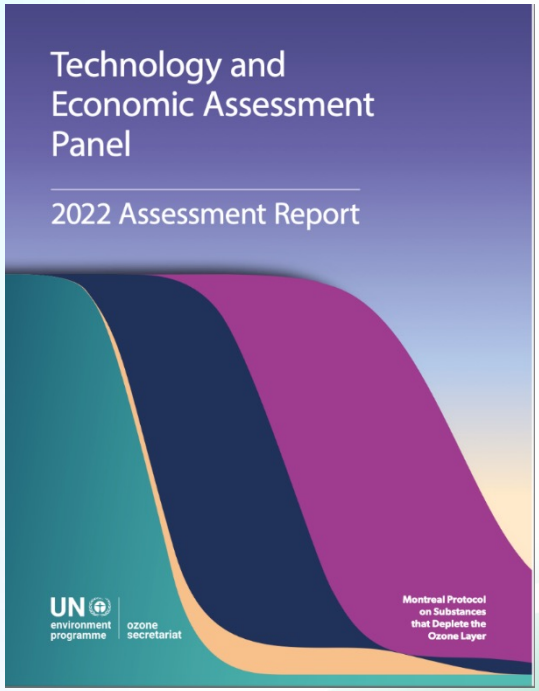
Technology and Economic Assessment Panel (TEAP)



2019-2022
Quadrennial Assessment Report

UN environment
United Nations Environment Programme

TEAP

45th OEWG
Bangkok, 3-7 July 2023

TEAP and its Technical Options Committees

The Technology and Economic Assessment Panel (TEAP):

- Three TEAP co-chairs
- Four Senior Experts
- Thirteen co-chairs of the five Technical Options Committees (TOCs):

- Flexible and Rigid Foams TOC (FTOC)
- Fire Suppression TOC (FSTOC)
- Methyl Bromide (MBTOC)
- Medical and Chemicals TOC (MCTOC)
- Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC)

We gratefully acknowledge the nearly 150 experts from around the world who serve on TEAP, its TOCs and Task Forces on a voluntary basis and who contributed to the 2022 assessments.

TEAP Reports 2019-2022

- In addition to its annual Progress Reports and bi-annual reports on Critical Use Nominations for methyl bromide, since the 2018 Assessment Report, TEAP has prepared **thirty-three** special reports in response to various Decisions issued by the parties to the Protocol.

- Full versions of these reports can be found on the Ozone Secretariat website

  http://ozone.unep.org/science/assessment/teap

Decision XXXI/2: Potential areas of focus for the 2022 quadrennial reports

To request the [TEAP]…to consider the following topics, among others:

a) ***Technical progress in the production and consumption sectors*** *in the transition to technically and economically feasible and sustainable alternatives and practices that minimize or eliminate the use of controlled substances in all sectors;*

b) ***The status of banks and stocks of controlled substances*** *and the options available for managing them so as to avoid emissions to the atmosphere;*

c) ***Challenges*** *facing all parties to the Montreal Protocol in implementing Montreal Protocol obligations and maintaining the phase-outs already achieved, especially those on substitutes and substitution technologies, including challenges for parties related to feedstock uses and by production to prevent emissions, and potential technically and economically feasible options to face those challenges*

d) *The impact of the phase-out of controlled ozone-depleting substances and the phase down of HFCs on* ***sustainable development;***

e) *Technical advancements in developing alternatives to HFCs suitable for usage in countries with* ***high ambient temperatures****, particularly with regard to energy efficiency and safety.*

TEAP 2022 Assessment Key Messages ODS

- Actions under the Montreal Protocol support continued progress in consumer, commercial, industrial, agricultural, medical and military sectors, with ODS no longer used in many applications worldwide.

