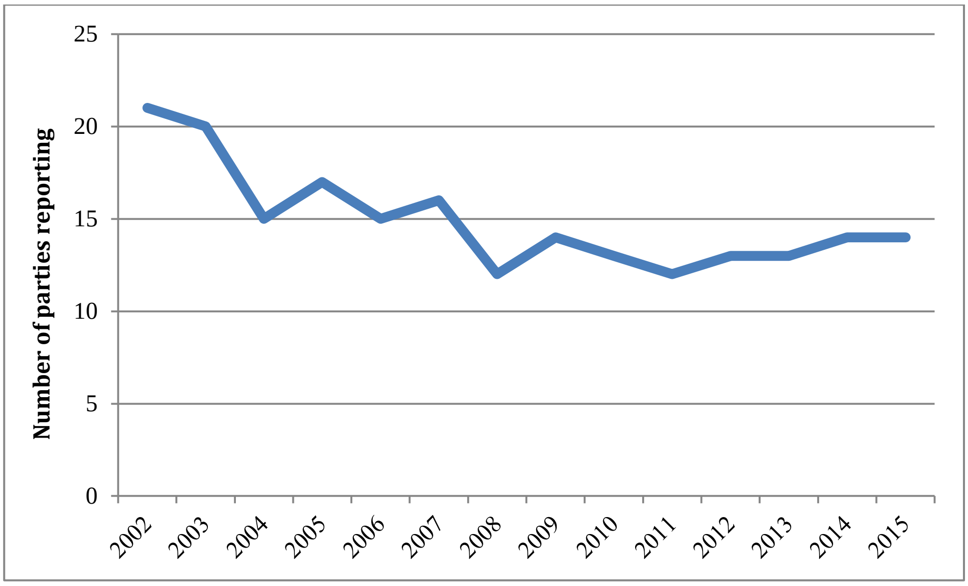


Figure 5.2 Number of parties reporting production or importation of controlled substances for feedstock uses



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[6] Annex AI CFCs -11, -12, -113, -114, -115; Annex BII carbon tetrachloride; Annex BIII 1,1,1 trichloroethane; Annex CI HCFCs. "Other" includes 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.

5.2.5.3 Estimated emissions of ODS

Emissions are not reported by parties, and the estimation of ODS emissions is inexact. The sophistication of the operating facility can heavily influence emission levels. Highly automated, tight and well-instrumented facilities with proper, closely observed, procedures can have ODS emission levels as low as 0.1% of the ODS amount used as feedstock. At the other extreme, batch processes of limited scale with less tight facilities, with less concern for operational excellence, could have emission levels up to 5% of the ODS amount used as feedstock. The largest volumes of feedstock use are likely to be at the least emissive end of the scale because large capacity plants have the most investment and are better able to control emission levels. The higher emissions levels are based on industry input and anecdotal experience, with no citable references.

For the purpose of compiling national greenhouse gas inventories, the Intergovernmental Panel on Climate Change (IPCC) recommends an emissions factor for HFCs from their manufacture of 0.5%.[7] There is no similar international technical consensus for estimating ODS emissions associated with ODS feedstock uses, however, the chemicals, operational processes, and emissions abatement technologies involved are very similar and can be considered technically analogous to those for HFC production. In order to generate some indicative estimations of ODS emissions, the IPCC emission factor of 0.5% for HFC production has been applied as a surrogate for ODS used as feedstock. Using this surrogate emission factor, for guidance purposes only, estimated emissions associated with ODS feedstock and process agent uses in 2015 can be calculated as 5,421 tonnes, or 1,877 ODP tonnes.

Data compiled by the European Environment Agency (EEA) from reports by companies under the European ODS Regulation show that 154,542 metric tonnes (43,564 ODP tonnes) of ODS were produced for feedstock use within the EU in 2015[8]. Total emissions of feedstock were quoted as 116 metric tonnes, an emission factor of 0.07%. The emissions are less than half of the quantities reported in the European Pollutant Release and Transfer Register[9] from chemicals manufacture, which totalled 251 metric tonnes (26 tonnes of carbon tetrachloride, 5 of methyl chloroform, 36 of CFCs and 185 of HCFCs) but these include *all* emissions from *all* chemical manufacturers in the EU. Nevertheless, the relatively low rate of emissions achieved in the EU illustrates the effectiveness of local regulation and oversight, and industrial diligence, in the management and control of ODS emissions in feedstock uses.

The SPARC Report on the Mystery of Carbon Tetrachloride, a project of the World Climate Research Programme, was completed in July 2016[10]. This report estimates "reasonable

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

[8] Ozone-depleting substances 2015, Aggregated data reported by companies on the import, export, production, destruction, and feedstock and process agent use of ozone-depleting substances in the European Union, European Environment Agency Report No 19/2016, Luxembourg: Publications Office of the European Union, 2016, doi:10.2800/175145.

[9] European Pollutant Release and Transfer Register (E-PRTR), available at http://prtr.ec.europa.eu/, accessed February 2017.

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

emission factors” for reporting of production for feedstock use is 0.5-2.0%. The lower bound is consistent with the IPCC emission factor of 0.5% for HFC production that has been applied by MCTOC as a surrogate for ODS used as feedstock. Using the SPARC emissions factors, the range of emissions from feedstock uses for 2015 can be estimated as 5,421 to 21,682 tonnes, or 1,877 to 7,510 ODP tonnes.

5.2.5.4 How to minimize ODS feedstock emissions

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

Producers can follow specifically defined responsible use practices, which, *inter alia*, define equipment to control processes, closed-loop loading and recovery, and thermal destruction of vapour emissions. It is considered by MCTOC experts that, when strictly followed, these responsible use practices can limit ODS emissions to about 0.1% of the ODS amount used as feedstock in continuous processes, while less responsible operation, and batch processes, can lead to emissions as high as 5% of feedstock quantities.

Close cooperation between producers and regulators can continue to make these operations safe and environmentally sustainable.[11]

5.2.6 Solvent uses of ODS

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

5.2.7 n-Propyl bromide

n-Propyl bromide (1-bromopropane, $CH_3CH_2CH_2Br$, n-PB, CAS No. 106 94 5) is being used as a solvent in a range of applications. Its boiling point, 71°C, is comparable to that of CFC-113 (48°C), hexane (69°C), methyl chloroform (TCA, 74°C) and trichloroethylene (87°C), making it potentially attractive as a solvent with similar physical properties. Its solvent properties are typical of those of lower molecular weight hydrocarbons and organohalogen compounds. Due to the presence of bromine in the molecule, however, concerns have been expressed based both on its potential for ozone depletion and its toxicity. The atmospheric lifetime, and impact on ozone depletion, of *n*-propyl bromide have been evaluated in several studies, with derivations dependent on emissions location. In 2011, using a current-generation chemistry-transport model of the troposphere and stratosphere, Wuebbles *et al*. derived an atmospheric chemical lifetime of 19.6 days, and ODP of 0.011, for the global emissions case,

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[11] More information on responsible use practices can be found on the website of the Alliance for Responsible Atmospheric Policy at www.arap.org under Responsible Use Principles and Best Practices.

and 24.7 days, and an ODP of 0.0049 at northern hemisphere mid-latitudes[12]. *n*-Propyl bromide is not a controlled substance under the Montreal Protocol.

Regarding its toxicity, the National Toxicology Program report (NTP TR 564, August 2011) and the American Conference of Governmental Industrial Hygienists (ACGIH®) (February 2012) established a threshold limit value (TLV®) for *n*-propyl bromide of 0.1 ppm. In 2013, a peer-reviewed Draft Report on Carcinogens prepared by the U.S. National Toxicology Program concluded that *n*-propyl bromide is reasonably anticipated to be a human carcinogen[13]. In 2014, ACGIH published a time weighted average exposure limit (TWA) of 0.1ppm for *n*-propyl bromide. The Japan Society for Occupational Health set a TLV of 0.5ppm for *n*-propyl bromide in 2013.

The European Chemical Agency (ECHA) has classified *n*-propyl bromide as a Substance of Very High Concern (SVHC) and included it in the candidate list for authorisation, published in accordance with Article 59(10) of the REACH Regulation. This is the first step of the authorisation procedure, which aims to assure that the risks from SVHCs are properly controlled and progressively replaced by suitable alternatives. After a two-step regulatory process, SVHCs may be included in the Authorisation List and become subject to authorisation, meaning they cannot be placed on the market or used after a given date, unless an authorisation is granted for their specific use, or the use is exempted from authorisation. Companies may have legal obligations following such inclusion on the candidate list that are linked to the listed substance. According to the harmonised classification and labelling (CLP00) approved by the European Union, *n*-propyl bromide "*...may damage fertility and may damage the unborn child, is a highly flammable liquid and vapour, causes serious eye irritation, may cause damage to organs through prolonged or repeated exposure, causes skin irritation, may cause respiratory irritation and may cause drowsiness or dizziness*". In addition, the classification identifies that n-propyl bromide "*...is suspected of causing cancer and is harmful to aquatic life with long lasting effects*".[14]

n-Propyl bromide has been identified as one of ten chemicals designated by US EPA for further assessment (chemical risk evaluation) under the Toxic Substances Control Act (TSCA), based on high hazard concerns due to its toxicity profile and high exposure concerns due to its use in consumer products. TSCA requires US EPA to publish Final Scope documents for the initial ten chemicals undergoing risk evaluation by June 19, 2017 as part of a public consultation process. The scoping document will include information about each chemical substance, such as conditions of use, exposures, including potentially exposed or susceptible subpopulations, and hazards, that US EPA expects to consider in the risk evaluation. TSCA requires that these chemical risk evaluations be completed within three years of initiation (from December 19, 2016 for *n*-propyl bromide), allowing for a single 6-month extension.

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

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

[14] European Chemicals Agency (ECHA), Brief Profile of *n*-propyl bromide, available at https://echa.europa.eu/brief-profile/-/briefprofile/100.003.133, accessed April 2017.

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

The relatively low workplace exposure standards indicate that use of *n*-propyl bromide in solvent applications is likely to be problematic, and its use will likely be limited to applications where worker exposure is controlled and will require significant emission control.

Nevertheless, *n*-propyl bromide continues to appear as a marketed solvent at trade exhibitions with demand in a number of markets (e.g. China, Japan and the United States). Consumption of *n*-propyl bromide is as an electrical cleaning agent, degreaser or carrier solvent, as an intermediate in chemical manufacture, in spray adhesives, dry cleaning, insulation, and as a refrigerant flushing agent. *n*-Propyl bromide has also appeared in consumer aerosol cans as electronics cleaning and degreasing products, as adhesive products, as textile spot removers, and as paintable mould release agents.

Manufacture is occurring in a small number of countries, including China, Israel and the United States. Chemical manufacturers do not publicise their *n*-propyl bromide production data for commercial reasons. Parties to the Montreal Protocol are not required under Article 7 to report the production and consumption *n*-propyl bromide because it is not a controlled substance. China has estimated production capacity of about 10,000 tonnes per year, consumes (about 3-4,000 tonnes per year), and exports (about 5,000 tonnes) to other markets. The United States manufactured and imported about 8,500 tonnes in 2012, and nearly 12,000 tonnes in 2015[15]. Japan imported about 4,000 tonnes in 2014. The European Union imported about 2,000 tonnes, with maximum production of 3,600 tonnes. Information was not available for Israel.

