MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

2010 ASSESSMENT REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

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1 Executive Summary

Since the 2006 Assessment of the Technology and Economic Assessment Panel (TEAP), several important technical developments have taken place. The direction that some of these developments have taken could not have been predicted in 2006. The Panel's Technical Options Committees, on Chemicals (CTOC), on Foams (FTOC), on Halons (HTOC), on Methyl Bromide (MBTOC), on Medical Uses (MTOC) and on Refrigeration, AC and Heat Pumps (RTOC) have each issued a 2010 Assessment Report that document these new developments as well as progress along the lines described in the 2006 TEAP Assessment Report. The Executive Summaries of these reports form the body of the 2010 TEAP Assessment Report and their Abstract Executive Summaries, with the summaries of other chapters, form the Executive Summary of the 2010 TEAP Assessment Report."

1.1 Key Messages

- The Montreal Protocol is working. There is progress in every sector, with many applications phased out worldwide. However, some MDI, laboratory and analytical uses still depend on new production of Annex A and B substances authorized by essential use exemptions; some fire protection, refrigeration and air conditioning service, and minor other applications still depend on banked and recycled Annex A and B substances; critical use exemptions of MB continue to decline, however uncontrolled feedstock uses of MB continue and quarantine and pre-shipment (QPS) uses of MB continue to increase. It is technically and economically feasible in both Article 5 and non-Article 5 countries: to collect and destroy surplus ODSs not required for important uses; to reduce emissions of ODSs and HFCs substitutes for ODSs from refrigeration, air conditioning, and fire protection equipment; and to phase out HCFCs faster in new refrigeration and air conditioning equipment in Article 5 countries if financing is made available to go beyond compliance. Actions to speed phaseout, reduce emissions, and destroy ODS can take servicing needs of existing equipment into consideration.
- Adequate financing of ozone protection, or, in some cases, combined financing of ozone and climate protection can leapfrog high-GWP HFCs in some applications, avoiding a second transition out of HFCs under the Kyoto Protocol and complications of an increasingly large inventory of HFC equipment requiring servicing with HFCs that may be expensive or unavailable. Joint funding will require continuing technical and administrative cooperation as Protocols are modified, and particularly when the CDM provisions are modified in 2013 when the Kyoto Protocol must be updated.
- 'Bottom up' TEAP/CTOC estimates of uncontrolled uses such as feedstocks are significantly smaller than 'top down' estimates made by consideration of observed stratospheric concentrations and the estimated atmospheric lifetime of CTC.
- The opportunity to destroy unwanted ODSs is leaking away.
- Considerable interest has focused on the status of collection and potential destruction of ODS banks based on the potential ozone and climate benefits of the avoided emissions of ODS still remaining in equipment, products, and stockpiles. The window of opportunity is narrowing (over the next 10-15 years, primarily in the refrigeration sector) to increase ODS recovery at equipment end of life to avoid potential emissions altogether by destroying unwanted ODS. Little new, on-the-ground effort has occurred since the last assessment; with the exceptions of Canada, EU, and Japan, and the US. With the recent introduction of offsets project standards offering carbon credits for destruction of certain ODS, collection and destruction can be profitable based on both the potential ozone and climate benefits. The difficulty is that neither economic incentive is available in most countries nor the infrastructure to support the activities. Funding the full-cost effort for collection and destruction of the banks of unwanted ODS remains a challenge and a significant hurdle to demonstrating the viability of this opportunity.

    - Collection and destruction is highly profitable if both GWP and ODP value is paid to society but neither economic incentive is available in most countries;
    - Collection and destruction is not profitable without payment for environmental benefit;
    - It is counter-productive to compel collection and destruction without incentives.
- The technical developments that have occurred between 2006 and 2010, and which are described in this 2010 TEAP Assessment Report, have increased the technical and economic feasibility of each of the following outcomes for both Article 5 and non-Article 5 countries:
    - Accelerating the phase-out of consumption of most ODSs,
    - Limiting the use or reducing the emissions in many applications,
    - Collecting and destroying unwanted ODS contained in foam, refrigeration, and other equipment,
    - Leap-frogging the use of high-GWP HFCs when phasing out HCFCs, and
    - Phasing down the use of high-GWP HFCs in mobile air conditioning applications where ODSs are already phased out worldwide in new equipment.

The key TOC sector findings can be summarised as given below.

1.2 Chemicals (CTOC)

- Collaboration with the Executive Committee (MLF) will promote the reduction of ODS uses as process agents and their corresponding emissions by monitoring phase-out of process agent uses.
- The Ozone Secretariat and experts identified by the CTOC will continue to work with analytical chemists in Article 5 countries and with national and international bodies that establish standard methods with a view to implementing new non-ODS methods.
- Knowledge of ODS feedstock use and emissions is incomplete.
- Perhaps some carbon tetrachloride (CTC) feedstock uses could be replaced by not-in-kind manufacturing processes using non-ozone depleting substances (non-ODS). Parties may wish to consider CTOC periodic assessment of available and emerging alternatives and substitutes for feedstock uses with a view to restricting exempted uses.
- Regulatory and technical changes may continue to impact earlier phase-out of ozone depleting solvent applications by introducing non-ODS. New cleaning processes might be sought for the applications where suitable alternatives are not available.
- The phase-out of ozone depleting solvents in Article 5 countries will require: (1) access to information and knowledge about the acceptable alternatives, (2) economic assistance, and (3) identification of small and medium users.
- Efforts discussed in the SAP 2010 report have further refined the understanding of the substantial difference between CTC emissions derived with ‘top down’ methods (atmospheric concentrations and lifetimes), which are larger, and those from ‘bottom up’ methods (estimated production, uses and emissions), which are smaller and more variable. Work will need to continue with all parties involved (science, technology and industry) to identify the causes of the remaining differences in these estimates.

1.3 Foams (FTOC)

- Energy efficiency pressures are relentlessly forcing innovation in blowing agent technologies globally. Blends are playing an increasingly important role and the approach to optimisation is becoming ever more sophisticated. Unsaturated HFCs (HFOs) are likely to be available commercially earlier than originally expected (2013-2015) and are showing better thermal performance than saturated HFCs in early evaluations. However, widespread uptake will require substantial further validation of both performance and cost.
- Concerns persist over the availability of low-GWP replacements for HCFCs in Article 5 countries. It is not yet clear whether pre-blended hydrocarbons or methyl formate will provide totally adequate solutions for SMEs since the management of flammability issues related to blends may require significant reformulation. For methyl formate this could include the possibility of blending part of the blowing agent in the isocyanate stream. There are additional concerns in the case of methyl formate that the achievement of viable foam properties at desired densities may be challenging for some applications in the rigid PU sector.
- Recovery of appliance foams is at its most cost-effective in climate terms with high-GWP (CFC) blowing agents. However, this cost effectiveness will deteriorate as the product mix shifts towards lower-GWP HCFC-containing foams. ODS banks in foams installed in buildings have been further characterised, confirming that the flow of ODS containing foams from buildings will be at low level for the next decade. Marginal costs of recovery/destruction depend on demolition waste segregation practices, but are likely to be well above US$ 100 per tonne CO_2 saved for most scenarios.

1.4 Halons (HTOC)

- There appear to be sufficient halon 1211 and 1301 stocks to meet known needs for the foreseeable future. Supply and demand of these halons appears to be in balance although regionally stocks are not evenly distributed. The situation for halon 2402 is different in that the bulk of the much smaller bank of halon 2402 is in the Russian Federation and Ukraine but there is a significant demand from outside these Parties. Although no Party has expressed that it is unable to meet the demands of important uses of halon 2402, this may occur in the foreseeable future.
- Now that there is no global production of halons for fire protection uses, management of the remaining stock becomes crucial for ensuring sufficient halons for applications that need them. However, numerous Parties have not implemented halon bank management programmes or are experiencing significant challenges with their programmes, in particular with the reclamation or disposal of cross contaminated halons.
- The aviation sector, through their United Nations agency, the International Civil Aviation Organization (ICAO), has endorsed a schedule to replace halons on board new aircraft in the lavatory trash receptacles, hand-held extinguishers, engine nacelles, and auxiliary power units. The protection of cargo compartments remains a challenge for which there is no acceptable solution at this time, but for which research continues.

1.5 Medical Applications (MTOC)

- There has been significant global progress in the transition of CFC metered dose inhalers (MDIs) to CFC-free inhalers. Technically satisfactory alternatives to CFC MDIs are now available in almost all countries worldwide to cover all of the key classes of drugs used in the treatment of asthma and chronic obstructive pulmonary disease.

- Most Article 5 countries and the Russian Federation are expected to have completed transition from CFC MDIs by about the end of 2012. A notable exception is China, which plans to complete the CFC MDI phase-out in 2016.
- A cautious approach to CFC production for MDI manufacture is advisable since transition is moving quickly. It could be possible to complete the phase-out of CFC MDIs with careful management of existing CFC stockpiles, provided manufacture of pharmaceutical-grade CFCs in China continues to supply its own needs and those of the Russian Federation.
- Technically and economically feasible alternatives are also available for medical aerosol products other than MDIs. However, there are a few developing countries that are yet to complete the conversion of CFC-based medical aerosols to alternatives.
- There is a range of commercially available sterilization methods that will replace the use of CFCs and HCFCs in this sector over time. The use of CFCs in blends with ethylene oxide (EO) has been successfully phased out in non-Article 5 countries and in many Article 5 countries. An orderly phase-out of HCFCs in sterilization to meet Montreal Protocol HCFC phase-out schedules is readily achievable.

1.6 Methyl Bromide (MBTOC)

- MB phase-out for controlled uses has advanced significantly. Global consumption has been reduced by 88% from the aggregate baseline. The reduction in consumption of MB for soil fumigation has been the major contributor to the overall reduction in global consumption of MB, but consumption of MB for pest control in structures and for commodities has also declined significantly.
- Article 5 Parties have reduced consumption by approximately 72% of baseline, which is well ahead of phase out schedules, but further efforts are still necessary to ensure the full phase out deadline of 2015 can be met.
- By 2009, the MB phaseout has led to a 60% fall in anthropogenic bromine for MB in the troposphere and a 30% fall in effective chlorine load from MB in the stratosphere. Owing to the short (0.7 year) MB atmospheric lifetime, MB phaseout has a rapid benefit to ozone recovery.
- Technical alternatives exist for almost all controlled uses of methyl bromide.
- Phase-out for the remaining MB uses will be greatly influenced by the registration and the regulatory controls on several key chemical alternatives (including 1,3-dichloropropene, chloropicrin, methyl iodide and SF) and by the incentives for non-chemical alternatives and Integrated Pest Management.
- Implementation of barrier films in soil fumigation has become more widespread. They significantly reduce dosage rates and emissions of methyl bromide and alternative fumigants.
- Recent registration of methyl iodide in the USA (now including California) has reduced significant amounts of MB requested in Critical Use Nominations.
- Pre 2005 stocks of MB are anticipated to be exhausted for non-critical use sectors and critical use sectors in the US within the next 3 years.

- A regulatory proposal to phase-in the deregistration of sulfuryl fluoride (SF) for food contact in the United States may increase pressure to use MB for pest control in food processing and food commodities. SF has been an important alternative for those uses and the reason for decline in MB use.

- Increased use of MB for Quarantine and Pre-shipment (QPS) is offsetting gains made by reductions in controlled uses for soils, structures and commodities. Some of this increase is due to preplant soil use in propagation nursery sectors.

- TEAP estimates that currently available alternatives and substitutes could replace about 31% to 47% (1,937 to 2,942 tonnes) of QPS consumed in four categories of QPS use investigated. Since these four categories account for about 70% of total 2008 QPS methyl bromide use, the available technology can replace approximately 22% to 33% of total QPS consumption.

- Some Parties have stopped all uses of MB including QPS, other Parties have announced their intention to stop all uses in the near future.

- Parties contemplating controls on exempted MB use may wish to consider economic incentives that encourage minimal use, containment, recovery and recycling, as well as not-in-kind alternatives and substitutes for QPS uses of MB.

1.7 Refrigeration and Air Conditioning and Heat Pumps (RTOC)

- The required global phase-out of HCFCs, and the need to manage the lifetime operation of CFC- and also HCFC-based equipment, coupled with concerns to reduce global warming, drive transition from ozone depleting substance (ODS) refrigerants. The technical options are universal, but local laws, regulations, standards, economics, competitive situations and other factors influence regional and local choices.

- More than 60 new refrigerants, many of them blends, were introduced for use either in new equipment or as service fluids (to maintain or convert existing equipment) since the 2006 assessment report. The primary focus for examination of new refrigerants is on unsaturated hydrofluorocarbons and unsaturated hydrochlorofluorocarbons. The overarching climate change issue as well as changing refrigerant options for refrigeration and air conditioning will continue to advance equipment innovations. HFCs and non-fluorochemical options are increasingly used in most sectors, with emphasis on optimising system efficiency (expressed as Coefficient of Performance - COP) and reducing emissions of high Global Warming Potential (GWP) refrigerants.

- There are several low and medium GWP alternatives being considered as replacements for HCFC-22. These include lower GWP HFC refrigerants (HFC-32, HFC-152a, HFC-161, HFC-1234yf and other unsaturated fluorochemicals, as well as blends of them), HC-290 and R-744 (CO_2). HC-290 and some of the HFC refrigerants are flammable and will need to be applied in accordance with an appropriate safety standard. A high degree of containment applies to all future refrigerant applications, either for decreasing climate impact or for safety reasons. The latter aspect will also increase the need to advance charge reduction technologies.

- In commercial refrigeration stand-alone equipment, hydrocarbons (HCs) and R-744 are gaining market shares in Europe and in Japan; they are replacing HFC-134a, which is the dominant choice in most countries. In many developed countries, R-404A and R-507A have been the main replacements for HCFC-22 in supermarkets, however, because of their high GWP, a number of other options are now being introduced. Indirect systems are the most effective option for emissions reductions in new centralised systems for supermarkets. In two stage systems in Europe, R-744 is used at the low-temperature level and HFC-134a, R-744 and HCs at the medium temperature level.

- In industrial refrigeration, R-717 (ammonia) and HCFC-22 are still the most common refrigerants; R-744 is gaining in low-temperature, cascaded systems where it primarily replaces R-717 (ammonia), though the market volume is small.

- In air-to-air air conditioning, HFC blends, primarily R-410A, but to a limited degree also R-407C, are still the dominant near-term replacements for HCFC-22 in air-cooled systems. HC-290 is also being used to replace HCFC-22 in low charge split system, window and portable air conditioners in some countries. Most Article 5 countries are continuing to utilise HCFC-22 as the predominant refrigerant in air conditioning applications.

- Up to now, car manufacturers and suppliers have evaluated several refrigerant options for new car (and truck) air conditioning systems including R-744, HFC-152a and HFC-1234yf, all with GWPs below the EU threshold of 150. These options can achieve fuel efficiency comparable to the existing HFC-134a systems with appropriate hardware and control development. The use of hydrocarbons or blends of hydrocarbons has also been considered but so far has not received support from vehicle manufacturers due to safety concerns. The eventual decision which refrigerant to select for vehicle air conditioning will be made based on the GWPs of the above three options along with additional considerations including regulatory approval, costs, system reliability, safety, heat pump capability and servicing.

1.8 Remaining Military and Space Uses of ODSs (May 2008 TEAP Progress Report)

The primary remaining military ODS use is for halon in applications considered to be vital to operations lacking technically or economically feasible retrofit alternatives, or not yet budgeted or scheduled for retrofit or retirement. Like their civil aviation counterparts, some military aircraft continue to be produced with halon fire protection systems. CFC refrigerants continue to be used in some Naval vessels (ships and submarines) because: the refrigeration plants were designed specifically to use a particular ODS refrigerant, the refrigeration plants are sized according to the needs of the vessel, the acoustic signature of the vessel would be changed by using an alternative, and because the cost of removing the plant and replacing it is cost prohibitive. For example, in some vessel designs, the hull of the vessel must be opened in order to remove and replace the plant. For the latest TEAP findings on critical military and space uses see: TEAP, "2006 Assessment Report of the Technology and Economic Assessment Panel," United Nations Environment Programme, Nairobi, 2006, pp. 127-137.

The primary remaining Space applications for ODS uses are in thermal insulating foam, manufacture of solid rocket motors, and in cleaning of electronic and precision mechanical assemblies. In non-Article 5 Parties, military and space applications continue to be satisfied by recycling existing stocks of ODS, with a small number of uses met through Essential Use Exemptions previously granted by Parties to Poland (CFC-113 to clean torpedoes), The Russian Federation (Halon 2402 for fire protection; CFC-113 for aerospace applications) and the United States (methyl chloroform for manufacture of civilian and military rockets).

1.8.1 Unique Military and Space Uses of HCFCs

Most current use of HCFCs by military and space organisations is in applications that are not unique but may be vital to current operations. It can be expected that many of the ordinary HCFC uses will be replaced by the same technology that is implemented in civilian sectors. However, there are a few low-volume HCFC uses that are unique to military and space organisations and which are vital to safe operations. These unique uses can be: 1) phased out with new technology, 2) supplied from stockpiles or from recovered HCFCs, or 3) provided under terms of an Essential Use Exemption (if agreed by Parties).

Mission-vital HCFC uses include:

- Solvent HCFC-225 used for cleaning oxygen systems, electro-optical devices, precision navigation systems and similar components where a combination of materials must be compatible with the solvent and the solvent must remove soil with little residue left behind. Small amounts of CFC-113 and HCFC-225 will continue to be used for some *in situ* cleaning of oxygen systems having complex geometries.

- HCFC refrigerants used in a battlefield environment can be replaced with existing or new non-flammable or possibly mildly flammable HFCs, but cannot be replaced with non-fluorocarbon refrigerants such as hydrocarbons and ammonia owing to flammability and safety concerns in a battlefield environment. Some militaries are considering extending the use of HCFCs in some battlefield equipment for a few years by using recycled refrigerant rather than shifting to high-GWP HFCs to allow time for the technical maturity of low-GWP refrigeration systems, such as transcritical carbon dioxide. Military-unique systems tend to have very long development and operational lifetimes, lasting half a century or longer in both developed and developing countries. The systems are highly integrated, their designs are highly constrained in terms of space and weight, and modification costs are generally very high.

- HCFC-141b used for thermal insulating foam on the oxygen tank of the United States (U.S.) Space Shuttle is vital today, but is expected to be phased out when the next generation spacecraft replaces the Space Shuttle.

1.8.2 Continuing International Co-operation

There have been significant efforts over the years to spread awareness of the Montreal Protocol and the availability of measures militaries can take to manage the phase-out including: five workshops on the role of the military in implementing the Montreal Protocol (1991, 1994, 1997, 2001, and 2008); bilateral military-to-military technology co-operation projects involving Mexico, Thailand, Turkey, and Malaysia; and UNEP sponsored workshops in India and Jordan that included regional military participation.

Military and space organisations have invested significant effort and funding, and have made great strides to reduce their dependence on ODS. Modifications to existing systems and practices have been made where technically and economically feasible alternatives exist. Very few new military systems continue to rely on ODS. By demonstrating the feasibility of the alternatives, especially emerging technologies, military and space organisations continue to pave the way for the civilian sector transition away from ODS. For military and space applications that continue to need ODSs, military and space operators of reserve stocks have been diligent in preventing leakage and ensuring that ODSs are only used for vital applications.

The following actions will further minimise ODS emissions from continuing uses and reduce the need for essential use nominations:

- ✓ Fostering the continued collection and recycling of ODSs;
- ✓ Employing best practices for ODS recovery/recycling, storage, reuse and destruction;
- ✓ Ensuring flexibility that will enable transnational shipment necessary to supply recycled ODS for vital needs; and
- ✓ Planning to reduce future dependency on ODS through the use of alternatives and other options.

1.9 Report of the Task Force on Environmentally Sound Management of Banks of Ozone-Depleting Substances (Decision XX/7) 2009

In the period since 2006, TEAP has assessed further the characteristics of the ODS Banks identified in its earlier work. This has included two complementary reports prepared in response to Decision XX/7 in 2009 as well as further data analysis ahead of the Workshop on the Environmentally Sound Management of Banks held in Geneva in June 2010. Meanwhile, individual TOCs have monitored developments in their sectors in order to assess the cost-effectiveness of measures and likely future trends. Key conclusions from this work are as follows:

- The IPCC/TEAP Special Report on Ozone and Climate indicated total ODS and HFC bank sizes of 5.79 million tonnes in 2002 with forecast growth to 7.72 million in 2015. In this period ODS were expected to decline by 353,000 tonnes while HFCs were expected to grow by 2.41 million tonnes.
- More recent estimates of actual bank sizes have shown refrigerant banks at approximately 2.8 million tonnes in 2006 and foam banks at 3.53 million for the same year with a further 444,000 tonnes of CFC-11 contained in foams already in landfill.

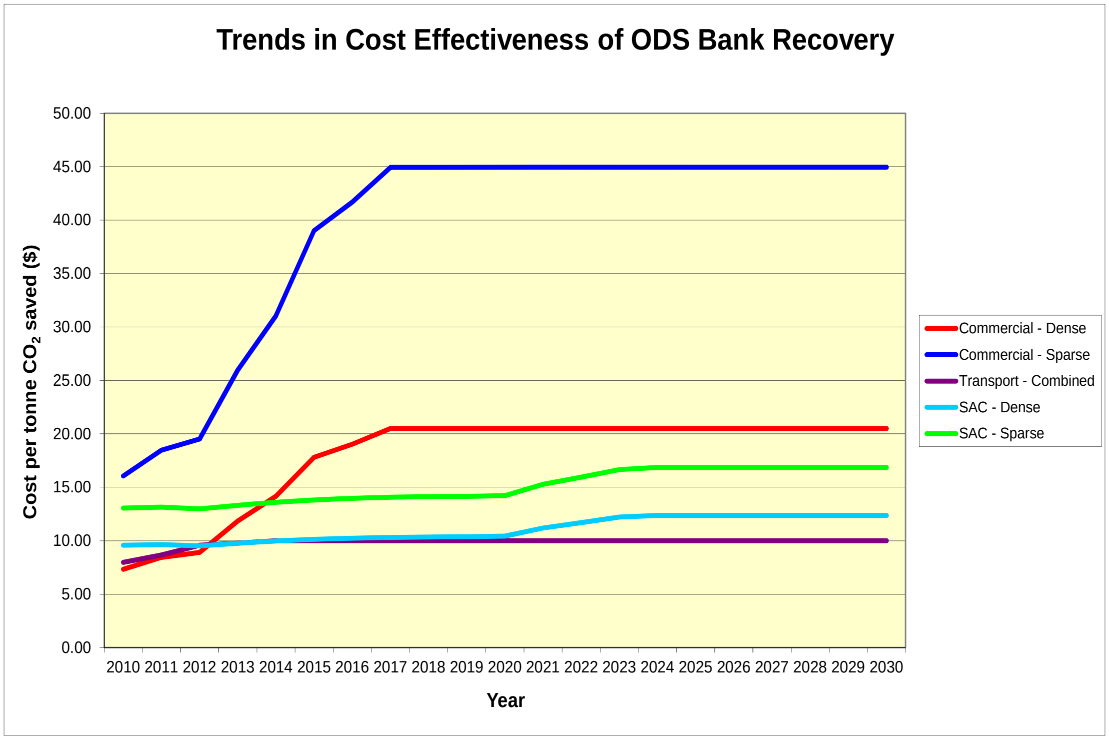
- The Phase 1 Report for Decision XX/7 showed that approximately 85% of this total is reachable, with around 47.5% (3 million tonnes) of the bank being in the low to medium effort categories.

Region	***ODS type***	***Low Effort***	***Medium Effort***	***High Effort***
(all in ktonnes)				
Developed Countries	CFCs	123.82	239.76	1009.08
	HCFCs	631.86	308.23	838.73
	Halons	44.32	15.00	-
Developing Countries	CFCs	160.79	225.80	154.27
	HCFCs	563.49	645.72	347.22
	Halons	22.24	28.95	-
Global		***1546.52***	***1463.46***	***2349.30***

- Further work on the cost-effectiveness of measures to recover ODS in banks suggests that, from a climate perspective, low effort banks could be recovered at an average cost of around $15 per tonne of CO_2-eq. while medium effort banks could require average investments equivalent to $35 per tonne of CO_2-eq. However, the effective cost of recovery and destruction will increase with time in many sectors because of reductions in the average GWP of the product mix within waste streams.

- Amongst the reachable banks, commercial refrigeration offers the largest potential recovery opportunity, but the cost effectiveness in climate terms is slightly worse than some other sectors because the primary ODS used in the sector has been HCFC-22 throughout (GWP=1780).

- Stationary Air Conditioning represents the largest refrigerant bank in tonnage terms (48% of total), but is of a similar magnitude to commercial refrigeration in climate terms. The disperse nature and ownership of Air Conditioning units has made it difficult to formulate effective recovery strategies.



- The TEAP analysis of the last four years has sought to differentiate between banks situated in densely populated (urban) areas and sparsely populated (rural) areas. An impact on cost from the higher recovery challenges is correctly anticipated, although the magnitude of that impact is only estimated at present.

- Although foamed products in appliances and buildings account for the largest banks, their emissions are relatively low. In addition, recovery and destruction is seen to be technically more challenging than for refrigerants. Most foams are currently positioned in the high effort category.

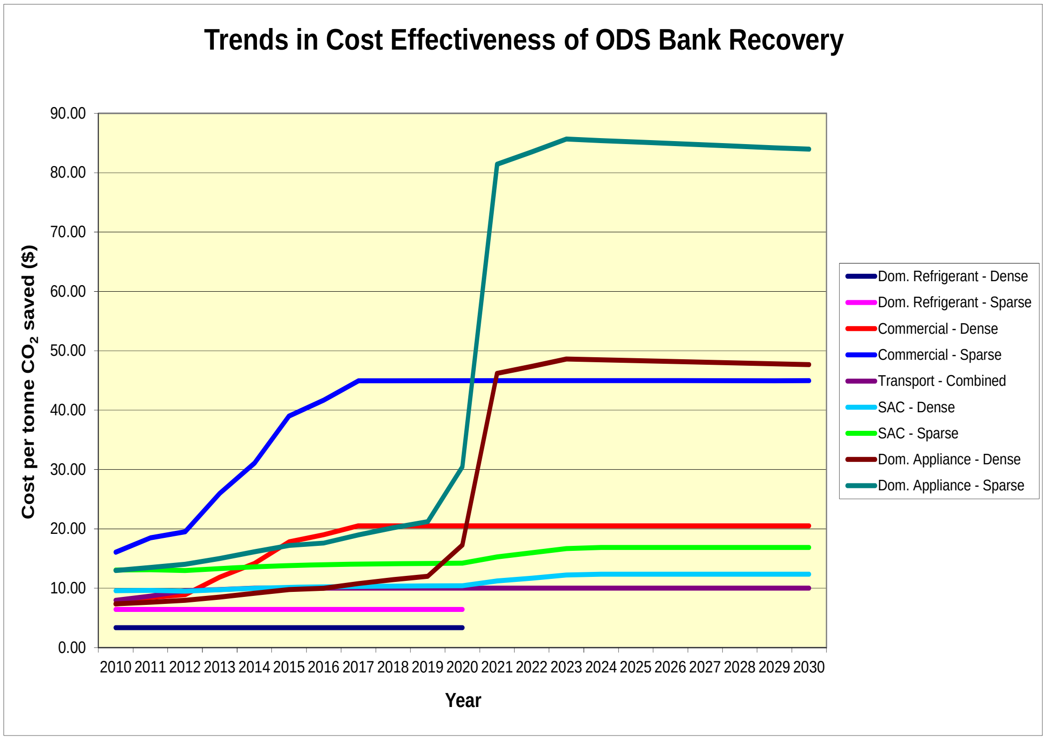
- Even the most accessible building insulation foams are expected to lead to bank management costs in excess of $100 per tonne CO_2 saved. The figure will depend to a significant extent on the demolition waste management practices mandated in the region. However, the relatively long lifetimes of buildings will result in low levels of blowing agent reaching the waste stream in the next decade. The statistical distribution around the average lifetime of buildings may also mean that any recovery/destruction provisions may need to be in place until around 2050 to capture a high proportion of the reachable bank.

- A further unknown in the evaluation of recovery options for ODS is the extent to which anaerobic degradation will take place in (managed) landfills. This could clearly impact baseline emissions and result in less benefit from end-of-life measures.

- For appliances, the major opportunity to achieve significant climate benefits is within the next 5-10 years. As the product mix moves from CFC-containing to HCFC/HFC containing, the expectation is that the costs of recovery/destruction will increase substantially in climate terms (see below).

Sector	*Low Effort*	*Medium Effort*	*High Effort*
Domestic Refrigeration – Refrigerant	DP	SP	
Domestic Refrigeration – Blowing Agent	DP	SP	
Commercial Refrigeration – Refrigerant	DP	SP	
Commercial Refrigeration – Blowing Agent	DP	SP	
Transport Refrigeration – Refrigerant	DP/SP		
Transport Refrigeration – Blowing Agent	DP/SP		
Industrial Refrigeration – Refrigerant	DP/SP		
Stationary Air Conditioning – Refrigerant	DP	SP	
Other Stationary Air Conditioning – Refrigerant	DP	SP	
Mobile Air Conditioning – Refrigerant	DP	SP	
Steel-faced Panels – Blowing Agent		DP	SP
XPS Foams – Blowing Agent			DP/SP*
PU Boardstock – Blowing Agent			DP/SP*
PU Spray – Blowing Agent			DP*/SP*
PU Block – Pipe		DP	SP
PU Block – Slab		DP	SP
Other PU Foams – Blowing Agent			DP/SP*
Halon – Fire Suppression	DP	SP	

DP = Densely Populated Areas; SP = Sparsely Populated Areas * Still technically unproven



- Although the carbon markets could have a role to play in financing future ODS bank management activities, the relatively low carbon price, coupled with a lack of internationally recognised protocols for validation/verification means that only the most cost-effective measures can be supported at present.

- For halons, the bulk of the bank, with the exception of contaminated materials, is being managed for re-use. It would therefore be inappropriate to consider recovery/destruction when vital future uses are envisaged and Essential Use Exemptions for production and consumption would otherwise need to be granted.

