MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

2014 ASSESSMENT REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

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1 Introduction

At the 23rd Meeting of the Parties to the Montreal Protocol held in Bali, Indonesia, in November 2011, Parties adopted Decision (XXIII/13) requesting the Scientific Assessment Panel (SAP), the Environmental Effects Assessment Panel (EEAP) and the Technology and Economic Assessment Panel (TEAP) to update their 2010 reports in 2014 for consideration by the Open-ended Working Group (OEWG-36) and by the Twenty-Seventh Meeting of the Parties in 2015 (MOP-27). In paragraph 5 of that decision, the Parties requested the TEAP in its 2014 report to consider the following topics:

(a) The impact of the phase-out of ozone-depleting substances on sustainable development, particularly in Parties operating under paragraph 1 of Article 5 and countries with economies in transition;

(b) Technical progress in all sectors;

(c) Technically and economically feasible choices for the reduction and elimination of ozone-depleting substances through the use of alternatives, taking into account their impact on climate change and overall environmental performance;

(d) Technical progress on the recovery, reuse and destruction of ozone-depleting substances;

(e) Accounting for: the production and use in various applications of ozone-depleting substances; ozone-depleting substances in inventories; ozone depleting substances in products; and the production and use in various applications of very short-lived substances;

(f) Accounting of emissions of all relevant ozone-depleting substances with a view to updating continuously use patterns and co-ordinating such data with the Scientific Assessment Panel in order periodically to reconcile estimated emissions and atmospheric concentrations.

Since the 2010 TEAP Assessment Report, important technical developments have taken place as the Montreal Protocol has reached key phase-out milestones. The year 2010 marked the end of global production for controlled uses of CFCs and halons. This milestone was quietly reached demonstrating steady progress under the Protocol, the successful conclusion of production shutdown projects, and clear demonstration of how far key sectors, previously dependent on CFCs and halons, had come in their transition to substitutes and alternative technologies.

In response to Decision XXIII/13, the Panel's Technical Options Committees, on Foams (FTOC), Halons (HTOC), Methyl Bromide (MBTOC), Medical Uses (MTOC) and Refrigeration, AC and Heat Pumps (RTOC) have each issued a 2014 Assessment Report that address these new developments as well as progress, and their main findings are described in the following sections of this advanced copy 2014 TEAP Assessment Report. The CTOC Assessment Report has recently been completed and is now included in this TEAP Assessment Report. Together with the Science and Environmental Effects Assessment reports, the 2014 TEAP Assessment Report and the TOC Assessment Reports form the direct response to the above-mentioned decision.

The 2014 TEAP Assessment Report comprises Executive Summaries form each TOC Assessment Report, plus summaries of the work undertaken by the Task Forces formed in response to those Decisions requiring specific and additional work. Abstracts of these Executive Summaries and key messages identified by each TOC are included in the introductory section to help identify the most relevant issues.

1.1 Overall key message

The Montreal Protocol is working because control measures have created incentives for new technology, because enterprises and organizations have worked hard to implement new technology and because the Multilateral Fund (MLF) has financed the agreed incremental costs of the transition for Article 5 Parties. With reaching each key phase-out milestone and with implementation of each new phase of technology, the Montreal Protocol has succeeded in reducing the production, use, and emissions of ODSs most of which are also potent greenhouse gases. Through these efforts, the world has avoided significant economic, environmental and health consequences of increases in ultraviolet radiation and climate change.

1.2 Significant technical progress

Progress in the transition to alternatives continues in every sector, resulting in significant benefits to the ozone layer and climate:

- All major ODS controlled under the Montreal Protocol continue to decline rapidly or have been phased out with a consequent impact on ozone layer recovery.
- Process agent uses are likely to continue to decline in the future as old products and manufacturing processes change, for example because of the use of different feedstocks. Similarly, solvent use of ODS has decreased substantially so that very few uses remain and alternative solvents are widely available.
- The phase-out of CFCs for MDIs is 98% complete. Technically and economically feasible alternatives to ODS are available for other medical aerosols, and there are a range of viable methods that can replace ODS for sterilisation.
- Almost 90% of controlled uses of methyl bromide have been phased out. Because 77% of MB applied is emitted to the atmosphere, the reduction in MB consumption, together with the short half-life of MB (0.7 years) has led to an equivalent 35% fall in stratospheric chlorine levels, a key contribution to ozone layer recovery.
- Adequate amounts of recycled halon stocks appear to be available to meet known needs for the immediate future.
- Even with continued growth in global use of foam blowing agents, progress continues in the transition away from ODS and the search for low-GWP options based on future availability and cost, particularly in the XPS sector. Blowing agent use in non-article 5 parties has doubled in the last decade, but hydrocarbons now account for 50%. One encouraging factor, particularly with HFOs/HCFOs, is that the thermal performance of the foams is, as a minimum, retained and in many cases improved over the HCFCs and HFCs that they are likely to replace. First phase HPMP implementation targeting HCFC-141b phase-out is generally running smoothly and especially within larger enterprises able to justify investment in hydrocarbon technologies.
- The refrigerant options available, and emerging today address the phase-out of ODS, especially HCFC-22, as well as concerns about climate change. However, the perfect refrigerant that is safe, low cost, energy efficient, environmentally sound for all uses is not yet available, nor is it likely to be developed. Refrigerants with a low direct climate impact are often flammable to some degree, and balancing this safety risk is an important issue both for companies and end users in the RAC sector. The use of carbon dioxide in commercial refrigeration is growing rapidly is driving several new refrigeration cycle concepts, such as the use of ejectors in the expansion process.

1.3 Challenges

Continuing progress across the various sectors will require Parties to take advantage of opportunities offered by new technologies and to remain vigilant to addressing the significant challenges that remain, and avoid nullifying the benefits achieved under the Protocol:

- Both governments as well as industry are making successful efforts to minimize emissions associated with ODS use in feedstock applications, however this use should continue to be monitored to ensure limited environmental impacts.
- Some progress has been reported by Parties on laboratory analytical methods that do not use ODS, however further work will be needed to ensure that alternative methods are adopted into national and international standards.
- It is technically and economically feasible to phase out remaining HCFC use in medical aerosols and sterilization.
- Exempted QPS uses are offsetting gains from phase-out of controlled use of MB while alternatives are immediately available for 40% of QPS uses. Article 5 Parties face challenges with illegal use and trade of MB because of weak tracking, combined with confusion between controlled and exempted QPS uses.
- In the absence of production for controlled uses of halons, important, continuing uses such as legacy military, aviation, and other systems, and uses on new aircraft are dependent on the global availability of recovered, recycled and reclaimed halons. These should meet international purity standards to reach markets where they are needed. Avoiding disruption in the supply of halon from banks, will require the collective efforts of Parties to address the uncertainty in the global inventory, to ensure purity standards are met, to address barriers to movement, and to ensure the ICAO transition goals for halons in aviation are met where alternatives are available.
- In foams, managing transition for the multitude of SMEs in both Article 5 and non-Article 5 parties remains a challenge, where lack of economies of scale may prevent investment in flammable solutions, leaving high GWP solutions as the only option, often with considerable emissions.
- Global banks of blowing agents in foams have been previously estimated to have grown from around 3 million tonnes in 2002 to an estimated 4.45 million tonnes (inclusive of hydrocarbons) in 2015. The opportunity to realize potential ozone and climate benefits from destroying unwanted ODS within banks, is declining as much of the ODS component of these banks will already be in the waste stream by 2020 as many products with limited lifecycles (e.g. appliances) reach the end of life.
- Due to the wide range of new refrigerants being developed and marketed, it is often quite difficult to identify the best refrigerant for each application. In particular, the challenge to determine the best refrigerants is most important in all commercial refrigeration sub-sectors, with their typical high demand for servicing, as well as in the rapidly growing air-to-air air conditioning sector, particularly in Article 5 countries. There is a major effort underway to address both the energy efficiency of the new refrigerants and the related safety issues in applications. The safe handling of refrigerants is of particular concern to Article 5 countries, and will require the establishment of good practice standards, and intensive education and training.
- Continuing and emerging issues for stratospheric ozone (e.g., carbon tetrachloride, very short-lived substances, and N_2O) will require the continued coordination of TEAP and the other Panels in order to inform the discussions and decisions of Parties related to these issues.

1.4 Consideration of low-GWP alternatives

- In various decisions during this reporting period, Parties increasingly consider the implications for climate to a greater degree during the ongoing phase-out of ODS and HCFCs in particular, with discussions facilitated by TEAP's review of the status of substitutes.
- There is a complex selection process ahead, where the market will have to determine which of

the many proposed new and old refrigerants will and can be used in the wide variety of RAC applications. It is premature to tell how many of the current low GWP refrigerant options will survive, and eventually the number of refrigerants candidates is likely to decrease. The continued rising global demand for refrigeration and air conditioning equipment represents both important environmental protection opportunities and challenges.

- In the short term, during the next 5-10 year period, industry is expected to progressively introduce low GWP alternatives, including carbon dioxide, hydrocarbons and other flammable alternatives. It is likely that different manufacturers and countries will opt first for a variety of alternatives before a single option is chosen (if at all). In the meantime, investigations will continue into "medium" GWP flammable HFCs, blends of saturated and unsaturated HFCs and HCs for both normal operating conditions as well as for high ambient temperature conditions.
- There will be a complex set of factors to be resolved, which once dealt with, will reduce the climate impact of RAC equipment operation. In addition to the choice of low GWP refrigerants, equipment (re-) design and changes in concept, are important drivers. These factors together will define the next generation of RAC equipment in the large variety of sectors.
- Regardless of the sector, technology transitions that can coincide with other process upgrades will be more cost-effective. The costs will be least where new RAC and foam manufacturing capacity investment is directed away from high-GWP options at the outset. Hence, efforts should be focused on ensuring that low-GWP options are well proven at the earliest opportunity in order to inspire investment confidence.

1.5 TEAP role, organisation, and challenges

- The role of TEAP and its TOCs continues to evolve in meeting the current needs of Parties. Where, originally, the three Panels were considered as the bodies that should carry out assessments pursuant to Article 6 under the Montreal Protocol (at least every four years), it is particularly the TEAP that has become a "standing advisory group" to the Parties on a large number of Protocol issues. The evolving role of the TEAP and its TOCs and other Temporary Subsidiary Bodies can be explained by the fact that the focus of the Montreal Protocol has shifted from introducing and strengthening control schedules (based upon assessment reports) to managing the use of controlled chemicals and to compliance with the Protocol. This implies the study of equipment, of use patterns, of trade, imports and exports etc.
- In the particular case of the MTOC and MBTOC, the emphasis of the work has largely shifted to the evaluation and recommendation of certain essential and critical use applications, respectively.
- In response to a number of Decisions taken by the Parties during this reporting period, TEAP has revised its Terms of Reference including Guidelines for Disclosure of Interests and Conflicts of Interests, updated procedures for nominations and appointments to TEAP and its TOCs, completed re-appointment procedures to the TEAP and all TOCs, and provided planned configurations for its TOCs through 2015 taken into account balance and required expertise based on anticipated workload under the current Montreal Protocol phase-out framework.
- TEAP has been challenged in this period with a significant transition in leadership as well as attrition through retirement of its members. Members of TEAP are generally also co-chairs of TOCs and thus have a broader role and greater expectation to bring their long-time understanding of the history of the Protocol, its decisions, its issues, and its processes into the technical outputs developed by their committees, and by the Panel. This is in addition to the particular technical expertise each member brings to the Panel. The concern and challenge to

TEAP and TOC leadership is to identify candidates with this history and experience as well as technical expertise in order for TEAP to continue to meet the significant demands of delivering outputs to support the deliberations of Parties.

- Similarly, the TOCs have also been challenged with attrition through retirement of members and increasing loss of expertise. The absence of funding for non-article 5 members makes participation increasingly difficult and of growing concern to the consensus process of the committees. Increasingly, this situation has extended to TOC co-chairs.
- There is a significant administrative burden related to the work of TEAP and its TOCs that has grown in recent years with the responses to various requests of the Parties; this situation if unaddressed will increasingly affect the delivery and timeline of TEAP's outputs.
- TEAP will continue to review its operations, organization, and planning as it moves forward in the next phase of progress implementing the Montreal Protocol.

2 Key TOC sector findings

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

2.1 Chemical TOC (CTOC)

- **Process Agents:** ODS are used as process agents to create unique yields (create specific reactions), selectivity (specific compounds) and/or resistance to harsh chemical environments. These properties make it difficult or impossible to convert to alternatives in a cost effective and timely manner. Most remaining process agent uses are long-standing processes that are operated at a high efficiency with minimal emissions. Process Agent uses are likely to continue to decline in the future as the products that they are used to manufacture cease to be used and manufacturing processes change.

- **Feedstocks:** CTOC has estimated that production of various ODS for feedstock use is approximately 440,000 ODP tonnes. Estimated emissions from feedstock uses of ODS are approximately 2200 ODP tonnes (based on an emission factor of 0.5%). The main ODS used for feedstock are Carbon tetrachloride and HCFC-22. Successful efforts to minimize emissions associated with ODS use in feedstock applications are being made. Evaluation of feedstock use and associated emissions should continue.

- **Solvents:** Very few uses of ODS as solvents remain and alternative solvents are widely available. The choice of an alternative may be limited by occupational health and safety regulations. Case studies of the availability and use of alternatives, and in some cases funding, will assist users in Article 5 countries to make the transition to non-ODS alternatives.

- **Lab and Analytical Methods:** Extensive information is available on laboratory analytical methods that do not use ODS. Limited progress in the transition has occurred. This can be accelerated through the increased involvement of Parties and their local analytical experts with their national Standards (Norms) Bureaus to prepare and then adopt appropriate national and international standards.

- **Destruction:** Little new information has been reported by Parties over the last decade on the destruction of unwanted ODS. There has been the development of a number of new destruction methods. Further work will be required to evaluate the future needs for destruction, bearing in mind that there would be climate benefits as well as reduction in risk to the ozone layer through inadvertent emissions.

- **CTC and Dichloromethane emissions**: Discrepancies reported between stratospheric concentrations of Carbon Tetrachloride (CTC) and estimates of uses and emissions have declined but require further investigation. Recently, increased concentration of dichloromethane has been observed, analysis suggests that these appear to be attributed mainly to its direct use as a solvent.