Parties may wish to consider providing MCTOC with production data for n-propyl bromide in order that global production quantities could be collated and reported.

5.2.8 Laboratory and analytical uses of ODS

Decision XV/8(2) requests TEAP *"...to report annually on the development and availability of laboratory and analytical procedures that can be performed without using the controlled substances in Annexes A, B and C (group II and group III substances) of the Protocol"*. A later decision XXVI/5(2) also requests TEAP *"...to report no later than 2018 on the development and availability of laboratory and analytical procedures that can be performed without using controlled substances under the Montreal Protocol"*. In light of decision XXVI/5(2), and the challenges in reporting annually on this topic, MCTOC will instead focus its resources and activity towards completing a report in 2018, as requested.

MCTOC wishes to bring to the attention of parties that it is seeking new members who are experts in laboratory and analytical uses. Parties may wish to consider nominating experts.

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

5.2.8.1 Laboratory and analytical uses of methyl bromide

Decision XVII/10(8) requests TEAP *"... to report in 2007 and every other year thereafter on the development and availability of laboratory and analytical procedures that can be performed without using the controlled substance in Annex E (methyl bromide) of the Protocol."*

Decision XVIII/15 authorizes the production and consumption of methyl bromide necessary to satisfy laboratory and analytical critical uses subject to the conditions applied to the exemption for laboratory and analytical uses contained in annex II to the report of the Sixth Meeting of the Parties, and adopts a category of laboratory and analytical critical use to allow methyl bromide to be used:

(a) As a reference or standard:

    (i) To calibrate equipment which uses methyl bromide;

    (ii) To monitor methyl bromide emission levels;

    (iii) To determine methyl bromide residue levels in goods, plants and commodities;

(b) In laboratory toxicological studies;

(c) To compare the efficacy of methyl bromide and its alternatives inside a laboratory;

(d) As a laboratory agent which is destroyed in a chemical reaction in the manner of feedstock;

In consultations with the MBTOC and MCTOC, TEAP believes that the current usage of methyl bromide as a reference or standard, in laboratory toxicological studies, and for comparison of methyl bromide and its alternatives inside a laboratory, is likely to be minor, possibly in the kilograms range globally. The likelihood of significant amounts (or any amounts) used this way has diminished as there are very few trials done on methyl bromide, with fewer on insect mortality studies and laboratory emission studies with barrier films. There is a possibility that these amounts, especially for insect mortality studies, could increase slightly if QPS uses were controlled further under the Montreal Protocol although the global quantities would remain very small.

Methyl bromide can also be used in a laboratory as a methylating agent in chemical reactions to deliver a methyl group to a chemical substrate. This application is also believed to be very minor. There are many alternatives to using methyl bromide as a methylating agent (see Annex 1). These alternatives are nearly always used in preference to methyl bromide. Methyl bromide is a toxic gas, which limits greatly its practicality in this application.

When compared with the quantity of methyl bromide still used in QPS (11,000 tonnes), in critical uses (628 tonnes), and in feedstock uses (4,072 tonnes in 2015), these laboratory and analytical uses of methyl bromide are minor.

In conclusion, there is a wide range of alternatives available for methyl bromide when used as a methylating agent, and an insignificant volume of methyl bromide used in this and other laboratory and analytical applications. TEAP plans to report further on this topic if and when parties make available new and different information.

5.2.9 Carbon tetrachloride emissions

Following the 2016 report by the World Climate Research Programme, under its Stratosphere-Troposphere Processes and Their Role in Climate (SPARC) project, entitled "The Mystery of Carbon Tetrachloride" [16], and the subsequent report by the TEAP and the Scientific Assessment Panel in response to decision XXVII/7 on an analysis of the discrepancies between observed atmospheric concentrations and reported emissions data on carbon tetrachloride, the "research direction suggestions" of the SPARC report were forwarded to the Ozone Research Managers of the Vienna Convention in March 2017 for consideration. This meeting agreed the need for further studies to refine the various loss processes contributing to the lifetime of CCl4 (stratosphere, ocean, and soil), along with studies to better define emissions sources.

The SPARC report analysed potential sources of emissions of carbon tetrachloride and estimated their magnitudes. Globally, it is estimated that 25,000 tonnes/year are emitted; regional contributions are 4,000 tonnes/year from the United States and 2,200 tonnes/year from the European Union. It is apparent that most of the global emissions are unreported (23,000 tonnes, or more than 90%): either inadvertent emissions from activities involving chlorine and leakage from old landfill (estimated to total 10,000 tonnes/year) or unreported emissions from industrial processes, including waste treatment (estimated at 13,000 tonnes/year).

5.2.10 Destruction technologies

MCTOC wishes to bring to the attention of parties that it is seeking new members who are destruction technology experts. Parties may wish to consider nominating experts.

In addition, in preparation for future work, including its 2018 Assessment Report, parties may wish to consider providing any relevant new information on destruction technologies to MCTOC.

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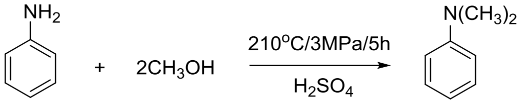
[16] SPARC (2016), SPARC Report on the Mystery of Carbon Tetrachloride. Q. Liang, P.A. Newman, S. Reimann (Eds.), SPARC Report No. 7, WCRP-13/2016.

Annex 1: Summary of methylating agent alternatives to methyl bromide

Methyl bromide (MB) can be used in a laboratory as a methylating agent in chemical reactions to deliver a methyl group to a chemical substrate. This application is believed to be very minor. There are many alternatives to using methyl bromide as a methylating agent. A summary of alternative methylating agents is presented below. These alternatives are nearly always used in preference to methyl bromide.

1.1 Methylating agent used under acidic conditions (methanol, dimethyl ether, dimethylaniline)

Methanol, dimethyl ether and dimethylaniline are very weak methylating agents. In the case of acidic conditions (Brønsted or Lewis acid), they methylate active amines and carboxylic acids as nucleophiles. Many of these reactions require the use of special catalyst or an autoclave.[2]



1.2 Methylating agent used under basic conditions

1.2.1 Methyl halide

1.2.1.1 Methyl Iodide, MeI

Methyl iodide is an excellent substrate for SN_2 substitution reactions. It is sterically open for attack by nucleophiles, and iodide is a good leaving group. It is used for alkylating carbon, oxygen, sulfur, nitrogen, and phosphorus nucleophiles.[3] The iodide leaving group in MeI may cause side reactions, as it is a powerful nucleophile. Being highly reactive, MeI is more toxic and carcinogenic than other methyl halides.

1.2.1.2 Methyl Chloride, MeCl

Chloromethane is employed as a methylating agent attacking C-, O-, N-, P-, S-, Se-, and Te-based nucleophiles; organometallic derivatives provide source of $Me^{\delta-}$ in reactions with >C=O, M–X, halogen, etc., and also as a base towards C–H; radical substitution of Me by C•, halogen, etc. The reactivity of methylation is lower than methyl iodide and methyl bromide.[4]

1.2.2 Methyl ester

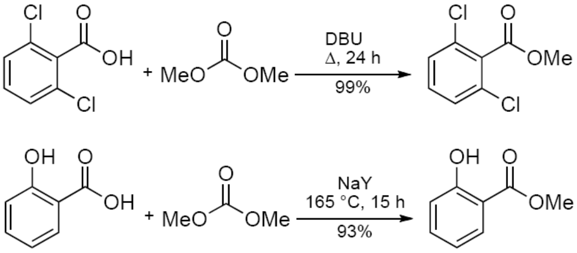
1.2.2.1 Dimethyl sulfate, DMS

Dimethyl sulfate is best known as a powerful reagent for the methylation of phenols, amines, and thiols. Typically, one methyl group is transferred more quickly than the second. Methyl transfer is typically assumed to occur via an SN_2 reaction.[5] Compared to other methylating agents, dimethyl sulfate is preferred by the industry because of its low cost and high reactivity.

1.2.2.2 Dimethyl carbonate, DMC

Dimethyl carbonate methylates anilines, phenols and carboxylic acids. It has been shown to be a safe and environmentally friendly replacement for DMS and methyl halides. But it is a relatively weak methylating agent compared to those traditional reagents.[6] In the presence of

K_2CO_3 or DBU it is more reactive. The reagent also methylates phenols but can be chemoselective for acids in the presence of NaY Faujasite.



1.2.2.3 *Methyl trifluoromethansulfonate, MTFS*

Methyl trifluoromethansulfonate is a powerful methylating reagent (about four orders of magnitude more reactive than methyl iodide and Me_2SO_4). It alkylates faster and with wider range of substrates than traditional methylating agents. One ranking of alkylating agents is $(CH_3)_3O^+ >$ MTFS ≈ MFS $> (CH_3)_2SO_4 > CH_3I$. It will alkylate many functional groups that are only weakly basic such as aldehydes, amides, and nitriles. It does not methylate benzene or the bulky 2,6-di-tert-butylpyridine.[7]

1.2.2.4 *Methyl fluorosulfonate, MFS*

Methyl fluorosulfonate is closely related to methyl trifluoromethansulfonate.[7]

1.2.2.5 *Methyl methanesulfonate, MMS*

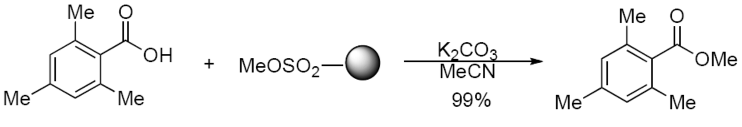
Methyl methanesulfonate is an exogenous alkylating agent and a carcinogen in biological research. It is also a suspected reproductive toxicant, and may also be a skin/sense organ toxicant. It is used in cancer treatment.[8]

1.2.2.6 *Trimethyl phosphate, TMP*

Trimethyl phosphate is a mild methylating agent for the preparation of methyl esters of hindered carboxylic acids and serves as an alternative to toxic Dimethyl Sulfate. It can also effect the *O*-methylation of unprotected amino acids, dimethylation of anilines and related heterocyclic compounds (purine, pyrimidine, imidazole et al.).[9]

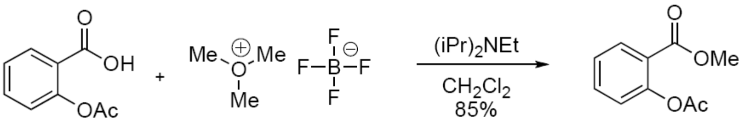
1.2.2.7 *Polymer-bound methyl sulfonate*

Instead of the sulfonate esters, modern alternative is to use polymer-bound methyl sulfonate, which is easily handled, allows simple work-up and is recyclable.[10]



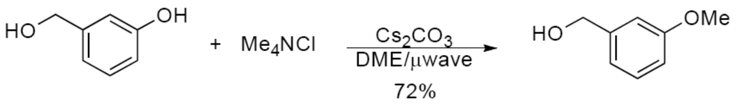
1.2.3 Oxonium salts (Me3O•BF4)