  - The phase-out of HCFC-22 in non- Article 5 (non-A5) parties is essentially complete, and progressing in A5 parties.
  - For almost every foam application, commercially available alternatives are used.
  - In methyl bromide, phase out of controlled, non-QPS uses, is virtually complete.
  - In sterilization, controlled substances are likely no longer used.
  - In aerosols, alternatives are available for almost all uses.
  - For refrigeration, air conditioning and heat pumps, alternative zero ODP refrigerants are available for all sectors.

TEAP 2022 Assessment Key Messages HFCs

- The planned HFC phase-down under the Kigali Amendment, as well as national and regional regulations, are driving industry towards lower-GWP HFC alternatives or not-in-kind technologies, particularly in RACHP and foam applications.
- This presents challenges in finding the best solution for each application, considering factors such as flammability, toxicity, availability, and operating conditions.
- Restricting the growth of products containing high-GWP and energy-inefficient RACHP equipment would reduce both the servicing tail of unwanted high GWP refrigerants, and energy demand.
- Supply shortages of low-GWP alternatives in some sectors coincided with increasing global demand. While these supply issues are less severe now, insufficient supply to meet new regulatory mandates could delay transition away from HFCs.

TEAP 2022 Assessment Key Messages (3)

- In most A5 parties, but especially in low- and very low-volume consuming countries (LVC, VLVC), the majority of ODS and HFC refrigerants are used for RACHP servicing. Ensuring support for proper training for servicing and recovery would reduce direct emissions of ODS and HFC refrigerants and also reduce indirect emissions from the loss in energy efficiency through proper maintenance of RACHP equipment.
- In specific foam applications some challenges remain, particularly for smaller enterprises in some A5 parties due to the availability, safety, and cost of some lower-GWP alternatives as well as product performance requirements.
- While global consumption of HFCs for electronics manufacturing and magnesium production is relatively small, it is increasing for electronics manufacturing, and the alternatives to HFCs currently include other fluorinated gases, many of which have higher GWPs.
- Transition away from high-GWP HFC-pressurized metered dose inhalers (pMDIs) is a major undertaking with serious potential public health risks for asthma and COPD patients unless it is carefully managed.

Per- and Polyfluoroalkyl Substances (PFAS) – 2022 Assessment

- TEAP determined to investigate and consider during Q1 2023, and report to parties on potential implications for the different sectors under the Montreal Protocol in the 2023 TEAP Progress Report at OEWG 45 in Bangkok

Flexible and Rigid Foams Technical Options Committee (FTOC)

2022 Quadrennial Assessment Report

Co-chairs

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FTOC 2022 Assessment Report

Generally, transitions to non-ozone depleting substances (ODSs) and low global warming potential (GWP) alternatives have been successful and continue to move forward.

- There is no single 'drop-in' foam blowing agent (FBA) replacement for currently used HCFCs or hydrofluorocarbons (HFCs).
- There are different technical, economic, safety, and environmental performance properties for each low global warming potential (GWP), zero ozone depletion potential (ODP) alternative and different needs for each market subsector.

Technical and economic challenges remain for some sectors and small and medium enterprises.

- The price of fluorocarbon blowing agents and flammability of other alternatives are especially challenging for Small and Medium Enterprises.

Foam Blowing Agent supply

- New low GWP foam blowing agent manufacturing capacity for hydrocarbons and HFOs has eased the shortage of supply.
  - Additional capacity required to alleviate the shortage suggests that there was insufficient supply to meet regulated needs for low GWP FBAs. Insufficient capacity to meet regulatory mandates could recur without intervention.
  - One company has announced that they will shut down their HFC-365 facility in 2023, following significant resource investment by foam manufacturers to convert to HFC-365.

Fire Suppression Technical Options Committee (FSTOC)

2022 Quadrennial Assessment Report

Co-chairs

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FSTOC 2022 Assessment Report

- Many halon applications have transitioned to alternatives, some of which are high-GWP HFCs.
- Halons are still needed for several enduring uses (e.g., oil & gas, nuclear power plants, military, civil aviation), the last of which is still growing.
- Classification and regulation of fire suppressants as PFAS will impact transition away from halons and high-GWP HFCs.
- Halon emissions may be higher than the FSTOC models predict.
  - For halon 1301, FSTOC needs further information on emissions from feedstock production and use, and location of emissions.
  - For halon 1211, FSTOC needs further information on regional emissions since global atmospheric concentration derived emissions are near or above reported amounts produced.
  - For halon 2402, FSTOC needs further information on emissions from decommissioning activities on the Asian continent.