- Although halons have high direct GWPs they have not been included in either of the two known voluntary ODS destruction protocols because of uncertainty related to their indirect GWPs. Owing to the fact that halons contain bromine and are potent ozone-depleting substances, it has been estimated that their indirect GWPs could be less than zero. If GHG reduction credits are provided in the future for destroying used halons, this could have a significant impact on the cost of recycled halon and its availability for important uses. In light of recent published data on the indirect GWPs of halons (Young et al., Atmos. Chem. Phys., 2009), the Parties may wish to consider requesting the Scientific Assessment Panel to clarify the extent of the climate benefits, if any, resulting from destroying banked halons.

- There are a few important fire protection applications such as crew bays of armoured vehicles where the only current options are to use recycled halon or a high GWP HFC. From a total environmental impact perspective, is it better to reuse an already produced, recycled halon or produce a high GWP HFC for the application? This is a challenge that the Parties may wish to consider.

- There is concern that the establishment of active halon bank management regimes has been slow to emerge in Article 5 Parties.

- Overall, flows of ODS into the waste stream are expected to peak globally at 200,000-225,000 tonnes per annum in the 2018-2020 window. The inclusion of ODS substitutes within the list of managed substances will see this figure grow to 400,000-450,000 tonnes per annum in 2030 and continue to grow thereafter. Nonetheless, there is expected to be sufficient destruction capacity to manage these quantities relatively easily. The more challenging aspect will be in relation to the logistics of getting the materials to the facilities. This challenge may lead to the deployment of smaller-scale, localised destruction units in some regions.

1.10 Response by TEAP and its MTOC to Decision XX/4: Campaign Production for Some Article 5 Parties Manufacturing Metered Dose Inhalers Which Use Chlorofluorocarbons (2009)

At their 17th MOP, Parties discussed the difficulties faced by some Article 5 Parties with respect to the phase-out of CFCs used in the manufacture of MDIs. In Decision XVII/14 the Parties expressed concern that Article 5 Parties that manufacture CFC MDIs might find it difficult to phase out these substances without incurring economic losses to their countries and the risk that, for some Article 5 Parties, 2007 CFC consumption for MDIs might exceed the amounts allowed for all CFC uses.

The Parties considered the issue again at their 18th Meeting and in Decision XVIII/16 requested: "TEAP to assess and report on progress at the 27OEWG and to report to the MOP19 on the need for, feasibility of, optimal timing of, and recommended quantities for a limited campaign production of chlorofluorocarbons exclusively for metered-dose inhalers in both Parties operating under paragraph 1 of Article 5 and Parties not operating under paragraph 1 of Article 5."

The TEAP and its MTOC included its response to Decision XVIII/16 in the April 2007 TEAP Progress Report. The 27th Open-ended Working Group discussed the possibility of maintaining the current system of "just-in-time production," but not achieve consensus, nor was consensus achieved at the 19th Meeting of the Parties.

In its 2008 TEAP Progress Report, MTOC reviewed new information available from the Multilateral Fund Secretariat, implementing agencies, countries, and industry sources and considered issues surrounding CFC MDI transition in both Parties manufacturing CFC MDIs and also Article 5 countries importing MDIs.

The Parties considered the issue of a final campaign production of CFCs (for MDIs granted an essential use exemption) at their 20th Meeting and, under Decision XX/4, requested the Technology and Economic Assessment Panel (TEAP) to present a report to their 21st Meeting, concerning timing, storage, distribution, and management, minimizing the potential for over- or under-production, contractual arrangements, and minimizing the production of waste non-pharmaceutical-grade CFCs and options for its disposal, to be preceded by a preliminary report to the 29th Open-Ended Working Group. A coordinated final campaign production for essential MDI uses was recommended previously by the TEAP and its Medical Technical Options Committee (MTOC) when it was understood that after 2009 only the CFC producer in Spain would be supplying the majority of CFCs needed for Article 5 countries, and that China would supply itself.

However, circumstances changed when the EC banned CFC production from 1st January 2010, making it difficult for TEAP and its MTOC to predict where essential use CFCs approved by Parties would be sourced for 2010 and beyond. Therefore, TEAP and its MTOC were unable in 2009 to provide Parties with a detailed response to Decision XX/4 and asked Parties to clarify the CFC production situation.

The report outlined options for the possible future supply of bulk pharmaceutical-grade CFCs to meet demand for MDI manufacture and estimated CFC requirements after 2009. Options considered in this report included supplying pharmaceutical-grade CFCs from a single production facility source or multiple production facilities.

TEAP and its MTOC suggested that Parties might wish to consider a fixed timetable for CFC production at a single facility or multiple facilities to avoid open-ended CFC production. Remaining stockpiles that would otherwise be destroyed were also suggested as a potential source of pharmaceutical-grade CFCs. TEAP and its MTOC cautioned that if Parties did not resolve the CFC production uncertainties, the default outcome could be that CFC MDI production ceased at the end of 2009 in many countries. TEAP and its MTOC recommended that Parties consider the source of production of CFCs for granted essential use exemptions for MDIs, and vigorously pursue opportunities to source stockpiles that would otherwise be destroyed.

TEAP and its MTOC emphasised that given the uncertainties and risks associated with the long-term supply of suitable quality CFCs after 2009, the highest priority for continued supply of metered dose inhalers was to complete transition as quickly as possible and ensure the expeditious introduction of CFC-free alternatives.

Parties took action to secure adequate supplies of pharmaceutical-grade CFCs through Decision XXI/4 and through Decision 60/47 of the Executive Committee. Decision XXI/4 requested Parties to report to the Secretariat on pharmaceutical-grade CFCs in existing stockpiles in order to make these CFCs available to supply authorised essential use requirements in 2010. The 60th Executive Committee Meeting, April 12-15, 2010, decided to modify the production sector agreements for China and India to allow CFC production for export of pharmaceutical-grade CFCs for 2010, with an annual review, for purposes of meeting essential use requirements of other countries provided that the exporting countries had specified reporting and verification systems in place. With technically satisfactory alternatives to CFC MDIs now available in almost all countries worldwide, and CFC consumption now decreasing, the pharmaceutical-grade CFC production uncertainties of the late 2000s have been resolved, and a CFC MDI supply crisis averted.

1.11 Quarantine and Pre-Shipment Report (Decision XX/6, report of November 2009)

Between 1999 and 2007 reported production of MB for QPS remained approximately constant on an annual basis and roughly at the same level (11,000 metric tonnes a year since 1995) as reported consumption.

QPS consumption in A5 countries has increased since 2000, particularly in the Asian region, while in non-A5 countries it has declined.

Five major QPS use categories were identified: fresh fruit and vegetables; grain; soil for preplant fumigation in situ; whole logs; and wood and wood packaging material. A discrepancy of about 1,300 tonnes for non-A5 Parties for 2007 between total consumption as represented by methyl bromide actually used and total consumption was apparent.

Uses that have been classified as QPS use by some Parties but not by others were: a) export coffee (Vietnam); b) export rice and cassava chips (Thailand, Vietnam); and c) soil for production of high health propagation material (USA). The Parties provided rationale as to why these situations qualify to be treated as QPS uses.

Development of methyl bromide alternatives for quarantine applications on commodities continues to be a difficult process, however there are technically effective alternatives approved and in use for at least some of the major categories of current quarantine use. Substituting uses for pre-shipment treatment is easier to achieve. Several soil treatment techniques and soilless systems can deliver propagation material produced to high plant health status.

Methyl bromide emissions from fumigations can be minimised through recapture and adoption of best practice, both directly through best use of the fumigant and indirectly by minimising the need to retreat after treatment failures.

Some Parties have discontinued use of QPS methyl bromide or have announced they intend to do so in the near future.

In the light of the information available on categories of use of methyl bromide for QPS purposes, alternatives available and key pests, the QPSTF was able to make preliminary estimates of uses and amounts that could possibly be replaced with alternatives.

1.12 Assessment of HCFCs and Environmentally Sound Alternatives (Decision XXI/9) May 2010

TEAP proposed a definition of low, medium and high GWP.

The latest comprehensive table with GWP values for a large variety of natural and synthetic substances can be found in the IPCC Fourth Assessment Report, Working Group I. The Global Warming Potential is based on the radiative forcing integrated over a specific time period due to a pulse emission of a unit mass of gas. The Kyoto Protocol has adopted GWP values for a time horizon of 100 years, but IPCC science assessments have generally presented GWPs for three time horizons, i.e., 20, 100 and 500 years.

The terms “high-GWP” or “low-GWP” are comparative in nature. The most commonly used ODS, representing more than 95 per cent of the global use of these substances have GWPs (100 year time horizon) between 700 and 4000, with a median value of slightly more than 2000. The TEAP proposal is to classify the 100-yr GWPs of greenhouse gases as “low” if less than 300, “moderate” if greater than 300 but less than 1000, and “high” if greater than 1000.

1.12.1 Methods and metrics

Methods and metrics can identify and quantify the benefits of technology superior in protecting ozone and climate. The results depend on the accuracy and completeness of the input data, the appropriateness of assumptions and the sophistication of the model. The ultimate choice of technology will be based on ozone depletion and also climate impact, health, safety, affordability and availability.

Choosing the lowest GWP substance may not always be the optimum approach because the GHG emissions from product manufacturing and product energy use often dominate the life-cycle carbon footprint. When available, LCCP calculations are the most comprehensive method to determine the direct and indirect greenhouse gas emissions at the product level. LCCP models need more development to be transparent, adaptable to local climate and electricity carbon intensity situations. When LCCP models are not available, appropriate, or the necessary data to apply them is not yet available, other methods and metrics will be useful.

1.13 Scoping Study on Alternatives to HCFC Refrigerants Under High Ambient Temperature Conditions (Decision XIX/8) May 2010

In the near term, regions with hot climates should be able to rely on the refrigerants and technologies that are currently commercially available to replace HCFC-22 (R-407C, R-410A and HC-290).

However, when replacing HCFC-22 products with those using R-410A or R-407C the application engineer will need to take into consideration the reduced capacity at the design ambient temperature when sizing the equipment for the design cooling load. The application engineer should consult the application data published by the manufacturer when making sizing decisions. In most cases R-410A or R-407C will only need to be sized 5-10% larger than HCFC-22 equipment to compensate for the lower capacity at ambient temperatures up to 50 °C. The increased cost of oversizing the equipment will be about 3% for a 10% increase in capacity.

HFC-32 is likely to become a longer-term replacement for R-410A. It has a GWP approximately 32% of that of R-410A and exhibits much better high ambient performance than R-410A. In addition, the design changes required to convert from R-410A to HFC-32 should be minor.

HFC-134a and HC-600a would seem attractive from the point of view that they have similar performance to HCFC-22 at high ambient temperatures. However, both of these refrigerants are low-pressure refrigerants. The use of these low pressure refrigerants would require extensive redesign of the base system components in order to achieve the same capacity and efficiency of the HCFC-22 system. Therefore, HFC-134a and HC-600a are not considered cost effective options to replace HCFC-22 in unitary air-conditioning applications.

A number of low GWP alternatives to HFC refrigerants are currently under development. However, because these refrigerants are in the early stages of development it is premature to list them as options to the current HCFC alternatives, in particular at high ambient temperatures.

In the longer term, as non-ODP and low-GWP technologies are developed to replace current HCFC-22, R-407C and R-410A products, equipment designed to operate with acceptable efficiency and capacities at the extreme environment conditions should become widely available in both developed and developing countries.

1.14 Cross-Sectoral Findings

The following are cross-sectoral findings:

- Technically and economically feasible substitutes are available for almost all applications of HCFCs, although transitional costs remain a barrier for smaller enterprises, particularly in developing countries.
- Accelerated phase-out of HCFCs could lead to incremental energy efficiency benefits if existing, less efficient, equipment is retired early.

- A considerable portion of the 3.5 million ODP-tonnes of ODS contained in banks is available for collection and destruction at costs that can be justified by benefits in reducing ODS and greenhouse gas emissions.
- Parties contemplating collection and destruction may wish to consider incentives for collection that avoid prolonged use of inefficient equipment, intentional venting or product dumping. In this context, the classification of ODS recovery and destruction activities as carbon offset projects could warrant further investigation.
- Since 2002, TEAP and its TOCs have undertaken extensive work to co-ordinate with the Intergovernmental Panel on Climate Change (IPCC) on climate protection and to refine and improve estimates of ODS banks and emissions. Parties may wish to consider whether additional co-ordination will provide useful policy-relevant technical information and, if so, how such co-ordination can be encouraged.

1.15 2007 Task Force on TEAP

The 1987 Montreal Protocol included a specific provision (Article 6) for periodic assessment and review:

> *"Beginning in 1990, and at least every four years thereafter, the Parties shall assess the control measures provided for in Article 2 on the basis of available scientific, environmental, technical, and economic information. At least one year before each assessment, the Parties shall convene appropriate panels of experts qualified in the fields mentioned and determine the composition and terms of reference of any such panels. Within one year of being convened, the panels will report their conclusions, through the Secretariat, to the Parties."*

The four original Montreal Protocol panels – 1) Panel for Scientific Assessment, 2) Panel for Environmental Assessment, 3) Panel for Technology Assessment, and 4) Panel for Economic Assessment – were informally organized in The Hague at the October 1988 'UNEP Conference on Science and Development, CFC Data, Legal Matters, and Alternative Substances and Technologies' and were formalized at the First Meeting of Parties, held in Helsinki in May 1989.

After 1990, the Panel for Scientific Assessment re-labelled itself "The Scientific Assessment Panel" (SAP); the Panel for Environmental Assessment re-labelled itself "The Environmental Effects Assessment Panel" (EEAP); and The Panel for Economic Assessment was merged with the Panel for Technology Assessment and re-labelled "The Technology and Economic Assessment Panel" (TEAP).

The permanent membership of the TEAP includes its Co-Chairs, the Co-Chairs of the Technical Options Committees, and Senior Expert Members. In any year, its temporary membership includes the Co-Chairs of any active Task Force.

Over 175 experts serve on the TEAP and its TOCs and subsidiary bodies. Since its creation, over 900 experts from about 65 countries have participated in the assessment process.

About 50 per cent of TEAP/TOC/Task Force members are from industry, 25 per cent from government, 15 per cent from universities, 5 per cent from NGOs, and the rest are from are from research institutes, hospitals, or list no affiliation. About one third are from Article 5 Parties and two thirds from non-Article 5 Parties.

Lists of TEAP and TOC members are given in the last chapter of this report.

2 Abstract Executive Summaries

2.1 Chemicals TOC

Current Status

After assessing information provided by Parties, 17 process agent uses were added to Table A (Annex to decision XXII/8) and 12 uses were deleted from Table A as processes were abandoned or modified. Reporting of emissions for including in Table B has been less than complete.

There are very few identified uses of ODS in laboratory and analytical procedures in non-Article 5 countries, but use (especially of CTC) as a chemical reactant continues and will be hard to replace. Some use continues in several Article 5 countries.

An extensive listing of known use of ODSs as feedstocks has been compiled. By using volumes suggested by the CTOC members and by following guidelines for emission calculations suggested by the IPCC for the UNFCCC, estimates of emissions from these feedstocks have been generated.

In 2009, CTOC identified 176 destruction facilities in 27 countries including new technologies not listed in the 2002 Task Force Report. Most destruction facilities are based on combustion in dedicated furnaces or equipment such as cement kilns and there has been some adoption of such technologies in Article 5 countries.

The TEAP/CTOC made a comprehensive review on CTC emissions, concluding that there is a significant discrepancy between reported emissions and the observed atmospheric concentrations under Decisions XVI/14 and XVIII/10.

What is left to be achieved

A better standard method of reporting of emissions needs to be agreed upon so that Table B (Annex to decision XXII/8) will give a more reliable picture of emissions arising from process agent uses. When the CTOC and MLF will produce a joint report in 2011 according to the Decision XXI/3 (5), further deletions from Table A and a more complete update on phase-outs or suggestions for phase-outs could be possible.

Advice by experts is required, together with modest financial support for alternatives that have already been identified to be tried in Article 5 countries, alongside current procedures that involve ODSs. New standard methods need to be developed.

There is a lack of reporting of use of ODSs as feedstocks. Also, at the current time, the majority of the production from ODS feedstocks is for HFCs, the production of which is not reported to a publicly accessible data bank. Should Parties wish quantification of feedstock emissions, reporting of ODS used in feedstock applications will be recommended. Expert opinion suggests that the IPCC guidelines are maximal values and actual emissions may be lower at well-managed facilities. Better emission control mechanisms need to be developed.

The major challenge is the complete phase-out of ODS solvents in Article 5 countries. Preferable alternatives have been identified and are generally available. Another hurdle to overcome is the economic impact on the small and medium size users who make up a major portion of the remaining ODS solvent market.

Recently several emerging technologies for ODS and HFC destruction have been requested for evaluation. Following Decision XXII/10, they will be reviewed when technical details are made available.

The studies have not yet been completed on the production and consumption of CTC with particular emphasis on feedstock uses with the goal to estimate emissions and try to reconcile them with values calculated by atmospheric scientists.

The way forward

A list of Parties with approved process agent uses could be provided to the Ozone Secretariat, so that requests for information could be targeted and followed up, rather than including such requests in global communications.

It would be helpful to the phase-out of ODSs in laboratory and analytical uses for the Ozone Secretariat and experts identified by the CTOC to work with national and international standards bodies to establish new standard methods of analysis that do not use ODS. TEAP and the CTOC will keep Parties informed of advances on these fronts.

Developed countries, in their inventory reporting, report to the UNFCCC the emission data for HFCs. Thus, discussions with UNFCCC may assist in developing new estimated sources of data for HFC production (which may have utilised ODSs as feedstock in their preparation). The reporting of ODS volumes for each feedstock uses by Parties through the Ozone Secretariat may enable a more complete quantification of this activity.

Regulatory changes will continue to impact on the use of solvents. In some cases, this may require solvent and/or equipment change or a new cleaning process. The definition of low-GWP (Global Warming Potential) and high-GWP alternatives, which TEAP has proposed, may help users in selecting more appropriate solvents.

Periodic review of available destruction technologies will be necessary to provide updated technical guidelines for destruction of ozone depleting substances such as CFCs, halons and methyl bromide as well as for HFCs.

Further studies will be needed to improve and reconcile bottom-up and top-down calculations, to search for other unreported CTC emission sources, to critically analyse UNEP inventory data and to possibly further revise the atmospheric lifetime of CTC.

2.2 Flexible and Rigid Foams TOC

Current status

HCFC phase-out is virtually complete in all non-Article 5 countries, with XPS in North America being the last major sector to make the transition. In this instance, the technology choice has been saturated HFCs, reflecting the demanding product range and process requirements that the XPS industry has in the region. Experience from this transition has made the industry wary about committing to any further transitions in the medium term, since proving emerging alternatives in these applications will involve substantial further effort.

Growth in thermal insulation foams continues to be driven by increasing energy efficiency requirements in appliances and buildings. Although hydrocarbons continue to be the primary solution in non-Article 5 countries, there is pressure in some sectors to further optimise these solutions by blending. While cyclopentane continues to play an important role in optimising blend performance, other components such as unsaturated HFCs (HFOs) and methyl formate are also being assessed at this time. Early work on unsaturated HFCs (HFOs) suggests that they deliver better thermal performance than their saturated counterparts, although toxicological work remains to be completed for those yet to be commercialised. In the interim, there is evidence that some enterprises manufacturing appliances in developing countries are already blending saturated HFCs with hydrocarbons to meet energy requirements.

HCFC phase-out in Article 5 countries continues to be a serious source of unease. In several sectors, particularly in rigid PU foams, previously identified low-GWP alternatives to HCFCs have yet to be fully proven in the field. This is particularly important since many of the enterprises expected to take up these technologies are SMEs and have little, if any, internal capacity to optimise formulations. There is concern that measures to manage flammability for methyl formate may require system houses to reformulate with more compatible polyols for rigid foam applications in order to reduce the risk. However, in a limited number of cases it may be more productive to blend methyl formate in the isocyanate component to obtain the required foam properties whilst avoiding flammable blends.

The management of ODS banks in appliance foams is currently being addressed by a variety of regulatory and voluntary frameworks and using a range of fully automated, semi-automated and manual technologies. Although there is evidence to suggest that fully automated approaches provide the most comprehensive recovery potential, the relevant cost-abatement curves would suggest that some semi-automated processes will have a place in the on-going management of ODS banks, particularly in areas where population densities are low or investment is restricted.

Efforts have been made to further characterise foam inventories in a number of regions. The flow of ODS-containing foams into the demolition waste stream from buildings is currently low and is likely to remain so for the next decade for most product types. Although the economics of recovery vary by region and are influenced by wider demolition waste management frameworks, even the most favourable circumstances lead to costs of above \$100 per tonne CO_2 saved on average. There will be a need for further innovation in the longer-term if recovery from this source is going to become economically feasible.

What is left to be achieved

Decisions need to be made at short notice within HCFC Phase-out Management Plans (HPMPs) on the choice of alternative to HCFCs in Article 5 countries. The prioritisation of ‘worst first’ embodied within Decision XIX/6 puts a strong focus on dealing with HCFC-141b applications in the early phases of implementation. Nevertheless, some countries are finding it easier to manage their compliance issues by phasing the foam sector transitions according to the ease with which projects can be implemented and the magnitude of their impact. Shortfalls are then being made up from other sectors.

There continues to be a need to characterise the performance of foams made from low-GWP alternatives in the range of applications envisaged. This is an on-going exercise, but is particularly important for technologies that do not have a significant history of use in non-Article 5 countries. The role of the Pilot Projects sponsored under the Multilateral Fund are especially relevant here and the work of UNDP on methyl formate, for example, has already cleared the way for wider use in the flexible moulded and integral skin sectors.

In non-Article 5 countries, the primary future interest is in further improving energy efficiency. However, an additional pressure may arise from proposals to see the phase-down in use of saturated HFCs. Apart from initiatives signalled under the Montreal Protocol itself, there is growing interest in seeing such a measure as part of the re-cast F-Gas Regulation in Europe. This may serve to strengthen research efforts in non-Article 5 countries towards low-GWP solutions and, in particular, towards the intelligent use of blends. There may be added spin-offs for Article 5 countries from this work, but these are unlikely to emerge in time for incorporation within relevant HPMPs.

Considerations will continue into the most appropriate strategies for ODS bank management in foams, with particular focus on ensuring that CFC capture from existing appliance-based banks is optimised before those opportunities are lost. This may involve the need to look at efficient ways of transferring existing technologies from non-Article 5 to Article 5 environments. The most appropriate funding mechanisms for such action are still under discussion, but these need to reach a conclusion soon if opportunities are going to be grasped.

The way forward

Although less emissive than the refrigeration and air conditioning sector, the foam sector continues to represent a substantial bank of long-lived ODS which provide opportunities for future management. Time pressures for management initiatives vary by sector, but ultimate policy decisions will depend on the emerging cost abatement curves on a wide range of other ozone layer protection and climate measures. It remains to be seen whether or not the recovery of ODS from buildings will become a viable option given the scattered nature of the sources involved and the efforts required for recovery.

For the immediate challenge of phasing out HCFC-reliance in Article 5 countries, there are a number of obstacles. The time pressure to resolve these only serves to add to the complexity of the situation and it may be that a number of unproven solutions need to be adopted in the short-term, with the potential downside risk to enterprises and investors alike. One of the consequences of this could be that enterprises choose to minimise their risks by choosing proven, but sub-optimal, technology solutions (e.g. high GWP or less energy efficient solutions) with the intent of making a second conversion when more appropriate solutions have become established.

2.3 Halons TOC

The current status, the on-going issues

The HTOC models estimate the end of year 2010 global bank of halons as follows: halon 1301 at 42,500 MT, halon 1211 at 65,000 MT, and halon 2402 at 2,300 MT. Parties have not indicated to the Ozone Secretariat that they are unable to obtain halons to satisfy their needs, although some Parties have expressed cost concerns to HTOC members.

Since 1 January 2010, the only production of halon 1301 has been in China and France for use as a feedstock in the manufacture of the pesticide Fipronil.

As yet, an alternative with all of the beneficial characteristics of the halon to be replaced has not been developed. Nevertheless, new agents and technologies continue to be developed. In particular, an unsaturated hydrobromofluorocarbon (HBFC) is being tested for aviation applications.

Halon banking is a critical part of halon management, yet there has been a lag in the establishment of banking and management programmes in Article 5 Parties globally.

Emissions, transformation and consumption of halon 2402 as a process agent by the Russian chemical industry has substantially reduced the total bank of halon 2402, and new uses in non-traditional applications are a cause for concern to the HTOC.

The HTOC continued its work with the International Civil Aviation Organisation (ICAO) – reference Decision XXI/7 - resulting in the development of a revised resolution, containing amended halon replacement dates agreed to by industry that was adopted at the ICAO 37th Assembly in September 2010 as Resolution A37/9.

Halons continue to be used by military organisations in many frontline applications where alternatives are not technically or economically feasible at this time. Nevertheless, the militaries of many Parties devote considerable effort and resources to reduce and eventually eliminate the use of halons wherever technically and economically feasible.

The way forward, towards the future

Now that there is no global production of halons for fire protection uses, management of the remaining stock becomes crucial for ensuring sufficient halons for applications that need them. As such, halon recycling is becoming even more important to ensure that adequate stocks of halons are available to meet the future needs of the Parties.

Destruction of halons for carbon credits may not provide the anticipated climate benefits.

The experience within Europe, where it was found that contaminated halons were making their way into the civil aviation industry, has highlighted the need for end users to be aware of the purity of any reclaimed or recycled halon that they purchase.

While there is no apparent shortage of recycled halon 2402 on a global basis, there are regional shortages today that Parties may wish to address.

National or regional banking schemes that maintain good records can minimise the uncertainty in stored inventory and stock availability. Parties may wish to encourage such national halon banking schemes to ensure that needs considered critical by a Party are met.

Future

Despite the introduction of new halon alternatives and the remarkable progress in switching to them, there will be an on-going need for halons for the foreseeable future.

Aviation applications are among the most demanding uses of halons and require every one of their beneficial characteristics. Given the 25–30 year life of civil aircraft, this dependency will continue well beyond the time when recycled halon is readily available.

Extensive research, development and testing have all but eliminated the need for halons in new designs of armoured vehicles, military aircraft, and naval vessels. Nevertheless, many legacy systems will continue to need halons until the end of the equipment life.

Existing oil and gas pipelines and production facilities in inhospitable climates will continue to use halons for fire suppression and explosion prevention as retrofit to available alternatives is not technically and/or economically feasible. Where an inerting agent is still required in occupied spaces, halon will be replaced by a high GWP hydrofluorocarbon (HFC) or a fluoroketone, where the temperatures permit.

The only halon alternative in a few applications will remain a high GWP HFC.

For other commercial/industrial applications, halons are no longer necessary and systems will continue to be decommissioned and replaced by systems using alternative agents. However, the cost to re-engineer and replace some legacy systems can be expensive and, in many cases, unless industry is mandated to do so, they will continue to rely on recycled halon from the halon bank to maintain the system.

2.4 Medical TOC

2.4.1 Metered dose inhalers

Current status

In 2009, about 2,300 tonnes of chlorofluorocarbons (CFCs) were used globally for the manufacture of metered dose inhalers (MDIs) for asthma and chronic obstructive pulmonary disease (COPD). This represents about a 50 percent reduction in global CFC use since the last assessment.

There has been significant global progress in the transition of CFC MDIs to CFC-free inhalers. Technically satisfactory alternatives to CFC MDIs are now available in almost all countries worldwide to cover all the key classes of drugs used in the treatment of asthma and COPD.

By 2010 every developed country had phased out the use of CFCs in MDIs, except the Russian Federation, which is yet to complete manufacturing conversion, and the United States, which is well advanced in its phase-out.

Despite initial challenges such as access to technology transfer and economic barriers, most developing countries are well advanced in their transition plans to phase out the use of CFCs. CFC consumption by Article 5 countries is estimated to have peaked in 2008 and 2009 at about 1,700 tonnes, and now appears to be decreasing.

In Article 5 Parties there has been substantial progress in the development and marketing of affordable CFC-free MDIs, with hydrochlorofluorocarbon (HFC) MDIs now becoming more competitively priced compared to CFC MDIs. As a result, there is now an adequate range of technically satisfactory and affordable CFC-free alternatives for CFC MDIs for beta-agonists (in particular, salbutamol) and inhaled corticosteroids (in particular, beclomethasone) available in many developing countries. Taking these issues into consideration, salbutamol and beclomethasone CFC MDIs can now be considered non-essential in most importing countries.

What is left to be achieved?

Current predictions are that most Article 5 Parties and the Russian Federation will have largely completed transition from CFC MDIs by about the end of 2012. A notable exception is China, which has current plans to complete CFC MDI phase-out in 2016.

The way forward

It could be possible to complete the phase-out of CFC MDIs with careful management of existing stockpiles, provided manufacture of pharmaceutical-grade CFCs in China continues to supply its own needs and those of the Russian Federation. A cautious approach to CFC production is advisable since transition is moving quickly and CFC production that is surplus to actual needs ought to be avoided, as otherwise it could subsequently require costly destruction.

2.4.2 Pharmaceutical aerosol products other than MDIs

Current status

Technically and economically feasible alternatives are available for all medical aerosol products. The manufacture of most CFC-containing medical aerosols in non-Article 5 Parties ceased around 1996, and in Article 5 Parties would have ceased around the end of 2009.

What is left to be achieved?

There are some developing countries that are yet to complete the conversion of CFC-based medical aerosols to alternatives. In China, some of the traditional Chinese aerosol manufacturers have encountered technical difficulties in their conversion to alternatives, with new formulations not meeting relevant quality standards. With the 2010 phase-out date for CFCs in developing countries, any current CFC consumption for medical aerosols could only be sourced from existing pre-2010 stockpile.

The way forward

Government authorities in China are coordinating with companies to resolve remaining technical issues. Full conversion of the medical aerosol sector in China, other than MDIs, is likely to be completed in 2012. The worldwide phase-out of CFC-containing medical aerosols will occur as part of each Article 5 country plan.

2.4.3 Sterilants

Current status

The use of CFCs in blends with ethylene oxide (EO) in sterilization has been successfully phased out in non-Article 5 countries and in many Article 5 countries. Total global use of CFCs in 2010 for sterilization is believed to be close to zero. Estimated global use of HCFCs in replacement mixtures is between about 500-700 metric tonnes in 2010, which amounts to less than 25 ODP tonnes worldwide. EO/HCFC use in non-Article 5 countries is declining, with regulatory restrictions being introduced. EO/HCFC use in Article 5 countries is about 200-400 tonnes.