In aqueous conditions, it is possible to use Meerwein methylation, using the corresponding oxonium salts ($Me_3O•BF_4$) with $NaHCO_3$. However, these salts are rapidly hydrolyzed in water. A better procedure with these reagents is to use dichloromethane as solvent and a bulky amine as base. Under these conditions, even sterically hindered or sensitive acids can be alkylated.[11]



1.2.4 Tetramethylammonium salts

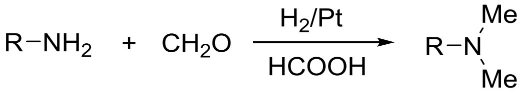
Tetramethylammonium salts are other replacement alkylating agents which are non-volatile and non-carcinogenic. However, due to their lower reactivity, high temperatures (such as the injection port during a gas chromatographic analysis) are required. For the alkylation of phenols, microwave conditions have been used with success. The reaction is chemoselective for the phenolic hydroxyl group over the alcohol.[12]



1.3 Methylating agent used under neutral conditions

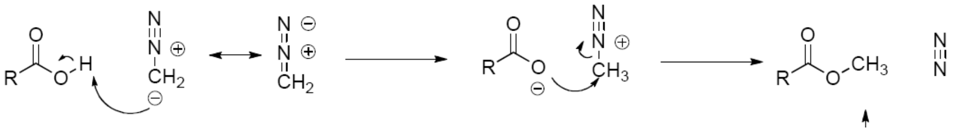
1.3.1 Formaldehyde aqueous solution

Formaldehyde aqueous solution can be used in methylation of primary or secondary amine (Eschweiler–Clarke reaction). Formic acid or H_2/Pt is also needed as the source of hydride. This reaction will not produce quaternary ammonium salts, but instead will stop at the tertiary amine stage.[13]



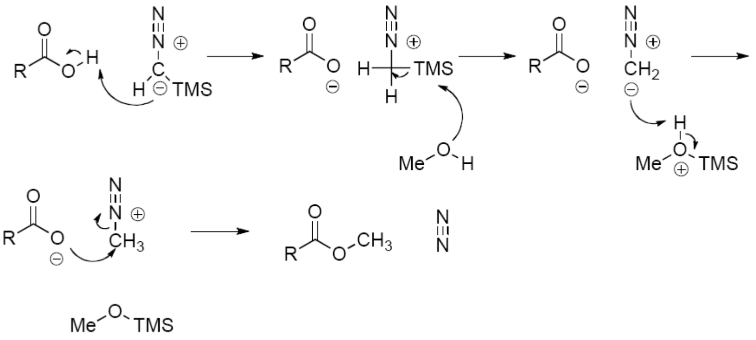
1.3.2 Diazomethane

The methylation of carboxylic acids and other acidic functional groups is often carried out in neutral conditions using diazomethane (CH_2N_2).[14] However, due to its toxicity and the explosive nature of diazomethane (as well as the danger in the preparation and the carcinogenicity of the commercially available precursors), several alternative reagents recently have been developed.

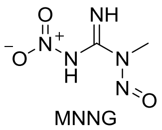


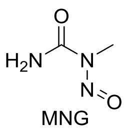
1.3.3 Trimethylsilyldiazomethane, TMSCHN2

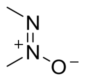
Trimethylsilyldiazomethane (TMSD) has been touted as a stable and safe alternative to diazomethane, but its use is constrained by its high cost and lower efficiency.[15]

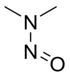


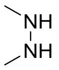
1.3.4 Methylnitronitrosoguanidine, MNNG , N-methyl-N-nitrosourea, MNU , Azoxymethane, AOM , N-Nitrosodimethylamine, NDMA , 1,2-dimethylhydrazine, DMH


MNNG


MNG


AOM

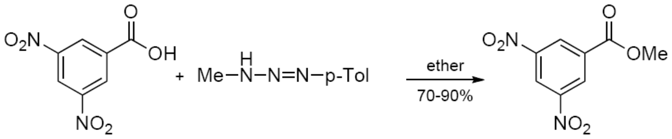

NDMA


DMH

MNNG, NMU, AOM, NDMA, and DMH are reliable carcinogen, mutagen, and teratogen in biological research. They all exhibit the toxicity by transferring methyl group to nucleobases in nucleic acids, which can lead to AT:GC transition mutations. The corresponding mechanisms of methylation are similar to diazomethane.[8]

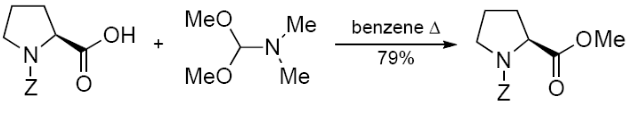
1.3.5 Aromatic triazenes

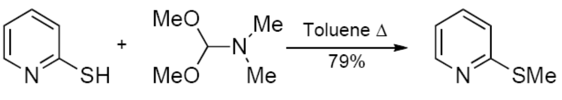
The aromatic triazenes, especially of *p*-toluidine, can be used as alkylating agents of carboxylic acids and vinylogous acids. However, these reagents are also carcinogenic and have the risk of being explosive.[16]



1.3.6 Dimethyl acetals of N,N-dimethylformamide (DMF)

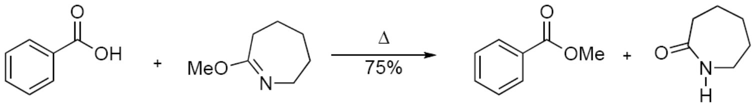
Dimethyl acetals of *N*,*N*-dimethylformamide (DMF) is often useful alkylating agents under neutral conditions. It is most commonly used to form the corresponding esters. Heterocycles with SH, NH and OH can also be methylated with DMF dimethyl acetal.[17]





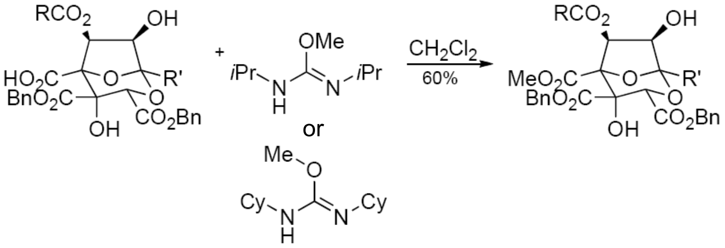
1.3.7 O-Methylcaprolactam

Related to the DMF acetals are the corresponding lactim ethers of cyclic amides. For example, *O*-methylcaprolactam has been shown to alkylate carboxylic acids at high temperatures.[18]



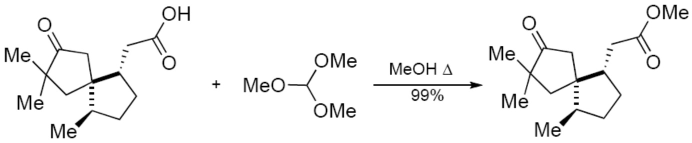
1.3.8 O-Methyl isourea

A variety of esters can be prepared, even in the presence of various functional groups with *O*-methyl isourea.[19] *O*-Methyl isourea is easily formed from methanol and dicyclohexylcarbodiimide (DCC) or diisopropylcarbodiimide (DIC).



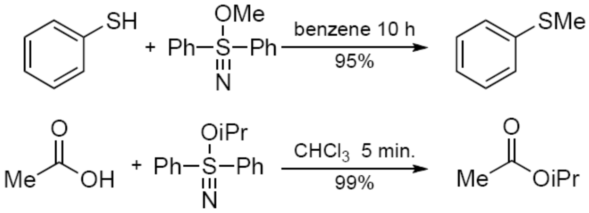
1.3.9 Trimethyl Orthoformate

Trimethyl Orthoformate can be used for the methylation of acids, including amino acids. The reaction is mild enough to chemoselectively form the ester in the presence of other functional groups. The reaction can also be run efficiently in room temperature ionic liquids as solvents.[20]



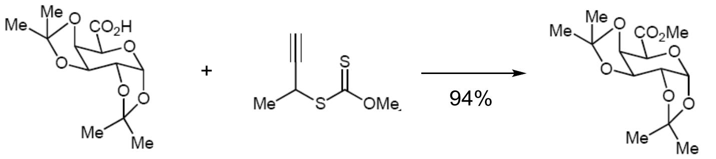
1.3.10 Alkoxy-λ6-sulfanenitriles (thiazynes)

The surprising chemistry of alkoxy-λ6-sulfanenitriles (thiazynes) has been investigated and these compounds have been found to alkylate carboxylic acids, thiols, phenols and sulfonic acids in essentially quantitative yields at room temperature.[21]



1.3.11 S-Propargyl xanthates

S-propargyl xanthates have been used for the esterification of acids. This method shows high reactivity (even for the synthesis of neopentyl esters, which are notoriously difficult to form) and complete inversion of stereochemistry for secondary alcohols.[22]



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

6.1. Introduction

In March 2017, the RTOC met at Amman in Jordan. Attending members were from non-A5 Parties: Czech Republic, Denmark, Germany, Italy, Japan, The Netherlands, Norway, UK, United States (US), and from Article 5 Parties: Brazil, China, Egypt, India, Jamaica, Jordan, Lebanon and Saudi Arabia.

The main purposes of the meeting were: (1) to update the RTOC members on the discussions and outcomes of Montreal Protocol meetings, (2) to illustrate the progress of the Task Force Decision XXVIII/4 *Establisment of regular consultations on safety standards* work, (3) to finish the 2017 RTOC Progress Report and (4) to continue the work for the 2018 RTOC Assessment Report in terms of content and organization. The contents of the several chapters were reviewed as well the chapter's membership.

The co-chairs announced the appointment of one new member from non-A5 Party (i.e., UK). The membership of RTOC at the time of the meeting stood at 38 members.

Discussion among members focused on the progress report to be released within several weeks after the meeting, the XXVIII/4 report and the assessment report.

In order to improve the communication among RTOC members a new web based system, supported by the Ozone Secretariat, is being established and it was described to the members

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

6.2. Refrigerants

In recent years there has been a focus on unsaturated fluorochemicals (HFOs) alone, or in blends with saturated HFCs, to replace fluids with high-GWP. The use of HCs, R-717 (ammonia), and R-744 (carbon dioxide) continues. Interest also continues for R-718 (water) and R-728 (air).

Since the publication of the RTOC 2014 Assessment Report, over 23 new refrigerants (21 blends), have been classified in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 34 with anticipated adoption by the International Organisation for Standarisation (ISO) 817. 16 of these refrigerants were listed in the RTOC 2016 progress report. The two single-compound refrigerants, HFO 1336mzz(Z) and HCC-1130(E), are low-pressure fluids not yet commercially produced in significant quantities. With the exception of the fluid R-514A, which is a blend of these two new single compound refrigerants, the other fluids are blends of components already included in the standards. The new blends are: R-407G, R-447B, R-449B, R-449C, R-452B, R-452C, R-453A, R-454A, R 454B, R-454C, R-455A, R-456A, R-457A, R-458A, R-459A, R-459B, R-460A, R-460B, R-513B, R-514A, and R-515A.

The new fluids are listed in table 6.1, 6.2, and 6.3, with GWP calculated as in the RTOC 2014 Assessment Report.