2.2 Flexible and Rigid Foams TOC (FTOC)

- Growth in the construction sector in Article 5 parties, coupled with the adoption of enhanced energy efficiency criteria for buildings has led to a growth in demand for thermal insulation materials in these regions

- Insulation foams have been the material of choice, although concerns over flammability have hindered adoption in some key markets, particularly where construction methods expose hazards. Differentiation between product types is increasingly occurring

- In non-Article 5 parties, an increasing focus for insulation use has been in existing buildings, where solutions are required to be both efficient and cost-effective. PU Spray foam has made considerable inroads as a result.
- Global blowing agent consumption is estimated to have reached approximately 390,000 tonnes annually in 2014 and is expected to continue to grow at around 4.8% per year through to 2020, leading to an overall consumption in excess of 520,000 tonnes with hydrocarbons representing over 50% of the total.
- The enactment of Decision XIX/6 has been the major driver for blowing agent transitions since 2010, although the implementation of Stage 1 of HCFC Phase-out Management Plans (HPMPs) has been hampered in some regions by administrative procedures.
- The focus of HCFC phase-out in the foam sector to date has been HCFC-141b based on the "worst-first" principle. However, this has led to a significant tail of HCFC-142b/22 use in the XPS sector which has continued to grow rapidly since 2010, particularly in Asia.
- There is some evidence to suggest that the XPS growth may have caused a nominal 'breach' in the 2013 freeze for Article 5 parties when taking the foam sector in isolation. However, this is unlikely to show at the reporting level because of potential counter-balances within other sectors of HCFC use.
- HFOs continue to be evaluated within the foam sector and are showing considerable promise, particularly as a result of their contributions to thermal efficiency even at relatively low levels within formulations. One manufacturer is already producing commercially with others likely to follow within the next two years. Ultimate system costs remain uncertain, as does the geographic availability of those HFOs still to be fully commercialised.
- The challenge of dealing with a multitude of SMEs in both Article 5 and non-Article 5 parties remains. Lack of economies of scale prevents the investment in flammable solutions, leaving high GWP solutions as the only option, often with considerable emissions.
- Oxygenated hydrocarbons such as methyl formate and methylal are being increasingly used Article 5 parties, especially in integral skin applications, although flammability remains an issue to be managed. There are also some minor HFO stability issues to be resolved in some low pressure PU Spray formulations.
- Banks of blowing agents are expected to exceed 5 million tonnes, inclusive of hydrocarbons by 2020. Much of the ODS component of these banks will already be in the waste stream by then as products with more limited lifecycles (e.g. appliances) reach end of life.
- Based on the climate benefit accruing from recovery, the average global warming potential of blowing agents in the waste stream will only further decline over the period through to 2020 making the economic justification for recovery more challenging.

2.3 Halons TOC (HTOC)

- There appear to be adequate halon stocks to meet known needs for the immediate future, provided they are recycled to international standards. While the actual quantities of halons may be substantial, their use is jeopardized by political borders, suspect quality, and uncertain quantities in specific locations.
- The HTOC is of the opinion 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 for service, in particular legacy systems, and will be for the foreseeable future.
- The fact that alternatives are used only in the lavatory fire extinguishing systems of in-production aircraft is a remarkably disappointing result, especially given the extensive research and testing efforts on aviation applications since 1993

- Of all the sectors, civil aviation is the least prepared to deal with diminishing halon supplies and, with the ultimate exhaustion of supplies, this sector will most likely be the one to request an Essential Use Nomination in the future.

2.4 Medical Applications TOC (MTOC)

- There has been significant global progress in the transition from CFC metered dose inhalers (MDIs) to CFC-free inhalers, with substantial and growing capacity to manufacture CFC-free inhalers. Technically satisfactory alternatives to CFC MDIs are available worldwide for all key classes of drugs for the treatment of asthma and chronic obstructive pulmonary disease. With the exception of China, the phase-out of CFC MDI manufacturing has been completed worldwide. Russia is in the final stages of manufacturing conversion to HFC MDIs, with completion likely in 2015. Global phase-out of CFC MDI manufacturing is expected in 2015-2016.
- For all other medical aerosols that are not MDIs, technically and economically feasible alternatives to ozone-depleting propellants (CFCs and HCFCs) are available. Medical aerosol products have been reformulated to use CFC-free propellants or replaced with aqueous formulations and other not-in-kind alternatives. Some HCFCs are used in medical aerosols, mostly in China.
- There is a range of viable methods that can replace the use of ozone-depleting substances in sterilization. The use of CFCs in blends with ethylene oxide (EO) has been successfully phased out in non-Article 5 Parties, and in many, possibly all, Article 5 Parties. The complete phase-out of HCFCs in sterilization uses to meet the Montreal Protocol schedule is readily achievable.

2.5 Methyl Bromide TOC (MBTOC)

- By 2014, over 60,000 tonnes of methyl bromide have been phased out for controlled uses representing over 80% of total global consumption of MB.
- Technically and economically feasible alternatives to MB have been found for virtually all controlled uses for pre-plant soil, structures and commodities uses.
- Of over 140 nominations submitted for critical use of over 18,000 tonnes by non-Article 5 Parties for 2005, only four still remain for less than 300 tonnes in 2016.
- Six critical use nominations were received from Article 5 Parties for 2015, the first year for which CUE’s are possible, for this group of Parties.
- Implementation of alternatives for a few remaining soil sectors has proven to be much more difficult than others, because of the need to achieve very high plant health standards and often official certification regulations (pest and disease free). More research in these sectors is needed.
- On average, 77% of the MB applied is emitted to the atmosphere. The dramatic reduction in consumption of MB has led to approximately 35% of the present fall in the stratospheric chlorine levels and is a key factor for the current ozone layer recovery presently observed.
- The short half-life of methyl bromide (0.7 years) in the stratosphere and the resultant reductions in MB use is thus one of the key reasons for the present ozone layer recovery.
- Emission reduction technologies have been shown to be very effective in reducing emissions by over 50%. Recovery technologies are also available, and can prevent over 80% of the emissions from commodity treatments, however less than 200 tonnes of MB are presently recaptured using these technologies.

- Further atmospheric reductions of bromine will be difficult unless controls are implemented on QPS use and the remaining critical uses of MB in Article 5 countries are phased out.
- MBTOC considers that a number of alternatives are immediately available for QPS uses and that 31 to 47% of the amount used for QPS in key consumption categories (timber and timber packaging, grain, logs and pre-plant soil uses), which account for 70% of the methyl bromide consumed could be phased out.
- Global production and consumption of MB for QPS purposes averages about 11,000 tonnes each year. In 2013, reported QPS consumption was over three times larger than controlled consumption.
- QPS consumption is significantly increasing particularly in some A5 countries.
- There is a need to avoid confusion in interpretation between QPS and non-QPS uses. For the same sector, some countries are considering MB use as QPS and others as controlled use. QPS definition should be harmonized at the international level and accepted by all the parties.
- Article 5 Parties face challenges ensuring the sustainability of the phase-out achieved. Weak tracking systems and sometimes confusion between controlled and exempted uses, make it difficult to track final use of MB imported into a country. This can lead to illegal use and trade and more robust systems need to be in place.
- More knowledge and information on MB feedstock use and emissions are required to further assess the impact of MB on the ozone layer.
- Regulatory and technical changes may continue to impact the MB phase-out by influencing the long-term availability of alternatives.

2.6 Refrigeration and Air Conditioning and Heat Pumps TOC (RTOC)

Refrigerants

- Whatever refrigerant is chosen will always have to be a balance between several factors, the availability and cost of the refrigerant (and the associated equipment), the system energy efficiency, the safety and convenience of applicability, environmental issues and many more.
- The perfect refrigerant does not exist, and is unlikely to come into existence. Choices will therefore include the existing low GWP refrigerants (e.g. R-717, R-744 or HCs) and the newly applied or developed chemicals. Many new alternatives are proposed which create a challenge in finding the right refrigerant for each application. One aspect of particular importance is that refrigerants with low direct impact on climate change are often flammable to some extent. With new refrigerant characteristics comes the need for new technology development and increased need for training.
- 21 refrigerants obtained standardized designations and safety classifications since the 2010 RTOC assessment report, including one new molecule: HCFC-1233zd(E). Approximately a quarter of the new refrigerants are blends which are replacements for HCFC-22. Of the new refrigerants twelve are blends of saturated HFCs and unsaturated HFCs (HFOs) of which seven blends are with class 2L flammability.

Domestic appliances

- Globally, new refrigerator production conversion from use of ODS was essentially completed by 2008. HC-600a or HFC-134a continue to be the refrigerant option for new production.

- It is projected that by 2020 about 75% of new refrigerator production will use HC-600a (possibly with a small share applying unsaturated HFC refrigerants) and the rest will use HFC-134a.
- Initial efforts to assess the use of HFC-1234yf in domestic refrigeration have begun, but they are not being pursued with high priority, due to cost implications and flammability.
- The heat pump clothe (laundry) dryer (HPCD) sales using HFC-134a are rapidly growing in the EU. HPCDs using R-407C and HC-290 have also been introduced. Alternative refrigerant solutions that are being explored include R-744, HC-600a and low GWP HFCs.

Commercial refrigeration

- In commercial refrigeration stand-alone equipment, hydrocarbons (HCs) and R-744 are replacing HFC-134a and R-404A and represent a significant market share in Europe and in Japan.
- Because of their high GWP, R-404A and R-507 are seen as refrigerants in many non-Article 5 countries as refrigerants to be replaced and, depending on the refrigeration capacities, hydrocarbons, R-744 or HFC refrigerant blends with lower GWP are the current chosen options.
- In supermarkets in Europe, two-stage CO_2 systems are recognized as viable option especially in moderate temperature countries. The technology is now spreading to other areas and development of concepts for hot climates is ongoing.
- Plug-in units with air and/or water cooled condensers are gaining market share. Particularly in the USA, distributed systems (condensing units with water cooled condensers installed in the sales area) are also installed in large numbers.

Industrial systems

- R-717 is widely used in industrial systems, but its adoption as a low GWP alternative to HCFC-22 in Article 5 countries is not universal due to safety concerns. The key requirements to facilitate this transition are education and training of designers and operators.
- Although HFCs are technically feasible for large industrial systems, the market sector is extremely cost sensitive and more expensive refrigerants are not favoured due to the large charge quantity required.

Transport refrigeration

- Low-GWP candidates for transport refrigeration include R-744, hydrocarbons, and HFC blends; however, various challenges are currently preventing them from widespread use. Intermodal container applications are at the forefront of developments; here the R-744 based system is available.
- In the case of a regulation banning the use of refrigerants above a certain GWP level (as in the EU), HFC blends will likely play a role in the 2020 timeframe as a retrofit to R-404A and (possibly) HFC-134a: their GWP is significantly lower and performances are close.
- Cryogenic and eutectic systems consist of potentially HFC-free stationary units and periodically recharged vehicle systems; they can be used on some transport routes

Air-to-air air conditioners and heat pumps

- HCFC-22 is still widely used in new and existing systems in Article 5 countries and to some extent in existing systems in non-Article 5 countries.
- The majority of new systems using an alternative to HCFC-22 use R-410A; some others are using R-407C, HFC-134a, HC-290 and HFC-32.

- There are a growing number of alternatives which have a medium to low GWP and are flammable that are being considered and evaluated by research entities and enterprises, meaning there is some degree of uncertainty over future selection of alternatives.

Water heating heat pumps

- For water heating heat pumps most systems commercialised today make use of R-410A, HFC-134a, R-407C, HC-290, HC-600a, R-717 or R-744. The majority of new equipment uses R-410A.
- In some Article 5 countries HCFC-22 is used. There are no technical barriers for replacing HCFC-22 by a non-ODS refrigerant in new systems. The main parameters in the selection of alternatives when switching over from HCFC-22 are efficiency, cost effectiveness, economic impact, safe use and easiness of use.
- HFC-32 and other medium and low-GWP HFC blends are under way to become commercially available. R-744 based water heating heat pumps have been mainly developed and commercialised in Japan. However, the expansion of this technology to other countries is limited by its high cost. R-717 has also been used in a small number of reversible heat pumps and absorption heat pumps.

Chillers

- The phase-out of ozone depleting refrigerants in chillers is going well. The use of HCFC-22 in chillers has been phased out in developed countries but use still continues in some Article 5 countries. The primary refrigerants currently used in chillers are HFC-134a, R-410A, and HCFC-123. HC-290, R-717 and R-744 are used as refrigerants, however, to a lesser extent.
- A number of new refrigerants with lower global warming potentials have been proposed for use in chillers. Evaluations by manufacturers and other laboratories are underway, but it is not clear which ones will be selected for commercialization. Trade-offs are apparent among GWP, energy efficiency, safety, and applied costs.
- Climate effects from chillers are dominated by their energy use. Thus, the ultimate goal in choosing new chiller refrigerant alternatives is to achieve the highest energy efficiency while remaining viable to chiller manufacturers, regulators, and users.

Vehicle air conditioning

- Now, at the end of 2014, it looks like as if more than one refrigerant will be used in the coming years for new car and light truck air conditioning. HFC-134a will remain largely adopted worldwide, HFC-1234yf will continue its growth in new models at least in the near future, and R-744 is expected to be implemented by German OEMs starting in 2017.
- New refrigerant options have GWPs enabling the GHG credits in US and are below the EU threshold of 150; both can achieve fuel efficiency comparable to the existing HFC-134a systems with appropriate hardware and control development.
- The worldwide spread of the two new refrigerants (HFC-1234yf and R-744) will be governed significantly by additional aspects like safety, costs, regulatory approval, system reliability, heat pump capability (especially for electric driven vehicles) and servicing.
- At the moment, it cannot be foreseen whether or not the old and new refrigerants will remain parallel in the market for a long period of time. It is also unclear if the bus and train sector will follow these trends. The use of hydrocarbons or blends of hydrocarbons has not received support from vehicle manufacturers due to safety concerns.

Sustainable refrigeration

- Refrigeration addresses fundamental human needs. In order to become more sustainable, the industry may consider the enhancement of current practices to: minimize the extraction of natural resources; avoid the emission of man-made substances such as refrigerants and solvents; protect fertile ecosystems from mining, water usage, and landfill of waste; promote education for sustainable production and consumption.
- From the perspective of refrigeration, air conditioning, and heat pumps, sustainability mainly refers to energy efficiency, use of renewable energy, and other options to reduce GHG emissions and the use of natural resources. In particular, the responsible choice and management of refrigerants are important sustainability aspects.