FSTOC 2022 Assessment Report (2)

- The run-out date for halon 1301 is now estimated to be 2-5 years sooner than in the 2018 Assessment Report: 2030 to 2049 as compared to 2032 to 2054
- Less halon 1301 is projected to be available to support enduring uses.
- The world's first pilot halon destruction for carbon offset occurred in February 2021 in the US.
- The FSTOC is concerned that destroying halon 1301 for carbon credits could contribute to global shortages / regional imbalances of halon 1301 needed for enduring uses.
- As the supply of newly produced HFCs for fire protection decreases in response to phase-down regulations, recycling becomes even more important as an alternative source of supply and is likely to increase in the future.

FSTOC 2022 Assessment Report (3)

- FSTOC continues to see issues regarding the loss of historical knowledge due to the length of time over which the Montreal Protocol activities have been implemented.
- FSTOC notes that this lack of experience and historical knowledge is becoming more challenging as it works with various parties and organizations on issues related to acquiring halons to meet their continuing needs. Parties may wish to address awareness programmes to re-establish this loss in institutional memory.
- The FSTOC continues to express concern with expanded use of flammable refrigerants.
  - This could be a significant issue, especially in A5 parties' HFC phase-down.
  - Parties may wish to consider ensuring continuing support for training / capacity building in A5 parties.

Methyl Bromide Technical Options Committee (MBTOC)

2022 Quadrennial Assessment Report

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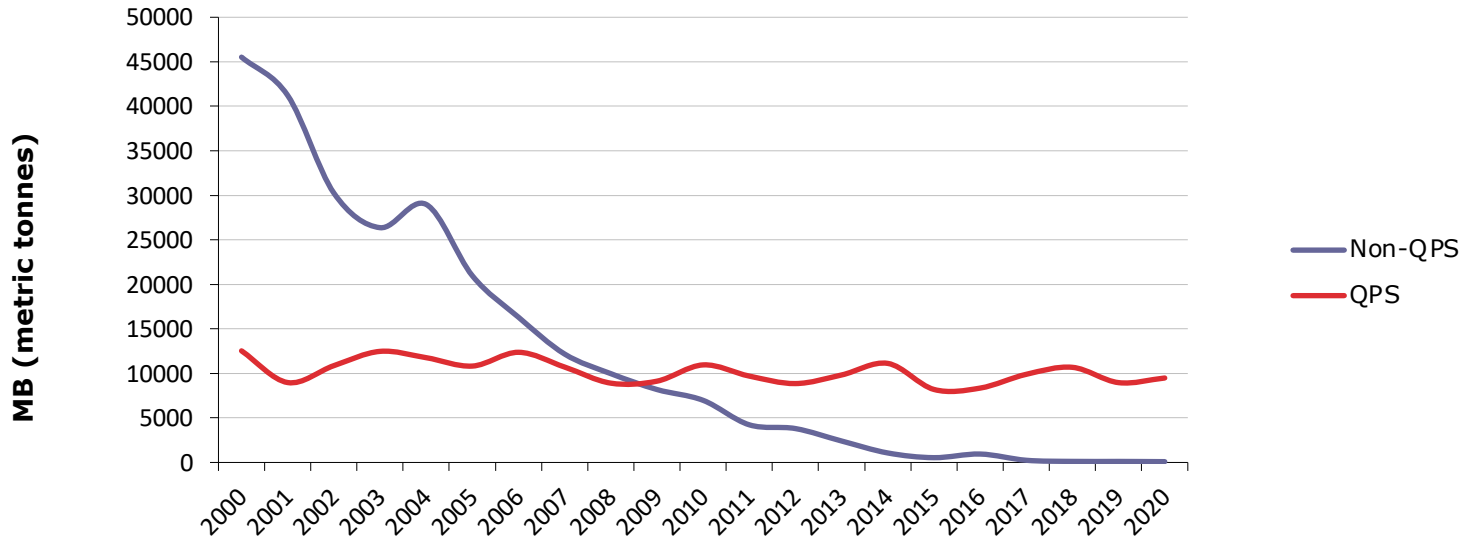
45th OEWG
Bangkok, 3-7 July 2023