Table 6.1. Single-compound refrigerants

Refrigerant Number	Chemical Formula	Chemical name	Molecular Weight	Boiling Point	Safety Class	GWP 100y	GWP 20y
HCC-1130(E)	CHCl=CHCl	trans-1,2-dichloroethene	96,9	47,7	B2	<1	3
HFC-1336mzz(Z)	CF3CH=CHCF3	cis-1,1,1,4,4,4-hexafluoro-2-butene	164,1	33,4	A1	2	6

Table 6.2. Zeotropic refrigerant blends

Refrigerant Number	**Refrigerant Composition (Mass %)**	**Molecular Weight**	**Bubble point/dew point (°C)**	**Safety class**	**GWP 100y**	**GWP 20y**
R-407G	R-32/125/134a (2,5/2,5/95,0)	100	-29,2/-27,2	A1	1 400	3 800
R-447B	R-32/125/1234ze(E) (68,0/8,0/24,0)	63,1	-50,1/-46,0	A2L	750	2 200
R-449B	R-32/125/1234yf/134a (25,2/24,3/23,2/27,3)	86,4	-46,1/-40,2	A1	1 400	3 200
R-449C	R-32/125/1234yf/134a (20,0/20,0/31,0/29,0)	90,3	-44,6/-38,1	A1	1 200	2 900
R-452B	R-32/125/1234yf (67,0/7,0/26,0)	63,5	-51,0/-50,3	A2L	710	2 100
R-452C	R-32/125/1234yf (12,5/61,0/26,5)	101,9	-47,5/-44,2	A1	2 200	4 100
R-453A	R-32/125/134a/227ea/600/601a (20,0/20,0/53,8/5,0/0,6/0,6)	88,8	-42,2/-35,0	A1	1 700	4 100
R-454A	R-32/1234yf (35,0/65,0)	80,5	-48,4/-41,6	A2L	250	890
R-454B	R-32/1234yf (68,9/31,1)	62,6	-50,9/-50,0	A2L	490	1 700
R-454C	R-32/1234yf (21,5/78,5)	90,8	-46,0/-37,8	A2L	150	540
R-455A	R-744/32/1234yf (3,0/21,5/75,5)	87,5	-51,6/-39,1	A2L	150	540
R-456A	R-32/134a/1234ze(E) (6,0/45,0/49,0)	101,4	-30,4/-25,6	A1/ A1	650	1 900
R-457A	R-32/1234yf/152a (18,0/70,0/12,0)	87,6	-42,7/-35,5	A2L	150	520
R-458A	R-32/125/134a/227ea/236fa (20,5/4,0/61,4/13,5/0,6)	89,9	-39,8/-32,4	A1	1 600	3 900

Refrigerant Number	Refrigerant Composition (Mass %)	Molecular Weight	Bubble point/dew point (°C)	Safety class	GWP 100y	GWP 20y
R-459A	R-32/1234yf/1234ze(E) (68,0/26,0/6,0)	63	-50,3/-48,6	A2L	480	1 700
R-459B	R-32/1234yf/1234ze(E) (21,0/69,0/10,0)	91,2	-44,0/-36,1	A2L	150	530
R-460A	R-32/125/134a/1234ze(E) (12,0/52,0/14,0/22,0)	100,6	-44,6/-37,2	A1	2 100	4 100
R-460B	R-32/125/134a/1234ze(E) (28,0/25,0/20,0/27,0)	84,8	-45,2/-37,1	A1	1 300	3 000

Table 6.3. Azeotropic refrigerant blends

Refrigerant Number	Refrigerant Composition (Mass %)	Molecular Weight	Normal boiling point (°C)	Safety class	GWP 100y	GWP 20y
R-513B	R-1234yf/134a (58,5/41,5)	108,7	-29,2/-29,1	A1	560	1 600
R-514A	R-1336mzz(Z)/1130(E) (74,7/25,3)	139,6	29,0/29,0	B1	1,7	5,2
R-515A	R-1234ze(E)/227ea (88,0/12,0)	118,7	-18,9/-18,9	A1	380	630

6.3. Domestic appliances

The decision by the Association of Home Appliance Manufacturers (AHAM) of North America to phase down HFC-134a in household refrigerators and freezers after 2024 gains greater significance following the Kigali Amendment. HFC-134a used in imports and exports, are due to be phased out under the US EPA's SNAP rule by 2021.

In view of the expected harmonization of UL 250 with IEC60335-2-40[17], the hydrocarbon charge limit in the US will be increased from 57 to 150 g. It is not yet clear whether the manufacturers will choose HC-600a or HFC-1234yf as both are flammable and still have to adhere to current and emerging safety and energy efficiency standards.

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[17] UL: Underwriters Laboratory

UL250: Household Refrigerators and Freezers

IEC: International Electrotechnical Commission

IEC60335-2-40: Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers

Globally, the use of HFC-1234yf in domestic refrigerators remains limited probably due to higher cost, and concerns on flammability. However, retrofitting of HFC-134a refrigerators with HFO-1234yf is feasible with (±3%) in energy consumption.

Following the Kigali Amendment, it is difficult to predict the proportions of use of refrigerants long-term. By 2020 around 75% of new refrigerators will likely contain HC-600a (a small proportion using HC/HFO blends) with the remainder containing HFC134a or HFO-1234yf.

Sales of heat pump clothes dryers (HPCD) using HFC-134a are growing rapidly in the EU. R-407C and HC-290 based systems are on the market, with R-744 providing significant efficiency gains. The use of HC-600a and low-GWP HFCs are being explored.

6.4. Commercial refrigeration

While the F-gas regulation 517/2014 is now effective in Europe, in the US EPA has published two final rules for change of status of refrigerants in several applications under its SNAP program. In commercial refrigeration, high GWP HFC blend R-404A is not allowed in new equipment from 1 January 2017 for supermarkets, from 1 January 2018 for condensing units, and from 1 January 2019 & 2020 for self-contained systems. For self-contained ice machines the use of R290 is approved in new equipment subject to charge limits. High-GWP blends such as R-404A are not allowed in new warehouse applications from 1 January 2023 and in new refrigerated food processing and dispensing equipment from 1 January 2021. Canada has signaled its intention to develop similar regulations. California is investigating the European F-gas regulation as a basis for its own regulations. These governments/administrations are moving towards disallowing high GWP HFC refrigerants and blends in new equipment.

Low-GWP refrigerants and HFC/HFO/HCFO blends (both A1 and A2L with GWPs in the range of 30-50% of the GWP of the refrigerants that they are replacing) are being approved for use in commercial refrigeration equipment. In supermarkets, condensing units and self-contained equipment, blends such as R-448A, R449-A, R-449B, R-450A, and R-513A are progressively used in Europe and the US. Component manufacturers (compressors, valves, controls) are approving existing products, as well as developing new products for use with these new refrigerants. In the self-contained equipment category, trials with HFO-1234yf and HFO-1234ze have also commenced. The use of R-407A and R-407F (at approximately half the GWP of R-404A and with similar performance in systems) continues to grow in many parts of the world.

Non-halocarbon refrigerants such as R-744 are increasingly being used in supermarket systems worldwide – both in cascaded systems (R-744 for low temperature cascaded with a second refrigerant like HFC-134a or similar and R-717 in limited cases) and in transcritical systems. Transcritical systems are undergoing extensive component and system R&D on ejector, adiabatic condensing, sub-cooling and parallel compression to reduce their energy consumption at higher ambient conditions. Walk-in applications with condensing units are increasingly using R-744. Self-contained systems are moving from R-404A and HCFC-22, to HC-290 or R-744. The use of HC remains limited by the charge limits for larger equipment. The lack of A2L standards (and their adoption in codes) is also slowing down the migration of commercial refrigeration applications from high-GWP HFCs to lower GWP options.

6.5. Industrial systems

Since the last progress report there has been increasing safety concerns with ammonia systems with pressure to move to low charge. However, low charge is not clearly defined and is used in different contexts, creating confusion about the terminology.

In chillers, where the primary refrigerant does not leave the unit, the recommended maximum refrigerant charge (0.025 kg/kW cooling capacity) can be achieved by using new heat exchanger technologies and avoiding receivers.

In large systems there are technical options to achieve the lower charge.

According to a recent report, ”[industrial] refrigeration makes up about 2 percent of current HFC consumption (in terms tonnes of CO2 equivalent), and is projected to grow about 6.7 percent annually from 2015 to 2050”. Market reports indicate a move from NH_3 to HFC in some countries after accidents due to neglected rules and standards. This underscores the importance of safe practice and safety training when dealing with toxic refrigerants.

HFC costs are driven towards low filling HFC strategies, as opposed to using higher priced HFO/HCFO options which still have some degree of flammability. This requires a risk-assessment before installation, especially if they are to be installed indoor. These refrigerants are mostly classified as A2L meaning that they exhibit a lower flammability than A2 but higher than A1.

Indirect fired absorption heat pumps of both the LiBr-H_2O and H_2O-NH_3 type are gaining ground. Those absorption heat pumps are fired by exhaust heat from industrial operations, such as heat rejected from internal combustion engines, gas fired turbines, steam and hot water boilers, etc. The overall thermal efficiency of those systems is attractive when compared to conventional vapour compression systems. An attractive feature is the lower absorbed power from the electric grid.

The growing use of district cooling is also an opportunity to maximise the system efficiency. For example, district heating suppliers can collect low value heat from refrigeration systems and use it as heat source for heat pumps for district heating.

In the future it will be hard to justify wasting energy, which could be used as a heat source for heat generators and heat pumps. Energy grids within large conurbations will reduce wastage where some consumers need heat and others provide heat in to the grid. Future systems may be based on wind and solar power generation with batteries to keep the systems running during night hours although this is challenging in places with long polar nights for several months.

6.6. Transport refrigeration

6.6.1. Ships

IMO, FAO[18] and the classification organisations will consider the impact of the Kigali amendment on the marine sector once CO_2 emission monitoring is rolled out. CO_2 equivalent emissions are now monitored. Reefer containers are not included at the moment.

R-717 is in use in fishing vessels, but the adoption of R-744 systems and especially trans-critical systems will require further development. Refrigeration equipment using low GWP refrigerants such as HC-290 is coming into use in provision rooms

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[18] IMO: International Maritime Organization

FAO: Food and Agriculture Organization

Cruise liners have extremely large AC systems, and flammable refrigerants are difficult to envisage without radical redesign. Indirect systems are mostly used today and they could be redesigned for flammable refrigerants.

6.6.2. Trucks, trailers and containers

The use of R-452A option is increasing. At least two large manufacturers offer R-452A as an alternative to R-404A. R-452A has similar cooling capacity, fuel efficiency, reliability and refrigerant charge as R-404A, but it offers a 45% GWP reduction.

Manufacturers of refrigeration systems for containers are testing lower GWP alternatives to HFC-134a. One manufacturer is working with two major shipping lines to test 100 units with R-513A. Two manufacturers have proposed using R-290 and HFC-32, with a long-term focus on energy efficiency. However, two others have expressed concerns about safety; one markets an R-744 unit and one is considering low flammable refrigerants in reefer containers as a solution.

Recent scientific studies do not yet come to consensus on the use of flammable refrigerants. Papers have described risk assessment studies over the product life cycle including design, commissioning, operation, maintenance and decommissioning, and the investigation of energy efficiency of the different replacement options.