What is left to be achieved?

There is a range of commercially available sterilization methods that will replace the use of ozone-depleting substances in this sector over time.

The way forward

An orderly phase-out of HCFCs in sterilization to meet Montreal Protocol HCFC phase-out schedules is readily achievable in Article 5 countries. By 2030 current sterilisers should be ready for replacement with available alternative technologies that do not use ozone-depleting substances. Hospital procurement should take the HCFC phase-out, and the coming redundancy of EO/HCFC sterilization equipment, into consideration in making future investment decisions.

2.5 Methyl Bromide TOC

What has been achieved

Global production for the methyl bromide uses controlled under the Protocol was reduced by 87% from 66,430 t reported in 1991 to 8,928 tonnes in 2009. Less than 5% of the production occurs in Article 5 countries, peaking at 2,397 tonnes in 2000 and falling to 29% (403 tonnes) in 2009.

Global consumption of methyl bromide for controlled uses was reported at 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. This fell to 8,148 tonnes in 2009. Historically, in non-Article 5 regions, 90% of methyl bromide was used for pre-plant soil fumigation and 10% for stored products and structures.

Since 2003, nine non-Article 5 Parties have applied for 'critical uses' after 2005 for non-QPS purposes. Of the initial 106 applications for 18,700 tonnes in 2003, CUN's have reduced to 36 applications for 1,453 tonnes for 2012. Many non-Article 5 countries have achieved complete phase out and others have notified intention to phase out post 2011 and 2012. For the remaining uses phase-out or substantial reductions have occurred in most sectors.

Article 5 countries have also reduced their baseline consumption of methyl bromide from 15,870 tonnes (average 1995 – 98) to 4,405 tonnes or 28% of the baseline. Several Article 5 Parties previously included among the largest users now report complete phase-out and others have made very significant reductions in their consumption since 2005.

MBTOC was able to identify alternatives for over 95% of controlled uses in 2009. Situations where no alternatives have been identified amount to less than 1,000 tonnes of methyl bromide. However local regulatory restrictions on the alternatives, rather than technical feasibility may restrict adoption.

The reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide with amounts used falling by 85%.

The more difficult remaining sectors include strawberry fruit and nurseries, ornamentals, perennial fruit and vine crops (particularly replant) and other kinds of nursery plant materials. Some uses previously considered under the CUN process have been reclassified as QPS by one country. Crops still using methyl bromide in Article 5 Parties are similar, but the quantities used in nurseries are smaller.

Significant progress in adoption of chemical and non chemical alternatives to replace methyl bromide as a pre-plant soil fumigant has been possible because of improved performance of new formulations of existing and new fumigants and increased uptake of non chemical alternatives i.e. grafted plants on resistant rootstocks. A key alternative for remaining uses, methyl iodide, has been registered in several countries. Some initially promising chemicals included in the past report have seen little further development, e.g. propargyl bromide, sodium azide, propylene oxide and are no longer regarded as potential alternatives to methyl bromide.

Phase-out in Article 5 countries has been achieved mainly through MLF investment projects, which have shown that a similar range of alternatives to those in use in non-Article 5 countries can be successfully adopted. Costs and different resource availability may lead to preference for different alternatives.

Food processing structures that currently use methyl bromide include flourmills, pasta manufacturing, and food and pet food production facilities. These structures are fumigated to control stored product (food) pests.

The main alternatives for disinfestation of flourmills and food processing premises are sulfuryl fluoride either alone or with supplemental heat or heat treatment alone. Full control of structural pests in some situations can be obtained without full site fumigation through a more vigorous IPM approach. A combination of heat, phosphine and carbon dioxide is also successful for specific pest situations.

For commodities, phosphine, sulfuryl fluoride and controlled atmosphere (CA) are the main techniques used to control pests. Each of these methods is used extensively to control pests of dried fruits and nuts, grains, cocoa beans and other stored foods. Sulfuryl fluoride is used when insects are resistant to phosphine.

In January 2011, the US Environmental Protection Agency (USEPA) proposed a regulation which would eventually eliminate the previous approvals for sulfuryl fluoride in foods and food processing structures, if there will be food contact. Fluorine levels in the total diet including water are considered by the USEPA to be injurious to health, however Australia reported that total Australian exposures to fluoride do not exceed human health standards.

Global production of methyl bromide for QPS purposes has been relatively stable over the last 10 years, at an average of 11,000 tonnes.

The average global QPS consumption has been relatively constant for the past 11 years and in 2009 was 11,197 tonnes. QPS consumption in Article 5 Parties has increased constantly over the past 10 years, while in non-Article 5 Parties it has been decreasing. QPS consumption was reported to be 39% higher than non-QPS consumption in 2009.

Technically feasible alternatives have also been identified for many QPS applications, particularly in the largest usage sectors of timber and timber packaging, grain, logs and preplant soil uses which use 70% of the methyl bromide consumed. There are however QPS uses or particular instances where such alternatives are not presently feasible.

Replacement of methyl bromide for QPS is a complex issue requiring consideration of biosecurity risk and complex regulations for use of methyl bromide and alternatives. Approvals are on a pest and product specific basis, and often follow lengthy bilateral negotiations. MBTOC estimates that currently available alternatives and substitutes could replace about 31% to 47% (1,937 to 2,942 tonnes) of QPS consumed in four categories of QPS use investigated. Since these four categories account for about 70% of total 2008 QPS methyl bromide use, the available technology can replace approximately 22% to 33% of total QPS consumption.

About 1,300 tonnes of consumption has been unidentified for use mainly by one Party over the period 2003-2007 when comparing a ‘bottom-up’ analysis and total consumption reported as per Article 7 data.

On average 75% of the applied methyl bromide is emitted from applications. Barrier films can reduce doses rates and emissions to less than 50%, but their adoption for the remaining uses of methyl bromide is unfortunately limited. Structural, commodity and QPS applications emit between 50 to 95% of the applied methyl bromide. The large drop in consumption, has led to a 70% fall in bromine in the troposphere and a 30% fall in effective chlorine load in the stratosphere. Owing to the short half life of methyl bromide (0.7 years) in the stratosphere, reductions in methyl bromide use is one of the few controlled ODS gases that will have a rapid effect on ozone recovery.

What is left to be achieved

Chemical alternatives in general, including methyl bromide, have issues related to their long-term suitability for use. In the EU, methyl bromide use was completely stopped (for all uses including QPS) in 2010, mainly due to health issues; in the USA and several other countries, methyl bromide and most other fumigants are involved in a rigorous review that could affect future regulations over their use.

For the remaining preplant soil uses in nurseries and some other sectors (strawberry fruit) it is important that studies with alternatives be conducted to measure pathogen thresholds and risk of spread of disease, and that a continual review of regulations is conducted to allow replacement of methyl bromide where feasible. In these cases, combinations of existing products and consideration of more sustainable non chemical alternatives need greater consideration.

Work is still needed to gain a better understanding of the economic and pest risk impacts of the methyl bromide phase-out. While the literature provides a useful starting point to the types of analysis that is required, it needs to be further extended to Article 5 Parties and to a wider range of methyl bromide uses such as the effect of removing methyl bromide use for quarantine applications.

For QPS treatments Parties are urged to continue efforts to minimize use and emissions of methyl bromide through containment and recovery and recycling methodologies to the extent possible.

Areas where technical alternatives are proving more difficult include some specific nursery situations where certification is required and situations where regulations prevent use of all alternatives, e.g. strawberry fruit in California.

In postharvest applications, MBTOC has not identified technically effective alternatives for only three uses: high moisture fresh dates, cheese infested while in storage and traditional Southern cured pork products in storages in the USA. Additionally, it is uncertain whether there are technically effective and practical alternatives that are sufficiently protective of immovable historical objects and museum components when infested with fungi.

The way forward

For preplant soil uses, continued market penetration of methyl iodide, mixtures of alternatives, and use of other methods will contribute to decline in uses of methyl bromide for nurseries.

It is strongly recommended that all remaining pre-plant uses of methyl bromide be applied with barrier films. In those instances where regulations currently prohibit their use or where farmers are reluctant to use barrier films, MBTOC would appreciate submission of data to support the reasons.

Further consideration of alternatives adopted in non-Article 5 Parties to replace methyl bromide is desirable for evaluation and registration (if necessary) in Article 5 Parties to limit the need for Critical Use nominations from Article 5 countries in 2015 and thereafter.

In postharvest applications, research is underway to identify and assess technically and economically feasible alternatives for pest control of high moisture fresh dates; cheese infested while in storage and traditional Southern USA cured pork products in storages. Additionally, more information is needed on technically effective and practical alternatives that are sufficiently protective of immovable historical objects and museum components when infested with fungi.

In the US, new regulations have been proposed to phase-in the removal of food contact for sulfuryl fluoride. An assessment of the potential for increase in the need to return to methyl bromide use, or preferably, technically effective and economically feasible scenarios to avoid returning to methyl bromide use, would be useful to MBTOC.

Parties may wish to give increased consideration to adoption of alternatives for the major usage sectors in QPS (timber and wood packaging materials, grains, logs) despite the existing exemption for this use under the Montreal Protocol. Efforts to improve knowledge on remaining uses of methyl bromide will help guide successful phaseout.

Revisiting technical and regulatory reasons for listing certain preplant soil uses under QPS exemptions is recommended.

2.6 Refrigeration, AC and Heat Pumps TOC

Current status

The required global phase-out of HCFCs, and the need to manage the lifetime operation of CFC- and also HCFC-based equipment, coupled with concerns to reduce global warming, drive transition from ozone depleting substance (ODS) refrigerants. The technical options are universal, but local laws, regulations, standards, economics, competitive situations and other factors influence regional and local choices. The primary current solutions are summarised below.

Refrigerants: More than 60 new refrigerants, many of them blends, were introduced for use either in new equipment or as service fluids (to maintain or convert existing equipment) since the 2006 assessment report. The primary focus for examination of new refrigerants is on unsaturated hydrofluorocarbons and unsaturated hydrochlorofluorocarbons. Additional refrigerants are still being developed to enable completion of scheduled phase-outs of ODSs. Significant focus is on alternatives, including blend components, offering lower global warming potentials (GWPs) to address climate change, forcing more attention than in the past on flammable or low-flammability candidates. Research continues to increase and improve the physical, safety, and environmental data for refrigerants, to enable screening, and to optimize equipment performance.

Domestic refrigeration: The conversion of new equipment production to the use of non-ODS refrigerants is essentially complete. More than one-third of newly produced units globally now use the refrigerant HC-600a; the balance uses HFC-134a. CFC emissions from the 150,000 tonnes domestic refrigerant bank are dominated by end-of-life disposal due to the high equipment reliability. Approximately 70% of the current, residual CFCs reside in Article 5 countries.

Commercial refrigeration: Hydrocarbons (HCs) and R-744 (CO_2) are gaining market shares for stand-alone equipment in Europe and in Japan; they are replacing HFC-134a, which is the dominant choice in most non-Article 5 and Article 5 countries. For condensing units and supermarket systems, the largest refrigerant bank consists of HCFC-22, which represents about 60% of the global commercial refrigerant bank. In developed countries, the replacement of HCFC-22 in supermarkets is dominated by R-404A and R-507A, however, a number of other options are used. In Europe, R-744 is used at the low-temperature level and HFC-134a, R-744 and HCs at the medium temperature level as alternatives to R-404A and R-507A because of their high GWP.

Industrial refrigeration: R-717 and HCFC-22 are the most common refrigerants for new equipment; cost considerations have driven small new systems to HFC use. R-744 is gaining in low-temperature, cascaded systems where it primarily replaces R-717 (ammonia), though the market volume is small for such systems. The ODS refrigerant bank consists of 20,000 tonnes of CFCs and 125,000 tonnes of HCFCs and HFCs. Annual ODS emission rates are in the range of 10-25% of the total banked refrigerant charge. R-717 remains the primary refrigerant in large industrial systems, especially those for food and beverage processing and storage.

Transport refrigeration: HCFC-22 has a low share in intermodal containers and road equipment, a high share in railcars (declining market) and a very high share in marine vessels. Today, virtually all new systems utilise HFC refrigerants (R-404A and HFC-134a). Non-fluorinated refrigerants have been commercialised to a small extent aboard marine vessels (R-717, R-744), and tested in marine containers, trailers (R-744) and trucks (HC-290). The refrigerant banks are estimated at 2,700 tonnes of CFCs and 27,200 tonnes of HCFC-22. The annual leak rate is in the range of 20-40%, depending on the specific application.

Air-to-air conditioners and heat pumps: HFC blends, primarily R-410A, but to a limited degree also R-407C, are still the dominant near-term replacements for HCFC-22 in air-cooled systems. HC-290 is also being used to replace HCFC-22 in low charge split system, window and portable air conditioners in some countries. Most Article 5 countries are continuing to utilise HCFC-22 as the predominant refrigerant in air conditioning applications. The refrigerant bank for unitary air conditioners is in excess of 1 million tonnes of HCFC-22.

Water-heating heat pumps: Air-to-water heat pumps have experienced significant growth in Japan, Australia, China, and Europe during the last five years, especially owing to the government incentives in Europe and Japan, and in the USA in prior years. HCFC-22 is currently mainly used in Article 5 countries. The HFC blends R-410A and R407C are currently used in European and other countries. R-744 heat pump water heaters were introduced to the market in Japan in 2001 and have seen a steady growth since then, again influenced by significant subsidies. HC-290 is being applied but its use in

Europe has decreased due to the introduction of the Pressure Equipment Directive. R-717 is mainly used for large capacity heat pump systems.

Chillers: HCFC-22 has been phased out in new equipment in the developed countries, but is still used in Article 5 countries. Both HCFC-123 and HFC-134a are used in centrifugal chillers. HFC-134a and R-410A are the most common options in smaller systems with scroll and screw compressors; limited R-407C usage is dropping. The application of HCs and R-717 in chillers is less common and extremely rare as a fraction of the total in large chillers.

Vehicle air conditioning: Today all new AC equipped passenger cars world-wide use HFC-134a; the transition from CFC-12 is complete for new systems, but not in old cars still in use especially in Article 5 countries. About one fifth of the total global refrigerant emissions are from Mobile Air Conditioning systems (about 60 percent if only HFC refrigerant emissions are considered); this includes the emissions in production, use, servicing, and end-of-life. Up to now, car manufacturers and suppliers have evaluated several refrigerant options for new car (and truck) air conditioning systems including R-744, HFC-152a and HFC-1234yf. These three options have GWPs below the EU threshold of 150 and can achieve fuel efficiency comparable to the existing HFC-134a systems with appropriate hardware and control development. The use of hydrocarbons or blends of hydrocarbons has also been considered but so far has not received support from vehicle manufacturers due to safety concerns. Most new bus or train air conditioning systems are currently equipped with the refrigerants HFC-134a or R-407C; fleet tests of R-744 systems in buses are ongoing.

What is left to be achieved

More than 100 refrigerants, including blends, are marketed at present, though approximately 20 consitute the overwhelming majority on a global basis and even that quantity is expected to fall as users converge on preferred options over time. Refrigerant manufacturers are in process of developing new candidates while equipment manufacturers are testing, selecting, and qualifying new refrigerants as well as associated lubricants and other materials. The technological options for air conditioning and refrigeration are expected to evolve over the next several years as designers continue to replace HCFC-22 with non-ODS alternatives and focus on developing lower GWP alternatives for R-410A and R-407C. There are several low and medium GWP alternatives being considered as replacements for HCFC-22. These include lower GWP HFC refrigerants (HFC-32, HFC-152a, HFC-161, HFC-1234yf and other unsaturated fluorochemicals, as well as blends of them), HC-290 and R-744. HC-290 and some of the HFC refrigerants are flammable and will need to be applied in accordance with an appropriate safety standard such as IEC-60335-2-40, which establishes maximum charge levels and ventilation requirements.

Several commercial chains have made good progress on the containment of refrigerant in supermarket systems. Indirect systems are the most effective option for emissions reductions and, in Europe, are gaining market share in new centralised systems for supermarkets. Technical development of alternatives in industrial refrigeration is expected to emphasise R-717 and R-744 in the near future. A significant amount of research, development and testing will be required before unsaturated HFCs can be deployed in large industrial systems, and even then their high refrigerant price will be an impediment to adoption. In heat pumps for water heating, further development of the lower GWP options is expected. In transport refrigeration, a rapid phase-out of remaining HCFCs due to the relatively short life span of intermodal containers, railcars and road vehicles (10-15 years) and marine vessels (< 25 years) is expected. Depending on the CO2 emissions associated with the electricity production and the energy efficiency of the systems, there is a large potential to reduce CO_2 emissions generated by fossil fuel operated heating systems by replacing them with heat pumps. The decision which refrigerant will be eventually selected for vehicle air conditioning will be made based on additional considerations along with the Global Warming Potential of the current alternative options (R-744, HFC-152a, and HFC-1234yf); these include regulatory approval, costs, system reliability, safety, heat pump capability and servicing.

World-wide, a significant amount of installed refrigeration equipment still uses CFCs and HCFCs. As a consequence, service demand for CFCs and HCFCs will continue. Refrigerant demand for service needs can be minimised by preventive service, containment, recovery, and recycling. Management of the CFC and HCFC banks in developing countries is an important issue. A critical step to address the refrigerant conservation topics above is thorough training of installers and service technicians, together with certification and regulation. Countries where programs have been successful have had comprehensive regulations requiring recovery and recycling, or destruction of refrigerant.

The way forward

The overarching climate change issue as well as changing refrigerant options for refrigeration and air conditioning will continue to advance innovations in this type of equipment. Many of the lower GWP refrigerant options are flammable, which increases the need to advance charge reduction technologies. HFCs and non-fluorochemical options are increasingly used in most sectors, with emphasis on optimising system efficiency (COP) and reducing emissions of high-GWP refrigerants. A high degree of containment applies to all future refrigerant applications, either for decreasing climate impact or for safety reasons. The competitive market is likely to result in refrigerant options for all common applications and either specialty products or equipment adaptation to accommodate new refrigerants for all applications, but the initial indications are that reduced efficiency is likely in several key uses. It is worth noting that manufacturing for refrigeration, air-conditioning, and heat pump equipment for export is increasing and is expected to increase further in Article 5 countries.

In domestic refrigeration, and to a lesser extent in commercial stand-alone equipment, an emerging trend is conversion from HFC-134a to HC-600a. Non-Article 5 countries completed the conversion from ODS refrigerants in domestic refrigeration approximately 15 years ago; older equipment now approaches the equipment useful lifetime; this results in non-Article 5 countries having a vanishing ODS refrigerant demand. The service demand for ODS refrigerants for domestic refrigeration in Article 5 countries is expected to remain strong for more than 10 years as a result of their later conversion to non-ODS refrigerants. In commercial stand-alone equipment in Article 5 countries, the use of HCs is expected to increase. For two-temperature centralised systems, R-744 is an option for the lower temperature level; in the near future, there will be the choice for the medium-temperature level for new low GWP HFCs on the one hand and R-744 or HCs on the other.

In industrial refrigeration, there are substantial banks of CFCs in Article 5 countries and HCFCs in both non-Article 5 and Article 5 countries that need addressing. Article 5 countries moving away from HCFCs (HCFC-22) might transfer to saturated HFCs, unsaturated HFCs if proven for use in industrial systems, to R-717 and R-744, or to other not-in-kind solutions. In transport refrigeration, HFCs will replace HCFCs and become a dominant refrigerant on passenger vessels and on small ships of all categories. The industry is working towards the use of non-fluorinated refrigerants in marine containers, trailers (R-744) and trucks (R-290); both are currently in the development and testing stage. In air-to-air air conditioning and heat pumps, HFCs, HFC blends and HC-290 are the most likely near-term refrigerants to replace HCFC-22 in most air conditioning applications. Contrary to non-Article 5 countries, the demand for service refrigerants in most Article 5 countries will consist of HCFC-22 and HFC-based service blends; this tendency is driven by long equipment life and is also due to the costs of the field conversion to alternative refrigerants. In heat pumps for water heating, HFC-32 or unsaturated HFCs such as HFC-1234yf or blends with this refrigerant will be studied for future use by taking into account the performance, costs and the necessary safety regulations in relation to their mild flammability.

The front running candidate among global car manufacturers for future vehicle air conditioning systems seems to be HFC-1234yf. One manufacturer has announced the intention to introduce this refrigerant in car serial production in 2013. OEMs indicate that they will design HFC-1234yf MAC systems in such a way that these systems can safely be used with HFC-134a refrigerant as well.

3 Executive Summaries of all TOCs

3.1 Chemical Technical Options Committee (CTOC)

3.1.1 Process Agents

In the last four years more than seventy process agent applications have been reviewed by the CTOC (see annex 1). Parties have approved 17 process agent uses, which are added to Table A. Also, 12 uses have been deleted from Table A as processes were abandoned or modified, often (but not always) as a result of MLF projects (Decisions XIX/15 and XXI/3).

As late as 2009, nominations for process agent status were still being received as Parties became aware of activities of their chemical industry sectors in which controlled substances were used. Reporting of emissions to Table B has been less than complete.

A better standard of reporting of emissions needs to be achieved so that Table B gives a more reliable picture of emissions arising from process agent uses. When the CTOC and MLF will produce a joint report in 2011 according to the Decision XXI/3 (5), further deletions from Table A and a more complete update on phase-outs or suggestions for phase-outs could be possible.

A list of Parties with approved process agent uses could be provided to the Ozone Secretariat, so that requests for information could be targeted and followed up, rather than including such requests in global communications.

3.1.2 Laboratory and Analytical Uses

There are very few identified uses of ODS in laboratory and analytical procedures in non-Article 5 countries. Some use continues in several Article 5 countries.

Advice by experts is required, together with modest financial support for alternatives that have already been identified to be trialled in Article 5 countries, alongside current procedures that involve ODS. New standard methods need to be developed.

Advice delivered by experts to practitioners at laboratory level is most valuable. It can be augmented by national or regional meetings, by provision of advice through electronic means, and via information transfer involving ozone officers. It would be helpful to the phase-out for the Ozone Secretariat and experts identified by the CTOC to work with national and international standards bodies to establish new standard methods of analysis that do not use ODS. TEAP and the CTOC will keep Parties informed of advances on these fronts.

3.1.3 Feedstocks

An extensive listing of known use of ODSs as feedstocks has been compiled. By using volumes suggested by members of the CTOC and following guidelines for emission calculations suggested by the IPCC for the UNFCCC, estimates of emissions from these feedstocks have been generated.

The volumes used in the report have been built up from expert knowledge and cannot be verified directly. There is poor reporting of use of ODSs as feedstocks. Also, at the current time, the majority of the production from ODS feedstocks is for HFCs whose production is not reported to a public source of data. To improve the estimate of use and emissions, it will be necessary to identify more complete public sources or for all Parties to report feedstock usage. In addition, the IPCC guidelines to not well represent actual emissions during use of ODS as feedstock. Expert opinion suggests that the IPCC guidelines are maximal values and actual emissions may be lower at well-managed facilities. Better emission mechanisms need to be considered.

Developed countries, in their inventory reporting, report to UNFCCC emission data for HFCs. Thus, discussions with UNFCCC may assist in developing new estimated sources of data for HFC production (which may have utilized ODSs as feedstock in their preparation). The reporting of ODS volumes for each feedstock uses by Parties through the Ozone Secretariat may enable a more complete quantification of this activity.

3.1.4 Solvents

Over 90 % of ODS solvent uses based on the peak consumption of 1994-95 have been reduced by changing to not-in-kind technologies and conservation. The remaining less than 10% of the ODS market is shared by several in-kind solvent alternatives.

The major challenge is the complete phase out of ODS solvents in Article 5 countries. Preferable alternatives have been identified and are generally available. Another hurdle to overcome is the economic impact on the small and medium size users who make up a major portion of the remaining ODS solvent market.

Regulatory changes will continue to impact on the use of solvents. In some cases, this may require solvent and/or equipment change or a new cleaning process. New idea of the definition of low-GWP and high-GWP alternatives, which TEAP has proposed, may cause a profound effect on the use of solvent.

3.1.5 Destruction Technologies

In 2009, CTOC identified 176 destruction facilities in 27 countries including new technologies not listed in the 2002 Task Force Report.

Recently several emerging technologies have been requested for evaluation. Following Decision XXI/10, they will be reviewed when technical details are made available.

Periodic review of available destruction technologies will be necessary to provide updated technical guidelines for destruction of ozone depleting substances such as CFCs, halons and methyl bromide as well as for HFCs.

3.1.6 Carbon Tetrachloride (CTC) Emissions and Opportunities for Reduction

The TEAP/CTOC made a comprehensive review on CTC emissions, concluding that there is a significant discrepancy between reported emissions and the observed atmospheric concentrations under Decisions XVI/14 and XVIII/10.

The studies have not yet been completed on the production and consumption of CTC with particular emphasis on feedstock uses with the goal to estimate emissions and try to reconcile them with values calculated by atmospheric scientists.

No new information on CTC emission was obtained from CTOC activities through 2010. Further studies will be needed to improve and reconcile bottom-up and top-down calculations, to search for other unreported CTC emission sources, to critically analyse UNEP inventory data and to possibly further revise the atmospheric lifetime of CTC.

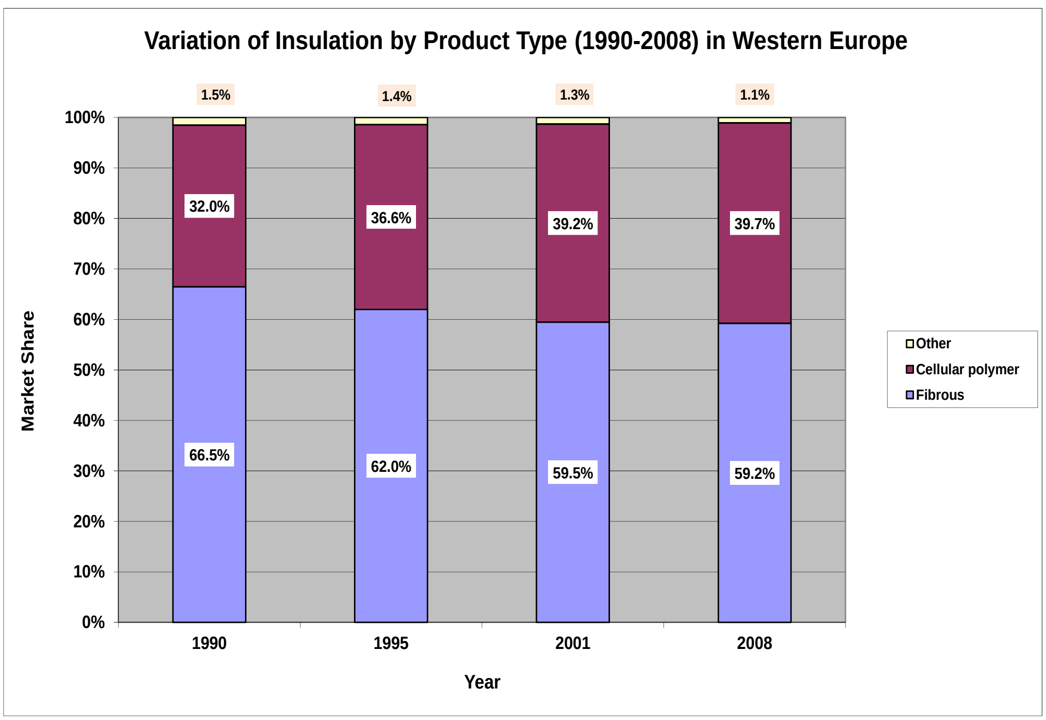
3.2 Foams Technical Options Committee

3.2.1 Introduction

The foam sector is facing a period of greater uncertainty than it has done since the initial decision to phase-out CFCs in the early 1990s. Although a large proportion of the industry has previously settled on hydrocarbons as their blowing agent of choice, there are increasing pressures to improve the thermal performance of foams – particularly in the appliance sector. Coupled with this, there are pressures to limit future use of saturated hydrofluorocarbons (s-HFCs) and to phase these down where possible. Finally, there is the time-certain schedule for phasing out HCFC use in Article 5 countries, but substantial uncertainties about the optimal choice of alternatives. These three trends are placing unparalleled stresses on the sector and there is a significant divergence of opinion at this time about the most appropriate way forward. The following sections provide further background on the issues faced.

3.2.2 Foam Market Dynamics

Growth in thermal insulation foams continues to be driven by increasing energy efficiency requirements in appliances and buildings. Space constraints in the built environment (e.g. cavity dimensions) have driven dramatic shifts from fibrous products to foam products in some markets in order to meet the required thermal performance. However, fibre has largely maintained its share through growth in the residential refurbishment sector where cost is a prime issue. An additional downward trend on foam use in non-Article 5 countries has been the on-going shift of appliance and refrigerated equipment manufacture to other regions where costs of manufacture are lower. The latest extension of a graph for Western Europe shown in previous reports indicates that this combination of factors has led to only a small overall net shift to the overall foam/fibre balance despite the turbulence of individual sectors:

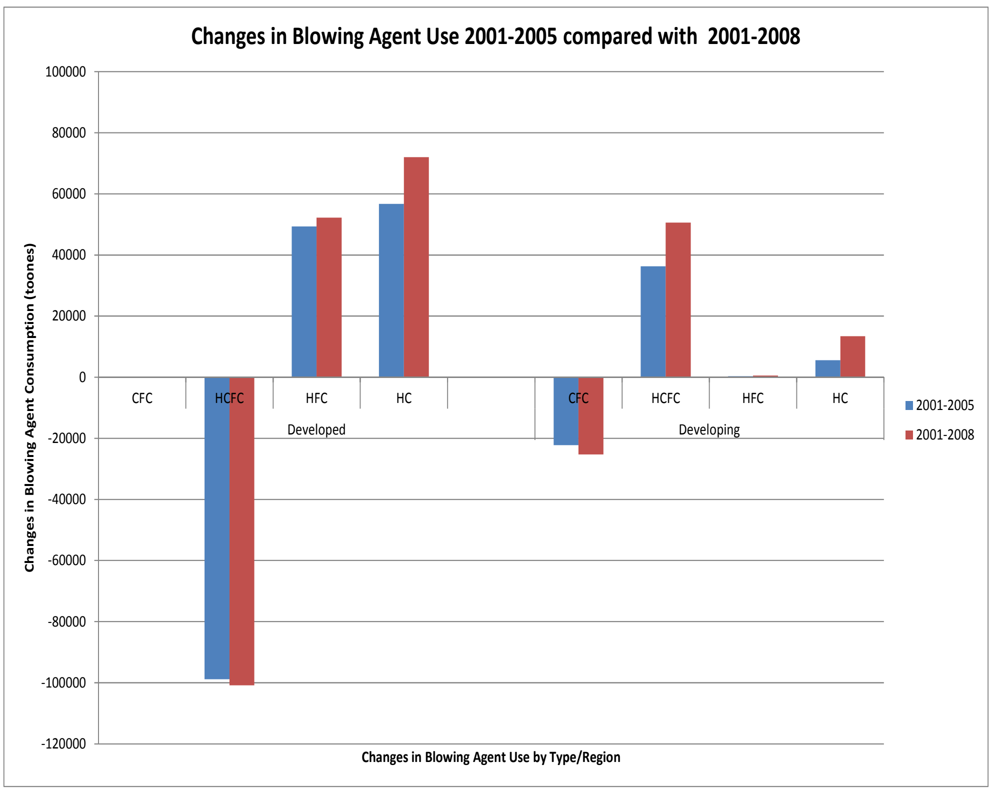


Nonetheless, the same region saw overall growth in thermal insulation sales to the domestic and commercial building sector of over 20% in the period between 2001 and 2008 despite the impact of the global downturn in 2008, thereby driving demand for appropriate blowing agents. This is likely to be representative of other non-Article 5 regions responding to the parallel drivers of climate change policy and energy security.