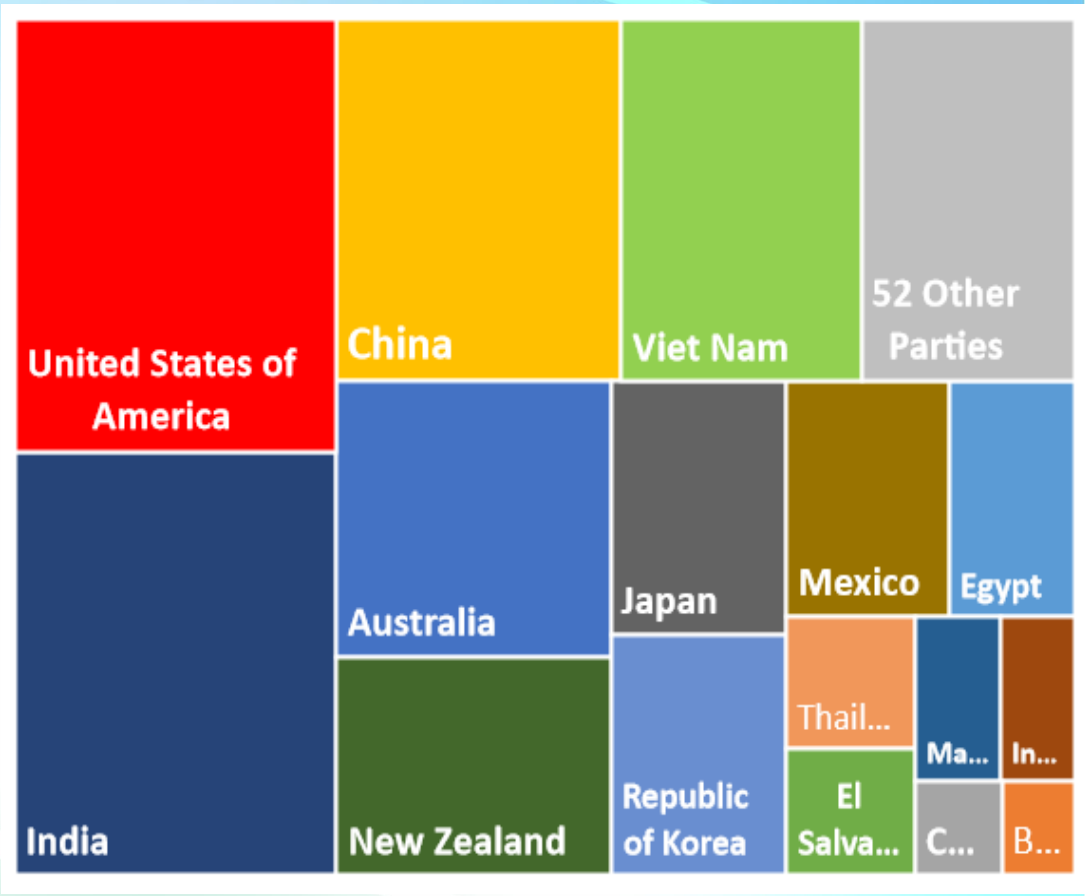
MBTOC - Controlled (non-QPS) vs QPS Uses