3 Abstract Executive Summaries

3.1 Chemical TOC (CTOC)

Process agents

Most of the ODS process agent uses remaining are long standing legacy processes which are difficult or impossible to convert. Almost all of discontinuation of process agents has resulted from plant closures rather than substitution, and uses will decline as chemical plants become obsolete or products are discontinued. CTOC is ready to work with Parties for improved reporting of emissions through targeted approaches to companies.

Feedstocks

A list of feedstock uses, with ODS volumes is now reported by Parties to the Ozone Secretariat, and emissions estimated. A total of 1137K metric tonnes ODSs were produced in 2013 (~ 25K ODP metric tonnes), a decrease of 5.4% in ODP tonnage from 2012.IPCC guidelines for emissions are probably an over-estimate, in that actual emissions may be lower at well-managed facilities. Developed countries report emission data for HFCs in their inventory reporting to UNFCCC. This could be extended to developing countries, and in parallel to the Ozone Secretariat. CH_2Cl_2 appears to be increasing in atmospheric concentration probably from direct use, and not from feedstock applications. Parties could consider collaboration with UNFCCC on metrics that could be used for leakage estimation, licensing production facilities to ascertain that emissions are below allowed levels, and annual reporting of volumes from both nonA5 and A5 Parties to the Ozone Secretariat

Solvents

In Article 5 Parties, CFC uses were completely phased out in 2012, and the phaseout of HCFC use in solvent application has begun. In non-Article 5 Parties, HFCs and HFEs have been used to replace the remaining HCFCs in certain application where the high cleaning performance is required. Recently HFOs are emerging in the market to replace HFCs and HFEs with middle to high GWP. The complete phase out of ODS solvents in Article 5 Parties is technically feasible, since alternatives are generally available. However, there is an economic impact on the small and medium size users who make up a major portion of the remaining ODS solvent market.

Laboratory and analytical Uses

There are very few identified uses of ODS in laboratory and analytical procedures in non-Article 5 Parties. Some use continues by several A5 Parties; alternatives are available, but not yet approved. The global laboratory and analytical-use exemption is extended until 31 December 2021. TEAP will report on the development and availability of laboratory and analytical procedures that can be performed without using controlled substances under the Montreal Protocol no later than 2018.

Destruction technologies

Since 2010, CTOC has reviewed several emerging technologies. Destruction of ODS presents special challenges to A5 Parties, with high installation and operating costs. It would be helpful to identify, define and establish support projects to cover high costs and technologies associated with local destruction facilities and/or capture and transport to regional facilities. A Task Force may be needed to assess options.

Carbon Tetrachloride (CTC) and Dichloromethane emissions

CTOC has reported for a number of years the discrepancy between ‘bottom up’ emissions of CTC to the atmosphere and ‘top down’ estimates based on stratospheric concentrations of CTC and estimates of its atmospheric lifetime. The gap has narrowed because the Scientific Assessment Panel (SAP) had revised the atmospheric lifetime for CTC in their OEWG report in 2012, increasing the value substantially. ‘Top down’ estimates thus indicate lower emission rates, reducing but not closing the gap. CTOC believes there have been unreported/under-estimated emissions of CTC connected with the use of phosgene in the production of methylene diphenyl di-isocyanate (MDI), a reactive substance used to make polyurethanes. Although CTOC has been unable to identify any additional emission sources that could narrow the gap further, CTOC will continue coordinating its efforts with the SAP to address this discrepancy.

3.2 Flexible and Rigid Foams TOC (FTOC)

Current status: trends in global foam use and impacts on blowing agent consumption

The global economic recession of 2008/9 has had some significant impact on investment within the construction sector since 2010, particularly in non-Article 5 parties. Project lead times associated with new-build projects (typically 2-3 years from initiation to completion) have meant that recovery of activities has only really surfaced in 2012/13.

However, investment in new construction in Article 5 parties has continued broadly unabated. Building renovation projects in Europe have been less affected by the downturn, partly because their lead times are shorter and partly because the investments are lower in magnitude. There is also recognition that, in most non-Article 5 parties, over 50% of the buildings that will be operational in 2050 have already been built. If progress on building energy efficiency and related CO_2 emissions is going to be made, then significant renovation will be necessary.

In all buildings, the demand for thermal insulation has increased substantially as their role in reducing energy dependency and greenhouse gas emissions has been recognised. New or improved thermal insulation requirements have emerged across the Middle East and throughout India, China and South Africa. Even though there has been some shift between fibre and foam market shares in China during the period, mostly as a result of fire concerns, the production of polyurethane chemicals had grown globally to just under 18 million tonnes by 2014.

Of this total production, an estimated 9.7 million tonnes is consumed in the foam sector annually with approximately 5.9 million tonnes being in rigid insulation foam, where it consumes blowing agents of interest to the Montreal Protocol. Other competing foam insulation materials are expanded polystyrene (never used ozone depleting substances), extruded polystyrene (XPS), phenolic and polyethylene foams. XPS foams are understood to consume about 1.25 million tonnes of polystyrene globally. Based on average blowing agent percentages of 5.5% w/w for polyurethane and 4.5% w/w for XPS, this leads to an estimated demand of approximately 380,000 tonnes between them with a further 10,000 tonnes being consumed by other foam types.

Current foam projections[1] predict on-going growth to 2019 of 4.8% per year, compared with 4.4% per year for 2009-2014. On this basis global blowing agent consumption will exceed 520,000 tonnes by 2020 unless there are further gains in blowing efficiency as technologies develop.

Based on these trends, the historic, current and future demand for physical blowing agents is summarised in Figure AES-1 below.

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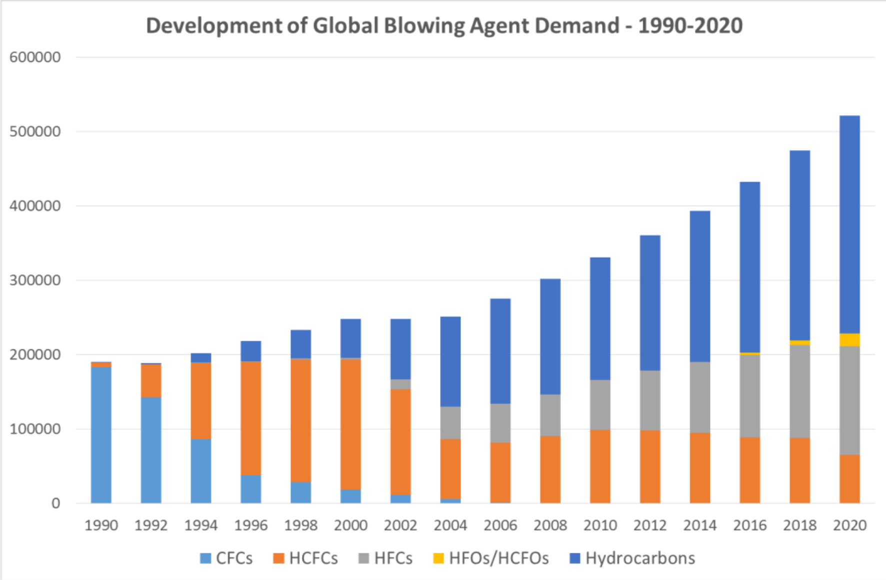
[1] RAPRA Report ‘The Future of Polymer Foams: Market Forecasts to 2019’



Source: FTOC

Figure AES-1: Growth in the use of Physical Blowing Agents by Type over the period from 1990 to 2020

Overview of progress and challenges related to blowing agent transitions

The major blowing agent transitions being driven by regulation currently are those in Article 5 parties resulting from Decision XIX/6 and being funded under national HCFC Phase-out Management Plans (HPMPs). First phase HPMP implementation is generally running smoothly, although there have been delays in the initiation of some plans owing to the significant administration involved. Since Decision XIX/6 requires a "worst first" approach, the phase-out of HCFC-141b has been particularly targeted over the period covered by this report. This has been broadly successful within larger enterprises where the critical mass of the operation is sufficient to justify investment in hydrocarbon technologies, often with individual enterprises being willing to co-fund the investment where the funding thresholds available under the Multilateral Fund have been insufficient.

Foams manufactured using other blowing agents, notably extruded polystyrene (XPS), have not typically been part of the first phase of most HPMPs. This is because there are no proven low-GWP alternatives to HCFC-142b/22 currently available. Although CO_2 technology is prevalent in Europe, it is still not clear whether it is sufficiently versatile for the variety of manufacturing plants operating in Article 5 parties. Other alternatives include hydrocarbons and ethers, but the flammability of these blowing agents is problematic when coupled with polystyrene itself which is also facing reformulation of brominated flame retardants. The situation has been further compounded in Asia since 2010 by a series of significant fires associated with insulation which have taken place during the construction phase of some high-rise buildings. Despite these concerns, investment in XPS manufacturing capacity has spiralled in response to increased demand for inexpensive and effective insulation. This has particularly been the case in Russia, the Middle East and parts of Eastern Europe and North Africa. The current choice of blowing agent in these regions are blends of HFC-134a/HFC-152a - not good for the climate, since these have relatively high GWP and the manufacturing process is typically quite emissive. There may be some hope that blends based on a combination of hydro fluoro olefins (HFOs) and/or hydro chloro fluoro olefins (HCFOs) together with hydrocarbons or ethers may ultimately satisfy the process and product requirements of XPS, but the continuing uncertainty is causing delay on conversions under relevant HPMPs. The net impact of these trends is projected in the Figure AES-2 below.

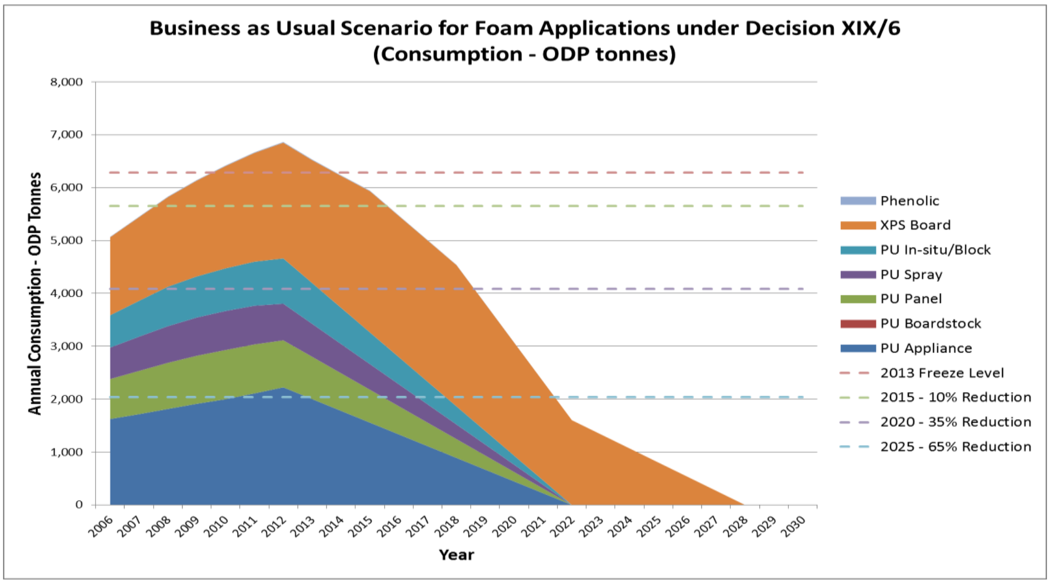


Figure AES-2: Evolution of consumption patterns for blowing agents in Article 5 Parties with time

The growth in XPS can be seen as potentially responsible for a breach of the 2013 Freeze – at least for the foams sector. However, this does not automatically mean that parties will be non-compliant with the Protocol, since there is always the potential to compensate in other sectors.

The other major factor that threatens the smooth phase-out of blowing agents is dealing with the challenge of small medium enterprises (SMEs). Lack of economies of scale prevents the adoption of hydrocarbons, while the adoption of high GWP alternatives results in high climate impact within processes which are typically less well engineered or are unavoidably emissive. Although transitions from HCFCs to HFCs were largely unavoidable in many non-Article 5 parties during phase-out of HCFCs, there is increasing pressure to switch to low-GWP technologies. In view of hydrocarbon flammability, the focus is on the potential role of non-flammable blowing agents such as HFOs/HCFOs or all water-blown formulations. For integral skin, oxygenated hydrocarbons such as methyl formate and methylal are becoming the blowing agent of choice while the major PU Spray Foam markets of the USA and Canada, look likely to adopt HFOs/HCFOs, with commercial systems now beginning to emerge.

Non-Article 5 parties in North America, Europe and Japan are now pursuing regulatory strategies to encourage the phase-out of HFC use in the foam sector. In Europe, this has been enacted under the re-cast F-Gas Regulation, while in the USA, the existing Significant New Alternatives Program (SNAP) is being explored as a tool for the de-selection of some blowing agent options. These regulatory initiatives could place particular pressure on the XPS industry in these regions, since universally acceptable alternatives are still to emerge.

The way forward: update on bank estimates and emerging management strategies

Global banks of blowing agents in foams are estimated to have grown from around 3 million tonnes in 2002 to an estimated 4.45 million tonnes in 2015[2]. Based on current consumption estimates, these will grow to well in excess of 5 million tonnes by 2020. However, a significant proportion of this bank will already have moved into the waste stream (typically landfill) by then. To deter this, ODS-containing foam is being increasingly treated as hazardous waste, but policing shipments is difficult when no simple way of determining foam blowing agent exists. The search for appropriate detection equipment continues for both the characterisation of waste and the monitoring of cross-border trade. A further option is to

[2] Data adapted from Special Report on Ozone and Climate (2005) – values include hydrocarbons

encourage voluntary intervention at decommissioning by assigning value to the process. Although climate benefits are the focus, the average global warming potential (GWP) of the waste stream will decrease with time as the average GWP decreases. Figure AES-3 illustrates this trend:

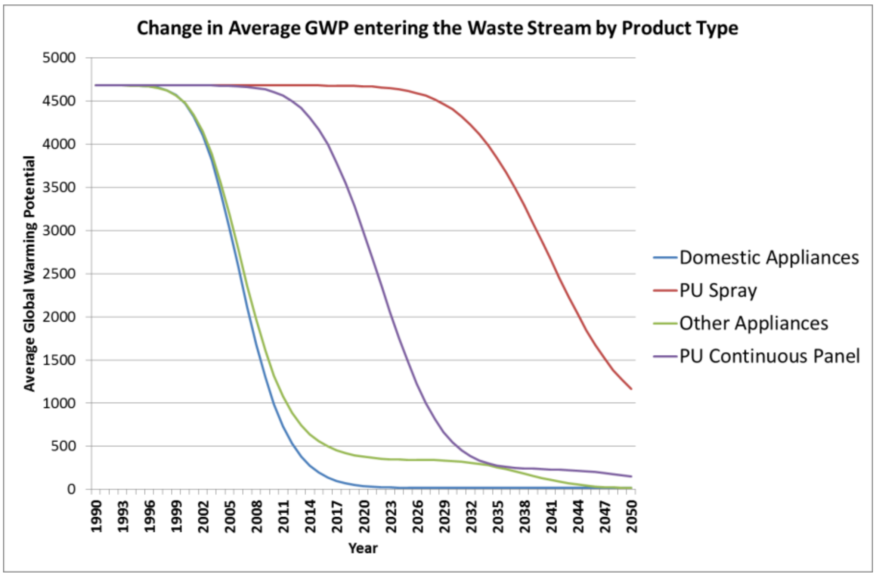


Figure AES-3: Expected decline in average GWP of the waste streams for typical foam applications

These trends imply that there is an urgent need to introduce effective waste management practices. Indeed, much of the climate benefit arising from appliances foams has already passed. This is being borne out in practice for many appliance recycling plants, where the associated climate benefit cannot now be relied upon as a justification for investment. As a result contractors are looking to minimise their upfront investment costs by adopting manual dismantling practices, even though there are associated emissions. This is especially the case in areas of low population density, where the economies of scale are more limited.