In Article 5 countries, the transformation in demand for thermal insulation has been even starker than for non-Article 5 countries in view of the increasing manufacturing base for global appliances and the recognition the building energy efficiency has a major contribution to make in combating climate change for Article 5 countries. As an example, the use of PU Spray Foam in China is understood to have grown to 70,000-80,000 tonnes, making it already the second largest market in the world for PU Spray Foam, with only the United States market larger.

3.2.3 Transitional Status

As at 2010, HCFC phase-out is virtually complete in all non-Article 5 countries, with XPS in North America being the last major sector to make the transition. In this instance, the technology choice has been saturated HFCs, reflecting the demanding product range and process requirements that the XPS industry has in the region. Experience from this transition has made the industry wary about committing to any further transitions in the medium term, since proving emerging alternatives in these applications will involve substantial further effort. As shown in the graph below, the main growth in blowing agent use between 2005 and 2008 had occurred with hydrocarbons, although there was also some additional use of HFCs. By contrast, only a very marginal further decline in HCFC use had taken place, highlighting the fact that the XPS sector in North America was not able to address its usage in the period to 2008, but was able to do so thereafter (see above).



In Article 5 countries, the phase-out of remaining CFC use has been completed with the main replacement for these residual applications being HCFCs. Growth has also continued in hydrocarbon use, largely driven by a further increase in the appliance manufacturing base in these regions.

Overall, the comparison between 2001-2005 and 2001-2008 time periods illustrates that the changes in the last four years have been relatively moderate compared with those of the previous four years.

Although hydrocarbons continue to be the primary solution in non-Article 5 countries, there is pressure in some sectors to further optimise these solutions by blending. While cyclopentane continues to play an important role in optimising blend performance, other components such as unsaturated HFCs (u-HFCs or HFOs) and methyl formate are also being assessed at this time. Early work on unsaturated HFCs suggests that they deliver better thermal performance than their saturated counterparts, although toxicological work remains to be completed for those yet to be commercialised. In the interim, there is evidence that some enterprises manufacturing appliances in developing countries are already blending saturated HFCs with hydrocarbons to meet energy requirements.

Decisions need to be made at short notice within HCFC Phase-out Management Plans (HPMPs) on the choice of alternative to HCFCs in Article 5 countries. The prioritisation of 'worst first' embodied within Decision XIX/6 puts a strong focus on dealing with HCFC-141b applications in the early phases of implementation. Nevertheless, some countries are finding it easier to manage their compliance issues by phasing the foam sector transitions according to the ease with which projects can be implemented and the magnitude of their impact. Shortfalls are then being made up from other sectors.

3.2.4 Likely Future Scenarios

In general terms, the future technology selections in both Article 5 and non-Article 5 countries continue to be uncertain. This makes it particularly difficult to forecast the precise blowing agent mix in the period to 2020 and the impact that this may have on bank composition at that time.

As noted above, HCFC phase-out in Article 5 countries continues to be a serious source of unease. In several sectors, particularly in rigid PU foams, previously identified low-GWP alternatives to HCFCs have yet to be fully proven in the field. This is particularly important since many of the enterprises expected to take up these technologies are SMEs and have little, if any, internal capacity to optimise formulations. There is concern that measures to manage flammability for methyl formate may require system houses to reformulate with more compatible polyols for rigid foam applications in order to reduce the risk. However, in a limited number of cases it may be more productive to blend methyl formate in the isocyanate component to obtain the required foam properties whilst avoiding flammable blends.

There continues to be a need to characterise the performance of foams made from low-GWP alternatives in the range of applications envisaged. This is an on-going exercise, but is particularly important for technologies that do not have a significant history of use in non-Article 5 countries. The role of the Pilot Projects sponsored under the Multilateral Fund are especially relevant here and the work of UNDP on methyl formate, for example, has already cleared the way for wider use in the flexible moulded and integral skin sectors.

In non-Article 5 countries, the primary future interest is in further improving energy efficiency. However, an additional pressure may arise from proposals to see the phase-down in use of saturated HFCs. Apart from initiatives signalled under the Montreal Protocol itself, there is growing interest in seeing such a measure as part of the re-cast F-Gas Regulation in Europe. This may serve to strengthen research efforts in non-Article 5 countries towards low-GWP solutions and, in particular, towards the intelligent use of blends. There may be added spin-offs for Article 5 countries from this work, but these are unlikely to emerge in time for incorporation within relevant HPMPs.

For the immediate challenge of phasing out HCFC-reliance in Article 5 countries, there are a number of obstacles. The time pressure to resolve these only serves to add to the complexity of the situation and it may be that a number of unproven solutions need to be adopted in the short-term, with the potential downside risk to enterprises and investors alike. One of the consequences of this could be that enterprises choose to minimise their risks by choosing proven, but sub-optimal, technology solutions (e.g. high GWP or less energy efficient solutions) with the intent of making a second conversion when more appropriate solutions have become established.

3.2.5 Banks, Emissions and Destruction

The management of ODS banks in appliance foams is currently being addressed by a variety of regulatory and voluntary frameworks and using a range of fully automated, semi-automated and manual technologies. Although there is evidence to suggest that fully automated approaches provide the most comprehensive recovery potential, the relevant cost-abatement curves would suggest that some semi-automated processes will have a place in the on-going management of ODS banks, particularly in areas where population densities are low or investment is restricted.

Efforts have been made to further characterise foam inventories in a number of regions. The flow of ODS-containing foams into the demolition waste stream from buildings is currently low and is likely to remain so for the next decade for most product types. Although the economics of recovery vary by region and are influenced by wider demolition waste management frameworks, even the most favourable circumstances lead to costs of above $100 per tonne CO_2 saved on average. There will be a need for further innovation in the longer-term if recovery from this source is going to become economically feasible.

Considerations will continue into the most appropriate strategies for ODS bank management in foams, with particular focus on ensuring that CFC capture from existing appliance-based banks is optimised before those opportunities are lost. This may involve the need to look at efficient ways of transferring existing technologies from non-Article 5 to Article 5 environments. The most appropriate funding mechanisms for such action are still under discussion, but these need to reach a conclusion soon if opportunities are going to be grasped.

Although less emissive than the refrigeration and air conditioning sector, the foam sector continues to represent a substantial bank of long-lived ODS which provide opportunities for future management. Time pressures for management initiatives vary by sector, but ultimate policy decisions will depend on the emerging cost abatement curves on a wide range of other ozone layer protection and climate measures. It remains to be seen whether or not the recovery of ODS from buildings will become a viable option given the scattered nature of the sources involved and the efforts required for recovery.

3.2.6 Specific Regional Messages

Developed Countries

- The growth of appliance foams and blowing agent use will continue broadly with general economic drivers, since markets are largely saturated. However, there may continue to be shifts in manufacturing location which will influence regional blowing agent consumption trends.

- Hydrocarbons are now almost fully optimised for appliances, but the relentless drive for energy efficiency is encouraging more focus on cyclo-pentane as a component of blends and, beyond that, interest in unsaturated HFCs (HFOs), which themselves are showing better potential thermal performance than current liquid HFCs. It may be that there is some switch from hydrocarbons to HC/u-HFC blends in future as well as a possible switch in North America from liquid HFCs directly to unsaturated HFCs over time depending on the future HFC policy in the United States.

- The growth in blowing agents for construction applications is driven by energy efficiency in new and existing buildings; there has been a slow-down in the construction of new buildings because of global recession but retrofitting continues with spray foam and other foam products (boards, etc). Nevertheless, growth in the demand for insulation foams has been dramatic over the last ten years with changes in market share between foam and fibrous insulation, the requirement for increased thicknesses and a relatively buoyant construction market.

- Hydrocarbons are the dominant blowing agent in the construction sector, with the exception of spray foam where s-HFCs continue to dominate due to safety issues, although there is likely to be a further proliferation of blends – perhaps with u-HFCs (HFOs) and/or methyl formate – particularly where the thickness requirements for insulation are perceived to be becoming unmanageable.

- In extruded polystyrene, the long-term future for blowing agent selection is still unclear, with a significant range of technologies in current use. The emergence of u-HFCs (HFOs) may prove of interest as a replacement for gaseous HFCs, particularly as a component of blends. Pressure for transition is likely to be greater in Europe where the F-Gas Regulation is currently under review. However, in North America there are no further plans to make transitions in the next 10 years since the transfer to gaseous s-HFCs has only just been implemented.

Developing Countries

- Economic growth rates in several key developing countries are likely to drive demand for appliances and other consumer goods over the coming years and these need to be reflected in the expected growth in demand for blowing agents.

- Since the appliance market is becoming largely a globalised market, future blowing agent selection is largely expected to follow the same patterns as in developed countries.

- Some appliance manufacturers have been or are considering moving from cyclopentane to blends of cyclopentane and HFCs to meet emerging energy efficiency standards and to better meet existing energy standards for products exported to developed countries.

- Focus on insulation materials for the construction market and, in particular, foam products varies substantially by developing country region, influenced primarily by climatic aspects and the ability to invest in infra-structure.

- There is evidence of considerable effort to refurbish existing dwellings in China and this has driven demand for PU spray foam as one of the most efficient technology options. Substantial growth in XPS has also been observed.

- There is much less clarity about the choice of blowing agent for the small/medium size enterprises in the construction sector and a variety of technology options (including pre-blended hydrocarbons, methyl formate,CO_2(water), liquid s-HFCs and u-HFCs) could all be used to some degree.

- Although methyl formate has SNAP approval by the US EPA for PU spray foam applications, it is still not clear whether the market will view the flammability issues as sufficiently differentiated from hydrocarbons to drive uptake. There is likely to be some use of methyl formate in those integral skin applications where CO_2(water) is not already established.

- Although commercialisation of the various u-HFCs (HFOs) under consideration is likely to occur slightly earlier than previously expected (perhaps 2013-2015), these technologies are still likely to be too late for the bulk of HCFC-141b transitions. Therefore two-step transitions may be necessary to take advantage of their properties. Since the investment costs are likely to be minimal for such technologies, a two-step strategy might be appropriate where the economics support it.

- Work on 'three-stream' technologies for spray foam (e.g. super-critical CO_2 and gaseous u-HFCs) may allow an earlier transition in some instances, although the investment implications are still being assessed.

3.3 Halons Technical Options Committee

3.3.1 Introduction

The following sector summaries show that despite the introduction of new halon alternatives and the remarkable progress in switching to them, there is still an on-going need for halons. As such, halon recycling is becoming even more important to ensure that adequate stocks of halons are available to meet the future needs of the Parties.

3.3.2 Global Production and Consumption Phase-out of Halons

As of January 1, 2010, halon production and consumption, as defined by the Montreal Protocol, for fire protection ceased. Additionally, there has been no essential use halon production since 2000 (as authorized by Decision VIII/9). However, halon 1301 (CF_3Br) continues to be produced in China and France for use as a feedstock in the manufacture of the pesticide Fipronil. The current total halon feedstock production quantities in these countries are not known to the HTOC, but have been increasing annually in China since 2005.

Since 2006, nine Parties have reported a negative production of halons for fire protection, indicating that they have been destroying halons. In addition, the last two producers of halons for fire protection, China and the Republic of South Korea, reported no exports in 2008 or 2009. However, some halons may have been exported as fire extinguishers and/or fire extinguishing systems. Only eight Parties operating under Article 5 reported importing newly produced halons in 2008, down from sixteen in 2006. The global trade in recycled halons is robust, but as would be expected, the trade in recycled halons by Article 5 Parties has been limited, since they were allowed to import newly produced halons through 2009.

Now that there is no global production of halons for fire protection uses, management of the remaining stock becomes crucial for ensuring sufficient halons for applications that need them.

3.3.3 Fire Protection Alternatives to Halon

Since the 2006 Assessment, there have been some changes made to national and international fire protection standards that affect some of the measures of performance and guidelines for use of the alternative agents. Some harmonisation has taken place, new minimum concentrations recommended for certain re-ignition risks, and new procedures developed for determining safe personnel exposure to the alternatives.

Alternatives based on hydrofluorocarbons (HFCs) continue to dominate the in-kind gaseous alternatives market for flooding applications, whereas alternatives based on hydrochlorofluorocarbon (HCFC)-123 are dominant for the much smaller in-kind streaming market. As yet, an alternative with all of the beneficial characteristics of the halon it is attempting to replace has not yet been developed. Nevertheless, new agents and technologies continue to appear on the market for specific applications. Most recent are pyrotechnic products that generate nitrogen or mixtures of nitrogen and water vapour, and unsaturated hydrobromofluorocarbons (HBFCs).

The selection of the best fire protection method in the absence of halons is often a complex process. Either alternative gaseous fire extinguishing agents, so called in-kind alternatives, or not-in-kind alternatives may replace halon but the decision is driven by the details of the hazard being protected, the characteristics of the gaseous agent or alternative method, and the risk management philosophy of the user.

3.3.4 Climate Considerations for Halons and Alternatives

HFCs, HCFCs, and to a much lesser extent perfluorocarbons (PFCs) have been commercialized as replacements for halons. The development of these chemicals for use in fire and explosion suppression applications was instrumental in achieving the halon production phase-out mandated by the Montreal Protocol. In some applications, HFC based agents are the only alternatives for halons.

The Technology and Economic Assessment Panel (TEAP) update of the Intergovernmental Panel on Climate Change (IPCC) / TEAP Special Report on Ozone and Climate concludes that the greenhouse gas (GHG) reduction potential from fire protection is small due in part to the relatively low emission level and the significant shift to not-in-kind alternatives. Nevertheless, in 2009 and again in 2010 amendments have been proposed that would add HFCs to the Montreal Protocol and slowly phase down their production. The Parties may wish to consider that any future HFC amendments or adjustments include provisions for fire protection uses that have no alternatives other than ozone depleting substances (ODSs) or the high global warming potential (GWP) HFCs.

There are a few important fire protection applications such as crew bays of armoured vehicles where the only current options are to use recycled halon or a high GWP HFC. From a total environmental impact perspective, is it better to reuse an already produced, recycled halon or produce a high GWP HFC for the application? This is a challenge that the Parties may wish to consider.

3.3.5 Global Halon 1211 and 1301 Banking

Halon banking is a critical part of the management of halons. Halon Bank Programmes must be accessible to all halon users or the risk of accelerated atmospheric emissions will escalate as users find themselves with redundant stock.

There has been an unanticipated lag in the establishment of halon banking and management programmes in Article 5 Parties globally. Halon banking operations can play a significant role in ensuring the quality and availability of recycled halon, in managing the halon use down to zero, and in assisting with emission data by providing regional estimates that should be more accurate than global estimates. National or regional banking schemes that maintain good records offer the opportunity to minimise the uncertainty in stored inventory and stock availability. Parties may wish to encourage such national halon banking schemes in order to ensure that needs considered critical by a Party are met.

Numerous Parties have not implemented halon bank management programmes or are experiencing significant challenges with their programmes. Some of the impediments include lack of a focal point for halon management, insufficient infrastructure, segmentation of halon users such as the military and industry with no sharing of information or resources, users' lack of awareness regarding environmental concerns, and lack of supportive policies. There are companies available globally that will purchase and "clean" cross-contaminated halons; however, in some Parties, because of a prohibition on halon exports, cross-contaminated halons are a financial liability and are reported to be vented to the atmosphere.

3.3.6 Global Halon 2402 Banking

Halon 2402 had been produced nearly exclusively in the former USSR, and at the time of production phase-out the bank of halon 2402 was very small and insufficient to support existing applications. As a consequence, the Parties allowed the Russian Federation to continue to produce limited quantities of halon 2402 from 1996 until the end of 2000 under the essential use process.

The applications of halon 2402 are a special case because the equipment that uses it was almost exclusively manufactured in the former USSR until its dissolution and in the Russia Federation and the Ukraine afterwards. This equipment mainly comprises military equipment and civil aircraft that was sold within the former USSR, Eastern Europe, and South-East and East Asia.

The Russian Federation and Ukraine, traditionally recognised as potential sources of halon 2402 for other Parties, still own a large installed capacity of halon 2402, but their markets are estimated as currently well balanced with no surplus available for outside customers. This is a problem for Parties whose installed base is very small and consequently bank of halon 2402 limited. Some of these Parties have managed to establish recycling and banking facilities with assistance from the GEF. It is also a problem for larger users, e.g., India, who traditionally relied on supplies from the Russian Federation and never established their own bank. Where possible such Parties are switching to other halons or alternatives.

Emissions, transformation and consumption of halon 2402 by the Russian chemical industry as a process agent has substantially reduced the total bank of halon 2402, and new uses in non-traditional applications are a cause for concern to the HTOC. While there is no apparent shortage of recycled halon 2402 on a global basis, there are regional shortages today that Parties may wish to address.

3.3.7 Global/Regional Supply and Demand Balance

Based on a review of the situation in a large number of the Parties, with the exception of aviation, it has been concluded that generally halons have been replaced by substitutes for all new applications where halons were traditionally used. However, the demand for recycled halons remains high for existing applications in some Parties. Nevertheless, to date the Parties have not indicated to the Ozone Secretariat that they are unable to obtain halons to satisfy their needs, although some Parties have expressed cost concerns to HTOC members. The HTOC therefore concludes that current demand is being satisfied by the available supply, although the extent of continued needs indicates there may be global or regional problems in the future.

3.3.8 Continued Reliance on Halons

Halon production for fire protection purposes ceased at the end of 1993 in non-Article 5 Parties and at the end of 2009 in all Parties. However, many Parties have allowed recycled halons to be used to maintain and service existing equipment. This has permitted users to retain their initial equipment investment and allowed halons to continue to be used in applications where alternatives are not yet technically and/or economically viable. In particular, these include civil aviation, military uses, and legacy systems in oil and gas production in cold climates, aerosol fill rooms, grain silos, paper production and milk powder processing plants.

Aviation applications of halon are among the most demanding uses of all three halons, and require every one of their beneficial characteristics, including dispersion and suppression at low temperatures, minimal toxic hazards to passengers and flight crew, and ground maintenance staff, and low weight and space requirements for the hardware. While alternative methods of fire suppression for ground-based situations have been implemented, the status of halon in the civil aircraft sector must be viewed in three different contexts: existing aircraft, newly produced aircraft of existing models, and new models of aircraft. All of them continue to depend on halon for the majority of their fire protection applications. Given the anticipated 25–30 year lifespan of civil aircraft, this dependency is likely to continue well beyond the time when recycled halon is readily available, and the time available for making the transition to halon alternatives may be much less than many in the civil aviation industry realize.

Another critical development since the last assessment report is the finding of contaminated halons making their way into the civil aviation industry as reported by the UK Civil Aviation Authority (CAA) to the European Aviation Safety Agency (EASA) in 2009, raising concerns about the acceptability of the remaining banks of halons.

The halon alternatives available for mainline civil aviation are essentially the same as those reported in the 2006 HTOC Assessment, with the exception that a "low GWP" unsaturated HBFC, known as 3,3,3-trifluoro-2-bromo-prop-1-ene or 2-BTP is currently undergoing tests for suitability in hand-held extinguishers.

As a follow on from the HTOC's work with the International Civil Aviation Organization (ICAO) – reference Decision XXI/7 – the HTOC has continued its cooperation with ICAO in the development of a revised resolution, containing amended halon replacement dates agreed to by industry that was adopted at the ICAO 37th Assembly in September 2010 as Resolution A37/9. In addition to the ICAO halon replacement dates, the European Union introduced legislation in 2010 that has "cut-off dates" and "end dates" when all halon systems or extinguishers in a particular application – including civil aviation - must be decommissioned.

Halons continue to be used worldwide by military organisations in many frontline applications where alternatives are not technically or economically feasible at this time. These include existing systems in crew and engine compartments of armoured fighting vehicles; engine nacelles, auxiliary power units, portable extinguishers, cargo bays, dry bays, and the fuel tank vapour space of certain military aircraft; and machinery spaces, fuel pump rooms, flammable liquid storage rooms, operational rooms, command centres and on flight decks of certain naval vessels. Nevertheless, the militaries of many Parties have devoted considerable effort and resources to reduce and eventually eliminate the use of halons wherever technically and economically feasible. Extensive research, development and testing have all but eliminated the need for halons in new equipment designs in armoured fighting vehicles, military aircraft, and naval vessels. For applications where an acceptable alternative has not yet been implemented, operational and maintenance procedures and training can and have been improved to minimize emissions and conserve the limited supplies of recyclable materials that are available. Supplies of halons from converted and decommissioned systems and extinguishers, both from within military organizations and from the open market, have been banked by many Parties to support their on-going military needs.

Existing oil and gas pipelines and production facilities in inhospitable climates continue to use halons for fire suppression and explosion prevention. For new facilities, companies are now adopting an inherently safe design approach to avoid or minimise hazards such as the release of hydrocarbons. Where an inerting agent is still required in occupied spaces, halon has been replaced by HFC-23 or Fluoroketone (FK)-5-1-12, if temperatures permit, as part of the facility protection design. As HFC-23 is the only alternative where very low temperatures are encountered, the question mentioned in 3.2.4 is relevant, i.e., should such a high GWP agent be diverted from destruction to replace an existing, recycled halon?

For other commercial/industrial applications, halons are no longer necessary and systems are gradually being decommissioned and replaced by systems agents using alternative agents. However, the cost to re-engineer systems to replace some legacy systems can be expensive and, in many cases, unless industry is mandated to do so, they rely on recycled halon from the halon bank to maintain the system.

In its 2006 Assessment, the HTOC detailed the status of the use of halon and their alternatives on board Merchant ships. Essentially the situation now is unchanged other than less ships are dependent upon halon owing to decommissioning of ships in the intervening period. For those remaining ships that still require halons, the industry appears to have concluded that this problem, if not solved, is certainly manageable for the near future.

3.3.9 Estimated Global Inventories of Halons 1211, 1301 and 2402

The HTOC 2010 Assessment indicates that at the end of 2010 the global bank of halon 1301 is estimated at approximately 42,500 MT, halon 1211 at approximately 65,000 MT and halon 2402 at approximately 2,300 MT. From this assessment, the HTOC remains of the opinion that adequate global stocks of halon 1211 and halon 1301 currently exist to meet the future needs of all existing halon fire equipment until the end of their useful life. However, there remains concern about the availability of halon 2402 outside of the Russian Federation and the Ukraine to support existing uses in aircraft, military vehicles, and ships. Much of the bank of halon 2402, which was intended to service fire protection needs for existing applications, was consumed within the Russian Federation as a process agent several years ago. In addition, a new product that encapsulates halon 2402 in a paint matrix is being commercialized in the Russian Federation that would further deplete supplies of halon 2402 to support existing uses. The HTOC is concerned that long-term, important users of halon 2402 will not have enough halon 2402 to support their needs if the bank continues to get depleted through use in non-fire protection uses and/or in new products.

Owners of existing halon fire equipment that would be considered as meeting the needs of one or more of the preceding categories would be prudent to ensure that their future needs will be met from their own secure stocks. Current and proposed regulatory programmes that require the recovery and destruction of halons will obviously eliminate future availability of halons as a source of supply for many needs. As adequate global supplies presently exist it would be unlikely that inadequate planning would serve as a reasonable basis for a future essential use nomination by a Party on behalf of an owner of a particularly important application for halons 1211, 1301 or halon 2402.

3.3.10 Practices to Ensure Recycled Halon Purity

The recent experience within Europe, where it was found that contaminated halons were making their way into the civil aviation industry, has highlighted the need for end users to be aware of the purity of any reclaimed or recycled halon that they purchase. With an impure halon the performance can range from poor or no fire extinguishing effectiveness to one where the impure agent may actually intensify the fire in the case where the impurity is a flammable material. Generally speaking, end users have to rely on the aftermarket supply chain to collect, process, test and certify that the halon agent is of acceptable purity, and it is this last step, relying on a supplier’s certification alone that can introduce risk with respect to agent purity. Thus it is important that a written purity certification is obtained from an internationally or nationally recognised testing laboratory that has tested the halon to internationally recognised standards, such as ISO, ASTM or GOST.

3.3.11 Halon Emission Reduction Strategies

Releasing halon into the atmosphere is fundamental to the process of flame extinction and enclosed space inertion. However, these necessary emissions only use a small proportion of the available supply of halon in any year. Most countries have discontinued system discharge testing and discharge of extinguishers for training purposes resulting in emission reductions in some cases of up to 90%. Additional and significant reductions of halon emissions can be realized by improving maintenance procedures, detection and control devices, etc., and through non-technical steps such as the development of Codes of Conduct, implementing Awareness Campaigns, workshops, and training, policies, and legislating regulations and ensuring enforcement. Halon emissions reduction strategies are a combination of “responsible use” and political regulatory action.

Good engineering practice dictates that, where possible, hazards should be designed out of facilities rather than simply providing protection against them. A combination of prevention, inherently safe design, minimisation of personnel exposure, passive protection, equipment duplication, detection, and manual intervention should be considered as well. Also, attention to maintenance programs and personnel training can add years to a halon bank by reduced emissions.

Emission reductions can be achieved by implementing a comprehensive Awareness Campaign. This should address a description of halons and their uses, environmental concerns related to the ozone layer, key goals and deadlines in the Montreal Protocol, country-specific policy and regulations on ODS, recycling requirements, alternatives and options, points of contact in government and fire protection community, and answers to Frequently Asked Questions such as “what do I do with my halon 1211 extinguisher?”

Avoidable halon releases account for greater halon emissions than those needed for fire protection and explosion prevention. Clearly such releases can be minimised.

3.3.12 Destruction

Since the 2006 Assessment, considerable interest has focused on the potential ozone and climate benefits from the avoided emissions of ODS still remaining in equipment, products, and stockpiles. The recent introduction of carbon credits for ODS destruction creates a limited window of opportunity to increase ODS recovery at equipment end of life and to avoid potential emissions altogether by destroying unwanted material. Halons, more than some of the other ODS, are readily accessible for collection, storage, and disposal, making them very attractive for potential ODS destruction projects under a carbon credit protocol. However, owing to the continued global demand for halons in applications such as aviation, the HTOC has recommended that destruction as a final disposition option should be considered only if the halons are cross-contaminated and cannot be reclaimed to an acceptable purity. The global phase-out of halons has been planned based upon halons being reclaimed and reused until the end of the useful life of the systems they are employed in and until there are no longer any important uses. Early destruction of halons undermines the long-range plan set by the Parties, imposes significant financial burdens on users who invested in their halon systems, and puts at risk uses that generally have the potential for preventing significant loss of life in a fire scenario.

There are also concerns that the availability of carbon credits for halon destruction may inadvertently lead to the wrong incentives – to actions that actually lead to more environmental harm and, worse, to potentially illegal activities, e.g., production simply for destruction credits since newly produced halon is technically indistinguishable from recycled halon. The Parties may wish to consider asking TEAP/HTOC to investigate the issues related to halon destruction further in order to better understand the full implications to the halon phase out under the Protocol, and the impacts to ozone layer recovery and climate protection.

3.4 Medical Technical Options Committee

3.4.1 Metered Dose Inhalers

Global CFC use for MDIs

The global use of chlorofluorocarbons (CFCs) to manufacture metered dose inhalers (MDIs) has decreased to about 2,300 tonnes in 2009 and is projected to decrease further to about 2,000 tonnes in

2010. In 2009, Article 5 countries used about 1,700 tonnes and the Russian Federation and the United States used about 580 tonnes of CFCs for the manufacture of MDIs. The total CFC use by Article 5 countries reduced by about 200 tonnes between 2008 and 2009, with some countries increasing (e.g. China) and others decreasing (e.g. India) consumption. There has been significant global progress in the transition of CFC MDIs to CFC-free inhalers, with substantial capacity to manufacture CFC-free inhalers.

CFC stockpiles are available in Venezuela and the United States (total of about 951 tonnes of CFC-11 and -12, with 367 tonnes of CFC-114 that may not be consumed). These may be enough to cover estimated CFC requirements for MDIs for 2010, 2011 and 2012. It could be possible to complete the phase-out of CFC MDIs with careful management of existing global CFC stockpiles without manufacture of new pharmaceutical-grade CFCs, except for China that can manufacture for its own needs and those of the Russian Federation. A cautious approach to CFC production is advisable since transition is moving quickly and CFC production that is surplus to actual needs ought to be avoided, as the excess would subsequently require costly destruction.

Technically satisfactory alternatives are available

It is now over 16 years since the first introduction of a hydrofluorocarbon (HFC) MDI for the short-acting beta-agonist salbutamol in the United Kingdom in 1994. Technically satisfactory alternatives to CFC MDIs (HFC MDIs and dry powder inhalers (DPIs)) to treat asthma and chronic obstructive pulmonary disease (COPD) are now available in almost all countries worldwide. There are sufficient CFC-free alternatives available to cover all key classes of drugs used in the treatment of asthma and COPD.

By 2010 every developed country had phased out the use of CFCs in MDIs, except the Russian Federation, which is yet to complete manufacturing conversion, and the United States, which is well advanced in its phase-out. Substantial global progress has continued in the development and launch of HFC MDIs and DPIs and now most companies based in non-Article 5 countries have completed their phase-out of CFC MDIs.