- By 2022, 99.8% of MB consumption for controlled use has reportedly been phased out; only 43.6 t were approved for use under CUE in 2022 compared to 16,050 t in 2005.
- Alternatives now exist for all pre-plant soil and non-QPS structural and commodity uses of MB.
- MB production is entirely for exempted QPS and feedstock uses



MBTOC - Quarantine and Preshipment

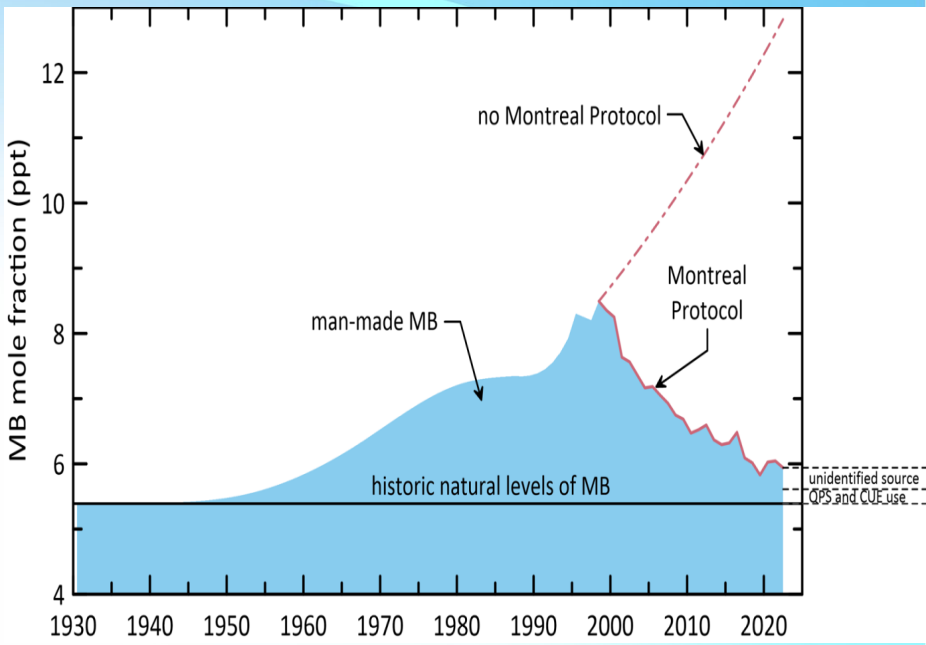
- Global MB consumption for QPS use fluctuates at around 10,000 t/yr with 95% occurring in 17 countries.
- Only 55 of 198 parties report use of MB for QPS
- Recapture technologies are available to reduce emissions.
- Alternatives exist for the majority of PS treatments (30-40% of total QPS). These include irradiation, ethane-dinitrile (EDN), hydrogen cyanide (HCN), sulfuryl fluoride (SF).
- Concern continues about SF, a key alternative to MB, owing to its GWP (i.e. 4780) and the impact of its possible inclusion under the EU F-gas regulation.



Relative Proportion of QPS Use Globally 2015-2020

Methyl Bromide Emissions

- Anthropogenic emissions of MB have declined by ~71% from the peak emission of ~ 50,000 tonnes in 1998.
- MB emissions have remained relatively stable for the last six years with no obvious decline.
- Major concerns are:
  - 10,000 t of MB is used for QPS treatments; over 80% is emitted.
  - There is an unexplained gap in bottom up vs. top down measurements in atmospheric concentrations.
- Owing to the short lifetime of MB in the atmosphere (0.7 years), adoption of alternatives has an immediate benefit in reducing atmospheric MB levels.



Trend in anthropogenic MB concentration (Southern hemisphere)

Medical and Chemicals Technical Options Committee (MCTOC)

2022 Quadrennial Assessment Report

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Aerosols and Medical: Key Messages

- Most aerosol propellants migrated to hydrocarbons and dimethyl ether; some migrated to HFCs or still use HCFCs, where flammability, toxicity, safety, VOC content, are considerations.
- Alternatives are available but might not be suitable in all circumstances. Parties may wish to consider the advantages of reducing HFC use in aerosols.
- Sterilization technologies and applications continue to deploy environmentally safer processes as best practice.
- With alternatives available, MCTOC believes that sterilization using controlled substances is no longer a relevant risk for the Montreal Protocol.
- MCTOC will not include sterilization in future technical updates.