In the truck/trailer and marine sector, no large manufacturer has yet commercialized solutions with flammable refrigerants. However, successful field trials of a small truck unit using R-290 in South Africa have been published. A major shipping line has purchased 100 units with R-744 for evaluation. Trials of R-744 trailers, with two large supermarket chains in Europe, are continuing.

A prototype truck/trailer cooling system (Dearman cryogenic/mechanical) has completed a three-month trial, and is in pre-production.

For reefers, the ISO technical committee for thermal containers is developing new standards for safe operation with flammable refrigerants. A draft of ISO 20854 on the risk based assessment for design and operation is out for national voting in 2017, and the next revision of ISO 1496-2 will include an energy efficiency test.

6.7. Air-to-air air conditioners and heat pumps

There has not been a substantial change since the 2016 progress report. In non-A5 parties, all products use non-ODS refrigerants. There is an increasing proportion of production of air conditioners in Article 5 countries that do not use HCFCs. Globally, approximately one half of all new AC units now use non-ODS refrigerants.

Replacement of HCFC-22 production is continuing. HFC-32 is now increasingly used in residential split and light commercial air conditioners (<8kw) in Japan, South East Asia, and Australia, with introduction starting in Europe.

Various HFC/unsaturated HFC blends, such as those comprising HFC-32, HFC-125, HFC-134a, HFC-1234yf and HFC-1234ze are under R&D. In China, conversion of production lines to HC-290 is underway, but there is limited market introduction due to stringent safety standards, except for small and portable units. In India, there is widespread commercialization of production of HC-290 split air conditioners, with production line conversions underway in several other high ambient temperature countries. Some enterprises within the Middle East still see R-410A, R-407C and HFC-134a as suitable alternatives to HCFC-22.

Acknowledging that almost all medium and low-GWP alternatives are flammable there has been significant progress with the development of new requirements for safety standards (particularly for increasing refrigerant charge size), with one working group addressing A2L and another on A2 and A3 refrigerants. Due to the complexities of the process it is unclear by when amendments will be finally published. Numerous research activities are investigating a variety of aspects including risk assessment related to the application of flammable refrigerants in air conditioning equipment.

6.8. Water heating heat pumps

In Europe, Japan and the US, new and progressively restrictive legislation on minimum energy efficiency for space heating and water heating heat pumps has limited the number of air to water heat pumps on the market. For the moment, there is no major impact on the refrigerants currently used, and in Europe equipment with lower GWP refrigerants is expected to be launched.

China is strongly promoting heat pumps to reduce the air pollution caused by fossil fuel heating. There is a strong demand for heat pumps that can operate down to -20°C ambient temperature while delivering space heating water higher than 60°C at a good energy efficiency.

In Japan, HFC-32 has been introduced in a water heating system by one manufacturer to compete with the R-744 products on the market. With HFC-32, the water temperature is limited to 65°C, but this is an attempt to provide a cost-competitive and high-energy efficiency alternative for domestic use.

6.9. Chillers

Manufacturers continue to refine their designs by offering newly designed compressors with advanced impellers and screw and scroll rotors, along with the use of variable speed drives, permanent magnet motors, and more sophisticated control systems. There continues to be expanded offerings of centrifugal compressors that are oil free through the use of magnetic bearings or other proprietary bearings that use refrigerant as the lubricant. This is notable as it may avoid some of the issues associated with moving to alternative refrigerants and the lubricants that are needed in conventional compressors.

After years of R&D and field trials, an array of options is emerging and chiller manufacturers are moving to lower GWP alternative refrigerants. Table 6.1 is an abbreviated table of the dominant refrigerants that are currently used in chillers and the refrigerants that are likely to replace them.

Table 6.4 Emerging refrigerants used in chillers

Product	Refrigerants Presently in	Emerging Refrigerants
Large chillers with centrifugal compressors using low pressure refrigerants	Chlorofluorocarbon (CFC)-112 HCFC-123 [1] HFC- 245fa	HCFO-1233zd R-514A
Large chillers with centrifugal compressors using medium pressure refrigerants	CFC-12[2] HFC-134a	R-513A HFO-1234yf HFO-1234ze
Mid-size chillers with positive displacement (screw) compressors	CFC-12[2] HFC-134a	R-513A HFO-1234yf[3] HFO-1234ze[3] HC-290[4]
Small chillers with positive displacement (scroll or recip.) compressors	HCFC-22[2] R-407C R-410A	HFC-32[3] R-452B[3] R-290[4]

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

[2] *Phased out but may be used for servicing in Article5countries;* [3] *Classified as A2L refrigerant (flammable)*

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

In future, the use of ammonia and water (R-717, R-718) as refrigerants may become increasingly important, although there are still significant technical challenges before widespread application (see 2014 RTOC Assessment Report for more detail). These refrigerants were omitted from Table 1 for simplicity.

Most major manufacturers have made early introductions of new products that use lower GWP refrigerants, but there has not been widespread uptake due to uncertainty of refrigerant supply and cost.

Regulation is driving the adoption of new low-GWP. In Europe, certain countries have imposed taxes on high-GWP HFC containing products to create a financial incentive for switching to products containing low GWP refrigerants. In the US EPA phase out date of 1 January 2024 for chillers using higher GWP refrigerants HFC-134a, R-410A and R-407C, will allow manufacturers to complete design, implementation and commercialization.

It is too early to tell if many manufacturers will offer retrofit packages to upgrade existing chillers with emerging lower GWP refrigerants. One manufacturer has recently announced the ability to retrofit existing centrifugal chillers with a low-GWP refrigerant. Competitive pressures will drive changes in the retrofit market over coming years.

6.10. Mobile air conditioning (MAC)

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

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

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

The current systems are of direct expansion type. Indirect expansion (secondary loop) systems are starting to appear on electrified vehicles that require specific thermal management system and battery refrigeration.

Counterfeit refrigerants are becoming a major issue, even when HFC-134a is relatively inexpensive (~ US $5/lb or US $11/kg). Counterfeit HFC-134a contains multiple CFC, toxic, or corrosive components and can destroy equipment and injure end-users. The counterfeit risk will likely become even more important as more expensive refrigerants (e.g. R-1234yf) become available.

The high price of HFC-1234yf (~ US$ 40-45/kg) with even higher retail prices is currently a barrier for its uptake in developing countries

The progressive diffusion of electrified vehicles in the main automotive markets (Europe, North America and China) will lead to the diffusion of electric air conditioning likely with heat pump function and to the use of refrigeration to enable the proper battery management.

6.11. Sustainable refrigeration

Sustainable refrigeration refers to the reduction of environmental and social impacts of refrigeration equipment, mainly in its energy sources and usage, and the minimization of emissions along "closed loop" life cycles. The main aspects involved are:

- Direct impact produced by refrigerant choice
- Importance of energy efficiency and related emissions, based on annual operational and local conditions
- Renewable resources as a basis for sustainable refrigeration systems
- Refrigeration and food losses,
- Involvement of cold chains in sustainability-related initiatives

Climate-related environmental impacts have been highlighted after the UNFCCC Paris Agreement, and the Montreal protocol Kigali amendment, leading to more detailed discussion on LCCP (Life Cycle Climate Performance). Life cycle emission analysis for both refrigerant and the related equipment in which they operate is needed to select the optimal refrigerant for a specific application, since a wrong conclusion can arise from the assessing the impact of the refrigerant alone.

6.12. Not-in-kind technologies

Interest continues to grow in NIK technologies as more and more applications utilize NIK technology for projects that have traditionally used only vapour compression technology. Four examples are given below:

- *Magnetocaloric technology* units are in beta testing at three sites in various configurations. They are already in use in refrigerated display cabinets. Medical refrigerators, beverage dispensers, store plugins, and wine cellars are some of the applications currently under testing. Larger (20 kW and above) versions are under development for industrial applications.

- *Indirect evaporative cooling* achieved forward strides during 2016 with improved COP reported to be 25 to 27, and modular capacities of 13, 26, 39, 52, 78, 104 and 156 kW (3.7, 7.4, 11, 17.8, 22.2, 29.6 and 44.35 TR respectively). They are commercially available. Water consumption has been reduced to significantly lower levels (~1.2 l/hr per kW cooling at maximum operating conditions).
- *Absorption refrigeration* units, with recovered thermal heat or with solar heat, of the indirect type operated by LiBr/H_2O solution, is generating interest, especially for larger systems in article 5 countries where electric energy is in short supply. The pending commercialization of third generation absorption units outside their manufacturing base countries is also a new development. Their higher heat ratio efficiency of 1.6 to 1.8 make them economically feasible when compared to other cooling systems.

- *Adsorption refrigeration* has been available commercially since 2014. Recently, the heat ratio efficiency of these units has improved.

6.13. High ambient temperature (HAT)

There is continued work on the research projects for testing alternative refrigerants at HAT conditions. EGYPRA is testing eight refrigerant alternatives in custom-built prototypes built by Egyptian manufacturers, will conclude in the second quarter of 2017. ORNL phase-II tested alternatives in rooftop units built by manufacturers from HAT countries. PRAHA phase-II is optimizing the design of the prototypes that were built for phase-I and testing further alternatives. A workshop on HC-290 took place in April 2017. A workshop on risk assessment at HAT conditions is planned for October 2017.

In January 2017, the four HAT research project results, (which also includes AREP-II), were presented at a joint-session at the ASHRAE winter meeting in Las Vegas, Nevada, US. A comparison of the results showed a lot of similarity between the in the outcomes from the research programme, but emphasised the need for design optimization of the equipment used for a better comparison.

The emphasis in the coming months will be to provide information related to HAT conditions to the Kigali Decisions XXVIII-3 on energy efficiency and XVIII-4 on safety through members of the High Ambient Working Group (HAWG) who are also members of the XXVIII-3 and XVIII-4 working groups.

6.14. Modelling of RACHP systems

The 2018 Assessment Report will provide overall considerations of modelling issues, rather than the commercial information on the amounts of product manufactured, exported and imported. Data about product inventories and production amounts will be an important part of the modelling efforts for banks and emission estimates (following the bottom-up approach).

In principle, three types of models (with emphasis either on banks and emissions or on energy consumption in the third case) are used to calculate data for RAC applications. Most of the models have a component that calculates direct and-or indirect emissions from installed RAC equipment. As reported in 2016, these are the following:

1. Thermodynamics based models that calculate energy efficiency and energy consumption for an R/AC application under certain circumstances.
2. Inventory models that calculate the amounts of refrigerant charged into refrigeration and air conditioning equipment based on sales data of various types of equipment for a country or region, which can be defined as the bank of refrigerants. This is the type of model being applied in the various Task Force reports, as mentioned above.
3. Models that focus on the total climate-relevant emission reductions. They depart from many assumptions or data on the number of pieces of equipment of certain types in the AC subsector and from test data regarding energy efficiency improvements possible by changing refrigerants, do not look at very detailed assumptions as in bottom up models.