3.3 Halons TOC (HTOC)

The current status, the on-going issues

The HTOC models estimate the size of the global halon banks in 2014 are: halon 1211 - 33,000 MT; halon 1301 - 43,000 MT; and halon 2402 - 9,000 MT.

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.

While no single alternative has been commercialized that covers the wide range of applications of halons, there are a multitude of alternatives that collectively can be used to meet the fire protection requirements of all non-aviation future applications, although with technical or economic penalties, or both, and likely civil aviation future applications also with technical or economic penalties. Civil aviation has yet to try to validate and implement technically viable solutions with weight and/or space penalties.

To date, the two low GWP candidates for engine nacelles have not passed all required tests by the civil aviation safety authorities. Airframe manufacturers have chosen not to pursue qualification and installation certification for HFC-125 owing to weight penalties, and more recently, growing controls by individual jurisdictions.

The HTOC has a serious concern that many users are relying on halon imports for their most important uses, such as civil aviation and military.

Some A5 users are now encountering difficulties obtaining sufficient quantities of halon, with potential serious consequences.

For military applications, generally speaking, halon is only required to support legacy systems and their variants, and new military aircraft based on commercial designs with airworthiness certifications. Alternatives are available for all other new system designs.

What is left to be achieved

Careful management of the remaining stock of halons is crucial for ensuring sufficient halons for applications that need them. As such, halon recycling to international standards is very important for ensuring that adequate stocks of halons are available to meet the future needs of the Parties.

It is very important that countries invest in halon bank management programmes for connecting recyclable halon to users.

Some applications, including those in the military, aviation, and oil & gas sectors, will continue to require use of high-GWP chemical alternatives or the original halon to meet the fire protection requirements.

Although the regional disparity in the distribution of halon itself does not constitute necessarily a regional problem, it is anticipated that regional imbalances may result in shortages in one country or region with excesses in other countries and regions

Parties may wish to revisit the global strategic approach to halon bank management in order to avoid a severe supply disruption that would lead to an Essential Use Nomination. This could include development of updated training and awareness materials and programs, which address the harmonization of import and export regulations, purity and other halon bank management needs.

The way forward, the future

The HTOC is of the opinion 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 for service, in particular legacy systems.

Five new low-GWP chemicals are in various stages of evaluation as alternatives for halons; however, none of these prospective alternatives are expected to be commercially available for years, if at all.

Legacy oil and gas production facilities in the far north will continue to require the use of halons in occupied spaces owing to severe ambient (very low temperature) conditions. However, owing to the adoption of alternatives in new facilities, this sector has reduced its future demand for the diminishing supplies of halons.

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

While the halon requirements of civil aviation initially appear modest in comparison to the total inventory available today, civil aviation neither owns nor controls the ever reducing quantities of halons needed to support existing aircraft, much less new aircraft, for an additional 30 or more years.

Of all the sectors, civil aviation is the least prepared to deal with diminishing halon supplies and, with the ultimate exhaustion of supplies, this sector will most likely be the one to request an Essential Use Nomination in the future

3.4 Medical TOC (MTOC)

Metered dose inhalers

Current status

The global use of CFCs to manufacture metered dose inhalers (MDIs) in 2013 was about 300 tonnes, a reduction of almost 90 per cent from the last assessment. Annual CFC consumption in MDIs has dramatically decreased by 97 per cent from its peak of about 10,000 tonnes in 1997. In the last two decades, CFC MDI manufacturing has consumed almost 70,000 tonnes of CFCs under essential use exemptions.

There has been significant global progress in the transition from CFC MDIs to CFC-free inhalers, with substantial and growing capacity to manufacture CFC-free inhalers. Technically satisfactory alternatives to CFC MDIs are available worldwide for all key classes of drugs for the treatment of asthma and chronic obstructive pulmonary disease.

By moving from CFC MDIs to HFC MDIs and dry powder inhalers (DPIs), not only have emissions of ozone depleting substances been eliminated, but there have also been benefits for climate change. Salbutamol HFC MDIs account for the large majority of HFC use in inhalers. At present, salbutamol HFC MDIs are significantly less expensive per dose than multi-dose DPIs, making them an essential and affordable therapy. A minority of patients (10-20 per cent or less) cannot use currently available alternatives to HFC MDIs.

What is left to be achieved

With the exception of China, the phase-out of CFC MDI manufacturing has been completed worldwide. China, alone, nominated CFCs for MDI manufacture in 2015, which is likely to be its last Essential Use Nomination. Russia is in the final stages of manufacturing conversion to HFC MDIs, with completion likely in 2015.

The way forward

Global phase-out of CFC MDI manufacturing is expected in 2015-2016. Surplus CFC stockpiles may need to be destroyed. Global HFC demand for MDI manufacture (9,400 tonnes in 2014) is estimated to increase annually by 2 per cent for the period to 2025. DPIs may play an increasing role over the next decade.

Other Medical Aerosols

Current status

Technically and economically feasible alternatives to ozone-depleting propellants (CFCs and HCFCs) are available for all other medical aerosols. Medical aerosol products have been reformulated to use CFC-free propellants or replaced with aqueous formulations and other not-in-kind alternatives. Estimated HFC consumption is less than 1,000 tonnes per year, with the majority for nasal inhalation, throat topical medication, and nitroglycerin sublingual application.

What is left to be achieved

HCFC use is about 100 ODP tonnes or less worldwide (HCFC-22 and HCFC-141b), with the majority used in China.

The way forward

The complete phase-out of HCFCs in medical aerosols to meet the Montreal Protocol schedule is readily achievable. Many factors affect the selection of a given propellant or not-in-kind replacement for medical aerosol products, and these will need to be considered in phasing out HCFCs. HFC consumption is not likely to grow in the near future.

Sterilants

Current status

The use of CFCs in blends with ethylene oxide (EO) has been successfully phased out in non-Article 5 Parties, and in many, possibly all, Article 5 Parties. Estimated global use of HCFCs in sterilization is less than 500-700 metric tonnes, which amounts to less than 25 ODP tonnes worldwide. EO/HCFC use in Article 5 Parties is estimated to be less than 200-400 tonnes. EO/HCFC use has been significantly reduced by using less gas per sterilizer load, 100 per cent ethylene oxide, and by hospital conversion to other technologies.

What is left to be achieved

There is a range of viable methods that can replace the use of HCFCs in sterilization.

The way forward

The complete phase-out of HCFCs in sterilization uses to meet the Montreal Protocol schedule is readily achievable. Hospital procurement should take the HCFC phase-out, and the coming redundancy of EO/HCFC sterilization equipment, into consideration in making future investment decisions.

3.5 Methyl Bromide TOC (MBTOC)

Current status

MBTOC considers that technical alternatives exist for almost all remaining controlled uses of methyl bromide (MB). Regulatory and/or economic barriers may limit the implementation of some key alternatives affecting the ability to completely phase-out MB in some countries. The more difficult remaining soil sectors include strawberry and raspberry nurseries, strawberry fruit and ginger. The sole remaining non-QPS commodity use in non-Article 5 countries is for mites on dry cure ham in Southern USA.

Since 2009, MB production and consumption continued to fall in both non Article 5 and Article 5 Parties. At the end of 2013, over 99% and 86% of controlled uses of MB had been phased out respectively in non-Article 5 and Article 5 countries (ahead of the phaseout deadline of 2015 for the latter group).

In 2013, global *production* for MB uses that are controlled under the Protocol was 2,493 tonnes, which represented 9% of the 1991 reported production data (66,430 tonnes). Less than 0.5% of production occurred in Article 5 countries

In 2013, global *consumption* of MB for controlled uses was approximately 2,950 tonnes down from the baseline of over 60,000 tonnes in 1995. On average 77% of the applied MB is emitted to the atmosphere from applications of MB. Of over 140 nominations for critical uses submitted by non-Article 5 Parties for 2005, only four still remain for 2016. Six nominations were received from Article 5 Parties for 2015, despite this year being the first year for which CUE’s are possible, for this group of Parties.

The large reduction in consumption has led to a dramatic reduction of 40,000 tonnes of anthropogenic bromine in the atmosphere, and this has contributed to approximately 35% to the present decline in equivalent effective stratospheric chlorine (EESC). The short half-life of methyl bromide in the stratosphere (0.7 years) and the resultant reductions in MB use is thus one of the key reasons for the present ozone layer recovery. Further atmospheric reductions of bromine will be difficult unless controls are implemented on QPS use and the remaining critical uses and use of MB in A5 countries are phased out (Fig. AES-4).

Use of barrier films continues to show that dose rates and emissions can be reduced by 30 and 50% respectively. MBTOC considers barrier films when available, should be mandated for all remaining soil uses. Structural, commodity and QPS applications emit between 50 to 95% of the applied MB. Present use of recapture technology is estimated at less than 200 tonnes. Greater adoption of this technology is possible for all remaining controlled and non-controlled (QPS) uses of MB.

Production and consumption of MB for QPS is still not controlled under the Montreal Protocol, despite some regions of the world achieving complete phase out of MB for this use. MBTOC still maintains that a number of alternatives are immediately available for QPS uses and that between 31 and 47% of the amount used for QPS in key consumption categories could be phased out and replaced with alternatives. Technically and economically feasible alternatives have been identified for many QPS applications, particularly in the largest usage sectors of timber and timber packaging, grain, logs and preplant soil uses which account for 70% of the MB consumed.

Global production and consumption of MB for QPS purposes averages each year to approximately 11,000 tonnes. In 2013, reported QPS consumption was over three times larger than controlled consumption. This was partly due to the continued decrease in the non-QPS uses, as well as re-categorisation by some Parties of uses previously considered non-QPS to QPS.

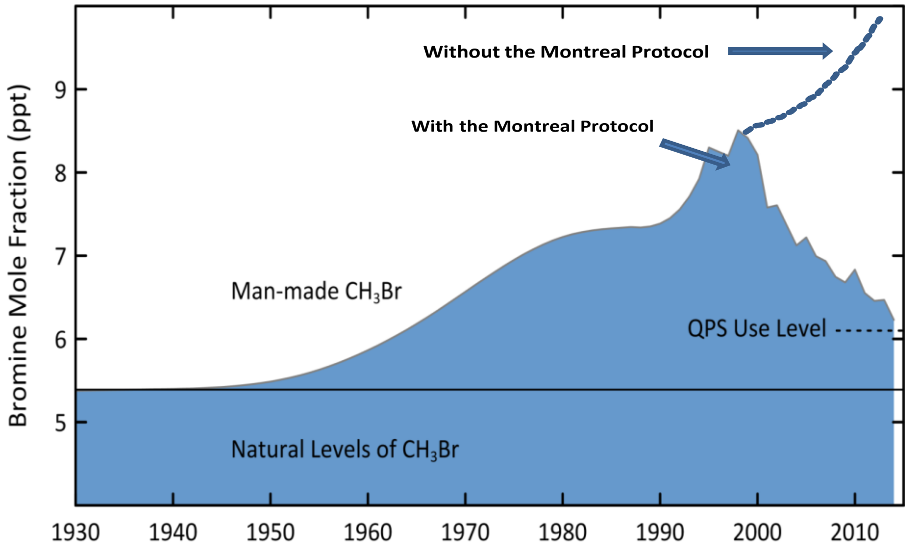


Figure AES-4 The impact of the MB restrictions in non-Quarantine and Preshipment (QPS) use on reduction in bromine concentrations in the troposphere since the late 1990's

QPS consumption in Article 5 Parties has increased constantly over the past 15 years, and in 2013 represented 56% of global QPS consumption.

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, substrate production and biofumigation.

Progress with developing and implementing alternatives for structures and commodities include studies on alternative fumigants such as phosphine, sulphuryl fluoride, CO2, ethylene format and ozone, as well as controlled atmospheres with elevated temperature or raised pressure, on microwave, radio frequency or ionizing radiation, and heat. MBTOC has identified feasible alternatives for dates –including high moisture dates – and considers replacement of MB in this sector is no longer of concern. The only sector yet to find alternatives is dry cured ham in Southern USA.

Phase-out in Article 5 countries has been achieved mainly through MLF-funded 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.

What is left to be achieved

Replacing the 11,000 tonnes of MB for QPS uses or ensuring a significant reduction in emissions coming from QPS is a key challenge for the Montreal Protocol.

Better understanding of the sources and sinks of MB now that the soil and commodity fumigation uses have been reduced dramatically, is becoming particularly important.

Efforts are still required to minimize use and emissions of MB through containment and recovery and recycling methodologies to the extent possible.

Chemical alternatives in general, have issues related to their long-term suitability for use. Worldwide, fumigants are involved in a rigorous review that could affect future regulations over their use. As an example, MB was banned for all uses in the EU, mainly due to health issues. MBTOC thus encourages Parties to adopt integrated pest management strategies with strong non-chemical components in order to maintain sustainable production in all sectors.

For the remaining preplant soil uses in nurseries and some other sectors (e.g. ginger, strawberry fruit) it is important that studies with alternatives not only continue, but that they focus on measuring pathogen thresholds and risk of spread of diseases. Also, continual review of regulations is required to allow for replacement of MB where feasible. In these cases, combinations of existing products and consideration of more sustainable non-chemical alternatives also need greater consideration.