Most developing countries are well advanced in their transition plans to phase out the use of CFCs. Despite initial challenges such as access to technology transfer and economic barriers, progress has been significant with a number of countries nearing completion of their transition to CFC-free inhalers faster than expected. CFC consumption by Article 5 countries is estimated to have peaked in 2008 and 2009, and now appears to be decreasing. Current predictions are that most Article 5 countries will have largely completed transition by about the end of 2012. A notable exception is China, which in recent years has shown increasing consumption of 15-30 per cent year on year, with current plans to complete the phase-out of CFC MDIs in 2016.

A barrier for developing countries has been that replacement hydrofluorocarbon (HFC) MDIs manufactured by multinational companies in developed countries can be more expensive than CFC MDIs manufactured in developing countries, meaning that poor patients cannot afford them. However, there has been substantial progress in the development and marketing of affordable CFC-free MDIs, especially those manufactured in Article 5 countries. HFC MDIs are now becoming more competitively priced compared to CFC MDIs. As a consequence, there is now an adequate range of technically satisfactory and affordable CFC-free alternatives for CFC MDIs for beta-agonists (in particular, salbutamol) and inhaled corticosteroids (in particular, beclomethasone) available in many developing countries. Taking these issues into consideration, salbutamol and beclomethasone CFC MDIs can now be considered non-essential in most importing countries.

Global HFC use for MDIs

It is estimated that about 4,000 tonnes of HFCs are used to manufacture MDIs, accounting for a very small proportion of total HFC usage (estimated at 1-2 per cent). Based on current consumption and projected growth rates of MDI use, annual consumption of HFCs for MDIs is estimated to be between 7,000-10,500 tonnes by 2015.

By moving from CFC MDIs to HFC MDIs and DPIs, not only have emissions of ozone depleting substances been eliminated, but there have also been benefits for climate change. According to rough estimates of carbon footprints of inhaler products, HFC MDIs have about 10 times less climate impact than CFC MDIs. DPIs have an even lower comparative climate impact, about 100 times less than CFC MDIs and 10 times less than HFC MDIs.

Patient health considerations

It is important to note that MDIs, DPIs and novel delivery systems play an important role in the treatment of asthma and COPD, and no single delivery system is considered universally acceptable for all patients. Healthcare professionals continue to consider that a range of therapeutic options is important. Any consideration of policy measures to control HFCs should carefully assess patient health implications with the goals of ensuring patient health and maintaining a range of therapeutic options. Each country has its own unique and complex makeup in terms of availability of medicines, overarching health care systems, and patient preferences.

3.4.2 Pharmaceutical aerosol products other than MDIs

Technically and economically feasible alternatives are available for all medical aerosol products. Other than MDIs, the manufacture of most CFC-containing medical aerosols in non-Article 5 countries ceased around 1996, and in Article 5 countries would have ceased around the end of 2009.

However, there are some countries that are yet to complete the conversion of CFC-based medical aerosols to alternatives. In 2009, Argentina (1.2 tonnes), China, Dominican Republic (24 tonnes), and Serbia (18.1 tonnes) were still consuming CFCs to manufacture medical aerosols. With the 2010 phase-out date for CFCs in developing countries, any current CFC consumption for medical aerosols could only be sourced from existing stockpile.

In China, some of the traditional Chinese aerosol manufacturers have encountered technical difficulties in their conversion to alternatives, with new formulations not meeting relevant quality standards. Government authorities are coordinating with the enterprises to resolve these technical issues. It is expected that, other than MDIs, full conversion of the medical aerosol sector in China will be completed in 2012.

3.4.3 Sterilants

The use of ethylene oxide (EO)/CFC blends for sterilization has been successfully phased out in non-Article 5 countries and in many Article 5 countries. Although it is difficult to be certain, global total use of CFCs in 2010 for this application is believed to be close to zero.

EO/hydrochlorofluorocarbon (HCFC) mixtures (10 per cent by weight EO in a mix of HCFC-124 and HCFC-22) are virtual drop-in replacements for the 12/88 mixture using CFC and were introduced as transitional products for sterilization in those countries that employed 12/88 extensively. Estimated global use of HCFCs in sterilization in 2010 is between about 500-700 metric tonnes, which amounts to less than 25 ODP tonnes worldwide. EO/HCFC use in non-Article 5 countries is estimated to be declining with regulatory restrictions being introduced. EO/HCFC use in Article 5 countries is estimated to be between about 200-400 tonnes.

With the Montreal Protocol phase-out schedule for HCFCs for Article 5 countries, an orderly phase-out of HCFCs in sterilization uses is readily achievable in Article 5 countries. The useful lifetime of an EO/HCFC steriliser is about 20 years when well maintained. Therefore by 2030 current sterilisers should be ready for replacement with available alternative technologies that do not use ozone-depleting substances. Hospital procurement should take the HCFC phase-out, and the coming redundancy of EO/HCFC sterilization equipment, into consideration in making future investment decisions.

There is a range of commercially available sterilization methods that can replace the use of ozone-depleting substances in this sector, including: heat (moist heat or dry heat), radiations, alkylating processes (such as EO, formaldehyde) and oxidative processes (including hydrogen peroxide vapour, hydrogen peroxide gas plasma, liquid peracetic acid, and ozone). Further sterilization methods are under investigation for commercialization.

The provision of good quality health services requires effective sterilization of health care products to prevent transmission of infection. Sterilization requires strict application of the principles of quality management to ensure validation of the selected process and implementation of effective routine control; reliable equipment; and knowledge of materials compatibility. Validation of sterilization processes is important to ensure the attainment of sterility and to avoid materials compatibility problems. No sterilant or sterilization process is compatible with all potential products.

3.5 Methyl Bromide Technical Options Committee

3.5.1 Mandate and report structure

Under Decision XIX/20(2) taken at the Nineteenth Meeting of the Parties to the Protocol in 2007, the Parties requested the Assessment Panels to update their 2006 reports in 2010 and submit them to the Secretariat by 31 December 2010 for consideration by the Open-ended Working Group and by the Twenty Third Meeting of the Parties to the Montreal Protocol, in 2011.

As required under Decision XIX/20(2), the MBTOC 2010 Assessment reports on advances since 2006 to replace Methyl Bromide (methyl bromide) used under Critical Use by non-Article 5 Parties and continued reduction in methyl bromide use in Article 5 countries to meet the required phase out schedule in 2015. It also reports on the situation of use for QPS presently exempt from controls under the Montreal protocol. It also shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of methyl bromide to the atmosphere, and strategies to reduce those emissions.

3.5.2 The Methyl Bromide Technical Options Committee (MBTOC)

As of December 2010, MBTOC had 39 members: 13 (33%) from Article 5 Parties and 26 (67%) from non-Article 5 Parties. Members come from 11 developing and 14 industrialised countries. In order to respond to the large number of tasks, TEAP subdivided MBTOC into three subcommittees in 2010: Soils (MBTOC-S), Structures and Commodities (MBTOC-SC) and Quarantine and Pre-Shipment (QPS).

3.5.3 Methyl bromide control measures

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Control schedules leading to phase-out were agreed in 1995 and 1997. There are a number of concerns apart from ozone depletion that have also led countries to impose severe restrictions on methyl bromide use. These concerns include, toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by methyl bromide and its derived bromide ion are also concerns.

The control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, were for phase out by 1 January 2005 in non-Article 5 countries and for Parties operating under Article 5 of the Protocol (developing countries) a 20% cut in production and consumption, based on the average in 1995-98, from 1 January 2005 and phase out by 1 January 2015. Since 2003, nine non-Article 5 Parties have applied for 'critical uses' after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol. Of the initial 106 applications for 18,700 tonnes, the number has declined to 36 applications for 1,453 tonnes in 2012. Use of methyl bromide under the 'Critical Use' provisions is available to Article 5 countries after 2015.

Article 2H also provides exemptions for the amounts of methyl bromide used for QPS purposes.

3.5.4 Production and consumption trends

At the time of writing this report, all Parties had submitted data to the Ozone Secretariat for controlled uses in 2009. Some countries have revised or corrected their historical consumption data at certain times, and in consequence official figures and baselines have changed. In the few cases where data gaps exist, data from the previous year were assumed to apply to methyl bromide production or consumption. All tonnages are given in metric tonnes in this report.

In 2009, global production for the methyl bromide uses controlled under the Protocol was 8,928 tonnes, which represented 13% of the 1991 reported production data (66,430 tonnes). Less than 5% of production occurred in Article 5 countries. Methyl bromide production in Article 5 countries for controlled uses peaked in the year 2000 at 2,397 tonnes, falling to 29% of the baseline, 403 tonnes, in 2009 (aggregate baseline for all Article 5 regions is 1,375 tonnes, i.e. average of 1995-98 production).

Global consumption of methyl bromide for controlled uses was reported to be 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. Global consumption was estimated at 20,752 tonnes in 2005 falling to about 8,148 tonnes in 2009. Historically, in non-Article 5 regions, about 91% of methyl bromide was used for pre-plant and about 9% for stored products and structures. The official aggregate baseline for non-Article 5 countries was about 56,083 tonnes in 1991. In 2005 (the first year of critical use provisions), this consumption had been reduced to 11,470 tonnes, representing 21% of the baseline. Since soil uses of methyl bromide have predominated historically, the reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide. Consumption of methyl bromide for structural and commodity purposes has also declined significantly.

Many non-Article 5 countries have achieved complete phase out (Switzerland, New Zealand, countries of European Community). Israel and Japan have notified intention to phase out post 2011 and 2012 respectively (for preplant soil uses). For the remaining uses phase-out or substantial reductions have occurred in most sectors. Several Article 5 Parties previously included among the largest users now report complete phase-out (i.e. Brazil, Turkey, Lebanon). Other Article 5 Parties have made very significant reductions in their consumption since 2005 and aggregate consumption is now at 28% of the baseline (72% has been replaced).

In 2010, the Meetings of the Parties approved CUEs of 2,565 tonnes for use in 2011 and 1,534 tonnes for 2012 or about 3% of the non- Article 5 baseline.

3.5.5 Consumption trends at national level

In 1991 the USA, European Community, Israel and Japan used nearly 95% of the methyl bromide consumed in non-Article 5 countries. In 2007 the approved or licensed consumption for CUEs was reduced to 17%, 3% and 12% and 10% of the respective baselines. In 2009 permitted levels of consumption (for CUEs) in these four Parties was 11%, 0% and 8% and 4% of their respective baselines.

The Article 5 consumption aggregate baseline is 15,870 tonnes (average of 1995-98), with peak consumption of more than 18,100 tonnes in 1998. Many Article 5 countries increased their methyl bromide use during the 1995 – 1998 time period. Total Article 5 consumption has been reduced to 4,405 tonnes which is 28% of the baseline in 2009. A MBTOC survey of ozone offices, regional networks and national experts in 2010 provided information on the breakdown of methyl bromide uses in major methyl bromide-consuming countries. In 2009, an estimated 90% was used for soil and 10% for commodities/structures, not including QPS, in Article 5 regions.

The vast majority of Article 5 Parties achieved the national freeze level in 2002. In 2005, 94% of Article 5 parties (136 out of 144) either reported zero consumption or achieved the 20% reduction step by the required date; and in many cases they achieved this several years earlier than required by the Protocol. Presently, all Article 5 Parties are in compliance with this reduction step. Further, in 2009, 90% of the Article 5 Parties (133 of 147 Parties) reported national consumption of less than 50% of the national baseline. A large proportion (78%) of Article 5 Parties (115 Parties) reported zero methyl bromide consumption in 2009.

3.5.6 Alternatives to methyl bromide

MBTOC assumes that an alternative (Refer Decision IX/6 1(a)(ii)) demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex. Additionally, it is recognised that regulatory requirements, or other specific constraints may make an alternative available in one country but unavailable in another specific country or region. When evaluating CUNs, MBTOC accounts for the specific circumstances of each Party.

MBTOC was able to identify alternatives for over 95% of controlled uses in 2009. Situations where no alternatives have been identified amount to less than 1,000 tonnes of methyl bromide. However these figures may be influenced by local regulatory restrictions on the alternatives for the remaining uses. Technically effective alternatives have not yet been identified by MBTOC for the following controlled uses of methyl bromide:

- For pre-plant uses: Certain nursery plants

- For post-harvest: stabilization of high-moisture fresh dates, cheese and cured pork products infested in storage in the USA, immovable museum artefacts (especially when attacked by fungi in some circumstances).

At this time, technically feasible alternatives have also been identified for many QPS applications, but there are QPS uses or particular instances where such alternatives are not presently feasible.

Further research or development, including refinement and extension of existing techniques is needed to address these areas. Additionally, the resolution of regulatory issues would also strongly contribute to the use of alternatives.

3.5.7 Impact of registration on availability of alternatives

MBTOC considers that technical alternatives exist for almost all remaining controlled uses of methyl bromide. However regulatory or economic barriers exist that limit the implementation of some key alternatives and this can affect the ability to completely phaseout methyl bromide in several non-Article 5 countries.

It should be noted that chemical alternatives in general, including methyl bromide, have issues related to their long-term suitability for use. In the EC, methyl bromide use was completely stopped (for all uses including QPS) in 2010, mainly due to health issues; in the USA and several other countries, methyl bromide and most other fumigants are involved in a rigorous review that could affect future regulations over their use.

In January 2011, the US Environmental Protection Agency (USEPA) proposed to eventually eliminate the previous approvals for the use of sulfuryl fluoride (SF) for foods and in food processing structures if there would be food contact. EPA's sulfuryl fluoride human health risk assessment shows that, in some US locations, aggregate exposure from drinking water containing fluoride from natural background sources is already too high for certain identifiable subpopulations , in particular children under the age of 7. Although sulfuryl fluoride residues in food contribute only a very small portion of total exposure to fluoride, when combined with other fluoride exposure pathways, including drinking water and toothpaste, EPA has concluded that the tolerance (legal residue limits on food) no longer meets the safety standard under the Federal Food, Drug, and Cosmetic Act (FFDCA) and the tolerances for sulfuryl fluoride should be withdrawn. The position of Australia is different: Australia reported that total Australian exposures to fluoride – including those from commodities treated with sulfuryl fluoride – do not exceed human health safety standards. Therefore approvals of sulfuryl fluoride in Australia will not change.

Thus, consideration of the long-term sustainability of treatments adopted as alternatives to methyl bromide is still vitally important; both chemical and non-chemical alternatives should be considered for adoption for the short, medium term and longer term.

3.5.8 Alternatives for soil treatments

The reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide with amounts used falling 85% from about 57,400 tonnes in 1992 to approximately less than 6,500 tonnes in 2009, in non-Article 5 Parties and about 3,960 tonnes in Article 5 Parties.

The main crops for which methyl bromide is still being used in non-Article 5 countries are strawberry fruit, nurseries for the production of propagation material for forests, and strawberries and ornamentals (cut flowers and bulbs) and to a lesser extent in vegetable crops such as cucurbits (melons and cucumbers), peppers, eggplants and tomatoes, in perennial fruit and vine crops (particularly replant). Some uses previously considered under the CUN process have been partially reclassified as QPS (e.g. forest nurseries). Crops still using methyl bromide in Article 5 Parties are similar (cucurbits, strawberry fruit, tomatoes and other vegetables), but use in nurseries is much smaller.

Since the 2006 MBTOC Report, adoption of chemical and non chemical alternatives to replace methyl bromide as a pre-plant soil fumigant has shown significant progress, particularly due to improved performance of new formulations of existing chemical fumigants (1,3 D/Pic, Pic alone, metam sodium) and new fumigants (methyl iodide, dimethyl disulfide), but also due to increased uptake of non chemical alternatives i.e. grafted plants on resistant rootstocks.

Since 2008, iodomethane (methyl iodide) has been registered in several countries (USA, New Zealand) and dimethyl disulfide (DMDS) in USA and others. On the other hand, some initially promising chemicals included in the 2006 assessment report have seen little further development, e.g. propargyl bromide, sodium azide, propylene oxide and are no longer regarded as potential alternatives to methyl bromide. Also, the world has seen an increase in regulations on alternatives, with tighter regulations on all fumigants in the US and a banning of many fumigants (Chloropicrin, Pic EC, 1,3-D/Pic) in the EC.

Chemical alternatives

The following fumigants are currently available in many regions and due to relative similar efficacy to methyl bromide are being adopted as alternatives.

- Iodomethane or methyl iodide (MI), a liquid fumigant which has been recently tested on a wide range of crops by drip and shank-injection and found to be highly effective at controlling a wide range of soilborne pathogenic fungi, nematodes, and weeds.
- Chloropicrin (trichloronitromethane) (Pic), which is effective for the control of soilborne fungi and some insects and has limited activity against weeds. Combination with virtually or totally impermeable films (VIF, TIF) is an effective strategy to reduce application rates keeping satisfactory efficacy. However, the increase in use of Pic in strawberry production in the USA and Israel and the move to in bed strip treatment of many fumigants following the phaseout of methyl bromide has resulted in increase in infestation with *Macrophomina phaseolina*. It is anticipated that other soil borne pathogens may emerge as well.
- 1,3-Dichloropropene (1,3-D), which is used as a nematicide and also provides effective control of insects and suppresses some weeds and pathogenic fungi. 1,3- D as a single application has no effect in controlling fungi or bacteria. As with chloropicrin, 1,3-D can be combined with virtually or totally impermeable films (VIF, TIF) with satisfactory efficacy.
- Fumigants which are based on the generation of methyl isothiocyanate (MITC), e.g. dazomet, metam sodium and metam potassium, are highly effective at controlling a wide range of arthropods, soilborne fungi, nematodes and weeds, but are less effective against bacteria and root-knot nematodes. For this reason their use is often found in combination with other chemical treatments or IPM controls. The efficacy of MITC against fungal pathogens is variable, particularly against vascular wilts.
- Dimethyl disulfide (DMDS), which has been registered recently, appears to be highly efficient against various nematodes, including *Meloidogyne* spp, but is less effective on fungal pathogens. Again, DMDS is more effective when combined with VIF or TIF films.
- Furfural, which has also been registered recently, appears to be highly efficient against nematode and fungi, particularly in golf courses.

The future of soil disinfestation lies in combining available fumigants with other methods, or other fumigants and non fumigants chemical to obtain acceptable performance.

Non chemical alternatives

- Solarisation, alone or combined with biofumigation or low doses of fumigants, has continued to gain wider adoption as a methyl bromide alternative in areas with sunny climates and where it suits the cropping season and the pest and disease complex (e.g. Morocco, Israel, Jordan, Brazil).
- Steaming has been adopted for high value crops grown in protected agriculture e.g. greenhouses, as more cost-efficient systems are developed.
- Biodisinfestation has been very effective on a limited scales where growers use high amounts of organic material and are committed to the techniques' success (e.g. southern Spain).
- Soilless culture is a rapidly expanding cropping practice worldwide, primarily for protected agriculture, which has offset the need for methyl bromide, especially in some flower crops, vegetables and for seedling production including forest seedlings. In particular, flotation systems, based on soilless substrates and hydroponics, have replaced the majority of the methyl bromide for tobacco seedling production worldwide. The adoption of this technique is currently expanding into vegetable production and some ornamentals.

- Soil reduction (redox) potential, where wheat or rice bran are mixed in the soil, which is then flooded with the water and covered to maintain high temperatures and anaerobic conditions is widely used in Japan to control nematodes and fungi attacking tomatoes and strawberries. The process encourages generation of organic compounds such as acetic acid. When combined with solarisation it is efficient even in cooler regions such as the northern part of Japan.
- Grafting, resistant rootstocks and resistant varieties are now commonly used to control soilborne diseases in vegetables, particularly tomatoes, cucurbits, peppers and eggplants in many countries. They are generally adopted as part of an integrated pest control system, or combined with an alternative fumigant or pesticide, and have led to the reduction or complete replacement of methyl bromide use in several sectors in different countries.

Combination of chemical and non chemical alternatives

The combination of chemical with a range of non-chemical alternatives continues to expand as effective strategies to overcome problems due to the narrow spectrum of activity of some single control methods. Soil solarisation and grafting vegetable crops onto resistant rootstocks for instance has proven to be a valuable non-chemical alternative. Similarly the efficacy of grafted plants can be greatly enhanced by combining it with biofumigation, green manures, and chemicals such as MITC generators, 1,3-D and non- fumigant nematicides. Combinations of fumigant alternatives (MI, 1,3-D/Pic, MNa/Pic) with LPBF or relevant herbicides have been shown to be effective for nutsedge (*Cyperus spp*.), which is the key target pest for several CUNs. Finding alternatives for nursery industries is proving difficult as growers are uncertain of the risk of spread of diseases provided by the alternative products. Also, regulators often lack the data to determine if alternatives meet the quality standards (e.g. certification requirements),

Crop specific strategies implemented both in non-Article 5 and Article 5 regions are discussed in detail in the 2010 Assessment Report. These include alternatives used for the major crops (strawberries, tomato, cucurbits, peppers, eggplants, forest, fruit and strawberries nurseries and ginger) using methyl bromide in specific climates, soil types and locations, as well as combinations of alternatives, application methods and others.

3.5.9 Alternatives for treatment of post-harvest uses: food processing structures and durable commodities (non-QPS)

Food processing structures that currently use methyl bromide include flour mills, bakeries and other food production and storage facilities. These structures are fumigated to control stored product (food) pests.

Durable commodities are primarily foods (and sometimes non-food products) with low moisture content that, in the absence of pest attack, can be safely stored for long periods. The remaining durable commodities fumigated with methyl bromide in some non-QPS applications include milled rice, various dried fruits and nuts, rice, fresh market chestnuts, dry cure ham and cheese in storage houses.

The main alternatives to the disinfestation of flour mills and food processing premises are sulfuryl fluoride (including combinations of SF and heat) and heat (as full site or spot heat treatments). Some pest control operators report that full control of structural pests in some food processing situations can be obtained without full site fumigation through a more vigorous application of IPM approaches. Other pest control operators report success using a combination of heat, phosphine and carbon dioxide.

Phosphine fumigation has emerged as the leading treatment of infested commodities. Treatment of commodities with sulfuryl fluoride has also expanded to significant levels.

Regulatory considerations

Many commercial companies have undertaken significant efforts and Parties to conduct research, apply for registration, and register alternatives to optimize their legal use. The cost of registration for a small market may be prohibitive. This can result in one Party having access to a technically effective alternative that is not available to other Parties.

In the European Community and the United States, methyl bromide and most other fumigants are involved in a rigorous (re-) review that could affect future regulations over their use. As examples of this, several contact insecticides previously used to control stored food pests have been deregistered in the European Union.

Additional registration issues arise where treatments will be used on food commodities or where treatments used in food processing buildings might transfer residues to food because the maximum residue limits (MRLs) for the residual chemicals must also be registered in importing countries. In recent years, some large methyl bromide-volume consuming countries have both published and revoked maximum residue levels for the residues of some methyl bromide alternatives in food commodities.

As an example, in France, approval of the use of SF on fresh chestnuts has been withdrawn. The SF treatment resulted in a fluoride residue in chestnuts which exceeded the European Union 25 ppm MRL.

Additionally, the US Environmental Protection Agency has recently proposed to phase in the deregistration of food uses for sulfuryl fluoride (SF) in the US. Adoption of SF has played a leading role in reductions in use of methyl bromide for stored product protection in the US.

This situation does not only affect the use of SF on food commodities. Lack of maximum residue limits (MRLs) for fluorine residues resulting from the use of SF has been cited as a reason for the continuing need for methyl bromide in several critical use nominations.

MBTOC also advises the Parties that environmental concerns about using sulfuryl fluoride amongst milling and food processing companies should not be underestimated as an obstacle to adoption of this methyl bromide alternative.

Defining IPM and its elements

IPM is a sustainable pest risk management approach combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks. Although a reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners, MBTOC notes that onward from this point there is a divergence in the definition on IPM.

IPM is sometimes defined as not including full site chemical treatments, and also only including the very minimal or complete non-use of other pest control chemicals.

On the other hand, some people define IPM as a means of minimizing chemical use, but also incorporate full-site or curative treatments as part of an IPM programs. These may involve fumigation or other processes. In the context of phasing out methyl bromide, IPM should be considered a required pre-requisite to the use of full site chemical treatments by methyl bromide and other fumigants.

Given this divergence of definition, and to avoid confusion, MBTOC has placed information about full site treatments by fumigation or heat in the section on pest control in flour milling and food processing, whereas non-chemical IPM approaches and techniques are discussed in the extensive IPM section.

Pest control alternatives in flour mills and food processing facilities

Alternatives most often used in the milling and food processing sectors are, heat treatment (full site or as spot heat (combined with the use of a further pest barrier method) and sulfuryl fluoride (SF), either alone or with the addition of supplemental heat in a combination treatment.

Although concerns were reported with the use of each alternative, there were no reports indicating that any particular mill structure, type or conformation completely lacked a technically effective alternative treatment (while mindful that evidence from trials still does not indicate ideal efficacy of SF treatments in killing pest eggs).

Pest control alternatives for commodities

The most commonly used alternatives for control of pests in stored commodities are phosphine and sulfuryl fluoride.

Since the last Assessment Report in 2006, adoption of controlled atmosphere (CA) techniques has significantly increased and so this subject is covered in more detail, with its own section. The infested products are exposed to CA in airtight climate rooms equipped to handle variable sorts and quantities of products. The temperature, oxygen and humidity are controlled in each room within a specified range of parameters known to be lethal to the pest(s). The treatment normally requires 1 to 6 days, depending on the type infestation and product temperature.

Since pest control of dates is a problem of several countries, and since there have been separate decisions of the Montreal Protocol concerning pest problems of high moisture dates. MBTOC has prepared a separate section on this issue in Chapter 5 of the Assessment Report. Parties, particularly Algeria and Tunisia, have discussed with deep concern the problem of controlling pests in high-moisture dates. Currently methyl bromide is used by several Parties to disinfest dates and prevent fermentation. In the United States, dates are included in a commodity CUN.

Additionally, MBTOC has prepared two cautionary notes about the emergence of psocids in stored products and efforts needed to avoid and control pest resistance.

3.5.10 Rate of adoption of alternatives

Generally, time is required to allow the relevant industry to transition to available effective alternatives once these are identified. Since the critical use process commenced in 2005, most industries show a reduction in nominated quantity requested from that of the preceding year, reflecting progressive adoption of alternatives; while others have the same or similar quantities of methyl bromide nominated. Some CUNs show comparatively slow rates of adoption. Reviews show that in most instances the adoption rates varied between 10 and 25% per year. This includes Article 5 countries that have adopted alternatives through investment projects, where the rate of adoption is on average between 20 and 25% per year.

Analysis of the data indicates that by the end of 2009, 95% reduction of methyl bromide use or complete phase out of methyl bromide has occurred for tomato crops in Australia, Japan, New Zealand, Portugal, Spain, Greece, Belgium, and the UK; in strawberry fruit in Australia, Belgium, Greece, Japan, Portugal and Spain; and in peppers or eggplants in Australia, Greece, Israel, Malta, New Zealand, Spain and the UK. Reductions in the range of 40 - 80% have been made in the US and Israeli strawberry fruit industries and 70% in the US tomato industry since 2005. Israel has found transition difficult mainly because some formulations of alternatives are not registered and restrictions on the use of a key alternative, chloropicrin exist; also because of the occurrence of specific pests (*Verticillium dahliae* race 2, *Orobanche* spp.). Israel, however, recently informed Parties that it will no longer seek CUE's post 2011. Regulatory restrictions in the US have also limited uptake of a leading alternative, 1,3-D in California but recent high adoption rates of methyl iodide and a 3 way treatment (chloropicrin, 1,3-D, metham sodium) have seen substantial reductions in methyl bromide use in the southeast of the USA. Japan will phase out all methyl bromide soil fumigation in 2013 with alternatives such as IPM and other chemicals.

Many examples of successful phase-out or significant use reduction are available from Article 5 countries including several previously included in the list of largest users (e.g. Turkey, Brazil, China, Zimbabwe, Kenya, Morocco and others).

3.5.11 Alternatives to methyl bromide for quarantine and pre-shipment applications (exempted uses)

Since the 2006 Assessment Report, significant work was conducted by a Quarantine and Pre-Shipment Task Force (QPSTF) appointed by TEAP in response to Decision XX/6 and by MBTOC in response to Decision XXI/10. For quarantine and pre-shipment purposes, methyl bromide fumigation is currently often a preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities. However, in 2008 IPPC published recommendations for replacement or reduction of the use of methyl bromide as a phytosanitary measure.

Although QPS uses are usually for commodities in trade, (soil uses for strawberry, deciduous and rose nurseries have been identified since the first CUE), some Parties have identified some methyl bromide soils uses as being quarantine uses. Alternatives to these uses are discussed in the chapter on soils.

Usually quarantine treatments are only approved on a pest and product specific basis, and following bilateral negotiations. This process helps ensure safety against the incursion of harmful pests, but also often requires years to complete. For this and other reasons, replacing methyl bromide quarantine treatments can be a complex issue. Many non-methyl bromide quarantine treatments are, however, published in quarantine regulations, but they are often not the treatment of choice. Nevertheless, implementation of alternatives to methyl bromide for QPS has occurred since the 2006 MBTOC Assessment Report, and in response to Decision XXI/10 MBTOC has made initial estimates of amounts of methyl bromide used for QPS purposes that could be replaced with alternatives, for the major use categories.

Article 2H exempts methyl bromide used for QPS treatments from phaseout. The European Community banned all uses of methyl bromide in its 27 member states including QPS, as of March 2010. Other countries show significant reductions in their methyl bromide consumption for QPS; Brazil has announced that it will stop QPS use of methyl bromide in 2015.

Global production of methyl bromide for QPS purposes in 2009 was 8,922 tonnes, increasing by 6.5% from the previous year. Although there are substantial variations in reported QPS production and consumption on a year-to-year basis, there is no obvious long term increase or decrease. Israel, USA and China together accounted for 94% of the global QPS production in 2009.

Global QPS consumption was 11,256 tonnes in 2009, which was 26% more than in 2008 but close to the average for the past 11 years (11,197 tonnes). QPS consumption was reported to be 39% higher than non-QPS consumption in 2009, due to continued reduction in non-QPS consumption and increased QPS consumption from 2008 to 2009. MBTOC reports, however, indicate that non-QPS uses are higher than reported, as data on consumption does not match quantities exempted for CUE uses, Parties also continue to use methyl bromide from pre 2005 stockpiles and leakage is occurring from QPS stocks to non-QPS uses. It should also be noted that consumption is different to actual use.