Status and on going progress for the different model types:

1. One of the main purposes of the use of thermodynamic models is to investigate the characteristics and energy efficiency of (new) refrigerants or refrigerant blends compared to a base case. In 2016-17 one important contribution was published by McLinden et. al, who investigated a very large number of low GWP fluids, based on alkanes, olefines, triple bound molecules, ethers etc. They used a simple thermodynamic model to investigate capacity and COP (energy efficiency) characteristics compared to the currently used R-410A. Although it was concluded that there might be some new fluids to be considered, these are expected to not lead to real improvements to the existing ones. Propane like fluids are the ones with good characteristics (i.e., propane, propene, cyclopropane, isobutane, propyne).
2. In 2016, this method has been used in the Decision XXVII/4 Task Force report, in order to further investigate the demand for low GWP fluids for the RAC sector until 2050. In particular, the conversion period of the manufacturing in certain sub-sectors was considered. After mid-2016, the method was used to create a sort of database for the demand of all RAC subsectors for a business as usual case for 2015-2050, this for non-Article 5 and Article 5 parties. Next to RAC, estimated data (extrapolated to the future) were generated for other HFC consuming sectors (foams, aerosols, fire protection). Using the data, the HFC amendment proposals were compared, in particular where it concerns the climate benefit compared to a BAU case. Good results were obtained which could be used in the discussions towards the baseline and reduction schedules laid down in the Kigali Amendment. It should be mentioned that the demand is directly linked to economic growth parameters as well as assumptions on leakage during lifetime.
3. The method described gives the potential of savings in emissions towards the future. An overall analysis of the emission potentials of various sectors, including PFCs and HFC-23, has been given in a publication by Purohit and Hoglund-Isaksson. They also give estimates for abatement costs. Where the study is based on an existing emissions calculating model, it is also clear that the results are dependent on multiple assumptions regarding physical parameters and geographical distribution of emissions, where underlying assumptions on demand etc. are needed. Results are therefore far more dependent on the quality of changing technology data and physical input data than on the analytical type of modelling. The Purohit study also goes into first abatement costs determinations.

The adoption of the Kigali amendment will drive new studies of the impact of the use of lower GWP fluids. This will likely include new emphasis on energy efficiency. The quality of the rapidly evolving technical data will be fundamentally important, in order for the modelling to provide correct and timely conclusions on the mitigation offered by lower GWP refrigerant fluids, and for prioritising policy.

7 Decision XXVIII/8 Report on Issues Related to the Phase-out of HCFCs

Executive Summary

1. At their 28th Meeting, in 2016, parties took Decision XXVIII/8, “Phase-out of hydrochlorofluorocarbons”, which requested the TEAP to provide further assessment of the issues related to the phase-out of HCFCs, provided in response to Decision XXVII/5, and requested parties to provide relevant information for use by TEAP in providing this assessment.

2. TEAP appreciates the responses it has received to date from Armenia, Bangladesh European Union, Jamaica, Japan, Mauritius, Mexico and the US, and has incorporated the information where appropriate in this assessment.

3. Consideration of the various types of data for HCFC consumption in A5 parties predicts that the 2020 HCFC consumption will be lower than the allowed HCFC production under the Protocol. Based on this comparison, as well as from extrapolations performed, the conclusion drawn by TEAP in 2016, that no BDN production would be needed by non-Article 5 parties after 2020, remains unchanged.

4. The Decision XXVII/5 report finding remains unchanged that very specific small (yet unidentified) RAC uses in niche applications could be potentially essential (satisfying the criteria set out in Decision IV/25).

5. While it remains difficult to draw conclusions related to specific servicing needs, quantities of newly produced HCFC-123 and certain HCFCs for RAC blends may be required in non-Article 5 parties for the period 2020-2030 in certain applications.

6. After 2030, when the 0.5% servicing tail is no longer available for non-Article 5 parties, it is possible that newly produced HCFCs may be needed to service existing equipment that use HCFC-123 or HCFC blends in very specific critical applications, although this is not yet clear.

7. In fire protection, the Decision XXVII/5 report estimate remains unchanged that (as an upper limit for planning purposes and to assess impacts on the environment) volumes of HCFC-123 (for the production of HCFC-based Blend B) not exceeding 750 tonnes annually in non-Article 5 parties could be needed (combined with potential amounts required for servicing, this would imply a total consumption of about 900 tonnes annually, or almost 20 ODP tonnes).

8. The Decision XXVII/5 finding remains unchanged that no information was found that any HCFC uses in the foam sector could be considered as potentially essential after 2020.

9. The Decision XXVII/5 finding remains unchanged that it is possible that some niche solvent applications, such as aerospace or military, might require small quantities of HCFCs, to service existing equipment (e.g., HCFC-121, -122a, -141b and -225ca/cb).

10. The Decision XXVII/5 finding remains unchanged that essential uses for non-Article 5 parties are likely to be required for laboratory and analytical uses, and for the research into and development of new substances, and perhaps for some solvent uses. It is estimated that these applications might require of the order of tens of tonnes annually (i.e., in the order of 1 ODP tonne).

11. TEAP and its MCTOC have become aware of several manufacturing processes that currently use HCFCs as solvents in processes that might be considered similar to process agent uses, and would be potentially impacted by the 2020 phase out. Known applications include processes using HCFC-141b and HCFC-225ca/cb as solvents. The total known use of HCFCs in such processes is around 100 tonnes. Alternative processes are under development and expected to be completed by 2020. However some uncertainties still remain. **Parties may wish to consider clarifying whether they know of solvent uses of HCFCs in processes that might be considered similar to process agent uses. Parties may further wish to consider clarifying how to treat any existing HCFC solvent uses in processes that are similar to process agent uses in relation to the 2020 control measures under Article 2.**

7.1. Decision XXVIII/8 and TEAP's approach to this response

At their 28th Meeting, in 2016, the Parties took Decision XXVIII/8, "Phase-out of hydrochlorofluorocarbons", which requested the TEAP to provide further assessment of the issues related to the phase-out of HCFCs, provided last year in response to Decision XXVII/5, and requested parties to provide relevant information for use by the TEAP in providing this assessment, which states:

Aware that parties not operating under paragraph 1 of Article 5 of the Montreal Protocol (non−Article 5 parties) are taking measures to reduce and eventually eliminate the production and consumption of the ozone-depleting substances listed in Annex C, group I (hydrochlorofluorocarbons),

Recognizing a need for continued consideration of issues related to hydrochlorofluorocarbons as indicated in paragraphs 12, 13, and 14 of decision XIX/6, and taking into account the report of the Technology and Economic Assessment Panel in response to decision XXVII/5,

Noting that Article 5 parties may require access to hydrochlorofluorocarbons produced by non-Article 5 parties to satisfy their basic domestic needs after 2020,

1. To request the Technology and Economic Assessment Panel, in relation to Annex C, group I, substances:

    a. To continue to assess sectors, including subsectors, if any, where essential uses for non‑Article 5 parties may be needed after 1 January 2020, including estimates of the volumes of hydrochlorofluorocarbons that may be needed;

    b. To continue to assess the servicing requirements for refrigeration and air-conditioning equipment and any other possible needs in other sectors between 2020 and 2030 for non-Article 5 parties;

    c. To continue to review recent volumes of production of each of the hydrochlorofluorocarbons to satisfy basic domestic needs and to make projected estimates of such future production and estimated needs of Article 5 parties to satisfy basic domestic needs beyond 1 January 2020;

2. To request the Panel to report on the assessment referred to above to the Open‑ended Working Group at its thirty-ninth meeting, in 2017;

3. To invite parties to provide relevant information to the Ozone Secretariat by 15 March 2017 for inclusion in the Panel's assessment;

To respond to Decision XXVIII/8, TEAP continued to collect relevant information including the information provided by parties, contained in the Annex to this chapter, and updated the Decision XXVII/5 assessment where needed. The effort was conducted primarily electronically. Some preliminary information and findings were presented and discussed at the TEAP meeting, 1-5 May 2017, in Kyoto, Japan. A final draft was included as a separate chapter of the TEAP Progress Report, which was sent to UNEP's Ozone Secretariat, in the latter part of May 2017.

7.2. Update for HCFC production for BDN

It seems unlikely that significant quantities, if any, of HCFCs produced in non-Article 5 parties would be required to meet BDNs of Article 5 parties. No new information as derived from the data presented in the 2016 Decision XXVII/5 report, based upon (1) Article 7 consumption data reporting, (2) Country Program data and (3) HPMP derived consumption data, has become available. This implies that, as far as can be concluded at present, Montreal Protocol allowed Article 5 HCFC production could satisfy Article 5 HCFC consumption for the year 2020 and several years beyond.

TEAP is of the opinion that inclusion of one additional year of data does not change its previous assessment.

7.3. Update on servicing needs and essential uses

7.3.1. Fire protection

There is no change from the Decision XXVII/5 report. TEAP and its Halons Technical Options Committee estimate that (as an upper limit for planning purposes and to assess impacts on the environment) volumes of HCFC-123[19] not exceeding 750 tonnes annually in non-Article 5 parties could be needed to meet requirements (combined with the potential amounts required for servicing, this would imply a total consumption of about 900 tonnes annually of HCFC-123 or, almost 20 ODP tonnes).

7.3.2. Foams

There is no change from the Decision XXVII/5 report. TEAP and its FTOC have not been able to identify any uses that could qualify as potentially essential after 2020.

7.3.3. RAC

The Decision XXVII/5 report finding remains unchanged that very specific small (yet unidentified) RAC uses in niche applications could be potentially essential (satisfying the criteria in IV/25). While it remains difficult to draw conclusions related to specific servicing needs beyond 2020, quantities of newly produced HCFC-123 and certain HCFCs for R/AC blends may be required in non-A5 parties for the period 2020-2030 (and beyond), where recycling is not practical (due to resulting compositional changes to the blend), existing installed equipment is critical, and flammable refrigerants may not be suitable as alternatives (such as in some military applications)[20]. However, after 2030, when the 0.5% servicing tail

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[19] The name Blend B was created by the US Environmental Protection Agency during the approval process under its Significant New Alternatives Policy program in the early 1990s

[20] Australia indicates a potential need for HCFC blends for servicing requirements for existing military R/AC applications. Australia indicates no need for HCFC-22 servicing amounts since these can be recovered during the decommissioning of equipment in 2020-2030.

is no longer available for non-A5 parties, it is possible that newly produced HCFCs may be needed to service existing equipment that use HCFC-123 or HCFC blends in very specific critical applications, although this is not yet clear. The source of supply of servicing requirements for pure, non-blended HCFC fluids could potentially come from recycled and reclaimed material from existing RAC and fire protection equipment reaching end of life post 2020.

7.3.4. Medical applications and chemical sectors

MCTOC reviewed the potential sectors and sub-sectors where essential uses of HCFCs for Parties not operating under Article 5 may be needed after 2020. At present, MCTOC considers that essential uses for non-Article 5 parties are likely to be required for laboratory and analytical uses, for example to be used as analytical standards for the measurement of atmospheric levels of HCFCs, and for the research into and development of new substances. For example, the European Union reports the following laboratory and analytical uses that may continue to require HCFCs post-2020 due to slow progress in moving to alternatives.