Work is still needed to gain a better understanding of the economic and pest risk impacts of the MB phase-out, particularly in Article 5 Parties and to a wider range of MB uses such as the effect of removing MB use for quarantine applications.

Challenges that may put the sustainability of the phase-out achieved in Article 5 Parties at risk include: the continued unrestricted supply of MB in light of the exemption for QPS uses; weak or insufficient tracking systems, that do not always ensure that MB imported for QPS purposes does not deviate to controlled uses; and the long term viability of some alternatives, which may be restricted by development of pest resistance, regulatory issues, economic infeasibility and other factors.

The remaining areas where technical alternatives are proving more difficult include some specific nursery situations (strawberries, raspberries) especially where certification is required and situations where regulations prevent use of all alternatives, e.g., ginger production in China. In postharvest applications, MBTOC has not identified technically effective alternatives for Southern cured pork products in storages in the USA.

The way forward

For remaining pre-plant soil uses, continued market penetration of chemical alternatives (i.e. chloropicrin), mixtures of alternatives, and use of other methods such as soilless production systems, will contribute to replacing MB.

It is strongly recommended that all remaining pre-plant uses of MB be applied with barrier films. These are also encouraged when using alternative fumigants.

In postharvest applications, research to identify and assess technically and economically feasible alternatives for pest control in traditional Southern USA cured pork products in storages should be continued.

Parties may wish to give increased consideration to adoption of alternatives for the major usage sectors in QPS as studies and experience continue to show successful results with various alternatives in key sectors (timber and wood packaging materials, grains, logs, pre-plant soil fumigation in nurseries, fresh fruit and vegetables) despite the existing exemption for this use under the Montreal Protocol. Revisiting technical and regulatory reasons for listing certain preplant soil uses under QPS exemptions is also recommended.

Particularly in Article 5 Parties, the QPS exemption may pose risks to the phase-out achieved, as MB continues to be freely available if intended for this use. Potentially, MB imported for QPS purposes could be used in controlled uses, now forbidden under the Protocol (except for critical uses). Further, applications can be erroneously identified as QPS when they should in fact be controlled.

Sustaining the phase-out achieved in Article 5 Parties becomes especially important from 2015 onwards. The continuity of programs established through projects - particularly technical assistance and training - needs consideration. These activities should further include health-related risks associated with both MB phase-out and its chemical alternatives. Promoting linkages with other environmental/sustainability initiatives already in place in many countries and encouraging information exchange within productive sectors locally or at the regional level can provide good options that Parties may wish to consider to help reach this goal.

3.6 Refrigeration, AC and Heat Pumps TOC

Refrigerants

Current status

Whatever refrigerant is chosen will always have to be a balance between several factors, the availability and cost of the refrigerant (and the associated equipment), the system energy efficiency, the safety and convenience of applicability, environmental issues and many more. The refrigerant options emerging today address the phase-out of ODS, especially HCFC-22, as well as concerns about climate change. The perfect refrigerant does not exist and is unlikely to come into existence. Choices will therefore include existing low GWP refrigerants (e.g. R-717, R-744 or HCs) and the newly applied or developed chemicals. Many new alternatives are proposed, which create a challenge in finding the right refrigerant for each application. One of the important aspects is that refrigerants with a low direct impact on climate change are often flammable to some extent.

What is left to be achieved

The industry will keep searching for the right candidate for each application. In some cases this may be as simple as changing the refrigerant, while in other cases this will require redesign of the system or even a change of system topology. The search is a trade-off between cost, safety, energy efficiency, while limiting the need for redesign. One particular concern is the acceptance of flammability in some form or the other.

The way forward

There is a complex selection process ahead, where the market will need to find out which of the many proposed new and old refrigerants will be used in each application. Part of the complexity is that the market is unlikely to be able to support many different refrigerants for the same application.

This will result in a period in time, likely to last a couple of decades, where the industry will have to work with both the currently established refrigerants as well as new refrigerants addressing ozone depletion and/or climate change concerns. In the long run, the number of candidates is likely to fall, but it is too early to tell which or even how many of the current refrigerant candidates will survive.

Domestic appliances

Current status

Globally, new refrigerator production conversion from the use of ODS was essentially completed by 2008. HC-600a or HFC-134a continue to be the refrigerant options for new production. Initial efforts to assess the use of HFC-1234yf in domestic refrigeration have begun, but it is not being pursued with high priority, as in automotive applications, due to cost implications and flammability.

The heat pump clothe (laundry) dryer (HPCD) using HFC-134a is rapidly growing in the EU, with manufacturers from both the EU and Japan. HPCDs using R-407C and HC-290 have also been introduced.

What is left to be achieved

It is projected that, by 2020, about 75% of new refrigerator production will use HC-600a (possibly with a small share applying unsaturated HFC refrigerants) and the rest will use HFC-134a. Alternative low GWP refrigerant solutions are being explored for HPCDs. This includes R-744, HC-600a and low GWP HFCs.

The way forward

A number of improved energy efficiency design options are fully mature, and future improvements of these options are expected to be evolutionary. Extension of these to an all-global domestic market would yield significant benefit, but is generally constrained by the availability of capital funds and related product cost implications.

Commercial refrigeration

Current status

Commercial refrigeration is one of the application sectors where the refrigerant demand is the highest for servicing, due to the large emission level of refrigerants from supermarket systems. The phase-out of HCFC-22, being the dominant refrigerant in Article 5 countries, is important for supermarkets, where it can be replaced by high-GWP refrigerants such as R-404A or R-507A or lower GWP options from the R-407 family (R-407A, C or F) or the low GWP options such as R-744 or HCs. For stand-alone equipment, large global companies have taken commitments to phase-out, where low GWP HFCs, CO_2, and hydrocarbons are the leading choices.

What is left to be achieved

In Article 5 countries, the phase-out of HCFC-22 in the case of condensing units and centralized systems asks for rapid refrigerant choices. The current low-GWP options require a significant technical background to implement, particularly for e.g., two-stage CO_2 systems, this in high ambient temperature conditions. So the HFC refrigerant blends, with GWPs ranging from 1500 to 2100 are possible immediate options, rather than choosing R-404A or R-507A.

The way forward

Low environmental impact, energy efficiency, simple maintenance, low refrigerant emissions and costs are the drivers for the next generation of refrigerants in commercial refrigeration. For the low refrigeration capacities of stand-alone systems, many of those criteria are currently met by R-744 or HCs. For large refrigeration capacities and for all climate conditions there are still a number of options open. The phase-out of high GWP refrigerants is a certainty, the replacement options R-744 and hydrocarbons are known, but the replacement low-GWP HFCs options are still not well known.

Industrial systems

Current status

Non-fluorinated refrigerants are widely used in industrial systems, particularly in Europe, Scandinavia and North America. The most common refrigerant in these systems is R-717, used in a few cases in cascade systems with R-744. Safety standards and regulations are well developed in these markets and the incidence of serious injury and fatal accidents is extremely low. The HFC use in these markets is confined to specialist niches.

What is left to be achieved

R-717 use is less common in some sub-sectors in Europe and North America, for example in France and New Jersey, where regulations make it more difficult to construct new ammonia systems; as a result, HCFC-22 was favoured in these jurisdictions. This matches the situation in many Article 5 countries where R-717 is not widely used, due to a lack of expertise in designing and operating systems. There is no inexpensive and widely available low GWP alternative to HCFC-22 for industrial systems in the currently available group of HFCs and unsaturated HFCs. The options for addressing the HCFC phase-out in Article 5 countries are therefore to find ways to use R-717, to accept the higher refrigerant cost for existing HFCs or to develop a suitable low GWP fluorinated refrigerant.

The way forward

The main conclusion drawn from this survey is that greater training of designers, installers, operators and maintenance crews is required to facilitate the move away from ozone depleting substances in all subsectors of industrial systems. New fluids are unlikely to be developed for the majority of industrial systems. The low GWP refrigerants R-717, R-744 and HCs are the dominant choices in several of the applications covered, and this is expected to remain in the future. However, there are some niche applications that use high GWP HFCs, which applications need to be addressed in the future.

Transport refrigeration

Current status

The vast majority of trucks, trailers, vans and intermodal containers uses the non-ozone depleting refrigerants R-404A and HFC-134a. While most new vessels use HFC refrigerants, new fishing vessels increasingly use R-717 or R-744. However, the installed base at sea is still largely dominated by HCFC-22. The industry has been focusing on numerous environmental issues, making progress in reductions of engine pollution emissions, fuel consumption, noise levels and refrigerant charge. In addition, some manufacturers have made commitments to replace the current refrigerants with R-744 or R-452A in some first applications.

What is left to be achieved

Refrigerated vessels using HCFC-22 will continue being retrofitted with R-417A, R-422D and R-427A. In parallel, the industry will be looking for lower GWP alternatives in all sub-segments including R-717 and R-744 in shipping vessels. Cooperation between governments and manufacturers must continue in order to reflect the very specific transport refrigeration requirements. While introducing lower GWP solutions, the industry must ensure the best trade-offs among GWP, performance, indirect emissions, life cycle costs, etc, while safety and compliance are in no way compromised.

The way forward

In the short term, the industry will progressively introduce lower GWP alternatives to R-404A such as R-452A (GWP around 2000, it will be introduced in Europe for new production in 2015), R-448A and R-449A (GWP around 1400), R-744. In a longer time frame, other HFC blends and -within certain charge limits- possibly hydrocarbons or other flammable alternatives will be addressed. Lower GWP refrigerants will also be gradually applied in vessels when their applications mature in other segments and gain more confidence. Cryogenic and eutectic systems are proven solutions, and will continue playing a role on road transport.

Air-to-air air conditioners and heat pumps

Current status

Air-to-air air conditioners and heat pumps: HCFC-22 remains the dominant refrigerant in use, where the refrigerant bank for unitary air conditioners is estimated to be in excess of 1 million tonnes. In new systems, HCFC-22 is only being used in Article 5 countries. The HFC blend R-410A is the most common alternative, further, to a limited extent R-407C along with HFC-134a are used in regions with high ambient temperatures. HC-290 is being used in split systems, window and portable air conditioners. HFC-32 is being used in split systems and is being proposed for larger ducted and multi-split systems. These various alternatives have also been found to achieve performance approaching, as good as or better than HCFC-22.

What is left to be achieved

In general there is still a significant proportion of the sector throughout almost all Article 5 countries that remains to be shifted from HCFC-22 to a zero ODP alternative. Because of the high GWP of R-410A, investigations into medium and low GWP alternatives are continuing. In cooler climates, R-744 is available for commercially sized systems and the technology is further being explored. There are a large number of new mixtures being considered for air conditioning systems primarily consisting of HFCs and unsaturated HFCs, such as R-444B, R-446A and R-447A. Although there is concern over the use of R-410A in high ambient temperatures, appropriate design measures can be used to help remedy the relatively greater degradation in performance; nevertheless, work is underway to investigate this and other refrigerants further.

The way forward

The forthcoming direction remains unclear in terms of which alternatives this sector, sub-sectors and regions will settle upon. It is likely that different manufacturers and countries will opt for a variety of alternatives before any single option is chosen (if at all). In the meantime, investigations will continue into medium GWP flammable HFCs, HFC/unsaturated HFC blends and HCs for normal operating conditions as well as high ambient temperature conditions.

Water heating heat pumps

Current status

Air-to-water and water-to-water heat pumps have experienced significant growth in Japan, Australia, China, and Europe during the last ten years. HCFC-22 is still used in some Article 5 countries. The HFC blends R-410A and R-407C are currently used in Europe 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 due to strong government support. In the past, the number of HC-290 applications in Europe has decreased, due to the Pressure Equipment Directive, however, recently a range of HC-290 compressors have become available. R-717 is mainly used for large capacity heat pump systems.

What is left to be achieved

Based on regulations in Europe, the water heating heat pump industry is looking to alternatives with a lower GWP than the one for R-410A.

The main challenge is to come with an efficient, cost effective, safe and easy to use solution. It is expected that other regions will follow the tendency to reduce the GWP value of refrigerants.

The way forward

For water heating heat pumps, HFC-32 or blends with unsaturated HFCs will be studied for future use by taking into account the performance, costs and the necessary safety regulations in relation to their lower flammability. R-744 systems will be optimised and used wherever possible, taking into account costs that will apply. HC-290 and R-600a will be used where possible, taking into account the costs involved and safety in regards to flammability.

Chillers

Current status

The phase-out of ozone-depleting refrigerants in chillers is moving along well. The CFCs have been essentially phased out for new equipment and the CFC banks are decreasing in existing chillers. The current generation of chillers using zero-ODP refrigerants had been introduced without a sacrifice in reliability or energy efficiency. HC-290, R-717 and R-744 are also being used in chillers. Water as a refrigerant is currently being used in absorption chillers and had been recently announced in vapour compression based chillers. The use of HCFC-22 in new equipment has been phased out in developed countries; many Article 5 countries also have stopped its use in new equipment. Limits set for HCFC-22 production and its rising costs have contributed to the conversion of new and existing chillers to zero ODP refrigerants.

What is left to be achieved

The energy consumption of chillers dominates their environmental impact because the latest generation of chillers has low leak rates and, therefore, low direct global warming impact. The issue, then, is to determine which of the new refrigerants has high energy efficiency in chillers while being safe to use and having acceptable application costs. Major efforts have been launched to propose and test new lower-GWP refrigerants to replace the higher-GWP refrigerants currently in use.

The way forward

Testing of new, lower GWP refrigerants started several years ago and is continuing. At this juncture it is not clear which refrigerants may be selected for commercialisation. Trade-offs are apparent among GWP, energy efficiency, safety, and applied cost. Refrigerants that are non-flammable with the A1 refrigerant safety classification generally have GWPs of 600 or more. Refrigerants with low GWP (<150) generally are flammable. All flammable refrigerants require special safety considerations. A2L refrigerants will not be widely used without changes to safety standards and building codes.