Aerosols and Medical: Key Messages (2)

- Pressurised metered dose inhalers (pMDIs) for asthma and COPD contain HFC-134a and HFC-227ea as propellants.
- Dry powder and soft mist inhalers, where available, affordable and suitable, have much lower carbon footprints than pMDIs with high GWP propellants.
- Lower GWP HFC-152a and HFO-1234ze(E) propellants are under development.
- Complex considerations are necessary when patients and healthcare professionals make an informed choice about a patient's inhaled therapy.
- Transition away from high GWP HFC pMDIs is a major undertaking with serious potential public health risks unless carefully managed.
- Parties may wish to consider the range of technical and economic issues associated with the transition from high GWP HFC pMDIs to ensure adequate supplies of pMDIs and other inhalers during HFC phase-down.

Chemicals: Key Messages

- Increase in ODS feedstock uses is mostly due to HCFC feedstock uses; recent increase in CTC feedstock use is due to HFO production.
- Manufacture of HCFC-22 generates HFC-23 by-production and emissions, for which Article 2J establishes destruction requirements.
- Manufacture of TFE/HFP from HCFC-22 feedstock generates by-production and emissions of HFC-23 and PFC-c-318 (c-C4F8) with very high GWPs.
- These combined estimated emissions as CO_2e, without consideration of their possible abatement, are larger than estimated emissions of HFC-23 from HCFC-22 production assuming 0.1% emissions are achieved. Parties may wish to consider the significance of these emissions.
- Parties may wish to consider any actions concerning:
  - Those HFCs not listed in Annex F with GWPs above 53 with known commercial use.
  - Anaesthetics that are halogenated ethers (HFEs and HCFEs) and other halogenated ethers (e.g., HFEs used as solvents) with GWPs above 53 with known commercial use.

Chemicals: Key Messages (2)

- For process agent applications, most removals of process agent applications from Table A have resulted from plant closures, rather than substitution of the ODS process agent. For some remaining ODS process agent applications, no alternatives are currently available.
- For solvent uses, alternatives to controlled substances include not-in-kind technologies and in-kind solvents (chlorinated solvents and fluorinated solvents, including high-GWP HFCs not listed in Annex F and low-GWP HFOs, HCFOs and HFEs, and their blends).
- For laboratory and analytical uses, parties may wish to consider actions to facilitate the adoption of ODS alternatives in A5 parties, such as international cooperation between different standards organisations and between parties.

Chemicals: Key Messages (3)

- For semiconductor and other electronics manufacturing, HFCs are used for etching circuits, chamber cleaning, and as heat transfer fluids to control temperature. For magnesium production, HFC-134a is used as a cover gas.
  - Alternatives include a range of fluorinated chemicals, many with higher GWPs, e.g., SF_6 for etching, chamber cleaning, and magnesium production.
  - For semiconductor and electronics manufacturing, emissions controls significantly reduce HFC emissions.
- Some parties appear to report HFC production/consumption in semiconductor manufacturing in the same way as other emissive uses, whereas other parties treat it as feedstock use excluding the portion resulting in HFC emissions.
- Parties may wish to consider how to treat HFC production and consumption for semiconductor uses for the purposes of Article 7 data reporting.

Destruction Technologies: Key Messages

- Decision XXX/6 requests TEAP to assess destruction technologies listed (in annex II to the report of the Thirtieth Meeting of the Parties) as not approved or not determined, as well as any other technologies.
- Parties may wish to consider inclusion of cement kilns as an approved destruction technology for dilute sources of ODS and Annex F, Group 1, HFCs, for which there is already approval for concentrated sources.
- Parties may also wish to consider removing the category, Portable Plasma Arc, as a separate approved technology to rationalise the list of approved destruction technologies.