Total Article 5 QPS consumption was 5,433 tonnes in 2009. Consumption of methyl bromide for QPS uses in Article 5 Parties shows an increasing trend over the past 10 years, while in non-Article 5 Parties it has been decreasing. Among the Article 5 Parties, nine reported consumption of more than 100 tonnes, accounting for 89% of the Article 5 QPS consumption in 2009. Total Non-Article 5 QPS consumption was 5,823 tonnes in 2009, which was 87% more than reported in 2008, largely due to an increase in Israel's consumption. Five non-Article 5 Parties consumed more than 100 tonnes in 2009, accounting for 99% of the QPS consumption in non-Article 5 Parties.

One hundred and fifty eight Parties (82%) either consumed less than 10 tonnes of QPS, or they reported zero or provided no report in 2009, or they had never reported consumption prior to 2009. Thirty Parties (16%) reported consumption of more than 10 tonnes in 2009 and of these, six reported consumption of more than 500 tonnes.

A discrepancy of about 1,300 tonnes for non-Article 5 Parties over the period 2003-2007 has existed between total consumption as represented by methyl bromide actually used, estimated by 'bottom-up' analysis, and total consumption reported as per Article 7 data. This error has mainly been attributed to reported QPS methyl bromide consumption by the US under Article 7 and estimates of its annual actual use as a fumigant. At this time the fate of this surplus is unidentified, but could include accumulation of QPS-labeled stocks of methyl bromide.

While there remain some data gaps and uncertainties, information supplied by the Parties allowed MBTOC to estimate that four uses consumed more than 70% of the methyl bromide used for QPS in 2008: 1) Sawn timber and wood packaging material (ISPM-15); 2) Grains and similar foodstuffs; 3) Pre-plant soils use; and 4) Logs. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, MBTOC calculated that 31% to 47% of consumption in 2008 these categories (or about 31% of global consumption) was immediately replaceable with available alternatives. Detailed descriptions of alternatives and their technical and economic feasibility are provided in Chapter 6 of the Assessment Report.

MBTOC estimated that in Article 5 Parties that more than 60% of the methyl bromide used in sawn timber and wood packaging material could be replaced by heat or alternative fumigants; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and 30-70% for pre-shipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; and 10-20% of the methyl bromide used in *logs* could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking and heat. There was no categorisation of methyl bromide as QPS used on soil in Article 5 Parties.

In non-Article 5 Parties MBTOC estimated that more than 60-80% of the methyl bromide used in sawn timber and wood packaging material could be replaced by heat or non-wooden pallets; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and more than 80% for preshipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; about 50-95% of the methyl bromide used in soil could be replaced by alternative fumigants, provided the alternatives meet certification standards and a key alternative (methyl iodide/ Pic) was available; and 10-20% of the methyl bromide used in logs could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking and heat.

For perishables, there are various approved treatments, depending on product and situation, including heat (as dry heat, steam, vapour heat or hot dipping), cold (sometimes combined with modified atmosphere), modified and controlled atmospheres, alternative fumigants, physical removal, chemical dips and irradiation.

The technical and economic feasibility of alternatives to methyl bromide used for QPS in all countries mainly depend on the efficacy against quarantine pests of concern, the infrastructural capacity of the country, end-use customer requirements, phytosanitary agreements where relevant, and logistical requirements and regulatory approval for the use of the alternative.

3.5.12 Progress in phasing-out methyl bromide in Article 5 Parties

An analysis of progress in phasing-out methyl bromide in Article 5 Parties, remaining challenges and constraint to adoption of alternatives becomes more important as the 2015 deadline for complete phase out of methyl bromide in Article 5 Parties approaches. Phase out has been achieved mainly through MLF investment (or phase-out) projects and alternatives chosen generally follow those identified as successful through demonstration projects or research carried out in the same country or in regions with similar circumstances, including non-Article 5 countries. Costs, logistics and in some cases different resource availability may lead to preference for different alternatives in Article 5 compared to non-Article 5 countries.

The projects showed that for all locations and all crops or situations tested, one or more of the alternatives proved comparable to methyl bromide in their effectiveness in the control of pests and diseases targeted in the projects in these Article 5 countries. A demonstration and technical assistance project to identify alternatives for high moisture dates – which has been particularly difficult – is now underway, with phosphine and modified atmospheres (CO_2) giving encouraging results.

By December 2010 the Multilateral Fund (MLF) had approved a total of 373 methyl bromide projects in nearly 80 countries. This included 44 demonstration projects for evaluating and customising alternatives (now for the largest part finished); 126 initiatives for the preparation of new projects, awareness raising, data collection, policy development and others; and 113 investment projects for phasing-out methyl bromide (of which 41 are presently on-going). Additional methyl bromide phaseout activities have been funded directly by Article 5 countries and/or agricultural producers, bilateral assistance from some countries and the Global Environment Facility.

MLF projects approved by December 2010 are scheduled to eliminate a total of 12,794 metric tonnes of methyl bromide in Article 5 countries, generally ahead of the 2015 deadline. Of these, 10,320 tonnes had been replaced by December 2010. Phase out schedules agreed under the projects aim to replace methyl bromide at an average annual rate of about 22.5% per year, in a total of 4.4 years on average (range 3-6 years). This includes countries that are small, medium and large methyl bromide consumers.

Projects have encouraged the combination of alternatives (chemical and non-chemical) as a sustainable, long term approach to replacing methyl bromide. This has often implied that growers and other users change their approach to crop production or pest control and may even have to make important changes in process management. Adapting the alternatives to the specific cropping environment and local conditions (including economic, social and cultural conditions) is essential to success.

Early phase-out has brought by additional benefits to Article 5 Parties for example by improving production practices, making productive sectors more competitive in international markets and training large numbers of growers, technical staff and other key stakeholders.

In December of 2010, all Article 5 Parties had reported consumption of methyl bromide for controlled uses to the Ozone Secretariat and all Parties were in full compliance with Montreal Protocol commitments.

3.5.13 *Economic criteria*

The purpose of the economics chapter is to provide the framework within which decisions on the economic feasibility of Critical Use Nominations (CUNs) are made, and to survey the existing literature to provide an overview of economic information relating to alternatives as a guide to what is known about the economic impact of the methyl bromide phase-out. A review of the existing literature shows that there are three main methodological approaches that have been used to determine economic outcomes from adoption of alternatives to methyl bromide. These include:

- Articles that report only the changed (increased) costs of using methyl bromide alternatives;
- Articles that use some form of partial budgeting technique
- Articles that report the sector-wide or even economy-wide impact of the use of methyl bromide alternatives

The variation in the means of assessing economics highlights the fact that little research has been done to increase understanding of the actual impacts of the methyl bromide phase-out. The existing literature is narrow in the sense that it relates primarily to the USA and a narrow range of methyl bromide uses. Economic data is available in some Article 5 countries that are implementing MLF projects but the MBTOC economic group did not assess these data.

TEAP/MBTOC have been asked to assess the economic feasibility of Critical Use Nominations. However, although Decision Ex. I/4 lays out the general scope of work for Parties and TEAP, guidance concerning economic feasibility benchmarks is lacking.

The review in this Assessment Report has shown that much work is still needed to gain a better understanding of the true impacts of the methyl bromide phase-out. While the literature that has been reviewed here provides a useful starting point to the types of analysis that is required, it needs to be extended to countries outside of the USA (especially in Article 5 countries) and to a wider range of methyl bromide uses.

3.5.14 *Emissions from methyl bromide use and their reduction*

Estimates of the proportion of methyl bromide used that is released into the atmosphere vary widely due to differences in usage pattern; the condition and nature of the fumigated materials; the degree of gas tightness; and local environmental conditions Under current usage patterns, the proportions of applied methyl bromide eventually emitted to the atmosphere are estimated by MBTOC to be 46 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 59 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 75%, 17,041 tonnes based on estimated use of 22,860 tonnes in 2009.

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering and condition; period of time that a surface covering is present; soil conditions during fumigation; methyl bromide injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest effect on emissions.

Studies under field conditions in diverse regions, together with the large scale adoption of Low Permeability Barrier Films (LPBF), have confirmed that such films allow for conventional methyl bromide dosage rates to be reduced. Typically equivalent effectiveness is achieved with 25 –50% less methyl bromide dosage applied under LPBF compared with normal polyethylene containment films.

The use of low permeability barrier films (VIF or equivalent) is compulsory in the European Union (EC Regulation 2037/2000). In other regions LPBF films are considered technically feasible for bed fumigation. However, in the State of California in the US a regulation currently prevents implementation of VIF with methyl bromide (California Code of Regulations Title 3 Section 6450(e). This regulation resulted from concerns of possible worker exposure to methyl bromide when the film is removed or when seedlings are planted due to altered flux rates of methyl bromide.

For QPS treatments, Decisions VII/5(c) and XI/13(7) urge Parties to minimize use and emissions of methyl bromide through containment and recovery and recycling methodologies to the extent possible. There has been limited research into the development of recovery and recycling systems for methyl bromide. There are now several examples of recovery equipment in current commercial use. All these units use are based on absorption of used methyl bromide on activated carbon. Some are designed for recycling of the recaptured methyl bromide while others include a destruction step to eliminate the sorbed methyl bromide, thus minimising emissions. There is increasing adoption of these systems, though this has been driven by considerations other than ozone layer protection, e.g. occupational safety issues or local air quality. In the absence of regulations, companies reported they would not invest in the systems, because their competitors (who had not made the investment) would then have a cost advantage.

3.6 Refrigeration, AC and Heat Pumps TOC

3.6.1 Refrigerants

More than 60 new refrigerants were introduced for use either in new equipment or as service fluids (to maintain or convert existing equipment) since the 2006 assessment report. Significant focus is on alternatives, including blend components, offering lower global warming potentials (GWPs) to address climate change. That pursuit forces more attention than in the past on flammable or low-flammability candidates. Most of the new refrigerants are blends containing hydrofluorocarbons (HFCs) or in some cases blends of HFCs and hydrocarbons (HCs), the latter typically added to achieve miscibility with compressor lubricants to facilitate lubricant return to compressors.

Additional refrigerants including blend components still are being developed to enable completion of scheduled phase-outs of ozone-depleting substances (ODSs). They include unsaturated fluorochemicals with primary focus on unsaturated HFCs and hydrochlorofluorocarbons (HCFCs), also identified as hydrofluoro-olefin (HFO) and hydrochlorofluoro-olefin (HCFO) compounds. Considerable effort continues for examination of broader use of ammonia, carbon dioxide, and HCs. Research continues to increase and improve the physical, safety, and environmental data for refrigerants, to enable screening, and to optimise equipment performance.

The report updates and expands summary data for assessment of the new refrigerants as well as comparison to refrigerants already retired or being replaced as ODSs or for other environmental, performance, or safety reasons. The environmental data included are consistent with the 2010 WMO Scientific Assessment supplemented with additional data, to fill voids, from other consensus assessments and published studies.

The new assessment updates the tabular data summaries from prior assessments. The revised data reflect consensus assessments and published scientific and engineering literature where possible. The summaries address refrigerant designations, chemical formulae, normal boiling point (NBP), critical temperature (T_c), occupational exposure limits, lower flammability limit (LFL), safety classification, atmospheric lifetime (t_{atm}), ozone depletion potential (ODP), global warming potential (GWP), and control status. The updated chapter also summarises the ODP and GWP values prescribed for regulatory reporting.

The status of data for the thermophysical properties of refrigerants, which include both thermodynamic properties (such as density, pressure, enthalpy, entropy, and heat capacity) and transport properties (such as viscosity and thermal conductivity), is generally good for the most common and alternative refrigerants. Data gaps exist, however, for the thermodynamic and transport properties of blends and less-common fluids as well as for the transport properties of many fluids (but especially so for blends and for some of the new unsaturated fluorochemicals and blends containing them). The data situation for the less-common fluids is more variable; there is a need to collect and evaluate the data for such candidates. Significant research still is needed, but is not expected to retard scheduled ODS phase-outs.

A major uncertainty for all of the refrigerants is the influence of lubricants on properties. The working fluid in most systems is actually a mixture of the refrigerant and the lubricant carried over from the compressor(s). Research on refrigerant-lubricant mixtures is continuing. The need for further studies is driven by the introduction of new refrigerants, by the great variety of lubricants in use and being introduced, and by the often highly proprietary nature of the chemical structures of the lubricant and/or additives.

This chapter summarises data for refrigerants and specifically those addressed in subsequent sections of this assessment report. It discusses thermophysical (both thermodynamic and transport) properties as well as heat transfer, compatibility, and safety data.

This chapter does not address the suitability, advantages, and drawbacks of individual refrigerants or refrigerant groups for specific applications; such discussion is addressed for specific applications where relevant in subsequent chapters.

The updated chapter reviews the status heat transfer and compatibility data for refrigerants. It recommends further research of:

- test data for shell-side boiling and condensation of zeotropic mixtures
- local heat transfer data determined at specific values of vapour quality
- microchannel heat exchanger refrigerant-side heat transfer data including flow distribution effects
- effects of lubricants on heat transfer, especially for ammonia, carbon dioxide, hydrocarbons, unsaturated HCFCs, and unsaturated HFCs
- more accurate evaporation and condensation data for hydrocarbons for both plain tube and enhanced tubes
- inside-tube condensation heat transfer data for carbon dioxide at low temperatures such as –20 °C
- heat transfer correlations for carbon dioxide supercritical heat rejection and two-phase evaporation

3.6.2 Domestic Refrigeration

Conversion of new domestic refrigerator production to non-ODS refrigerants is essentially complete. Broad-based refrigerant alternatives continue to be HC-600a and HFC-134a. In 2008, 36% of production units used HC-600a or a binary blend of HC-600a and HC-290; 63% used HFC-134a. The remaining 1% used regionally available refrigerants, such as HFC-152a. Second generation non-ODS refrigerant conversion from HFC-134a to HC-600a is complete in Japan and has begun in the United States and other countries. Significant extension of this second generation conversion is expected over the next decade. By 2020 it is estimated that three-fourths of refrigerant demand for new refrigerator production will be for HC-600a and one-fourth will be for HC-134a. No new technologies have surfaced which are cost and efficiency competitive with current vapor-compression technology.

Service conversion to non-ODS refrigerants has significantly lagged original equipment conversion. The distributed, individual-proprietor character of the service industry resists coordinated refrigerant management efforts. Field service procedures typically use originally specified refrigerants. Non-Article 5 countries completed new production conversion from ODS refrigerants approximately 15 years ago. This time span is approaching the useful equipment lifetime so service of ODS refrigerant containing products is transitioning to a sunset issue in these countries. Service demand for ODS refrigerants in Article 5 countries is expected to remain strong for more than ten years as a result of their later conversion to non-ODS refrigerants. Unless there is governmental intervention, service demand for CFC-12 refrigerant is expected to continue.

Enhanced product energy efficiency provides benefit to reduced global warming during the use phase of the refrigerator life cycle. Existing state-of-the-art models contain multiple, mature efficiency improvement options. Extension of these to all global products would yield significant benefits, but realization will be constrained by capital funds availability.

In 2006 the global domestic refrigerant bank was estimated to be 153,000 tonnes consisting of 40% CFC-12, 54% HFC-134a and 6% HC-600a. The bank is equally divided between non-Article 5 and Article 5 countries. An estimated 71% of residual CFCs reside in Article 5 countries. Annual emissions from this bank were estimated to be 6.8%. The majority of domestic refrigerators never require sealed system service. Consequently, emissions are dominated by end-of-life product disposition; inferring legacy product emission management may be the largest opportunity for emission avoidance.

3.6.3 Commercial Refrigeration

Commercial refrigeration comprises three different families of systems: centralized systems installed in supermarkets, condensing units installed mainly in small shops and stand-alone units installed in all types of shops. The refrigerant choices depend on the levels of conservation temperatures and the type of systems.

The number of supermarkets worldwide is estimated to 280,000 in 2006 covering a wide span of sales areas varying from 400 m2 to 20,000 m2. The populations, in 2006, of vending machines and other stand-alone equipment are evaluated to 20.5 and 32 million units, respectively, and condensing units are estimated to 34 million units. In 2006, the refrigerant bank was estimated at 340,000 tonnes and was distributed as follows: 46% in centralised systems, 47% in condensing units, and 7% in stand-alone equipment. The estimated sharing of refrigerant per type is about 15% CFCs which are still in use in Article 5 countries, 62% HCFCs the dominant refrigerant bank and still for many years, and 23% HFCs which have been introduced in new equipment in Europe and Japan as of 2000.

Stand-alone Equipment: HFC-134a fulfils most technical constraints in terms of reliability and energy performance for stand-alone equipment. When GWP of HFC-134a is considered prohibitive in relation to HFC emissions (country regulation or company policy), hydrocarbon refrigerants (isobutane and propane, i.e. HC-600a and HC-290) or CO_2 (R-744) are the current alternative solutions, presenting in most of the cases the same technical reliability and energy performance as HFC-134a. In the near future, unsaturated HFCs such as HFC-1234yf could be considered as an adapted solution, since the retrofit from HFC-134a to this new refrigerant is expected being rather simple, even if long term reliability has to be assessed. Energy efficiency standards are being issued or revisited in order to lower energy consumption of various types of stand-alone equipment.

Condensing Units: Their cooling capacities vary from 5 to 20 kW mostly at medium temperature. The refrigerant charge varies from 1 to 5 kg for HCFCs or HFCs and also HCs. HCFC-22 is still the most used refrigerant in the U.S. and in all Article 5 countries. For new systems, R-404A is the leading choice for cost reasons; the condensing units using the refrigerant R-404A are cheaper compared to HFC-134a units of the same cooling capacity because of smaller compressor. Nevertheless in hot climate and for medium temperature applications, HFC-134a is used due to its better energy performances at high ambient temperatures.

Supermarket systems: The size of centralized systems can vary from refrigerating capacities of about 20 kW to more than 1 MW related to the size of the supermarket. Refrigerant charges range from 40 up to 1500 kg per installation. The dominant refrigerant used in centralized systems is still HCFC-22. In Europe, new systems have been mainly charged with R-404A, but HFC-134a, ammonia (R-717), HCs and R-744 have been tested in many stores. R-744 is now considered off the shelf solution by the two major European manufacturers. Several designs have been experimented in hundreds of stores: distributed systems, indirect systems, cascade systems. Those designs have been developed in order to reduce the refrigerant charge to use more easily flammable or toxic refrigerants, or to limit the charge of high GWP HFCs. At the low temperature level the use of R-744 appears as an interesting option in terms of GWP, energy efficiency and even costs especially when HFCs are highly taxed. At the medium level temperature, the search for the best option is still ongoing. In the near term, servicing of current HCFC-22 may pose a problem due to possible shortage of this refrigerant. Several HFC blends are proposed to retrofit HCFC-22 installations with or without oil change, but those retrofit blends have not gained until now a significant momentum.

3.6.4 Industrial Systems

Industrial systems are characterised primarily by the size of the equipment and the temperature range covered by the sector. This includes industrial cooling, industrial heat pumps and industrial air-conditioning. Industrial systems have special design requirements, including the need for uninterrupted service, which are not typically provided by traditional HVAC practices. Rankine cycle electrical generation systems using relevant fluids are also considered in the industrial systems chapter.

R-717 is the most common refrigerant in industrial systems, although with significant regional variations around the world. Where R-717 is not acceptable for toxicity reasons, R-744 has been used, either in cascade with a smaller R-717 plant, in cascade with a fluorocarbon or rejecting heat direct to atmosphere in a high pressure (“transcritical”) system. In some cases, for example freezers or IT equipment cooling, R-744 offers additional advantages in performance or efficiency which merit selection ahead of any other refrigerant without consideration of toxicity or environment.

There is also a significant bank of HCFC refrigerant in industrial systems, particularly HCFC-22. Individual system charge can be high – in some cases several tonnes of refrigerant. These systems tend to have longer life than commercial equipment, often lasting over 20 years, but leakage rates can be high, particularly in older plants. A “drop-in” blend for replacing HCFC-22 in flooded industrial systems has not been developed; the common replacement blends used in commercial refrigeration such as R-407A or R-422D are difficult or impossible to use in large industrial systems. The cost of these blends is also a significant barrier to their use.

HFCs have not been widely used in large industrial systems. Where they have been adopted it is generally in low charge systems in order to reduce the financial consequences of refrigerant loss. It is very unlikely that unsaturated HFC refrigerants, whether single compounds or blends, will be adopted for use in industrial systems because in addition to cost considerations the risk of refrigerant decomposition due to the presence of contaminants is too great. HFC-245fa and HFC-134a have also been used in power generation units, utilising the Rankine cycle, although these systems are not yet widely available on the market.

Users of HCFCs in smaller industrial systems are now faced with the choice of whether to switch to HFCs and face a possible phase-down, or to change to R-717 or R-744 and deal with the change in operating practices that those refrigerants would require.

3.6.5 Transport Refrigeration

Transport refrigeration includes transport of chilled or frozen products by means of road vehicles, railcars, intermodal containers, and small insulated containers (less than 2 m^3) and boxes. It also includes use of refrigeration and air conditioning on merchant, naval and fishing vessels above 100 gross tonnes (GT) (about over 24 m in length).

Transport refrigeration is a niche market in terms of refrigerant banks compared to other sectors. There are about 4,000,000 road transport refrigeration units, and about 950,000 marine container units in operation today, to mention the largest segments in terms of fleet size. Most equipment has a refrigerant charge below 6 kg. Although refrigerant charge can reach several tons aboard large vessels, their fleet is relatively small. There are approx. 150,000 marine vessels above 100 GT in the world fleet; thereof small and medium size vessels have the largest share.

The equipment lifetime is usually between 10 and 15 years for intermodal containers, railcars and road vehicles, and 20 to 25 years for equipment aboard marine vessels.

The vapor compression cycle is the technology used predominantly in transport refrigeration equipment. CFC and HCFC refrigerants can be found in older equipment. HCFC-22 has a low share in intermodal containers and road equipment, but a high share in railcars (declining market) and a very high share in marine vessels, where it remains to be the dominant refrigerant. The CFC and HCFC banks have been decreasing. Retrofit options to R-502 include R-408A, R-402A and R-404A.

Virtually all new systems utilize HFC refrigerants (HFC-134a, R-404A). Non-fluorinated refrigerants have been commercialized to a small extent aboard marine vessels (R-717, R-744), and tested in marine containers, trailers (R-744) and trucks (R-290). A wider application of these refrigerants in practice has not been possible so far because of various technical constraints. There is no practical experience with HFC-1234yf and other low-GWP candidate fluids in transport refrigeration.

Although hydrocarbons are technically feasible and may even outperform HFC systems, flammability makes people concerned about their use. Where they do not exist, standards need to be developed to address the safety concerns.

Carbon dioxide (R-744) is one of a few promising solutions in transport refrigeration. While direct emissions of R-744 are negligible, indirect emissions of R-744 may be comparable to HFCs depending on the climate where the vehicle is operated. Aboard marine vessels, because operation under high ambient temperatures is commonly required, R-774 use has been limited to low temperature stages of cascade or indirect system applications.

Due to safety concerns, use of ammonia (R-717) has been limited to indirect and cascade systems on larger ships which do not carry passengers but professional crew only. HFC refrigerants will continue to be used on passenger vessels, and on small ships of all categories. Ammonia has not been used in road vehicle and container transport in vapour compression cycles.

The transport industry is working to reduce the overall CO_2 emissions. The refrigerant type can influence both direct and indirect equivalent CO_2 emission of a vehicle. Refrigerant charge reduction, refrigerant leakage rate minimization (for example use of hermetic/semi-hermetic compressors instead of open drive), and the use of low-GWP refrigerants influence the direct contribution. Design changes that would improve the energy efficiency can reduce the indirect contribution.

Transition of power supply systems from traditional diesel engines to alternative propulsion systems (hybrid, electric, etc.) will influence refrigerantion system change and the choice of low-GWP refrigerants in the future.

As in other refrigeration sectors, research and development of other not-in-kind systems, such as magnetic or acoustic refrigeration, remains in the laboratory prototype stage. Absorption and adsorption systems with water are under development.

3.6.6 Air-to-air air conditioners and heat pumps

On a global basis, air conditioners for cooling and heating (including air-to-air heat pumps) ranging in size from 2.0 kW to 420 kW comprise a significant segment of the air conditioning market (the majority are less than 35kW). Nearly all air conditioners and heat pumps manufactured prior to 2000 used HCFC-22 as their working fluid. The installed base of units in 2008 represented an estimated HCFC-22 bank exceeding one million metric-tonnes. Approximately 85% of the installed population uses HCFC-22. In 2008, HFC demand globally represented approximately 32% of the total refrigerant demand for these categories of products. Most Article 5 countries are continuing to utilise HCFC-22 as the predominant refrigerant in air conditioning applications.

Options for new Equipment

HFC refrigerant blends R-410A and R-407C are the dominant alternatives being used to replace HCFC-22 in air-conditioners. HC-290 is also being used to replace HCFC-22 in products having low refrigerant charges.

Air conditioners using R-410A and R-407C are widely available in most non-Article 5 countries. Also, equipment using R-410A and R-407C is being manufactured in some Article 5 countries; especially in China where a large export market has created demand for these products. However, these units are typically not sold in the domestic market because of their higher cost.

There are several low and medium GWP alternatives being considered as replacements for HCFC-22 and the high GWP HFCs (R-410A and R-407C). These refrigerants include lower GWP HFC refrigerants, HC-290 and R-744. HC-290 and some of the HFC refrigerants are flammable and will need to be applied in accordance with an appropriate safety standard such as IEC-60335-2-40, which establishes maximum charge levels and ventilation requirements.

A number of moderate and low GWP HFC refrigerants are being considered for use in air conditioners. These include: HFC-32, HFC-152a, HFC-161, HFC-1234yf and blends of HFC-1234yf with other refrigerants.

HFC-32 is a class A2L flammable HFC having a GWP of 675, which is approximately 30% that of R-410A. R-410A systems can be redesigned for HFC-32 with minor modifications. However, because of its A2L flammability rating it will need to be applied using a safety standard such as IEC-60335-2-40.

HFC-152a is an A3 flammable low GWP HFC having thermodynamic characteristics similar to HFC-134a. While it has been evaluated as an alternative to HCFC-22, it is unlikely to be commercialized in unitary air conditioning applications because its low density and flammability result in significantly increased system costs.

HFC-161 is a flammable low GWP refrigerant, which is being evaluated as a low GWP alternative to HCFC-22. Like all flammable refrigerants, it would need to be applied using appropriate safety standards.

Pure HFC-1234yf is not likely to be used as a replacement for HCFC-22 in air conditioners because of its low volumetric capacity. However, HFC-1234yf can be blended with other non-ODP refrigerants to arrive at thermodynamic properties similar to either HCFC-22 or R-410A. Blends of this type are under development, but are not commercially available.

Hydrocarbon refrigerants are also low GWP alternatives to HCFCs and HFCs for low charge applications. The most frequently used hydrocarbon refrigerant in air conditioning applications is HC-290. The high flammability of HC-290 limits its use to lower charge applications. Therefore all flammable refrigerants need to be applied using an applicable safety standard such as IEC-60335-2-40, which addresses the design requirements and charge limits for flammable refrigerants. Several manufacturers in China and India are now introducing low charge HC-290 split air conditioners.

R-744, CO_2, offers a number of desirable properties as a refrigerant. However, R-744 has a low critical point temperature, which results in significant efficiency losses when it is applied at the typical indoor and outdoor air temperatures of air-to-air air conditioning applications; particularly in high ambient climates. However, a number of cycle enhancements and component additions can be made to improve the efficiency of R-744 systems. While the addition of efficiency enhancing components can improve the efficiency of R-744 systems, they also substantially increase the system cost. In order for R-744 systems to become commercially viable, cost effective mitigation of the efficiency issue will be required.

High Ambient Considerations

In the near term, regions with hot climates should be able to rely on the refrigerants and technologies that are currently commercially available to replace HCFC-22 (R-407C, R-410A and HC-290). However, when replacing HCFC-22 products with those using R-410A or R-407C the application engineer may need to take special consideration of the reduced capacity at the design ambient temperature when sizing the equipment for the design cooling load. When replacing HCFC-22 in low charge applications (small split, window and portable room air conditioners), the system designer may want to consider the use of HC-290. In the longer-term products using HFC-32, new low and medium GWP HFC blends and HC-290 are the preferable options for high ambient air conditioning applications. R-744 is not a preferred option for high ambient air conditioning applications because its very low critical temperature results in significant performance degradation during high ambient operation.

3.6.7 Water heating heat pumps

Heat pumps are classified by heat source (air, water, or ground) and heat sink (air, water), resulting in designations such as “air to water” (air source, water sink) heat pumps. This chapter covers only systems where water is the sink. The products for industrial process heating are covered in chapter 5 “*Industrial systems*”. Air-to-air heat pumps are covered in chapter 7 (*Air-to-air air conditioners and heat pumps*).

Heat pump water heaters are designed especially for heating service hot water (including domestic water) to a temperature between 55 and 90 ºC.

Space heating heat pumps heat water for distribution to air handling units, radiators, or under-floor panels. The required water temperature depends on the type of emitter, low temperature application ranging from 25 to 35°C for under floor heating, for moderate temperature application such as air handling units around 45 °C, for high temperature application such as radiant heating 55 to 60°C and for very high temperature application as high as 65 to 80°C such as for the fossil fuel boiler replacement market. The required warm water temperature affects the selection of the refrigerant. Heat pump systems are more efficient at lower sink temperatures, but each product must fulfill the required operating temperature.

Air-to-water heat pumps have experienced significant growth in Japan, Europe, China, and Australia during the last five years.

Efficient heat pumps can reduce global warming impact compared with fossil fuel burning systems significantly. The reduction depends on the efficiency level of the heat pump and the carbon emission per kWh of the electricity generation. The tendency of decarbonisation of electricity strengthens this positive effect year by year. Also the efficiency levels of the heat pumps are improving year by year. However, heat pumps tend to be higher in cost than fossil fuel systems because they employ complicated refrigerant circuits, larger heat exchangers and other special features. Government support programmes in Europe and Japan to promote heat pump systems have resulted in a rapid growth of heat pump system sales in recent years. More than 1 million air-to-water heat pumps were sold worldwide in 2008. Predictions of sales show very large growths in USA, Japan, China and Europe.