Vehicle air conditioning

Current status

Today the overwhelming majority of new AC equipped passenger cars world-wide use HFC-134a. The transition from CFC-12 is complete for new systems, but there are still cars in use especially in Article 5 countries. In order to meet the EU MAC Directive and to harvest potential US EPA CO2 credits, OEMs evaluated several refrigerant options for new car (and truck) air conditioning systems. As a result, some car manufacturers have started to equip certain models with HFC-1234yf. Owing to safety concerns regarding the A2L-refrigerant HFC-1234yf, other car manufacturers work on R-744 systems in order to introduce them into the market by the year 2017. Both options have GWPs enabling the GHG credits in US, they are below the EU threshold of 150 and both can achieve fuel efficiency comparable to the existing HFC-134a systems with appropriate hardware and control development. Also owing to safety concerns the use of hydrocarbons or blends of hydrocarbons has not received support from vehicle manufacturers. 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 on-going.

What is left to be achieved

At the end of 2014 it looks likely that more than one refrigerant will be used in the coming years for car and light truck air conditioning. HFC-134a will remain largely adopted worldwide, HFC-1234yf will continue its growth in new models at least in the near future, other new low GWP synthetic refrigerants or refrigerant blends (e.g. R-445A) may be implemented, and R-744 is expected to be implemented by German OEMs starting in 2017.

The way forward

Along with the Global Warming Potential issue the future spreading of the two refrigerants HFC-1234yf and R-744 in the worldwide vehicle air conditioning market will be significantly governed by additional considerations like safety, costs, regulatory approval, system reliability, heat pump capability (especially for electric driven vehicles) and servicing. At the moment, it cannot be foreseen whether or not the old and the new refrigerants will see parallel use in the market for a long period of time. Without existing regulations it is also unclear whether the bus and train sector will follow these trends.

Sustainable refrigeration

Current status

Refrigeration, air conditioning, and heat pump equipment are vital means to address the human fundamental needs in areas such as food conservation, food security, health care, water heating, and thermal comfort worldwide. There are however a number of negative environmental impacts from the use of such equipment that need to be minimized through careful consideration of design, operation, and end of life aspects of these equipment and the refrigerants they use.

What is left to be achieved

Negative environmental impacts from refrigeration, air conditioning, and heat pump equipment must be managed through careful and systematic assessment when choosing new refrigerants, by reducing CO_2 emissions along the equipment life cycle, and through environmentally sound and socially fair end of life procedures.

The way forward

Enhancement towards sustainability demands proper national and regional regulation, expansion of voluntary programs aiming higher levels of energy efficiency, adoption of state-of-the-art energy management technologies, use of life cycle assessment tools, expansion of awareness and training initiatives across the industry value chain.

4 Executive Summaries of all TOCs

4.1. Chemical Options Committee (CTOC)

4.1.1 Process agents

Nominations for process agent status were still being received as late as 2013 as Parties became aware of activities of their chemical industry sectors in which controlled substances were used.

Most of the process agent uses remained are of long standing, and the ODS are used as solvents to create unique yields, selectivity and/or resistance to harsh chemical environments, with the result that production is achieved with high efficiency. Legacy processes built around these properties make it difficult or impossible to convert in a cost effective and timely manner. Almost all of the removals of process agents from Table X/14, which at one stage included over 40 examples, have resulted from plant closures rather than substitution of other substances for the ODS process agent.

Three process agent uses have been discontinued and removed from Table A. 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. This could be achieved by developing a list of Parties with approved process agent uses to the Ozone Secretariat to enable better targeting of requests for information and follow up.

What is left to be achieved?

Improved reporting on Process Agent uses and emissions.

The way forward

Assist Parties with improved tools to encourage better reporting of process agent use. Process agent uses are expected to decline as chemical plants become obsolete or products are discontinued.

4.1.2 Feedstocks

An extensive listing of known use of ODSs as feedstocks has been compiled. Using volumes as reported by Parties to the Ozone Secretariat, a profile of feedstock use has been generated. By following guidelines for emission calculations suggested by the IPCC for the UNFCCC, feedstock emission estimates have been generated. Data for emissions are shown for production for feedstock use. A total of 1137K metric tonnes ODSs were produced in 2013 representing about 25K ODP metric tonnes. This was an increase in production of 0.35% vs. 2012 levels and a decrease of 5.4% in ODP tonnage.

Reported volumes of feedstock uses are expected to be fairly complete with a possible exception of some small batch uses. Earlier communications concerning feedstock reporting has increased such data provided by Parties. During the past three year period during which improve data were provided to the CTOC, use of feedstocks has shown virtually no growth.

IPCC guidelines for emission estimation do 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. Improved estimates of emissions could be achieved with improved UNFCCC guidelines or other accepted practices. Developed countries report to UNFCCC emission data for HFCs in their inventory reporting. 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. Such reporting has not yet been established on a regular basis for developing countries.

Both governments as well as industry are making successful efforts to minimize emissions associated with ODS use in feedstock applications. An overview of such measures is provided to assist Parties to limit environmental impacts. Continued use of process permits limiting emissions along with Party oversight would likely allow for further improvements.

Concerns of use of CH2Cl2 as feedstock could be adding to observed increases in atmospheric concentrations are addressed. Our conclusion is that such increases are not from feedstock applications but rather from direct uses.

What is left to be achieved?

Feedstock use is a long term activity. Accurate assessment and awareness of the extent of feedstock uses and volumes are needed annually. Improved estimation procedures would enhance quantification of environmental impacts of these practices.

The way forward

Annual summaries of feedstock data submissions to the Secretariat for inclusion in CTOC Progress and/or Assessment Reports. Increase guidance from the UNFCCC on metrics that could be used for leakage estimation. Encourage Parties to license production facilities and to provide their own oversight that such emissions are below allowed levels.

4.1.3 Solvents

In Article 5 parties, CFC uses were completely phased out in 2012, and the phase-down of HCFC use in solvent application began. In non-Article 5 Parties, HFCs and HFEs have been used to replace the remaining HCFCs in certain application where the high cleaning performance is required. Recently HFOs are emerging in the market to replace HFCs and HFEs with middle to high GWP.

The Threshold Limit Values (TLV) of n-PB has been reset from 10ppm to 0.1ppm by American Conference of Governmental Industrial Hygienists (ACGHI). It indicates the use in solvent applications seems problematic.

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.

What is left to be achieved?

Complete phase out of the use of HCFCs in solvent application

The way forward

The phase-out of HCFCs in Article 5 Parties is scheduled in 2035. Although solvent contribution to the Ozone layer depletion is relatively small with respect to the other applications, the transition to the alternative technologies can be undertaken as the alternatives are already available. One issue is how to support small and medium enterprises where solvent is not well-managed. These may be one of the significant emission sources of Dichloromethane.

4.1.4 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.

Now, the global laboratory and analytical-use exemption is extended until 31 December 2021. TEAP is requested to report on the development and availability of laboratory and analytical procedures that can be performed without using controlled substances under the Montreal Protocol no later than 2018;

What is left to be achieved?

Further reduction in ODS use for Laboratory and Analytical purposes.

The way forward

CTOC will be vigilant in raising awareness of alternative methods. Parties can take steps to implement new standard methods (NORMS) that do not use ODS. Parties should report on successful alternatives so that this knowledge can be shared (an example was the use of butane or LPG in assessing the activity of activated carbon prepared from coconut husks).

4.1.5 Destruction technologies

Since 2010, CTOC has reviewed several emerging technologies following Decision XXI/10.

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.

What is left to be achieved?

Analysis of the needs for the future destruction of unwanted ODS.

The way forward

Destruction of ODSs presents special challenges to A5 Parties. As the volumes are low, high unit costs make it difficult to justify installation and operation in each country. It would be helpful to identify, define and establish support projects to cover high costs and technologies associated with local destruction facilities and/or capture and transport to regional facilities. Support is also needed to help define how to deal with regulatory issues associated with transport of wastes should that be the selected option. .

4.1.6 Carbon Tetrachloride (CTC) and Dichloromethane emissions

TOC has reported for a number of years on the discrepancy between emissions of CTC to the atmosphere based on 'bottom up' estimates based on production and consumption and typical emission rates, and 'top down' estimates based on stratospheric concentrations of CTC and estimates of its atmospheric lifetime.

The Scientific Assessment Panel had revised the atmospheric lifetime for CTC in their OEWG report in 2012, increasing the value substantially. 'Top down' estimates thus give lower emission rates, by 10-20 Ggramme/year, to maintain the observed stratospheric concentration of CTC. Diffuse emissions could contribute 8-12 Ggramme/year, and together these figures significantly reduce the discrepancy between the two types of estimate by as much as 18-32 Ggramme/year. The gap between the two estimates of emissions has thus been reduced but not entirely closed.

CTOC has become aware that historically there may have been previously unreported or under-estimated emissions of CTC connected with the use of phosgene, for example in the production of methylene diphenyl di-isocyanate (MDI), a reactive substance that is used to make polyurethanes. It is also indicated that phosgene produced from chlorine and carbon monoxide is usually contaminated with CTC, the presence of which may not be taken into account when emissions are taken into account.

CTOC has also studied other possible emission sources. However, additional emission sources that could narrow the gap significantly could not be found.

Dichloromethane (methylene chloride) emissions to the atmosphere have been increasing since 2006

The source of the additional 300,000 tonnes emitted annually is conjectural but most of it must come from use of dichloromethane itself as solvent or cleaning agent; it is beyond reason that the source is fugitive emissions from feedstock. If that were the case, more dichloromethane would have been lost to the atmosphere than the amount used to make HFC-32 - economically disastrous as well as impossible in a developed economy under environmental legislation.

What is left to be achieved?

Better understanding of the mismatch between estimates of emissions, measured stratospheric concentrations, and lifetimes.

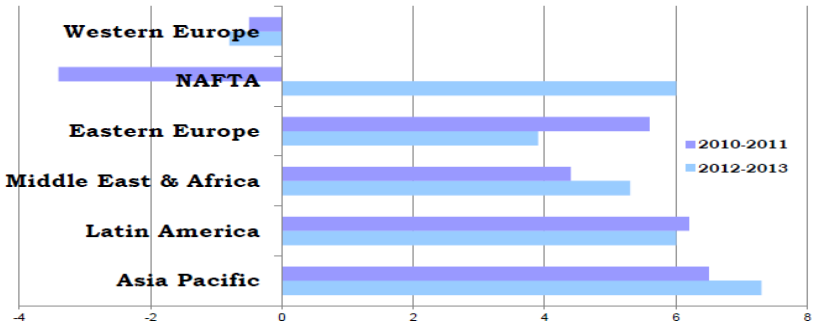
The way forward

Collaboration with the Scientific Assessment Panel, the UNEP inventory data and to further revise the atmospheric lifetime of CTC.

4.2 Flexible and Rigid Foams Technical Options Committee (FTOC)

4.2.1 Trends in global foam use and impacts on blowing agent consumption

The global economic recession of 2008/9 has had some significant impact on investment within the construction sector since 2010, particularly in non-Article 5 parties. The project lead times associated with new-build construction projects (typically 2-3 years from initiation to completion) have meant that recovery of new construction activities has only really surfaced in 2012/13.

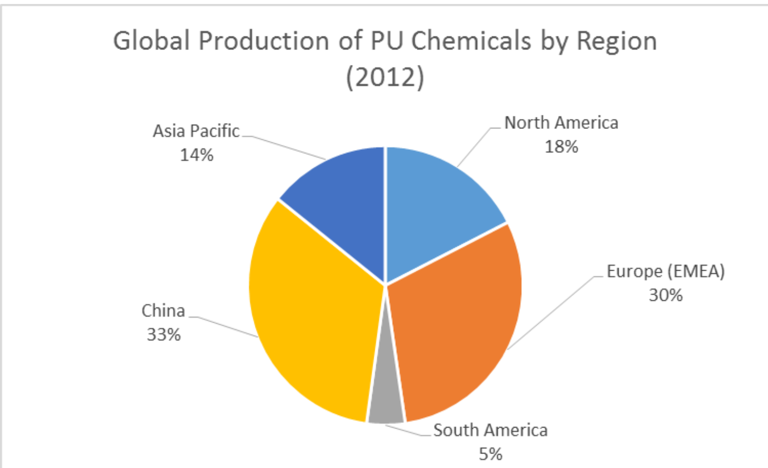


Source: IHS Global Insight

Figure ES-1: Growth in construction spending 2010/11 vs 2012/13 (%)

However, investment in new construction within Article 5 countries has continued broadly unabated. This is indicated in the Figure ES-1 above. Building renovation projects in Europe have been less affected during the period, partly because their lead times are shorter and partly because the investments are lower in magnitude. Typically, Article 5 parties are focused on new construction for the most part, while non-Article 5 parties are increasingly turning to renovation strategies. This is partly a recognition that, in most non-Article 5 parties, over 50% of the buildings that will be operational in 2050 have already been built. If impacts on building energy efficiency and related CO_2 emissions are going to be made, then significant renovation programmes will be required.

In both new construction and renovation, the demand for thermal insulation has increased substantially as the role of buildings in reducing energy dependency and associated greenhouse gas emissions has been recognised. New or improved thermal insulation requirements have emerged across the Middle East and throughout India, China and South Africa. While there has been some shifting between fibre and foam market shares in China during the period, partially as a result of a temporary moratorium[3] on the installation organic insulation materials (including polyurethane and polystyrene) arising from fire concerns, the production of polyurethane chemicals globally has grown by 8.8% over the same time period to just under 18 million tonnes. Figure ES-2 illustrates the geographic spread of this production and indicates the growing importance of Article 5 regions in both the production and consumption of polyurethane chemicals.



Source: PU Magazine

Figure ES-2: Regional distribution of PU chemical production in 2012 (~18 million tonnes)

[3] Rescinded in December 2012

Of this total production, 9.7 million tonnes is estimated to be consumed in the foam sector annually with approximately 5.9 million tonnes being in the rigid insulation foam sector, where it consumes blowing agents of interest to the Montreal Protocol. Other competing foam insulation materials are expanded polystyrene (never used ozone depleting substances), extruded polystyrene (XPS), phenolic and polyethylene foams. XPS foams are understood to consume approximately 1.25 million tonnes of polystyrene globally. Based on average blowing agent percentages of 5.5% w/w for polyurethane and 4.5% w/w for XPS, this leads to an estimated demand of approximately 380,000 tonnes between them with a further 10,000 tonnes being consumed by other foam types.