- Reference chemical (in analytical methods) e.g. HCFC-21, HCFC-22, HCFC-31, HCFC-122, HCFC-123, HCFC-124, HCFC-133, HCFC-141b, HCFC-142b, HCFC-151a, HCFC-233;
- Feedstock (reagent in laboratory chemical synthesis) e.g. HCFC-22, HCFC-242, HCFC -252;
- Solvent (inert solvent in laboratory chemical synthesis) e.g. HCFC-31;
- Reference chemical (in toxicological studies) e.g. HCFC-21;
- ODS as a component in samples to be tested.

The quantity of HCFCs imported and produced in the European Union for these laboratory and analytical uses is, and will most likely remain, below 1 ODP tonne21.

It is possible that some other niche solvent applications, such as aerospace or military, might also require small quantities of HCFCs, potentially to service existing equipment (e.g. HCFC-122, -122a, -141b, -225). For example, HCFC-225 replaced CFC-113 in precision cleaning and cleanliness verification of sensitive equipment, such as oxygen systems, in aerospace applications. HCFO-1233zd has undergone successful laboratory testing for this application, but for at least one important user there is currently no on-going production of large systems that would allow the proving of the efficacy of this solvent in the actual conditions of use. If HCFO-1233zd or other alternatives, such as HFEs, fail to demonstrate adequate performance, the application would need to continue to use HCFC-225 (or the original CFC-113). It is estimated that this application would require small quantities, possibly in the order of 10s of tonnes annually (i.e., in the order of 1 ODP tonne). Parties may identify these and other potential uses as the phase-out approaches and bring them to the MOP for consideration as essential uses by the parties. It would be unlikely for all such HCFC solvent uses to exceed several hundred metric tonnes (i.e., several ODP tonnes) in total per year. However this is not yet clear, or whether any quantities would be available and suitable from stockpile or recycled sources.

MCTOC has become aware of several manufacturing processes that are currently using HCFCs as solvents in processes that might be considered similar to process agent uses, and

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21 The average annual HCFC production and import for laboratory and analytical uses in recent years was 0.006 ODP tonne (0.014 in 2013, 0.003 in 2014 and 0.003 ODP tonnes in 2015).

potentially impacted by the 2020 phase out in HCFC production and consumption. Known applications include processes using HCFC-141b and HCFC-225 as solvents. They are used either as reaction solvents or solvents for extractive distillation. The total known use of HCFCs as solvents in such processes is around 100 tonnes. Alternative processes not using HCFCs are under development for each of these known processes, and expected to be completed by 2020. However some uncertainties still remain, with feasibility studies not yet finished, and customer evaluation of the new products still underway.

Parties may be aware of other such uses of HCFCs although none (including those aforementioned) have been reported under decision XXII/8 (3), which states *"To request each party to report to the Ozone Secretariat, by 15 March 2011, if possible, or 1 July 2011 at the latest, the specific applications for which it uses controlled substances as process agents and to continue to report such information in the context of the annual reports required by decision X/14;"*

Parties have made a range of decisions relating to the use of controlled substances as process agents. These decisions were taken as a consequence of the control measures under Article 2 and the essential use decision IV/25 in the mid-1990s, and notably in relation to ODS such as CFCs and CTC. In 1994, TEAP had been unable to recommend production and consumption under essential use exemptions for these uses under decision IV/25. Decision VI/10 sought to clarify the situation after some Parties had interpreted use of controlled substances in certain applications, where they were used as process agents, as feedstock applications, while other Parties had interpreted similar applications as use and thereby subject to phase-out.

Decision X/14(7) states "That Parties should not install or commission new plant using controlled substances as process agents after 30 June 1999, unless the Meeting of the Parties has decided that the use in question meets the criteria for essential uses under decision IV/25;"

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

The essential use decision IV/25 relates to controlled substances for the purposes of the control measures in Article 2 of the Protocol, with an exemption authorised by Parties allowing the production and consumption of controlled substances after their mandated phaseout under Article 2.

These decisions (IV/25, X/14(7) and XVII/6(4)) refer to controlled substances generally and do not explicitly exclude HCFCs. Taken together, these decisions require that, from 1999 onwards, Parties should not install or commission new plant using controlled substances as process agents, including HCFCs, unless Parties have agreed that they meet the essential use criteria under decision IV/25. No new plant applications using HCFCs have been referred for consideration, and no existing HCFC uses have been reported under decision XXII/8 (3).

Parties may wish to clarify whether they know of other such solvent uses of HCFCs in processes that might be considered similar to process agents uses.

Parties may also wish to clarify how to treat any existing HCFCs solvent uses in processes that are similar to process agent uses in relation to the 2020 control measures under Article 2.

Sterilants and aerosols uses will almost certainly not require any production of HCFCs for essential uses in non-Article 5 parties. There are a variety of technically and economically feasible alternatives to the use of HCFCs in sterilization and aerosols, making them unlikely to be justifiable as an essential use in non-Article 5 parties.

Annex 2: Parties' submissions in response to Decision XXVIII/8

TEAP appreciates the responses it has received to date from Armenia, Bangladesh, European Union, Jamaica, Japan, Mauritius, Mexico and the US, and has incorporated the information where appropriate into this assessment. The substantive parts of parties' submissions have been compiled in a separate document, in pdf format. The document, posted at the same time as this report, can be found on the website of the Ozone Secretariat at the following link: http://conf.montreal-protocol.org/meeting/oewg/oewg-39/presession/background-documents/annex2-to-TEAP-progress-report-May2017.pdf

8 Other TEAP matters

8.1 TEAP and TOCs organisation

As indicated in Annex 1, TEAP currently includes 18 members including 4 Senior Experts and nearly 150 experts who serve on its five TOCs. In TEAP's Decision XXIV/8 Task Force Report (May 2013), TOCs membership numbers in the 2014-2018 period were anticipated to remain the same or decrease from the 2013-2014 period due to anticipated attrition during the 2014 reappointment process; the exception to this was RTOC which was predicted to retain or increase its previous membership numbers based on anticipated workload. Annex 1 of this report provides updated TOC membership lists, which include the start dates and current terms of appointment for all members.

During this 30th Anniversary year of the Montreal Protocol, TEAP recognises and is grateful for the voluntary service of the TEAP and TOCs members, past and present, and their substantial contributions to the successful protection of the ozone layer. TEAP looks forward to the contributions of continuing and new members to the TOCs in the 2018 assessment report period.

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

8.1.1 FTOC

Following the simultaneous resignation of the co-chairs, TEAP co-chair Ashley Woodcock has acted as interim co-chair through 2016/17. Paulo Altoe (Brazil) has been appointed as A5 co-chair since 1 January 2017. FTOC had a successful meeting in Manchester in March 2017, concurrently with MCTOC, which enabled cross-cutting discussions. FTOC has produced Progress Reports for 2016 and 2017 and members have participated in the responses to Decision XXVIII/5 on replenishment and Decision XXVIII/8 on phaseout of HCFCs. It is anticipated that a new non-A5 co-chair could be identified in 2017 for appointment in 2018. In addition to the interim co-chair, FTOC has 22 members (9 from A5 parties and 13 from non-A5 parties). Five new members have been appointed in the last 12 months, and two members have retired.

8.1.2 HTOC

Two members and co-chair Dave Catchpole (UK) retired at the end of 2016. Three new members and one new Consulting Expert have been added to the HTOC in 2017: Ms. Laura Green, (US) to provide expertise in fire protection in the oil and gas sector (lost with the retirement of Mr. David Catchpole); Dr. R.P. Singh, (India) (to continue regional expertise that was lost with the retirement of Mr. H.S. Kaprwan), and Ms. Elvira Nigido, Australia, and Ms. Pat Burns, (US) to increase the HTOC expertise in international supplies and banking of halons and alternatives.

8.1.3 MBTOC

MBTOC membership is at a historical low with 16 members (including one economist), but still it retains the required expertise in soils, structures and commodities and QPS to complete the current tasks. Nevertheless, MBTOC is still seeking to recruit experts for the nursery industries, particularly an expert having a clear understanding of issues affecting the strawberry runner industries globally.

8.1.4 MCTOC

The new MCTOC, which combines sectoral topics from the old CTOC and MTOC, has been functioning now for more than one year. Chemicals and medical (inhalers) members met together for MCTOC's inaugural meeting in 2016. Chemicals and aerosols members only met in 2017, without medical (inhalers) members. A full meeting of members will again be held in 2018 in the assessment year. The exception is sterilants members, who continue to participate solely via correspondence. In readiness for its assignments, MCTOC co-chairs have been working to recruit new experts in areas of chemicals manufacturing, solvents, and sterilants, and continues to seek new experts in destruction technologies, laboratory and analytical uses, aerosols and inhalers. The two-year term of Helen Tope (Australia) as MCTOC co-chair is due to conclude in 2017.

8.1.5 RTOC

Roberto Peixoto and Fabio Polonara are co-chairs of RTOC after Lambert Kuijpers stepped down as co-chair after 30 years of outstanding service. He continues to support RTOC with his experience and competence as a member.

RTOC met annually over the last two years, and will move to two meetings per year in 2017 and 2018, to prepare the 2018 Assessment report. The RTOC has 38 experts nominated from 20 parties (14 members from A5 parties, 24 from non-A5 parties). Over the last two years, RTOC appointed 5 new members to meet the evolving need for specific expertise.

RTOC has been heavily involved in the Standards Task Force, the Replenishment Task Force, and Energy Efficiency discussions. RTOC has an excellent working atmosphere, and the Co-chairs will continue to monitor appropriate balance and expertise needs, as it responds to the post-Kigali agenda.

8.1.6. Senior Experts

There are presently 4 Senior Experts, all from Parties operating under A-5, including Rajendra Shende, who joined in 2017. We welcome Mr. Shende to the team.

8.2 Continuing challenges

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

The challenge to TEAP and TOC leadership remains to identify candidates with adequate history and experience as well as technical expertise and time, in order for TEAP to continue to meet the significant demands of delivering outputs to support the deliberations of Parties, without loss of continuity.

TOCs have been challenged with attrition through retirement of members and loss of expertise. The absence of funding for non-Article 5 members makes participation particularly difficult. This is of growing concern to the consensus process of the committees where a range of independent expert opinions is necessary. Absence of funding is also an issue for TOC co-chairs, so that essential co-chair activities such as travel to meetings and participation in other activities is becoming increasingly uncertain.

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

The members of TEAP and its TOCs provide their expertise and work on a voluntary basis and many are finding the increasing time commitment difficult/impossible to manage in the context of a full-time occupation.

TEAP is determined to re-invigorate its membership and leadership, but at the same time maintain involvement of TOC and senior expert members with substantial experience to ensure the continuity of its work for Parties. In view of the Kigali Amendment, TEAP is also considering recruiting contributing members with the expertise needed to address any knowledge gaps at least for a period of time. TEAP points out that 10 of 22 members will reach the end of current appointments in 2017 or 2018. This provides risk of loss of expertise and continuity, but is also an opportunity for re-invigorating and refocussing TEAP.