Banks and Stocks of Controlled Substances

- Effective management of banks, by maximising recovery, reuse, recycling, reclamation, and destruction after all other options have been exhausted, can minimise global impacts of potential emissions at end-of-life (EOL).
- The largest banks overall of controlled substances in RACHP and foams are currently in non-A5 parties and will rapidly reach EOL in the next decade.
- While ODS banks have been more concentrated in non-A5 parties, HFC banks are currently more evenly distributed between non-A5 and A5 parties.
- The quantity of banks in A5 parties will exceed those in non-A5 parties by the early 2030s, resulting from declining banks in non-A5 parties and the rapid uptake of HFC-containing equipment in A5 parties.
- With quantities potentially available for recovery and management expected to increase in A5 parties, timely efforts to establish effective EOL management capacity would have a significant impact, given the predicted size and growth of banks in larger industrialised A5 parties.

Banks and Stocks of Controlled Substances (2)

- Addressing the barriers to the transboundary movement of EOL ODS/HFCs will be important in supporting preferential recovery/recycling and environmentally sound destruction, thereby minimising emissions.

- Parties may wish to consider how relevant international treaty bodies can work together to facilitate transboundary movement of EOL ODS/HFCs.

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

2022 Quadrennial Assessment Report

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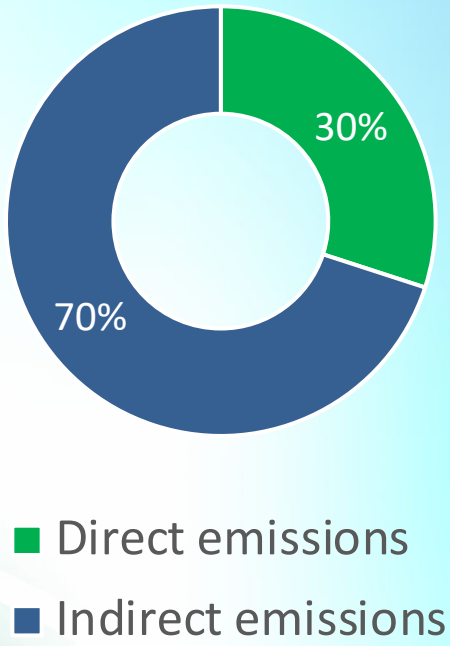
45th OEWG
Bangkok, 3-7 July 2023

RTOC Key Messages (1)

- The HFC phasedown focuses on direct greenhouse gas (GHG) emissions from the RACHP sector.
- Indirect GHG emissions, due to energy consumption, are much more impactful to climate change.
- RACHP indirect GHG emissions can be reduced significantly through improved equipment energy efficiency, reduced demand using high-performance buildings and cold-chain, and reduced carbon intensity of the electricity network.



RTOC Key Messages (2)

- There is no “ideal” refrigerant. Benefits and risks must be balanced; weighing several factors which include, environmental issues, suitability for the targeted use, availability, cost of the refrigerant and associated equipment and service, energy efficiency rating, safety, and ease of use.
- Recent safety standards enabled increased use of flammable refrigerants in self-contained commercial refrigeration, air-to-air AC, and heating only heat pump applications.
- Ultralow-, low-, and/or medium-GWP alternative refrigerants are available for all RACHP applications, but accessibility is still a major hindrance for the widescale adoption and progress toward the HFC phasedown.
- Proposed PFAS regulations are very broad and not product-specific at this time. Use of some HFO and HFCs could be affected by new policies.

RTOC Key Messages (3)

- Two new single component refrigerants (FIC-13I1 and HFO-1132(E)) and 23 new refrigerant blends have received designations and classifications by ASHRAE Standard 34 and/or ISO 817 since the publication of the 2018 RTOC Assessment Report.