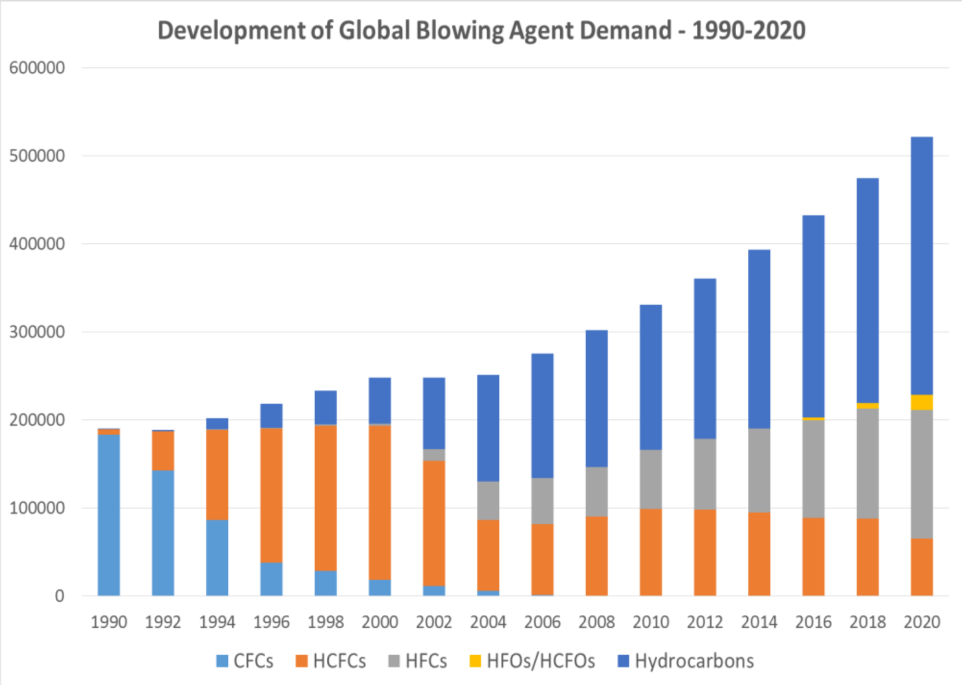


Figure ES-3: Growth in the use of physical blowing agents by type over the period 1990-2020 (source: FTOC report)

Current polymer foam projections[4] suggest on-going growth to 2019 of an average of 4.8% per year, which is slightly more rapid than the 4.4% per year achieved in the period 2009-2014. On this basis global blowing agent consumption can expect to exceed 520,000 tonnes by 2020 unless there are further gains in blowing efficiency as technologies develop. Based on trends in blowing agent selection monitored by the Foams Technical Options Committee, the historic, current and future demand for physical blowing agents is summarised in Figure ES-3 above.

4.2.2 Overview of progress and challenges related to blowing agent transitions

The major blowing agent transitions being driven by regulation at present are those in Article 5 parties resulting from the enactment of Decision XIX/6 and being funded under a series of national HCFC Phase-out Management Plans (HPMPs). HPMPs are currently in their first phase and implementation is generally running smoothly, although there have been delays in the initiation of some plans owing to the significant administration involved. Since Decision XIX/6 requires a “worst first” approach, the phase-out of HCFC-141b has particularly been targeted over the period covered by this report. This has been largely successful within larger enterprises where the critical mass of the operation is sufficient to justify investment in hydrocarbon technologies. Indeed, in several instances, individual enterprises have

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[4] RAPRA Report ‘The Future of Polymer Foams: Market Forecasts to 2019’

been willing to co-fund the investment where the funding thresholds available under the Multilateral Fund have been insufficient, despite the economies of scale.

Foams manufactured using other blowing agents, notably extruded polystyrene (XPS) which uses HCFC-142b, HCFC-22 or blends thereof, have not typically been part of the first phase of most HPMPs. Apart from the fact that the ozone depletion potentials (ODPs) of the blowing agents are lower than for HCFC-141b, there are no obvious alternatives currently available. Although CO_2 technology is prevalent in Europe, it is still not clear whether this will be sufficiently versatile to be used in the variety of manufacturing plants operating in Article 5 parties. Other alternatives include hydrocarbons and ethers, but the flammability of these blowing agents is viewed by many as problematic when coupled with a polystyrene matrix which is also facing reformulation of flame retardants following the action being taken on hexa-bromo-cyclo-dodecane (HBCD) under the Stockholm Convention. The situation has been further compounded in Asia since 2010 by a series of significant fires associated with insulation which have taken place in high-rise buildings (typically during the construction phase). Despite these concerns, investment in XPS manufacturing capacity has continued to spiral as demand for inexpensive and effective insulation has increased. This has particularly been the case in Russia, the Middle East and parts of Eastern Europe and North Africa. The current choice of blowing agent for these new installations, as well as for the existing ones, are blends of HFC-134a/HFC-152a. This is not a good choice for the climate, since these blends have relatively high Global Warming Potential (GWP) and the manufacturing process for XPS is also significantly emissive. There may be some hope that blends based on a combination of hydro fluoro olefins (HFOs) and/or hydro chloro fluoro olefins (HCFOs) together with hydrocarbons or ethers may ultimately satisfy the process and product requirements of XPS, but the continuing uncertainty is certainly causing delay on conversions under relevant HPMPs. The net impact of these trends is projected in the Figure ES-4 below:

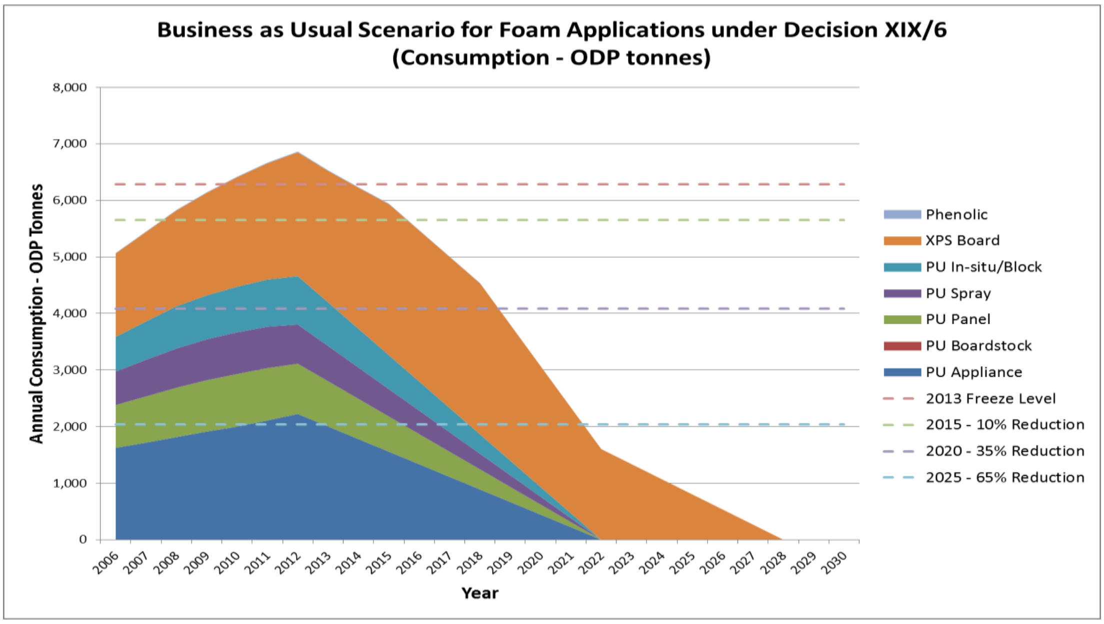


Figure ES-4: Evolution of consumption patterns for blowing agents in Article 5 Parties with time

The growth in XPS can be seen as potentially responsible for a breach of the 2013 freeze – at least for the foams sector. However, this does not automatically mean that parties will be non-compliant with the Protocol, since there is always the potential to compensate in other sectors. Nevertheless, the significance of the XPS challenge is self-evident.

The other major factor that threatens the smooth phase-out of blowing agents in both Article 5 and non-Article 5 parties is the challenge of dealing with a multitude of small medium enterprises (SMEs). In these instances, the lack of economies of scale does not allow for the adoption of hydrocarbons, while the adoption of high GWP alternatives such as HFCs will result in high levels of emission within processes which are either less well engineered or are unavoidably emissive because they are used in-situ (e.g. PU Spray Foams). Although transitions from HCFCs to HFCs were largely unavoidable in many non-Article 5 jurisdictions at the time of phase-out of HCFCs, there is increasing pressure now to switch to low-GWP technologies. With hydrocarbons being problematic from a safety perspective, the focus is on the potential role of non-flammable blowing agents such as HFOs/HCFOs or all water-blown formulations. In some specific market niches such as integral skin, oxygenated hydrocarbons such as methyl formate and methylal are becoming the blowing agent of choice. In the major PU Spray Foam markets of the USA and Canada, there are increasing signs that HFOs/HCFOs may have a significant role to play, with commercial systems now beginning to emerge.

Non-Article 5 parties in North America, Europe and Japan are now actively pursuing regulatory strategies to encourage the phase-out of HFC use in the foam sector, wherever possible. In Europe, this has been enacted under the re-cast F-Gas Regulation, while in the USA, the potential to utilise the existing Significant New Alternatives Program (SNAP) is being explored as a tool for the de-selection of some blowing agent options. These regulatory initiatives could place particular pressure on the XPS industry in these regions, since universally acceptable alternatives are still to emerge.

In summary, while HCFC phase-out and HFC avoidance are being pursued in tandem, the more challenging areas are yet to be fully tackled. Much still depends on the future availability and cost of low-GWP blowing agents. One encouraging factor, particularly with HFOs/HCFOs, is that the thermal performance of the foams is, as a minimum, retained and in many cases improved over the HCFCs and HFCs that they are likely to replace. The commercialisation plans for these blowing agents remain on track and the next 2-3 years should confirm acceptability within the various foam sectors.

4.2.3 Update on bank estimates and emerging management strategies

Global banks of blowing agents in foams have been previously estimated to have grown from around 3 million tonnes in 2002 to an estimated 4.45 million tonnes (inclusive of hydrocarbons) in 2015 (data adapted from the Special Report on Ozone and Climate 2005). Consumption is still typically outstripping emissions by around 250,000 tonnes/year, implying that banks of blowing agents will grow to well in excess of 5 million tonnes by 2020. However, a significant proportion of this bank will already have moved into the waste stream (typically landfill) by that time as installed foam products reach the end of their respective service lives. Figure ES-5 shows how this flow into the waste stream might vary by foam sector based on anticipated product lifetimes.

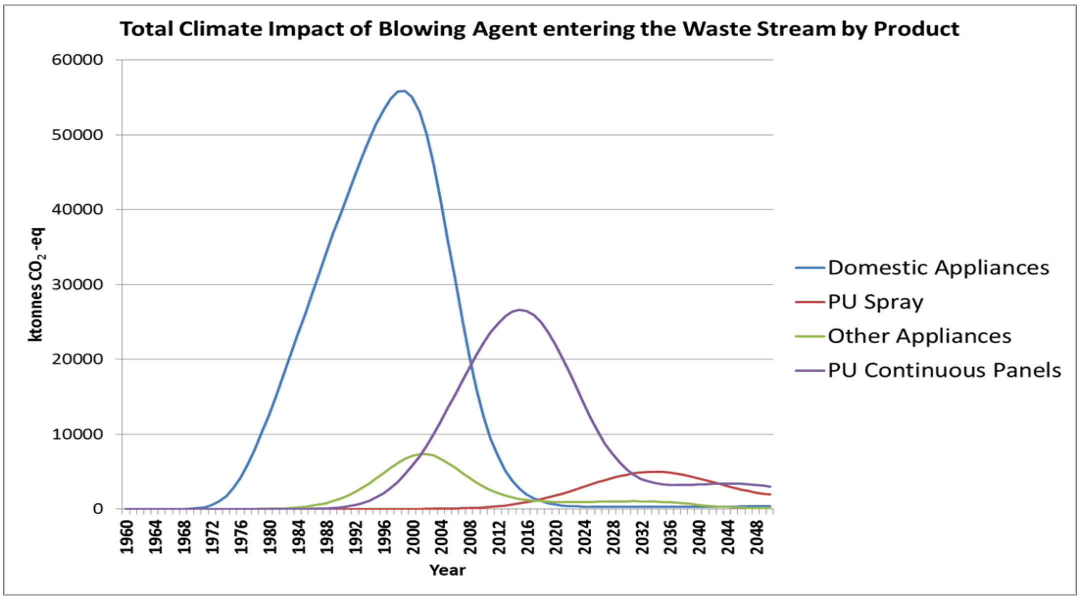


Figure ES-5: Variation in the size and timing of blowing agent waste flows

Once in the waste stream, such banks are broadly unreachable and the environment needs to rely on natural mechanisms such as anaerobic degradation to avoid the worst impacts of eventual blowing agent emission. Increasingly, ODS-containing foam is being treated as hazardous waste in a number of regions in an effort to avert uncontrolled landfilling, but the over-riding challenge is to be able to police shipments sufficiently well to avoid the practice when there is no simple way of determining foam blowing agent routinely. The search for appropriate detection equipment continues, since it would not only allow for the characterisation of waste, but would also assist customs officials on cross-border trade of foam products where blowing agent restrictions may be in force.

A further option is to encourage voluntary intervention at the point of decommissioning by assigning value to the recovery and destruction of the foam or its blowing agent. At present, this value is most likely to arise from the climate benefits associated with the activity. However, an additional point of concern is that the average global warming potential (GWP) of the waste stream will decrease with time as the very high GWP blowing agents (e.g. CFCs) become less prevalent. Figure ES-6 illustrates how this can happen:

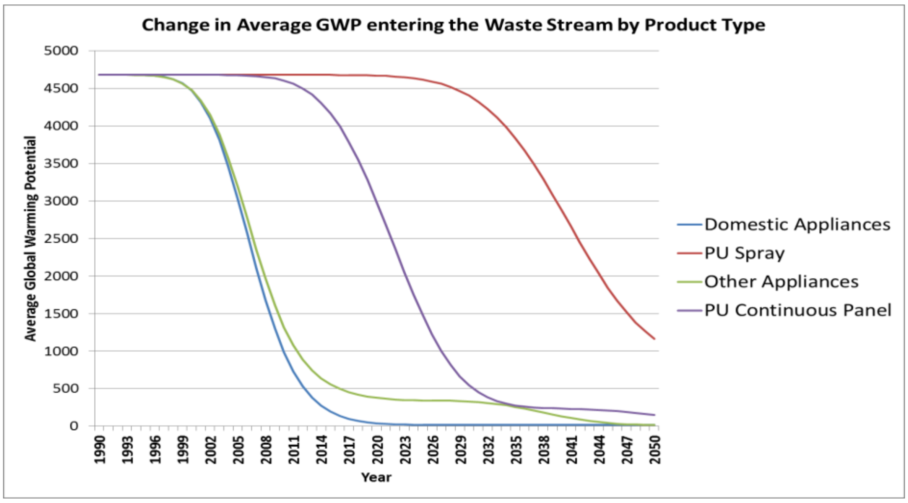


Figure ES-6: Expected decline in average GWP of the waste streams for typical foam applications

These trends imply that it is preferable to introduce effective waste management practices in the period prior to 2030 for PU Spray Foam. However, more importantly, they indicate that much of the climate benefit arising from the management of appliances foams has already passed. This is being borne out in practice for many appliance recycling plants, where the associated climate benefit cannot now be relied upon as a justification for investment. The consequence is that waste handling companies are looking to minimise their upfront investment costs in equipment and manual dismantling practices are becoming increasingly common for foam separation, even though there are associated emissions. This is especially the case in areas of low population density, where the economies of scale are more limited.