Current refrigerant options for new heat pumps

HFC-134a and HFC blends R-407C and R-410A are currently used for new water heating and space heating heat pumps to replace HCFC-22, R-407C with limited product redesign and R-410A for completely redesigned products.

HC-290 has properties similar to those of HCFC-22 apart from flammability. Until 2004 almost half of the heat pumps sold in the EU used HC-290. Use in Europe has declined due to introduction of Pressure Equipment Directive.

Development of R-744 heat pumps started around 1990. R-744 heat pump water heaters were introduced to the market in Japan in 2001, with heat pumps for heating of bath or sanitary water as the main application. The market for heat pump water heaters in Japan is steadily growing based on government and utility incentives.

Although the current market for space heating heat pumps for commercial buildings with combined radiator and air heating systems is limited, R-744 is consider to be a promising refrigerant.

R-717 is a non-ODS refrigerant and has a very low GWP, but it has higher toxicity and lower flammability characteristics. R-717 is used mainly for large capacity systems.

Future Refrigerant Options for New heat pumps

HFC-32 has a lower GWP of one third of R-410A. Heat pump with HFC-32 can achieve lower charge than heat pumps with R-410A. HFC-32 has a low flammability with a low burning velocity.

HFC-1234yf is similar in thermophysical properties to HFC-134a. For water heating and space heating heat pumps using HCFC-22, R-410A, R-407C, significant design changes would be required to optimize for HFC-1234yf. HFC-1234yf has low flammability with a low burning velocity. Due to the GWP value it has high potential in applications in systems that currently use HFC-134a. As sample supply of these refrigerants is very limited, it is too early to judge whether any of these chemicals will be commercialized and will show acceptable performance in heat pump systems.

Future refrigerants options for new heat pumps include current options R-410A, HFC-134a, HC-290, HC 600a, R-744, and R-717 as well as HFC-32 and new refrigerants.

Since the numbers of heat pumps covered by this chapter still are limited, the refrigerant bank is relatively small. Accordingly, the refrigerant emissions are low compared to other products. On the other hand, heat pumps will increase in quantity leading to higher net refrigerant requirements and emissions in future. However, it is important to emphasize that there is a large potential to reduce

CO_2 emission generated by fossil fuel combustion systems by replacing them with heat pump systems.

3.6.8 Chillers

Chillers predominantly are used for comfort air conditioning in commercial buildings and building complexes. They are coupled with chilled water distribution and air handling/air distribution systems. Chillers also are used for cooling in commercial and industrial facilities such as data processing and communications centers, electronics fabrication, and molding

Air-cooled chillers in capacities up to 1800 kW represent approximately 80 % of the annual unit production in chillers using positive displacement compressors (reciprocating piston, scroll, and screw). HFC-134a and R-410A are the most common refrigerants with the phase-out of HCFC-22. R-407C has been used as a transition refrigerant. Some chillers are available with R-717 or hydrocarbon refrigerants – primarily HC-290, HC-600a, or HC-1270 Such chillers are manufactured in small quantities compared to HFC-134a and R-410A chillers of similar capacities and require attention to flammability, and for R-717 also toxicity concerns, as reflected in safety codes and regulations. Chillers employing R-744 as the refrigerant are being marketed.

For water-cooled chillers, both positive displacement compressors and centrifugal compressors are used. Positive displacement water cooled chillers employ the same refrigerants as the air-cooled versions. Centrifugal chillers are dominant above 2 MW. Centrifugal chillers are provided with HCFC-123 or HFC-134a refrigerants though extremely limited use is made of HFC-245fa. HCFC-123 offers an efficient, very-low GWP option for centrifugal chillers. Under terms of the Montreal Protocol, use of HCFC-123 in new equipment will end in most developed countries by 2020 and by 2030 in Article 5 countries.

Existing chillers employing CFC refrigerants are being replaced slowly by new chillers using HCFC-123 or HFC-134a. Today's new chillers use 25-50% less electricity than the CFC chillers produced decades ago, so the savings in energy costs often justify replacement of aging CFC chillers. R-717 is not suitable for use in centrifugal chillers as its use would require four or more stages or, in very large capacities, a switch to axial compressor designs.

A continuing trend in chiller development is to improve both full-load and seasonal energy efficiency to address both energy-related global warming impacts and operating costs. A number of methods are used to achieve higher seasonal efficiencies. These include multistage compression with interstage economizers, use of multiple compressors to accommodate part-load conditions, continuous unloading capabilities for screw compressors, enhanced electronic controls, variable-speed compressor drives, and optimal sequencing of multiple chillers to maximize overall efficiency.

Refrigerants suggested as alternatives to ODS or high-GWP refrigerants in chillers include R-717, hydrocarbons, R-744, R-718, HFC-32, and new low-GWP refrigerants such as HFC-1234yf. Chillers using R-718 as refrigerant carry a cost premium over conventional systems because of their larger physical size and the complexity of their compressor technology, often entailing axial compressor designs operating under high vacuum. HFC-1234yf and other low- or ultra-low GWP refrigerants are too new to allow assessment of their suitability for use in chillers at this time, though that is likely to change in subsequent assessments.

Absorption chillers using working pairs ammonia-water (primarily in small capacities) or water-lithium bromide (generally in large capacities) are an alternative to chillers employing the vapour-compression cycle. They are particularly suitable for applications where surplus heat can be recovered. Other not-in-kind technologies in the research stage, such as thermoacoustic or magnetocaloric technologies, still are not ready for commercialization and may not be found suitable or competitive.

Of particular note for both ozone depletion and global climate change, chillers as a group incur very low release rates for refrigerants. The environmental impact of chillers is dominated by the energy-related global warming associated with their energy consumption over their operating life (typically 20 years and sometimes longer than 40 years). Refrigerant emissions, with their direct global warming contributions, are a small fraction of the total global warming impact of chillers except for regions with very low carbon intensity for power generation.

3.6.9 Vehicle air conditioning

Today all new passenger cars worldwide sold with air conditioning systems are using HFC-134a and the transition from CFC-12 is complete. About one fifth of the total global refrigerant emissions are from MACs (about 60 percent if only HFC refrigerant emissions are considered) including the emissions in production, use, servicing, and end-of-life. In the USA, 19% of the fleet of passenger vehicles is still using CFC-12 refrigerant based on recent survey results. The European Union has in place legislation for cars and light trucks banning the use of refrigerants with GWP>150 [e.g.; HFC-134a] in new-type vehicles from 2011 and all new vehicles from 2017. There are limited replacement refrigerants with a global warming potential (GWP) less than 150. Other countries will probably follow the regulatory direction of the EU or provide incentives to reduce the usage of HFC-134a in vehicles.

For MAC systems, the use of hydrocarbons or blends of hydrocarbons as a refrigerant has been investigated but has so far not received support from vehicle manufacturers as a possible alternative technology due to safety concerns. In Australia and the North America, hydrocarbon refrigerants have been introduced as drop-in refrigerants to replace CFC-12 (which is illegal in the USA and in some Australian states). These same refrigerants are used to a lesser extent for a replacement of HFC-134a.

Up to now, car manufacturers and suppliers have evaluated three refrigerant options for new car and truck air conditioning systems, R-744, HFC-152a and HFC-1234yf. All three have GWPs below the EU threshold of 150 and can achieve fuel efficiency comparable to existing HFC-134a systems. The CO2 equivalent impact of direct emissions from the refrigerant over the vehicle lifetime is much less than the impact related to the energy required to operate the system. The energy required to operate the MACs results in increased CO2 vehicle tail pipe emissions. Therefore, MAC systems designed to provide efficient cooling performance have become the major environmental goal. With the usage of appropriate controls and components, all three refrigerant options have been demonstrated to be comparable to HFC-134a with respect to cooling performance and total CO2 equivalents of MAC systems.

Hence, the global warming impact is almost identical for all three refrigerant options when considered on a global basis. Adoption of any of the refrigerant choices would therefore be of similar environmental benefit. The decision of which refrigerant to choose will have to be made based on other considerations, such as regulatory approval, cost, system reliability, safety, heat pump capability, suitability for hybrid electric vehicles, and servicing.

The emerging global car manufacturers' refrigerant choice for future car air conditioning systems seems to be HFC-1234yf and one manufacturer has announced the intention to introduce this refrigerant in car serial production in 2013. Currently, hurdles exist (miscibility with oil, stability problems in the presence of small amounts of water and air in the air conditioning system, mixing with HFC-134a, additional costs) that will require resolution prior to the commercial implementation of HFC-1234yf as refrigerant for car air conditioning. OEM's indicate that they will design HFC-1234yf MAC systems in such a way that these systems can safely be used with the refrigerant HFC-134a as well. This will affect the worldwide transition from HFC-134a to HFC-1234yf for MAC systems.

The development status of other refrigeration technologies, like sorption or thermoelectric systems, are still far away from serial production and presently show very poor price competitiveness and poor system performance and efficiency.

The rapid evolution of hybrid electric vehicles and electric vehicles with electrically driven compressors introduces new challenges for any new alternative refrigerant.

At present, no regulation exists that controls the use of fluorinated greenhouse gases as refrigerants for MAC systems in buses and trains. It is likely that the choice of refrigerant of passenger car air conditioning systems will influence the choice of refrigerant for air conditioning systems in buses and trains.

Worldwide, approximate 50% of the bus and train fleet is still equipped with HCFC-22 systems. The rest use mostly HFC-134a or R-407C systems. Most new bus or train air conditioning systems are equipped with the refrigerants HFC-134a or R-407C. The only reported low GWP refrigerant activities are on-going fleet tests of R-744 systems in buses.

4 TEAP and TOC Membership Information

4.1 Technology and Economic Assessment Panel Disclosure of Interests Status January 2011

Dr. Stephen O. Andersen
(Panel Co-chair)
P.O. Box 257
2317 North Road
Barnard, Vermont 05031-0257
U.S.A.
T 1 802-234-5251
E-mail: SOliverAndersen@aol.com

Dr. Stephen O. Andersen is Co-chair of the Technology and Economic Assessment Panel since 1989 and member of the Scientific Assessment Panel. He chaired and co-chaired the Solvents TOC from 1989 to 1995; co-chaired the first Methyl Bromide Scientific and Technical Assessment; and chaired or co-chaired TEAP Task Forces on process agents, HCFCs, HFCs and PFCs, collection-recovery-storage, destruction, and other topics. He was a member of the Steering Committee to the "IPCC/TEAP Special Report Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons" and author for other IPCC reports. When he retired from the U.S. Environmental Protection Agency September 1, 2009, he was Director of Strategic Climate Projects in the Climate Protection Partnerships Division and before that Deputy Director of the Stratospheric Protection Division. He was EPA Liaison to the U.S. Department of Defense (U.S. DoD) on Climate and Stratospheric Ozone Protection. He created EPA's first voluntary partnerships including accelerated ODS phase-out agreements in food packaging foam, mobile AC, and electronics and aerospace solvent applications; helped organise the Halon Alternatives Research Corporation (HARC), the Industry Cooperative for Ozone Layer Protection (ICOLP) and the World Semiconductor Council PFC Partnership; and created the US EPA Stratospheric Ozone and Climate Protection Awards.

Dr. Andersen is now Director of Research, Institute for Governance and Sustainable Development (IGSD); Senior Fellow at the Program on Governance for Sustainable Development, Bren School, University of California, Santa Barbara; and is a member of the Advisory Board of the Association of Climate Change Officers (ACCO) and member of the Editorial Board of the Journal of Mitigation and Adaptation Strategies for Global Change. As Director of Research for the IGSD, Dr. Andersen focuses on governance strategies that promote cost-effective, sustainable, fast-action technologies to protect climate that can be implemented in an effective, transparent, and verifiable way. He is also President of Future Generations Consulting Corporation. Dr. Andersen is an occasional consultant to UNEP on investment choices that minimize climate and other impacts when replacing ozone-depleting and high-GWP substances and has consulted to the Natural Resources Defense Council (NRDC) on strategies to reduce and eliminate HFC emissions. Stephen is currently an unpaid member of the International Advisory Committee for the Basil Convention projects "Pilot Destruction of Ozone Depleting Substances (ODS) and Persistent Organic Pollutants (POPs) and Legal Analysis of Feasibility of Transboundary Movements within Central American Countries" and "Feasibility Assessment and Preparation of the Destruction Banks of ODS and POPs in Central America."

Since retiring from EPA, Stephen has been an invited speaker sponsored by the Institute for Governance and Sustainable Development, State of California, University of Michigan, Vermont Law School, Scripps Institution of Oceanography, the Smithsonian Institution, the Mobile Air Conditioning Society, UNEP, the Government of India, the Industrial Technology Research Institute (ITRI), and Princeton University. In some cases, he has been paid an honorarium.

Prior to joining EPA he was a professor at University of Hawaii and College of the Atlantic and an employee of NGOs including the Environmental Law Institute, the Consumer Energy Council, and the Sierra Club. He was also an unpaid member of the Board of Directors of the Natural Resources Council of Maine, which is an affiliate of the National Wildlife Federation.

With K. Madhava Sarma, Stephen is author of "Protecting the Ozone Layer: The United Nations History," (Earthscan 2002); with Durwood Zaelke author of "Industry Genius: Inventions and People Protecting the Climate and Fragile Ozone Layer," (Greenleaf 2003); and with K. Madhava Sarma and Kristen N. Taddonio is author of “Technology Transfer for the Ozone Layer: Lessons for Climate Change,” (Earthscan 2007). With Guus J.M. Velders, John S. Daniel, David W. Fahey, and Mack McFarland, is author of “The Importance of the Montreal Protocol in Protecting Climate,” (Proceedings of the National Academy of Sciences (PNAS), 20 March 2007) and “The Large Contribution of Projected HFC Emissions To Future Climate Forcing,” (PNAS, 7 July 2009). With Mario Molina, Durwood Zaelke, K. Madhava Sarma, Veerabhadran Ramanathan and Donald Kaniaru is author of “Reducing Abrupt Climate Change Risk Using the Montreal Protocol and other Regulatory Actions to Complement Cuts in CO2 Emissions,” (PNAS, 12 October 2009). With Stella Papasavva is author of “GREEN-MAC-LCCP©; Life-Cycle Climate Performance Metric for Mobile Air Conditioning Technology Choice,” Environmental Progress & Sustainable Energy, American Institute of Chemical Engineering, and with Deborah J. Luecken, Robert L. Waterland, Stella Papasavva, Kristen N. Taddonio, William T. Hutzell, and John P. Rugh is author of “Ozone and TFA Impacts in North America from Degradation of 2,3,3,3-Tetrafluoropropene (HFO-1234yf), A Potential Greenhouse Gas Replacement,” Environ. Sci. Technol., 2010, 44 (1), pp 343–348.

Stephen Andersen earned his M.S. and Ph.D. in Agricultural and Natural Resources Economics from the University of California Berkeley, where in 1974 he co-authored the first assessment of the impact of stratospheric ozone depletion on agricultural crops. As an undergraduate, Stephen studied business administration.

Stephen’s spouse, Dr. Janet Andersen, retired from the U.S. EPA Office of Prevention, Pesticides, and Toxic Substances where she had been Director of the division that registers bio-pesticides, including potential substitutes for methyl bromide. Drs. Andersen have no proprietary interest in alternatives or substitutes to ODSs and do not own stocks in companies producing ODSs or alternatives and substitutes to ODSs. Janet is an occasional consultant to companies pursuing natural pesticides, including products that may help phaseout methyl bromide. Prior to September 2009, the U.S. EPA made in-kind contributions of wages, travel, communication, and other expenses and the U.S. DoD sponsored some travel. From September 2009 through October 2010, Stephen sponsored the travel and other expenses of participation in TEAP and Montreal Protocol meetings. Travel for continued participation on TEAP is sponsored by IGSD.

Mr. Paul Ashford
(Foams TOC Co-chair)
Principal Consultant
Caleb Management Services
The Old Dairy, Woodend Farm Cromhall,
Wotton-under-Edge
Gloucestershire, GL12 8AA
United Kingdom
T 44 1454 269 330
F 44 1454 269 197
M 44 7774 110 814

Paul Ashford has been the Co-chair of the Rigid and Flexible Foams Technical Options Committee and member of the TEAP since 1998. He is the owner and managing director of Caleb Management Services Ltd., a consulting company working in the chemical regulatory and sustainability arenas. Largely as a result of Mr. Ashford’s own background and expertise in the high GWP gases sector (ODS and their replacements), approximately 15-20% of the company’s turnover relates specifically to this sector.

Past and current projects include assisting the US EPA in engaging with the foam sector on ODS phase-out issues, preparing publications on the foam sector for UNEP DTIE, providing advice to UNDP on the climate implications of ODS phase-out and ODS bank management including a review of the co-funding options that might be available, assisting with the climate impact evaluation of HCFC phase-out management plans and the peer review of documentation prepared by UNIDO on the same subject. Paul has also assisted the UN Multilateral Fund Secretariat in the development of approaches for assessing the climate impact of technology transitions.

Additionally, Caleb has been involved in the quantification of ODS Banks in Foams in California (under contract to the California Air Resources Board) and in the United Kingdom (under contract to the Building Research Establishment). This work has extended to the validation of earlier work on banks in the EU-27 and the assessment of policy options for the European Commission (under contract to SKM Enviros). Paul Ashford was a member of the Working Group that supported the development of the ODS Protocol under the Climate

Action Reserve (CAR) and has also acted as an unpaid advisor to the development of the Voluntary Carbon Standard 'Extension of Scope' to include ODS destruction projects. Paul also acts as an occasional peer reviewer for ODS methodologies under the VCS programme.

Paul co-chaired the TEAP Task Force on the Supplementary Report to the "IPCC/TEAP Special Report: Safeguarding the ozone layer and the global climate system: issues related to hydrofluorocarbons and perfluorocarbons" (2005), the Task Force on Foams End-of-Life Issues (2005) and the Task Force on Emissions Discrepancies (2006). He also co-chaired the TEAP Task Force Response to Decision XVIII/12 and co-ordinated the Interim and Phase 2 Reports of the Task Force for Decision XX/7 on the sound management of ODS Banks. He has most recently acted as co-chair of the Task Force in response to Decision XXII/10 on destruction project criteria.

Paul gained a BSc. (Hons) in Chemistry at the University of Bristol in 1979. Until 1994, he worked in a variety of technical and commercial roles for BP Chemicals in a division that developed licensed foam technology using ODS and was responsible for the adoption of alternatives. He has over 25 years direct experience of foam related technical issues and has conducted numerous studies to characterise the foam sector and inform future policy development. His funding for TEAP activities, which includes some sponsorship of time, as well as coverage of travel and subsistence, is provided jointly under contract by the Department of Business, Innovation and Skills (BIS) and the Department of Environment, Food and Rural Affairs (DEFRA) in the UK.

Much of his earlier work on banks, emissions and foam end-of-life management, performed to inform both IPCC and TEAP processes was supported by the Alternative Flourocarbons Environmental Assessment Study (AFEAS) and the US EPA.

Neither Paul, nor any of his family members hold and stock or have any proprietary interest in any company involved in the manufacture of ODS or ODS substitutes or in any company involved in the management of ODS Banks or similar waste streams.

Prof. Mohamed Besri
(MBTOC Co-chair)
Department of Plant Pathology
Institut Agronomique et Vétérinaire Hassan II
Rabat
Morocco
E.mails: m.besri@iav.ac.ma, mohamedbesri@gmail.com
T/F +212 537 778 364
M +212 664 603 721

Prof Mohamed Besri is Co-Chair of MBTOC since 2005, and member of MBTOC since 1996. Prof. Mohamed Besri, retired in July 2011 as Professor of Plant Pathology and Integrated Disease Management at the Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco (HII IAVM), but he is still continuing all his previous activities (teaching, research, extension, national and international co-operation etc.) at the same Institute. Prof Besri is a visiting professor to many American, European and African universities. He is also member of various national and international associations and member of many executive committees and governing boards e.g. of the International Association for the Plant Protection Sciences (IAPPS) and of the International Association for Biological control (IOBC) and was Vice President and President of the Arab Society for Plant Protection. Prof. Besri was appointed by the Inter Academy Council (IAC) as member of the international study panel to write a report for the United Nations on "Realizing the promise and potential of African Agriculture: Science and technology strategies for improving agricultural productivity and food security in Africa" (www.interacademycouncil.net) and also as a member of an Ad Hoc Task Force to follow up the report recommendations. Prof. Besri is frequently invited as a speaker at national and international conferences dealing with methyl bromide and IPM and has authored or co authored many publications on alternatives to methyl bromide. Prof Besri has been awarded the medal of National merit by the King Mohamed VI for his contribution to the development of the Moroccan agriculture. Prof Besri is Academician, member of the Moroccan Academy of Sciences and technology. The HII IAVM has an interest in the topics of the Montreal Protocol because it houses specialists in Soil-borne Plant Pathogens. It advises the Ministry of Agriculture on all aspects of alternatives to Methyl Bromide. Prof. Besri has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS, alternatives or substitutes to ODSs. Prof. Besri works occasionally as a consultant to UNEP and UNIDO on matters related to the Montreal Protocol. Neither Prof. Besri's spouse, business partner or dependant children, work for or consult for any organization, which has an interest in the topics of the Montreal Protocol, nor do any of them have any proprietary interest in alternatives or substitutes to ODSs, nor do any of them own stock in companies producing ODS or alternatives or substitutes to ODSs or consult for organizations seeking to phase-out ODSs. Costs associated to travel, communication, and others related to participation in the TEAP, MBTOC, and relevant Montreal Protocol meetings, are paid by UNEP's Ozone Secretariat.

Mr. David Catchpole
(Halons TOC Co-chair)
Technical Consultant
3601 C Street, Suite 822
Anchorage
Alaska
U.S.A.
T 1 907 868 3911

Mr. David V. Catchpole, Co-Chair, Halons Technical Options Committee and Member, Technology and Economics Assessment Panel, works part time for Petrotechnical Resources Alaska (PRA), an Anchorage, Alaska based company that provides consulting services to oil companies in Alaska. From 1991 to 2004 he was a member of the HTOC. From 1970 until 1999, he was an employee of the BP group of companies, most recently BP Exploration Alaska, where he worked for nine years in the environmental department on alternatives to halon and on halon banking. Mr. Catchpole advises BP Exploration Alaska on fire protection and halon issues as his main activity for PRA. BP Exploration Alaska has an interest in the topics of the Montreal Protocol because it uses halon 1301 for explosion prevention and fire suppression in its enclosed oil and gas processing modules on the North Slope of Alaska. Mr. Catchpole has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs, however his retirement portfolio contains stock in BP plc. Mr. Catchpole's spouse does not work for or consult for any organization that has an interest in the topics of the Montreal Protocol. His spouse has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs and does not consult for organizations seeking to phase-out ODSs. Mr. Catchpole typically receives funding to support salary and travel to TEAP/TOC meetings from the Halon Alternatives Research Corporation, which is a not-for-profit industry coalition that in turn receives contributions for this funding from members. Current contributors are: BP Exploration Alaska, ConocoPhillips Alaska, DuPont, American Pacific, Firetrace, Halon Banking Systems, Wesco and Remtec.

Prof. Dr. Biao Jiang
(Chemicals TOC Co-chair)
Shanghai Institute of Organic Chemistry (SIOC),
Chinese Academy of Sciences (CAS)
354 Fenglin Road
Shanghai 200032
The People's Republic of China
T 86 21 54925201
F 86 21 64166128

Dr. Biao Jiang, Co-chair of the Chemicals Technical Options Committee since 2005, is Professor of Chemistry of Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences and a member of editorial advisory board of Chemical Communication, Royal Society of Chemistry, United Kingdom. He received his PhD in 1988 from Lanzhou University. After two years as postdoctoral research in the organometallic chemistry at SIOC, he spent three years as a visiting scientist working on the medicinal chemistry in DuPont-Merck Pharmaceutical Co., at the DuPont Experimental Station, Delaware, USA. In 1995, he returned to SIOC, where he is currently professor and was director from 2001 to 2009. Now he is a vice president of Shanghai Advanced Research Institute (SARI), Chinese Academy of Science. The research project of Professor Jiang's group involves the development of new methodology in asymmetric synthesis, total synthesis of marine natural alkaloids and steroids, fluorine-containing bioactive molecular, as well as organic process research and development of green chemistry. He has no proprietary interest in alternatives or substitutes to ODSs, and he does not own stock in companies producing ODS or alternatives or substitutes to ODSs. None of his family members have interest in matters before the Protocol. Cost of travel, communication and other expenses related to participation in the TEAP, CTOC, and relevant Montreal Protocol meetings are paid by UNEP.

Dr. Sergey Kopylov
(Halons TOC Co-chair)
Head of Research Centre
All Russian Research Institute for Fire Protection
VNIIPO
12, Balashikha
Moscow Region
T 7 495 521 9747
F 7 495 521 4394

Dr. Sergey Kopylov, Co-Chair, Halons Technical Options Committee and Member, Technology and Economics Assessment Panel, is the Head of the Scientific Centre of the All-Russian Scientific Research Institute for Fire Protection (VNIIPO). VNIIPO has an interest in the topics of the Montreal Protocol as a body responsible for technical control of Montreal Protocol related issues in Russia. VNIIPO has no proprietary interest in alternatives or substitutes to ODSs, does not own or own stock in companies producing ODSs or alternatives or substitutes to ODSs. Dr. Kopylov works as a technical expert to the Russian government on matters related to the implementation of the Montreal Protocol.

Dr. Kopylov's spouse does not work for or consult for any organization or company. Dr. Kopylov's spouse and children have no proprietary interest in alternatives or substitutes to ODSs, do not own or own stock in companies producing ODSs or alternatives or substitutes to ODSs and do not consult for organizations seeking to phase-out ODSs. Dr. Kopylov's travel to TEAP/HTOC meetings is paid for by UNEP's Ozone Secretariat.

Dr. Lambert Kuijpers
(Panel Co-chair, Refrigeration TOC Co-chair)
Eindhoven Center for Sustainability, ECfS
Technical University, Connector 1.15b
Het Eeuwsel 6
P.O. Box 513
NL - 5600 MB Eindhoven
The Netherlands
T 31 40 247 4463
F 31 49 247 6369
H 31 77 354 6742

Lambert Kuijpers, Co-chair of the Technology and Economic Assessment Panel since 1992 and Co-chair of the Refrigeration, Air-conditioning and Heat Pumps Technical Options Committee since 1989, works on a part-time basis for the Eindhoven Center for Sustainability, the Department “Technology for Sustainable Development” at the Technical University Eindhoven, The Netherlands. He co-chaired the TEAP Replenishment Task Forces since 1996 (the last is currently the 2011 TEAP Replenishment Task Force). He served on the Steering Committee to the “IPCC/TEAP Special Report “Safeguarding the ozone layer and the global climate system: issues related to Hydrofluorocarbons and Perfluorocarbons”. Dr. Kuijpers co-chaired the 2005 Task Force for the TEAP Supplementary Report to the IPCC/TEAP Special Report, the 2006 Task Force on Emissions Discrepancies and the 2007 Task Force on the Response to Decision XVIII/12. He co-ordinated the activities for the Task Force on Decision XX/8 and was involved in the work of the Task Force for Decision XX/7. He co-chaired the Task Force for Decision XXI/9 in 2010. He was a Lead Author for both the Third and the Fourth IPCC Assessment Report. He also was a Co-author, contributor and reviewing member of the Ozone Science Assessment Panel in 2005-2006 and 2009-2010. As co-chair of the Refrigeration, AC and Heat Pumps TOC he was actively involved in the drafting, peer reviewing and final composition of all Assessment Reports, the last one being the 2010 Assessment Report.

Until 1993, he worked for Philips Eindhoven (NL) in the development of refrigeration, air conditioning, and heat pump systems to use alternatives to ozone-depleting substances. He is financially supported (through the UNEP Ozone Secretariat) by the European Commission (and in certain years by some EU member state governments) for his activities related to the TEAP and the Refrigeration TOC. Dr. Kuijpers has no proprietary interest in alternatives or substitutes to ODS and does not own stock in companies producing ODS or alternatives or substitutes to ODS. He occasionally is a consultant to international organisations, such as the World Bank, UNIDO, UNEP DTIE and the Multilateral Fund. Dr. Kuijpers is a co-owner of the Re/genT BV Company, Netherlands, which he co-founded in 1993 and where he has a minority interest (this company is involved in the R&D of components and equipment for refrigeration, air-conditioning and heating). This implies that he has no influence in any business or management decisions taken within this company.

In 2009 and 2010, Dr. Kuijpers was co-author of several papers on the impact of the CDM under the Kyoto Protocol on HFC-23 concentrations in the atmosphere. He was a keynote speaker and a paper author in conferences on ammonia refrigeration held in Ohrid, Macedonia.

Ms. Bella Maranion
(Senior Expert Member)

Ms. Bella Maranion, Senior Expert Member, is a Program Analyst at the U.S. Environmental Protection Agency (USEPA). Ms. Maranion is a full time industry sector analyst and project manager in the USEPA's Stratospheric Protection Division, Washington, D.C. The USEPA has an interest in the topics of the Montreal Protocol because the Agency is responsible for implementing national regulations and policies to meet the US commitments under the Protocol. Ms. Maranion has no proprietary interest in alternatives or substitutes to ODSs or in companies producing ODSs or alternatives or substitutes to ODSs, and does not consult for organizations seeking to phase-out ODSs. Ms. Maranion's spouse and dependent children have no proprietary interest in alternatives or substitutes to ODSs or companies producing ODSs or alternatives or substitutes to ODSs and do not consult for organizations seeking to phase-out ODSs. Ms. Maranion’s travel to meetings is paid for by the USEPA.