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

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

Annex 3: TEAP and TOC membership and administration

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

1. Technology and Economic Assessment Panel (TEAP) 2017

Co-chairs	**Affiliation**	**Country**	**Appointed through**
Bella Maranion	U.S. EPA	US	2020
Marta Pizano	Consultant	Colombia	2018
Ashley Woodcock	University of Manchester	UK	2018
Senior Experts	**Affiliation**	**Country**	**Appointed through**
Suely Machado Carvalho	Consultant	Brazil	2019
Marco Gonzalez	Consultant	Costa Rica	2017*
Rajendra Shende	Terre Policy Centre	India	2020
Shiqiu Zhang	Peking University	China	2017*
TOC Chairs	**Affiliation**	**Country**	**Appointed through**
Paulo Altoé		Brazil	2020
Mohamed Besri	Inst. Agronomique et Vétérinaire Hassan II	Morocco	2017*
Adam Chattaway	UTC Aerospace Systems	UK	2020
Sergey Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2017*
Kei-ichi Ohnishi	Asahi Glass	Japan	2019
Roberto. Peixoto	Maua Institute (IMT), Sao Paulo	Brazil	2017*
Fabio Polonara	Universitá Politecnica delle Marche	Italy	2018
Ian Porter	La Trobe University	Australia	2017*
Helen Tope	Energy International Australia	Australia	2017*
Daniel P. Verdonik	Jensen Hughes	US	2020
Jianjun Zhang	Sen Yat Sen University	PRC	2019

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

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

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

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

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

3. TEAP Halons Technical Options Committee (HTOC)

Mr. D.V. Catchpole (UK) retired as HTOC co-chair in 2016 after more than 25 years of service to the HTOC and the Montreal Protocol. Mr. Adam Chattaway (UK) was appointed as HTOC co-chair by the parties at MOP-28. Ms. Laura Green was appointed as an HTOC member to provide expertise in fire protection in the oil and gas sector that would otherwise have been lost to the HTOC with the retirement of Mr. D. V. Catchpole. Mr. Robert Wickham has stepped down as a Committee member and is now a Consulting Expert. Mr. R.P, Singh (India) has been appointed as a Committee member to replace Mr. H.S. Kaprwan (India) who retired in 2016. Ms. Elvira Nigido (Australia) has been appointed as a Committee member and Ms. Pat Burns (US) has been added as a Consulting Expert to increase expertise in halon banking, global supplies and availability.

Co-chair	**Affiliation**	**Country**	**Appointed through**
Adam Chattaway	UTC Aerospace Systems	UK	2020
Sergey N. Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2017*
Daniel P. Verdonik	Jensen Hughes	US	2020
Members	**Affiliation**	**Country**	**Through**
Jamal Alfuzaie	Consultant - Retired	Kuwait	2018
Johan Åqvist	Åqvist Consulting Group	Sweden	2019
Youri Auroque	European Aviation Safety Agency	France	2019
Seunghwan (Charles) Choi	Hanju Chemical Co., Ltd.	South Korea	2018
Michelle M. Collins	Consultant- EECO International	US	2018
Carlos Grandi	Embraer	Brazil	2017*
Laura Green	Hilcorp	US	2020
Elvira Nigido	A-gas Australia	Australia	2020
Emma Palumbo	Safety Hi-tech srl	Italy	2018
Erik Pedersen	Consultant – World Bank	Denmark	2020
R.P. Singh		India	2020
Donald Thomson	MOPIA	Canada	2017*
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Env. Prot. Net.	Japan	2017*
Consulting Experts	**Affiliation**	**Country**	**Through**
Pat Burns	A-Gas Americas	US	One yr. renew. terms
Thomas Cortina	Halon Alternatives Research Corporation	US	
Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Env. Prot. Net.	Japan	
Nikolai Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	
Steve McCormick	United States Army	US	
John G. Owens	3M Company	US	
John J. O’Sullivan	Bureau Veriitas	UK	
Mark L. Robin	DuPont	US	
Joseph A. Senecal	Kidde-Fenwal Inc.	US	
Ronald S. Sheinson	Consultant - Retired	US	
Robert T. Wickham	Consultant-Wickham Associates	US	

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

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

Co-chairs	Affiliation	Country	Appointed through
Kei-ichi Ohnishi	Asahi Glass	Japan	2019
Helen Tope	Energy International Australia	Australia	2017*
Jianjun Zhang	Zhejiang Chemical Industry Research Institute	China	2019
Members	**Affiliation**	**Country**	**Appointed through**
Emmanuel Addo-Yobo	Kwame Nkrumah University of Science and Technology	Ghana	2018
Fatemah Al-Shatti	Kuwait Petroleum Corporation	Kuwait	2018
Paul Atkins	Oriel Therapeutics Inc. (A Novartis Company)	US	2018
Steven Bernhardt	Private consultant to Honeywell	US	2018
Biao Jiang	Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences	China	2018
Olga Blinova	Russian Scientific Center "Applied Chemistry"	Russia	2018
Nick Campbell	Arkema	France	2018
Jorge Caneva	Favaloro Foundation	Argentina	2018
Nee Sun (Robert) Choong Kwet Yive	University of Mauritius	Mauritius	2018
David Dalle Fusine	Chiesi Farmaceutici (seconded at Chiesi China)	Italy	2018
Eamonn Hoxey	EV Hoxey Ltd.	UK	2018
Jianxin Hu	College of Environmental Sciences & Engineering, Peking University	China	2018
Ryan Hulse	Honeywell	US	2020
Javaid Khan	The Aga Khan University	Pakistan	2018
Andrew Lindley	Independent consultant to Mexichem UK Ltd.	UK	2020
Gerald McDonnell	DePuy Synthes, Johnson & Johnson	US	2018
Robert Meyer	University of Virginia	US	2018
Tunde Otulana	Mallinckrodt Pharmaceuticals	US	2018
John G. Owens	3M	US	2020
José Pons Pons	Spray Quimica	Venezuela	2019
Hans Porre	Teijin Aramids	Netherlands	2018
John Pritchard	Philips Home Healthcare Solutions	UK	2018
Rabbur Reza	Beximco Pharmaceuticals	Bangladesh	2018
Paula Rytilä	Orion Corporation Orion Pharma	Finland	2019
Surinder Singh Sambi	Indian Institute of Chemical Engineers (Northern Region)	India	2018
Roland Stechert	Boehringer Ingelheim	Germany	2018
Kristine Whorlow	National Asthma Council Australia	Australia	2018
Ashley Woodcock	University of Manchester	UK	2019
Yizhong You	Journal of Aerosol Communication	China	2018

Consulting Experts	**Affiliation**	**Country**	**One year renewable terms**
Archie McCulloch	Independent Consultant to European Fluorocarbon Technical Committee (EFCTC)	United Kingdom	
Hideo Mori	Tokushima Regional Energy	Japan	
Lifei Zhang	National Research Center for Environmental Analysis and Measurement	China	

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

5. TEAP Methyl Bromide Technical Options Committee (MBTOC)

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

Co-chairs	**Affiliation**	**Country**	**Appointed through**
Mohamed Besri	Emeritus Professor, Institut Agronomique et Vétérinaire Hassan II	Morocco	2017*
Marta Pizano	Consultant - Hortitecnia Ltda	Colombia	2017*
Ian Porter	La Trobe University	Australia	2017*
Members	**Affiliation**	**Country**	**Appointed through**
Jonathan Banks	Consultant	Australia	2018
Fred Bergwerff	Oxylow BV	Netherlands	2018
Aocheng Cao	Chinese Academy of Agricultural Sciences	China	2018
Ken Glassey	MAFF – NZ	New Zealand	2018
Eduardo Gonzalez	Fumigator	Philippines	2018
Rosalind James	USDA	US	2020
Takashi Misumi	MAFF – Japan	Japan	2018
Christoph Reichmuth	Honorary Professor	Germany	2018
Jordi Riudavets	IRTA – Department of Plant Protection	Spain	2017*
Akio Tateya	Technical Adviser, Syngenta	Japan	2018
Alejandro Valeiro	Nat. Institute for Ag. Technology	Argentina	2018
Nick Vink	University of Stellenbosch	South Africa	2018
Suat Yilmaz	Min. of Food, Agriculture and Livestock	Turkey	2018

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

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

Co-chairs	**Affiliation**	**Country**	**Appointed through**
Roberto de A. Peixoto	Maua Institute, IMT, Sao Paulo	Brazil	2017*
Fabio Polonara	Universita' Politecnica delle Marche	Italy	2018
Members	**Affiliation**	**Country**	**Appointed through**
James M. Calm	Engineering Consultant	US	2018
Radim Cermak	Ingersoll Rand	Czech Rep	2018
Guangming Chen	Zhejiang University, Hangzhou	China	2018
Jiangpin Chen	Shanghai Jiao Tong University	China	2018
Daniel Colbourne	Re-phridge Consultancy	UK	2018
Richard DeVos	General Electric	US	2018
Sukumar Devotta	Consultant	India	2018
Martin Dieryckx	Daikin Europe	Belgium	2018
Dennis Dorman	Trane	US	2018
Bassam Elassaad	Consultant	Lebanon	2018
Ray Gluckman	Gluckman Consulting	UK	2020
Dave Godwin	U.S. EPA	US	2018
Marino Grozdek	University of Zagreb	Croatia	2018
Samir Hamed	Petra Industries	Jordan	2018
Martien Janssen	Re/genT	Netherlands	2018
Michael Kauffeld	Fachhochschule Karlsruhe	Germany	2018
Jürgen Köhler	University of Braunschweig	Germany	2018
Holger König	Ref-tech Consultancy	Germany	2018
Lambert Kuijpers	A/genT Consultancy (TUE Eindhoven)	Netherlands	2020
Richard Lawton	CRT Cambridge	UK	2018
Tingxun Li	Guangzhou University	China	2018
Dhasan Mohan Lal	Anna University	India	2018
Maher Mousa	MHM Consultancy	Saudi Arabia	2018
Petter Nekså	SINTEF Energy Research	Norway	2018
Horace Nelson	Consultant	Jamaica	2018
Carloandrea Malvicino	Fiat Ricerche	Italy	2018
Tetsuji Okada	JRAIA	Japan	2018
Alaa A. Olama	Consultant	Egypt	2018
Alexander C. Pachai	Johnson Controls	Denmark	2018
Per Henrik Pedersen	Danish Technological Institute	Denmark	2018
Rajan Rajendran	Emerson Climate Technologies	US	2018
Giorgio Rusignuolo	Carrier Transcold	US	2018
Paulo Vodianitskaia	Consultant	Brazil	2018
Asbjorn Vonsild	Vonsild Consulting	Denmark	2018
Yiroichi Yamaguchi	Toshiba Carrier	Japan	2018
Sauel Yana Motta	Honeywell	Peru	2018

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

Annex 4: 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 2017.

Body	**Required Expertise**	**A5/ Non-A5**
Foams TOC	Additives	A5 or non-A5
Halons TOC	Civil aviation Knowledge of halon alternatives and their market penetration Knowledge of banking and halon supplies	A5, South East Asia A5, Africa, A5, South America, and A5, South Asia A5, Africa, A5, South America
Methyl Bromide TOC	Issues related to the validation of alternatives to MB for certification of nursery plant materials related to movement across state and international boundaries and related risk assessment Expert in economic assessment of alternatives to MB	A5 or non-A5 Non-A5
Medical and Chemical TOC	Aerosols Destruction technologies Inhalers, including industry or clinical Laboratory and analytical uses	A5 or non-A5
Refrigeration TOC	Additional experts not currently required	-
Senior Experts]	Additional experts not currently required	