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight (kg/kmol)	Boiling Point (°C)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ppm)	GWP 100-year	GWP 20-year	ODP	GWP 100-yr in Montreal Protocol[a]	ODP in Montreal Protocol
HCC-1130(E)	CHCl=CHCl	trans-1,2-dichloroethene	96,9	47.7	B1	5.5 days	5.15E-03	<<1	<1	<0.0003		
HFO-1132(E)	CHF=CHF	trans-1,2-difluoroethene	64	–52.5	B2	1.3 days	2.46E-03	<<1	<<1			
HFO-1132a	$CF_2=CH_2$	1,1-difluoroethylene	64	–83	A2	4.6 days	4.32E-03	<<1	<1			

- Many of the alternative refrigerants that are now being used are expected to only play a temporary role in the phasedown process, as their GWP may still be high for future applications.
- HFC sector-specific end-uses are not included in Article 7 reporting data increasing the uncertainty for equipment-based modelling emissions and banks.

RTOC Key Messages (4)

- In 2022, there were an estimated 2 billion domestic refrigerators worldwide; the current production has mostly converted to HC-600a.
- For commercial refrigeration;
  - Retrofit of existing system can use low-and medium-GWP refrigerants.
  - New systems, the shift is to ultralow- and low-GWP refrigerants.
  - Maintaining or improving the energy efficiency, is also important in the expansion of a sustainable cold chain.
  - The most common ultralow- and low-GWP refrigerants being applied are R-744, HC-290, and HFO blends such as R-454C, R-454A and R-455A.
- The majority of refrigerated trucks and trailers still use high-GWP R-404A but new equipment in Europe and in North America uses R-452A with a significant reduction in GWP. R-513A or HFC-1234yf is replacing HFC-134a.

RTOC Key Messages (5)

- HFC-32 is broadly used in air conditioning equipment. Several medium-GWP HFC/HFO blends are being adopted, such as R-454B, R-452B and R-463A.
- Transition to HC-290 for single split and portable AC units is underway in China, South-East Asia, and Latin America.
- Larger, more complex, and distributed systems pose the greatest challenges to adoption of medium- and low-GWP alternatives;.
- A complete range of new chillers that use refrigerants with lower GWP, compared with the original HCFC or HFC refrigerant, is available in all major markets.

RTOC Key Messages (6)

- Heating only heat pumps have a role in buildings decarbonisation by replacing fossil-fuel powered heating systems.
- Refrigerant options for water heating heat pumps include Medium-GWP (HFC-32) and Low-GWP (R-454C, HC-290, HC-600a, R-744 and R-717).
- For MAC, HFC-134a is used globally. Where regulations require low GWP refrigerants, HFO-1234yf and R-744 provide market options. HFO-1234yf is widely adopted, especially for passenger vehicles.
- Not-in-kind technologies are not yet competitive with current vapour compression technology, except in niche applications (e.g., absorption chillers).

Sustainable Development: Impact of the ODS Phase-out

- **Decision XXXI/2 para (d)**: requested the TEAP, in its 2022 Assessment Report, to consider the *"impact of the phase-out of controlled ozone-depleting substances and the phase-down of HFCs on sustainable development."*
- The approach taken has been to consider key UN decisions, agreements and reports relevant to sustainable development, and to relate these to the impact of the global transition away from ODS in the various sectors of use, as addressed in TOCs quadrennial assessments.
- Elimination of the production and consumption of 99% of ODS, and the projected recovery of the stratospheric ozone layer, are among the biggest environmental success stories of the 21st century.
- The Kigali Amendment has challenged parties – especially A5 parties - with preparing for and achieving the HFC phase-down, sometimes whilst implementing the final stages of their HPMPs.

- For 35 years, the MP has contributed in many ways to the achievement of most SDGs. Its contributions are particularly significant in protecting human health, improving livelihoods, protecting the environment, fostering sustainable production practices, and improving food security.

- Contributions to industry and innovation, clean and efficient energy and economic growth are also important.