Ms. Michelle Marcotte
(MBTOC Co-chair)
Marcotte Consulting Inc.
(Marcotte Consulting Inc
is a Canadian corporation;
its President, Michelle Marcotte,
is located at:
10104 East Franklin Ave.
Glenn Dale, Maryland 20769
USA

Ms Michelle Marcotte was a member of the 1992 Methyl Bromide Assessment and subsequently a member of the Methyl Bromide Technical Options Committee between 1992 and 2005; she was confirmed as Co-Chair in 2005. Until 1993 she worked for MDS Nordion, a supplier of radiation processing equipment, which is an alternative to the use of methyl bromide in some commodity and quarantine situations. Since then, Ms Marcotte, through Marcotte Consulting, has provided consulting services to governments and agri-food companies in eight countries on agri-environmental issues, food technology, regulatory affairs, specialty chemicals such as disinfectants and radiation processing. Marcotte Consulting has an interest in the topics of the Montreal Protocol because of its long time market development work in food irradiation, an alternative to some methyl bromide uses (particularly quarantine and postharvest commodities), and because of its interest in food processing, food safety and trade. In the field of methyl bromide alternatives, Ms Marcotte has published case studies for pest control in food processing facilities, for stored commodities, for alternatives for quarantine and for greenhouse use. She is a member of the Canada Industry-Government Methyl Bromide Working Group and the Canada-USA Methyl Bromide Working Group; both organizations work to achieve phase out of methyl bromide in the agri-food sector. Marcotte has consulted to companies, industry associations, the International Atomic Energy Agency and USAID on irradiation as a methyl bromide alternative in food processing, quarantine and trade. She has also prepared consulting reports summarizing research in methyl bromide alternatives and case studies on food processing for US Environmental Protection Agency.

Ms Marcotte has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Ms Marcotte’s spouse is a consultant to the United States Department of Agriculture for quarantine issues and methyl bromide alternatives and is a member of MBTOC. He does not have proprietary interest in alternatives or substitutes to ODS and does not own stock in companies producing ODS or alternatives or substitutes to ODSs. Marcotte receives a consulting contract from Government of Canada, Environment Canada, a Party to the Montreal Protocol that is committed to the phase out of methyl bromide. Ms Marcotte pays for travel to TEAP, MBTOC and Montreal Protocol meetings out of consultancy funds provided by the Canadian government, Environment Canada, to support her work on MBTOC.

Prof. Dr. Roberto de Aguiar Peixoto
(RTOC Co-chair)
Maua Institute of Technology - IMT
Department of Mechanical Engineering
Praça Mauá 01
Sao Caetano do Sul
Sao Paulo - 09580-900
Brazil
T 55-11- 4239 3021
e-mail: robertopeixoto@maua.br

Prof. Dr. Roberto de Aguiar Peixoto, member of the RTOC, is a Professor of Mechanical Engineering at the Instituto Maua de Tecnologia – IMT (Maua Institute of Technology). Roberto de Aguiar Peixoto is a full time professor at the IMT campus in Sao Caetano do Sul, SP, Brazil. The IMT has an interest in the topics of the Montreal Protocol because it has undergraduate and graduate courses and research activities on refrigeration and air conditioning technologies, thermal sciences and energy and environment areas. Roberto de Aguiar Peixoto has no proprietary interest alternatives or substitutes to ODSs, does not own stock in companies producing ODS or alternatives or substitutes to ODSs, does not consulting for organisations seeking to phase out ODSs. Roberto's spouse has no interest in matters related to the Protocol. Roberto de Aguiar Peixoto works occasionally as a consultant to UNEP, and UNDP on matters related to the Montreal Protocol. Roberto A. Peixoto received a Bachelor of Science and a Master of Science in Naval Engineering from the University of Sao Paulo and a Ph.D. in Mechanical Engineering and Thermal Sciences from the University of Sao Paulo, Brazil. He is presently Professor of Mechanical Engineering at Maua Technological Institute (SP- Brazil), where he is teaching and co-ordinating studies and research in energy and environment area, and consultant to international institutions.

Ms. Marta Pizano
(Panel Co-chair, MBTOC Co-chair)
Consultant
Bogotá
Colombia

Ms. Marta Pizano is Co-Chair of TEAP since 2010, Co-Chair of MBTOC since 2005, and member of MBTOC since 1998. She presently chairs the MBTOC Quarantine and Preshipment (QPS) subcommittee. Ms. Pizano is a frequent consultant for the Montreal Protocol Implementing Agencies and has actively worked with methyl bromide users and other key stakeholders in many countries to identify and implement alternatives to methyl bromide.

She consults mostly for the United Nations Industrial Development Organization (UNIDO), but occasionally also United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP) and the World Bank (WB). She has also assisted the Montreal Protocol Multilateral Fund (MLF) in the preparation of studies relating to methyl bromide and other ozone-depleting substances (ODSs). All consultancies are conducted on a short-term assignment basis. Ms. Pizano has contributed to methyl bromide phase-out programs in over twenty Article 5 Parties around the world, assisting users with the adoption of sustainable alternatives and the implementation of IPM programs. She is frequently invited as a speaker at national and international conferences dealing with methyl bromide and has authored numerous publications on substitutes and alternatives to methyl bromide fumigation.

Currently, she is a member of the International Advisory Committee and a consultant for the Basel Convention projects on "Destruction of Ozone Depleting Substances (ODS) and Persistent Organic Pollutants (POPs)" which is being developed by the Basel Convention Regional Centre for Central America and Mexico.

Mr. Jose Pons Pons
(MTOC Co-chair)
Spray Química C.A
La Victoria
Venezuela

Jose Pons, member of the Technology and Economic Assessment Panel and Co-chair of the Medical Technical Options Committee since 1991, is President of Spray Química C.A. . Spray Química had an interest in the topics of the Montreal Protocol because it used ODS in some of its aerosol products for industrial maintenance. Mr. Pons is president of the Venezuelan Chamber of Aerosols, CAVEA and has worked in ozone layer protection since 1989. He has participated in several TEAP Task Forces and on the Steering Committee to the "IPCC/TEAP Special Report Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons". Mr Pons has no proprietary interest in alternatives or substitutes to ODS, does not own stock in companies producing ODS or alternatives or substitutes to ODS, does not have an interest in the outcome of essential use nominations, and does not consult for organisations seeking to phase out ODS. Mr Pons's spouse has no interest in matters before the Protocol; she is also a manager/engineer at Spray Química. Mr Pons has worked occasionally as a project reviewer for the MLF and implementing agencies on matters related to the Montreal Protocol. Travel related to participation in the TEAP and MTOC, and relevant Protocol meetings, are paid by UNEP's Ozone Secretariat. Spray Química makes in-kind contributions of wage, and miscellaneous and communication expenses.

Dr. Ian J. Porter
(MBTOC Co-chair)
Consultant and Principal Research Scientist
Primary Industries Research Victoria
Department of Primary Industries
Private Bag 15, Ferntree Gully Delivery Centre 3156,
Victoria, Australia.
T 61 3 9210 9222
F 61 3 9800 3521
M 61 (0) 417 544 080
Email: ian.j.porter@dpi.vic.gov.au

Dr Ian Porter is an Associate Professor with LaTrobe University and Principal Research Scientist with the Victorian Department of Primary Industries (DPI), but takes leave from this organisation to conduct Montreal Protocol duties. DPI has an interest in developing sustainable alternatives to methyl bromide and integrated pest management strategies for control of plant pathogens and pests, and issues related to biosecurity. He has been a member of a number of National Committees regulating ODS, has led the Australian research program on methyl bromide alternatives for soils since 1992 and has 29 years experience in researching sustainable methods for soil disinfestation of plant pathogens with over 250 research publications. He has been a member of MBTOC since 1997, chair of the Soils sub committee from 2001 and MBTOC Co-chair since 2005. Neither Ian, his wife or children have any proprietary interest in alternatives or substitutes to ODSs, nor own stock in companies producing ODS or alternatives or substitutes to ODSs. Dr Porter is presently leading national programs on integrated pest management and soil health in the Australian horticultural industries. He has acted as a key consultant for UNEP and UNIDO in developing programmes to assist China, Mexico and CEIT countries to replace methyl bromide. He regularly participates in workshops to assist countries with alternatives to methyl bromide and gives keynote addresses to international conferences on alternatives to methyl bromide in horticultural industries. He is presently funded by the European Commission through the Ozone Secretariat to support and attend MBTOC and TEAP activities and meetings. In kind contributions from the Victorian Department of Primary Industries and Australian Federal Government Research Funds have provided past support.

Mr. Miguel W. Quintero
(FTOC Co-chair)
Independent Consultant
AK 1 # 78-10, IV-601
Bogotá, Colombia
T 0057 1 349 2325
M 0057 31 426 37 857
miquinte@gmail.com

Mr. Miguel W. Quintero, Co-chair of the Foams Technical Options Committee since 2002, is an independent consultant in the area of polyurethane technology. He has been a professor at the Chemical Engineering Department at Universidad de los Andes in Bogota, Colombia, in the areas of polymer processing and transport phenomena from 2000 to 2006. Mr. Quintero worked over a 21 year period (1980 - 2000) for Dow Chemical at the Research & Development and Technical Service & Development Departments in the area of rigid polyurethane foam. In the period January 2007- October 2008, he returned to Dow Europe as Development Leader for Polyurethane Product Research, located in Freienbach, Switzerland.

As foam expert Mr. Quintero is a regular consultant for UNDP currently supporting the HPMP preparation process in Latin America. He is a member of the World Bank's OORG advisory group in the area of foams and he is also an advisor of Espumlatex, a Colombian system house active in the local automotive, thermal insulation and polyurethane flexible foam markets.

Costs associated with travel, communication, and others related to participation in the TEAP, FTOC and relevant Montreal Protocol meetings are paid by UNEP's Ozone Secretariat.

Mr. Quintero owns stock in The Dow Chemical Co., which is now or has previously been a producer of ozone-depleting substances and products made with or containing ozone depleting substances and their substitutes and alternatives. Mr. Quintero´s spouse and dependent children have no proprietary interest in alternatives or substitutes to ODSs, do not own stock in companies producing ODSs or alternatives or substitutes to ODSs, and do not consult for organizations seeking to phase-out ODSs.

Dr. Ian D. Rae
(Chemicals TOC Co-Chair)
16 Bates Drive
Williamstown, Vic 3016
Australia
T 0061 3 9397 3794
F 0061 3 9397 3794

Dr. Rae, Co-chair of the Chemicals Technical Options Committee since 2005, is an Honorary Professorial Fellow at the University of Melbourne, Australia, and a member of advisory bodies for several Australian government agencies dealing with chemical issues. He co-chaired the 2001 and 2004 Process Agent Task Forces. He was a member of the POPs Review Committee for the Stockholm Convention 2005-2009. On occasions, he acts as consultant to government agencies and to universities and companies and he has been an expert witness in a case involving alleged patent infringement involving HFC-134a and its lubricants. Neither he nor his wife owns stock in any company dealing with ozone depleting substances or their alternatives. He contributes the time for his own participation in TEAP activities. The Australian Government Department of the Sustainability, Environment, Water, Population and Communities finances the cost of travel and accommodation for Dr. Rae's attendance at meetings of the CTOC, TEAP, OEWG and MOP.

Dr. Helen Tope
(MTOC Co-chair)
Principal Consultant
Energy International Australia
Director, Planet Futures
Unit 2, 9 Osborne Street
Williamstown, Victoria 3016
Australia
T 61 3 9016 0435
F 61 3 9012 7935
M 61 414 563 474

Helen Tope, co-chair Medical Technical Options Committee since 1995, is Principal Consultant of Energy International Australia and also Director of Planet Futures with whom she is an independent consultant providing strategic, policy and technical advice and facilitation services to government, industry and other non-governmental organisations on climate change, ozone-depleting substances, and other environmental issues. Dr Tope's business has an interest in the topics of the Montreal Protocol because her potential clients are also interested in these topics. Dr Tope has no proprietary interest in alternatives or substitutes to ODS, does not own stock in companies producing ODS or alternatives or substitutes to ODS, does not have an interest in the outcome of essential use nominations, and consults for organisations that support the Montreal Protocol in phasing out ODS. Dr Tope's spouse, Mr. Michael Atkinson, is also her business partner, whose business has an interest in the topics of the Montreal Protocol. During 2010, TEAP Co-Chair Dr. Stephen O. Andersen, Mr. Atkinson and Dr. Tope were unpaid advisors to a UNEP project on investment metrics for identifying technology that minimizes climate and other impacts when replacing ozone-depleting and high-GWP substances. In 2010 Dr Tope's funding for travel to MTOC, TEAP and other meetings are provided from several sources. The Ozone Secretariat provides reimbursement for Dr Tope's travel associated with the TEAP/MTOC mission to the Russian Federation on CFC MDI transition from funds granted to the Secretariat for this purpose by the Governments of Finland and Sweden and by pharmaceutical companies, JSC

Moschimpharmpreparaty and JSC Altayvitamin, in the Russian Federation. The Ozone Secretariat provides a grant for Dr Tope's travel to the MTOC and TEAP meetings from funds granted to the Secretariat unconditionally by the International Pharmaceutical Aerosol Consortium (IPAC), which is a non-profit corporation. The Australian Government Department of the Environment, Water, Heritage and the Arts provides funding for the cost of travel and accommodation for Dr Tope's attendance of the OEWG-30. She makes considerable in-kind contributions of her time without compensation.

Dr. Daniel P. Verdonik
(Halons TOC Co-chair)
Hughes Associates
3610 Commerce Drive, STE 817
Baltimore, MD 21227-1652
U. S. A.
T 1 443 253 7587
F 1 410 737 8688

Dr. Daniel P. Verdonik, co-Chair, Halons Technical Options Committee and Member, Technology and Economic Assessment Panel, is the Director, Environmental Programs, Hughes Associates, Inc. Dr. Verdonik is a full time, salaried employee at Hughes Associates, Inc., in Baltimore, MD and Arlington, VA providing consulting services in fire protection and environmental management. Hughes Associates, Inc. has an interest in the topics of the Montreal Protocol because it provides a wide range of fire protection research, design and consulting services to government and corporate clients, including work related to halons and halon alternatives. Hughes Associates, Inc. provides consulting services to organizations that may be affected positively or negatively by the phase-out of ODSs. Dr. Verdonik has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs. Dr. Verdonik is a share holder in Hughes Associates, Inc., which does not own stock in companies producing ODSs, or alternatives or substitutes to ODSs. Dr. Verdonik currently provides consulting services through Hughes Associates, Inc. for the U.S. Army and the U.S. Environmental Protection Agency (USEPA) on matters related to the Montreal Protocol and has previously provided services through Hughes Associates, Inc. to Implementing Agencies, U.S. Navy, U.S. Air Force and Chemtura (now DuPont). Dr. Verdonik's spouse works for the USEPA, which has an interest in the topics of the Montreal Protocol because the Agency is responsible for implementing national regulations and policies to meet the U.S. commitments under the Protocol.

Dr. Verdonik's spouse and dependent child have no proprietary interest in alternatives or substitutes to ODSs, do not own stock in companies producing ODSs or alternatives or substitutes to ODSs, and do not consult for organizations seeking to phase-out ODSs. In the past, Hughes Associates, Inc. received funding to support Dr. Verdonik's salary and travel to TEAP/HTOC/TSB meetings from UN organizations such as the MLF and UNEP, U.S. government organizations such as the U.S. Department of Defense, the USEPA, and the U.S. National Aeronautics and Space Administration, and non-governmental organizations such as the Halon Alternatives Research Corporation, which is a not-for-profit industry coalition that in turn receives contributions for this funding from members. Current funding to Hughes Associates, Inc. is from the U.S. Army and the HARC contributors BP Exploration Alaska, ConocoPhillips Alaska, DuPont, American Pacific, Firetrace, Halon Banking Systems, Wesco and Remtec. From time-to-time, Hughes Associates, Inc. may also provide its internal support for labour and travel for Dr. Verdonik to attend TEAP/HTOC/TSB meetings.

Prof. Ashley Woodcock
(MTOC Co-chair)
North West Lung Centre
South Manchester University Hospital Trust
Manchester M23 9LT
United Kingdom
T 44 161 291 2398
F 44 161 291 5020

Prof. Ashley Woodcock, Co-chair of the Medical Technical Options Committee and Member of the Technology and Economic Assessment Panel, is a Respiratory physician at the University Hospital of South Manchester, and Head of the School of Translational Medicine for the University of Manchester. The Hospital and University have no direct interest in the topics of the Montreal Protocol. Prof. Woodcock has no proprietary interest in alternatives or substitutes to ODS, does not own stock in companies producing ODS or alternatives or substitutes to ODS, does not have an interest in the outcome of essential use nominations. Prof. Woodcock carries out unrelated consulting, research and educational lectures for pharmaceutical companies, all of which are near completion of phase out of CFC MDIs. He advises companies on study design for new drugs, some of which have been ODS replacements. Prof. Woodcock's spouse has no interest in matters before the Protocol. Prof. Woodcock does not work as a consultant to the UN, UNEP, MLF or Implementing Agencies. In the past, he has responded to requests for technical information on CFC MDI phase-out from the European Community and the United Kingdom Government. Travel and subsistence for meetings of TEAP, MTOC, OEWG, MOP meetings is paid from Hospital and University funds, and Prof. Woodcock's employers allow leave of absence.

Dr. Masaaki Yamabe
(Chemicals TOC Co-chair)
National Institute of Advanced Industrial
Science and Technology (AIST)
Onogawa 16-1 AIST West, Tsukuba
Ibaraki 305-8569
Japan
T 0081 90 6011 6498
F 0081 42 795 6498

Mr. Masaaki Yamabe, Co-Chair of the Chemicals Technical Options Committee since 2005, is a research advisor of the Research Institute of Science for Safety and Sustainability at the National Institute of Advanced Industrial Science and Technology (AIST), Japan. He was a member of the Task Force on HCFCs in 2003, on the TEAP Legacy in 2007 and on the decision XX/8 in 2009. He co-chaired the 2004 Process Agent Task Force. He served as a Coordinating Lead Author (CLS) of Chapter 10 in the "IPCC/TEAP Special Report Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons" in 2005. He was a member of the Solvents TOC during 1990-1996. Until 1999, Mr. Yamabe was Director of Central Research of Asahi Glass Company, which previously produced CFCs, methyl chloroform, and carbon tetrachloride, and currently produces and distributes HCFC, carbon tetrachloride, and HFCs. He is the co-inventor of HCFC-225, which is controlled under the Montreal Protocol as a transitional substance in the phase-out of ozone-depleting substances and is a substitute for CFC-113 in solvent and process agent applications. He owns stock in Asahi Glass Company that produces ozone-depleting substances and their substitutes. He also works for the Japan Industrial Conference for Ozone Layer and Climate Protection (JICOP) as a senior advisor. AIST, JICOP and Ministry of Economy, Trade and Industry (METI) share the financing involved in the travel and accommodation for Mr. Yamabe's attendance at the meetings of the CTOC, TEAP, OEWG and MOP.

Prof. Dr. Shiqiu Zhang
(Senior Expert)
College of Environmental Sciences and Engineering (CESE)
Director, Institute of Environment and Economy (IoEE)
Peking University
Beijing, 100871
PR China
T 86-10-62764974
E-mail: zhangshq@pku.edu.cn; zsqces@yahoo.com.cn

Dr. Shiqiu Zhang, Senior Expert Member of the TEAP, is a Professor on Environmental Economics and Policy, Director of Environment and Economy Institute and Deputy Dean of Environmental Science and Engineering of Peking University, China. She co-chaired the 2002, 2005, 2008, and 2011 Replenishment Task Forces. Dr. Zhang has no proprietary interest in alternatives or substitutes to ODSs, does not own stock in companies producing ODSs or alternatives or substitutes to ODSs. Dr. Zhang's spouse works for the Longtop Group of China which is not related with ODS or alternatives or substitutes to ODSs. Dr. Zhang's spouse and child have no proprietary interest in alternatives or substitutes to ODSs, do not own stock in companies producing ODSs or alternatives or substitutes to ODSs. The costs of travel, and other expenses related to participation in the TEAP and relevant Montreal Protocol meetings, are paid by UNEP's Ozone Secretariat

4.2 TEAP TOC Membership List Status January 2011

Technology and Economic Assessment Panel (TEAP)

Co-chairs	Affiliation	Country
Stephen O. Andersen	Institute for Governance and Sustainable Development	USA
Lambert Kuijpers	Technical University Eindhoven	Netherlands
Marta Pizano	Consultant	Colombia

Senior Expert Members	Affiliation	Country
Bella Maranion	US Environmental Protection Agency	USA
Shiqiu Zhang	Center of Environmental Sciences, Peking University	China

TOC Chairs	Affiliation	Country
Paul Ashford	Caleb Management Services	UK
Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II	Morocco
Biao Jiang	Shanghai Institute of Organic Chemistry	China
David Catchpole	Petrotechnical Resources Alaska	UK
Sergey Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
Michelle Marcotte	Marcotte Consulting LLC and Marcotte Consulting Inc	Canada
Roberto de A. Peixoto	Maua Technological Institute, IMT, Sao Paulo	Brazil
Jose Pons Pons	Spray Quimica	Venezuela
Ian Porter	Department of Primary Industries	Australia
Miguel Quintero	Consultant	Colombia
Ian D. Rae	University of Melbourne	Australia
Helen Tope	Energy International Consultancy	Australia
Ashley Woodcock	Wythenshawe Hospital Manchester	UK
Daniel Verdonik	Hughes Associates	USA
Masaaki Yamabe	National Inst. Advanced Industrial Science and Technology	Japan

TEAP Chemicals Technical Options Committee (CTOC)

Co-chairs	Affiliation	Country
Biao Jiang	Shanghai Institute of Organic Chemistry	China
Ian D. Rae	University of Melbourne	Australia
Masaaki Yamabe	National Inst. Advanced Industrial Science and Technology	Japan

Members	Affiliation	Country
D. D. Arora	The Energy and Research Institute	India
Steven Bernhardt	Honeywell	USA
Olga Blinova	Russian Scientific Center for Applied Chemistry	Russia
Jianxin Hu	College of Environmental Sciences & Engineering, Peking University	China
Michael Kishimba	University of Dar-es-Salaam	Tanzania
Abid Merchant	Consultant	USA
Koichi Mizuno	National Inst. Advanced Industrial Science and Technology	Japan
Keichi Ohnishi	Asahi Glass	Japan
Claudia Paratori	Coordinator Ozone Programme -CONAMA	Chile
Hans Porre	Teijin Aramids	Netherlands
John Stemniski	Consultant	USA
Fatemah Al-Shatti	Kuwait Petroleum Corporation	Kuwait
Nee Sun Choong Kwet Yive (Robert)	University of Mauritius	Mauritius

TEAP Flexible and Rigid Foams Technical Options Committee (FTOC)

Co-chairs	Affiliation	Country
Paul Ashford	Caleb Management Services	UK
Miguel Quintero	Consultant	Colombia

Members	Affiliation	Country
Terry Armitt	Hennecke	USA
Chris Bloom	Dow	USA
Roy Chowdhury	Australia Urethane Systems	Australia
Kyoshi Hara	JUFA	Japan
Mike Hayslett	Maytag/AHAM	USA
Mike Jeffs	ISOPA	Belgium
Candido Lomba	ABRIPUR	Brazil
Yehia Lotfi	Technocom	Egypt
Christoph Meurer	Solvay	Germany
Francesca Pignagnoli	Dow	Italy
Ulrich Schmidt	Haltermann/Dow	Germany
Enshang Sheng	Huntsman Co	China
Helen Walter-Terrinoni	Dupont	USA
Tom Werkema	Arkema	USA
Dave Williams	Honeywell	USA
Allen Zhang	Owens Corning	China

TEAP Halons Technical Options Committee (HTOC)

Co-chairs	Affiliation	Country
David V. Catchpole	Petrotechnical Resources Alaska	UK
Sergey Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
Daniel P. Verdonik	Hughes Associates	USA

Members		
Tareq K. Al-Awad	King Abdullah II Design & Development Bureau	Jordan
Jamal Alfuzaie	Kuwait Fire Department	Kuwait
Seunghwan (Charles) Choi	Hanju Chemical Co., Ltd.	South Korea
Michelle M. Collins	Consultant- EECO International	USA
Salomon Gomez	Tecnofuego	Venezuela
Andrew Greig	Protection Projects Inc	South Africa
Zhou Kaixuan	CAAC-AAD	PR China
H. S. Kaprwan	Consultant – Retired	India
Nikolai Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
David Liddy	United Kingdom Ministry of Defence	UK
John J. O'Sullivan	Bureau Veriitas	UK
Emma Palumbo	Safety Hi-tech srl	Italy
Erik Pedersen	Consultant – World Bank	Denmark
Donald Thomson	Manitoba Hydro & MOPIA	Canada
Caroline Vuillin	European Aviation Safety Agency	France
Robert T. Wickham	Consultant-Wickham Associates	USA
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan
Yong Meng Wah	Singapore Civil Defence Force	Singapore

Consulting Experts		
Thomas Cortina	Halon Alternatives Research Corporation	USA
Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan
Steve McCormick	United States Army	USA
John G. Owens	3M Company	USA
Mark L. Robin	DuPont	USA
Joseph A. Senecal	Kidde-Fenwal	USA
Ronald S. Sheinson	Naval Research Laboratory – Department of the Navy	USA
Ronald Sibley	Defense Supply Center, Richmond	USA

Medical Technical Options Committee (MTOC)

Co-chairs	Affiliation	Country
Jose Pons Pons	Spray Quimica	Venezuela
Helen Tope	Energy International Australia	Australia
Ashley Woodcock	University Hospital of South Manchester	UK

Members	Affiliation	Country
Emmanuel Addo-Yobo	Kwame Nkrumah University of Science and Technology	Ghana
Paul Atkins	Oriel Therapeutics Inc.	USA
Sidney Braman	Rhode Island Hospital	USA
Nick Campbell	Arkema SA	France
Hisbello Campos	Centro de Referencia Prof. Helio Fraga, Ministry of Health	Brazil
Jorge Caneva	Favaloro Foundation	Argentina
Christer Carling	Private Consultant	Sweden
Guiliang Chen	Shanghai Institute for Food and Drug Control	China
Antoine Haddad	Chiesi Farmaceutici	Italy
Charles Hancock	Charles O. Hancock Associates	USA
Eamonn Hoxey	Johnson & Johnson	UK
Javaid Khan	The Aga Khan University	Pakistan
Suzanne Leung	3M	USA
Nasser Mazhari	Sina Darou Laboratories Company	Iran
Gerald McDonnell	STERIS	UK
Hideo Mori	Otsuka Pharmaceutical Company	Japan
Tunde Otulana	Aerovance Inc.	USA
John Pritchard	Philips Home Healthcare Solutions	UK
Rabbur Reza	Beximco Pharmaceuticals	Bangladesh
Raj Singh	The Chest Centre	India
Roland Stechert	Boehringer Ingelheim	Germany
Ping Wang	Chinese Pharmacopoeia Commission	China
Adam Wanner	University of Miami	USA
Kristine Whorlow	National Asthma Council Australia	Australia
You Yizhong	Journal of Aerosol Communication	China

TEAP Methyl Bromide Technical Options Committee (MBTOC)

Co-chairs	Affiliation	Country
Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II	Morocco
Michelle Marcotte	Marcotte Consulting	Canada
Marta Pizano	Consultant	Colombia
Ian Porter	Department of Primary Industries	Australia

Members	Affiliation	Country
Jonathan Banks	Consultant	Australia
Tom Batchelor	Touchdown Consulting	Belgium
Chris Bell	Consultant	UK
Antonio Bello	Centro de Ciencias Medioambientales	Spain
Fred Bergwerff	Eco2, Netherlands	The Netherlands
Aocheng Cao	Chinese Academy of Agricultural Sciences	China
Peter Caulkins	US Environmental Protection Agency	USA
Ricardo Deang	Consultant	Philippines
Patrick Ducom	Consultant	France
Abraham Gamliel	Agricultural Research Organisation	Israel
Raquel Ghini	EMBRAPA	Brasil
Ken Glassey	MAFF	New Zealand
Alfredo Gonzalez	Fumigator	Philippines
Darka Hamel	Inst. For Plant Protection in Ag. And Forestry	Croatia
George Lazarovits	Agriculture and Agri-Food Canada	Canada
Andrea Minuto	CERSAA, Albenga	Italy
Takashi Misumi	MAFF	Japan

David Okioga	Ministry of Environment and Natural Resources	Kenya
Christoph Reichmuth	Humboldt University	Germany
Jordi Riudavets	IRTA – Department of Plant Protection	Spain
John Sansone	SCC Products	USA
Jim Schaub	US Department of Agriculture	USA
Sally Schneider	US Department of Agriculture	USA
JL Staphorst	Plant Protection Research Institute	South Africa
Akio Tateya	Japan Fumigation Technology Association	Japan
Robert Taylor	Consultant	UK
James Turner	Forest Research Institute (Scion)	New Zealand
Alejandro Valeiro	Department of Agriculture	Argentina
Ken Vick	Consultant	USA
Nick Vink	University of Stellenbosch	South Africa
Janny Vos	CABI International	The Netherlands
Chris Watson	Consultant	UK
Jim Wells	Environmental Solutions Group	USA
Eduardo Willink	Ministerio de Agricultura	Argentina
Suat Yilmaz	BATEM Horticulture Research Station	Turkey

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

Co-chair	**Affiliation**	**Country**
Lambert Kuijpers	Technical University Eindhoven	Netherlands
Roberto de A. Peixoto	Maua Technological Institute, IMT, Sao Paulo	Brazil

Members	**Affiliation**	**Country**
Radhey S. Agarwal	IIT New Delhi	India
James M. Calm	Engineering Consultant	USA
Radim Cermak	Ingersoll Rand	Czech Rep.
Guangming Chen	Inst. For Refrigeration and Cryogenic Eng., Shanghai	China
Denis Clodic	Ecole des Mines	France
Daniel Colbourne	Consultant	UK
Sukumar Devotta	Consultant	India
Martin Dieryckx	Daikin Europe	Belgium
Dennis Dorman	Trane	USA
Kenneth E. Hickman	Consultant	USA
William Hill	Consultant	USA
Martien Janssen	Re/genT	Netherlands
Makoto Kaibara	Panasonic, Research and Technology	Japan
Michael Kauffeld	Fachhochschule Karlsruhe	Germany
Fred Keller	Consultant	USA
Jürgen Köhler	University of Braunschweig	Germany
Holger König	Heat AG, Vienna	Germany
Edward J. McInerney	Consultant	USA
Petter Nekså	SINTEF Energy Research	Norway
Horace Nelson	Consultant	Jamaica
Alexander C. Pachai	Johnson Controls	Denmark
Andy Pearson	Star Refrigeration Glasgow	UK
Per Henrik Pedersen	Danish Technological Institute	Denmark
Sulkan Suladze	Consultant	Georgia
Paulo Vodianitskaia	Consultant	Brazil