4.3 Halons Technical Options Committee (HTOC)

The HTOC is of the opinion 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 for service, in particular legacy systems. 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.

4.3.1 Inventories of Halons

1. The rates of halon emissions based on atmospheric measurements of halon concentrations are similar to the rates of emissions based on model estimates. The estimated size of the global

halon banks in 2014 are: halon 1211 - 33,000 MT; halon 1301 - 43,000 MT; and halon 2402 - 9,000 MT.

2. The total quantities of inventories of halons are not necessarily available for redeployment for multiple reasons, e.g.:

    a. It is often the case that the quantities, locations and availability of halons stocks are not known either within countries or regions;

    b. Where halon quantities and locations are known it is because owners want to preserve these materials for their own use.

    c. Many countries have no halon bank management programme for connecting recyclable halon to users.

    d. Numerous reports have indicated halon quality is suspect due to lack of controls and infrastructure.

    Thus, while the actual quantities of halons may be substantial, their use is jeopardized by political borders, suspect quality, and uncertain quantities in specific locations.

3. The 2010 HTOC report projected a 2014 halon 1211 bank of approximately 50,000 MT, while the 2014 HTOC report estimates a bank of 33,000 MT. This is because the HTOC has raised its assumed emission rates for halon 1211, based on a recent assessment of the likely emissions from retired portable extinguishers, particularly in A5 Parties.

4. Although the regional disparity in the distribution of halon itself does not constitute necessarily a regional problem, it is anticipated that regional imbalances may result in shortages in one country or region with excesses in other countries and regions.

5. The HTOC has a serious concern that many users are relying on halon imports for their most important uses, such as civil aviation and military.

6. Some A5 users are now encountering difficulties obtaining sufficient quantities of halon, with potential serious consequences.

7. Parties may wish to revisit the global strategic approach to halon bank management in order to avoid a severe supply disruption that would lead to an Essential Use Nomination. This could include development of updated training and awareness materials and programs, which address the harmonization of import and export regulations, purity and other halon bank management needs.

4.3.2 Civil Aviation

1. The fact that alternatives are used only in the lavatory fire extinguishing systems of in-production aircraft is a remarkably disappointing result, especially given the extensive research and testing efforts on aviation applications since 1993.
.
2. To date, the two low GWP candidates for engine nacelles have not passed all required tests by the civil aviation safety authorities. Airframe manufacturers have chosen not to pursue qualification and installation certification for HFC-125 owing to weight penalties and more recently, growing controls by individual jurisdictions.

3. The civil aviation industry has decided to develop a single agent/approach and has formed the Engine/APU Halon Alternatives Industry Consortium (IC).

4. The International Coordinating Council of Aerospace Industries Associations (ICCAIA) has formed the Cargo Compartment Halon Replacement Working Group (CCHRWG) to begin to coordinate a single industry effort to find an alternative to halon 1301 in cargo bays.

5. While the halon requirements of civil aviation initially appear modest in comparison to the total inventory available today, civil aviation neither owns nor controls the ever reducing quantities of halons needed to support existing aircraft, much less new aircraft, for an additional 30 or more years.

6. Of all the sectors, civil aviation is the least prepared to deal with diminishing halon supplies and, with the ultimate exhaustion of supplies, this sector will most likely be the one to request an Essential Use Nomination in the future.

4.3.3 Military

1. Generally speaking, halon is only required to support legacy systems and their variants, and new military aircraft based on commercial designs with airworthiness certifications. Alternatives are available for all other new system designs.

2. The ultimate requirement of the military sector for halons cannot be calculated owing to the obvious uncertainty of future mission requirements.

3. It is unclear how many military organizations have made provisions to secure long-term supplies of halons.

4. Some military organizations are known to be completely reliant upon sources of halons outside of their own countries.

5. Adverse geopolitical events might lead to increased rates of depletion of known halon stocks and loss of access to out-of-country supplies.

6. Unlike the civil aviation sector, the military sector has incorporated alternatives to halons on many of its newer platforms, reducing its future demand for the diminishing supplies of halons.

4.3.4 Oil & gas operations

1. Generally speaking, halon is only required to support legacy facilities; all new facilities are halon-free.

2. Legacy facilities in the far north will continue to require the use of halons in occupied spaces owing to severe ambient (very low temperature) conditions.

3. Facility owners neither own nor control the quantities of halons needed to support operations over the continually extended time horizons. This situation will continue to place demands on the level of available halon stocks. However, owing to the adoption of alternatives in new facilities, this sector has reduced its future demand for the diminishing supplies of halons.

4.3.5 Alternative technologies

1. While no single alternative has been commercialized that covers the wide range of applications of halons, there are a multitude of alternatives that collectively can be used to meet the fire protection requirements of all non-aviation future applications, although with technical or economic penalties, or both and likely civil aviation future applications also with technical or

economic penalties. Civil aviation has yet to try to validate and implement technically viable solutions with weight and/or space penalties.

2. Some applications, including those in the military, aviation, and oil & gas sectors, require use of high-GWP chemical alternatives or the original halon to meet the fire protection requirements.

   Five new low-GWP chemicals are in various stages of evaluation as alternatives for halons; none of these prospective alternatives are expected to be commercially available for years, if at all.

4.4 Medical Technical Options Committee (MTOC)

4.4.1 Global CFC use for MDIs

There has been significant global progress in the transition from CFC metered dose inhalers (MDIs) to CFC-free inhalers, with substantial and growing capacity to manufacture CFC-free inhalers. The global use of CFCs to manufacture MDIs in 2013 was about 300 tonnes, a reduction of almost 90 per cent from the last assessment. Since global CFC use to manufacture MDIs peaked in 1997 at about 10,000 tonnes, there has also been a dramatic decrease in annual CFC consumption in MDIs of 97 per cent.

Of those Parties that reported, Article 5 Parties (China only) used about 165 tonnes, and non-Article 5 Parties (Russian Federation and the European Union) about 150 tonnes, of CFCs for the manufacture of MDIs in 2013. Annual CFC consumption by Article 5 Parties peaked at about 2,000 tonnes in 2007-2009, dropping to less than 200 tonnes in 2013. Only one Article 5 Party, China, nominated CFCs for MDI manufacture in 2015, which is likely to be its last Essential Use Nomination. No non-Article 5 Party nominated CFCs for MDI manufacture in 2015. These developments signal the imminent global phase-out of CFC MDIs, which in the last two decades has consumed almost 70,000 tonnes of CFCs under Essential Use Exemptions.

Stockpiles of pharmaceutical-grade CFCs are difficult to quantify accurately. Of the Parties that disclosed accounting frameworks, pharmaceutical-grade CFC stockpiles were reported to be about 545 tonnes at the end of 2013, with China possessing the majority of stockpiles (477 tonnes). Some Parties have gradually depleted their stocks, while other Parties are still manufacturing CFC MDIs and/or using CFC stockpiles as strategic reserves (China and possibly Russia). Some CFC stockpiles are surplus and may need to be destroyed. In practice, it has proved difficult to transfer stockpiles of pharmaceutical-grade CFCs between Parties and/or between companies due to complex commercial, technical, regulatory and logistical reasons. There are only a few examples of stockpile transfers that have occurred successfully.

4.4.2 Technically satisfactory alternatives are available

Technically satisfactory alternatives to CFC MDIs to treat asthma and chronic obstructive pulmonary disease (COPD) are available in all countries worldwide. There are sufficient CFC-free alternatives available for all key classes of drugs used in the treatment of asthma and COPD. The new treatments have different characteristics, which need explaining to patients, and training to use properly. Some patients have switched to HFC MDIs (different taste, softer spray, less cooling in the throat), and some switched to dry powder inhalers (DPIs), which require breath actuation (cheap single-dose capsules, or more expensive multi-dose devices).

With the exception of China, the phase-out of CFC MDI manufacturing has been completed worldwide. Russia is in the final stages of manufacturing conversion to HFC MDIs, with completion likely in 2015, and no reported use of CFCs to manufacture MDIs during 2014. Multinational pharmaceutical companies in non-Article 5 Parties have completed the development of alternatives to CFC MDIs for all major classes of drug. Some manufacturers continued to produce CFC MDIs until stocks were exhausted or regulatory requirements prohibited sale. Consequently, there was a small proportion of CFC MDIs still being manufactured and/or sold in non-Article 5 Parties until the end of 2013.

Manufacturing conversions in Article 5 Parties are almost completed, with China likely to cease CFC MDI manufacturing in 2015-2016. Despite initial challenges, such as access to technology transfer and economic barriers, progress has been significant with a number of Article 5 Parties completing their transition to CFC-free inhalers faster than expected. A range of alternatives are becoming available as CFC MDI manufacturing ceases, HFC MDI manufacturing increases, single- and multi-dose DPI availability increases, and imported CFC-free alternatives become more available. Some pharmaceutical companies in Article 5 Parties continued to manufacture and export CFC MDIs after manufacturing conversions to CFC-free alternatives commenced or were already well underway. These export practices probably slowed the introduction of CFC-free alternatives in importing Article 5 Parties.

4.4.3 Global HFC use for MDIs

Approximately 630 million HFC based MDIs are currently manufactured annually worldwide, using approximately 9,400 tonnes of HFCs in 2014 (95 per cent HFC-134a, 5 per cent HFC- 227ea). This corresponds to direct emissions with a climate impact of approximately 0.013 Gtonnes CO_2-equivalent. HFC emissions from MDIs are estimated as about 0.03 per cent of annual global greenhouse gas emissions. Global HFC demand for MDI manufacture is estimated to increase annually by 2 per cent for the period to 2025.

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 estimates of carbon footprints of inhalers, the climate impact of HFC MDIs is more than one-tenth the climate impact of CFC MDIs, and DPIs have about one-hundredth of the impact of CFC MDIs and less than one-tenth the impact of HFC MDIs.

DPIs are technically and economically feasible alternatives that could minimise the use of HFC MDIs. Nebulisers and emerging technologies may also be technically feasible alternatives for avoiding the use of some HFC MDIs. The exception is for salbutamol; currently salbutamol HFC MDIs account for the large majority of HFC use in inhalers, and are significantly less expensive per dose than multi-dose DPIs, making them an essential and affordable therapy. At present, it is not yet technically or economically feasible to avoid HFC MDIs completely because there are economic impediments in switching from HFC MDIs to multi-dose DPIs for salbutamol, and because a minority of patients (10-20 per cent or less) cannot use available alternatives to HFC MDIs. Nevertheless, DPIs may play an increasing role over the next decade.

4.4.4 Patient health considerations

Asthma and COPD are increasing in prevalence worldwide; the acceptance and use of inhalers are also increasing, especially in Article 5 Parties. The conversion to CFC-free inhalers has not had any adverse impact on patients. On the contrary, the extensive educational campaigns have had a positive impact on the health of patients by increasing the awareness of the benefits of inhaled therapy.

MDIs, DPIs and novel delivery systems all play an important role in the treatment of asthma and COPD, and no single delivery system is considered universally acceptable for all patients. Similarly, not all active ingredients are available equally as either an MDI or DPI. Healthcare professionals continue to consider that a range of therapeutic options is important. Each country has its own unique and complex makeup in terms of availability of medicines, overarching health care systems, and patient preferences. Clinicians and patients have their own preferences based on their own experiences in practice. What is common to all devices is the need to provide adequate training for correct usage to minimise errors, and for clinicians to prescribe the device that the patient can most easily use and afford. 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.

4.4.5 Other medical aerosols

The term aerosol product describes a product *pressurized* with a propellant that expels its content from a canister through a nozzle. Propellants can be compressed gases (nitrogen, nitrous oxide, carbon dioxide), or can be liquefied gases that are a liquid inside the pressurized container; these liquefied gas propellants include CFCs. Medical aerosols are used to deliver topical medication mostly onto the skin, but also to the mouth, and other body cavities. When the Montreal Protocol identified essential uses for CFCs, it differentiated oral inhalation (MDIs) from other medical aerosols, for which CFCs were considered non-essential.

Medical aerosols, that are not MDIs, cover a wide range of uses from simple numbing of pain, nasal inhalation, to the dosage of corticosteroids for the treatment of colitis. The availability and number of different medical aerosol products varies within countries and regions, and is closely related to the development of the local aerosol industries.

Technically and economically feasible alternatives to ozone-depleting propellants (CFCs and HCFCs) are available for all other medical aerosols. Other medical aerosol products were reformulated to use CFC-free propellants. CFC propellants were replaced mostly by hydrocarbons (butane, propane, isobutane, dimethyl ether (DME)), but also by HCFCs and HFCs, in specific applications. Medical aerosol products for use on or near nose or mouth, and also on babies, tend to use HFCs or nitrogen. For treatments where there is a significant risk of inhalation into the respiratory tract, HFCs are preferred, as their safety is well proven through use in MDIs. Propane or isobutane (and their blends) tend to cause an "oily" or slightly stinging taste. All other pressurised medical aerosol products tend to use propane/butane mixtures or DME and compressed gases to a lesser extent. Aqueous sprays and drops are well-established not-in-kind alternatives to nasal aerosol products. Aqueous formulations in general and other not-in-kind alternatives, such as creams, are also used in many applications.

Many external factors affect the selection of a given propellant, including regulatory approval of products, industry codes of conduct, Volatile Organic Compounds controls, and supplier controls of HFC-134a.

HCFC use is about 100 ODP tonnes or less worldwide (HCFC-22 and HCFC-141b), with the majority used in China. In 2010, the total amount of HFCs used for all aerosol products was equivalent to 5 per cent of global HFC consumption, and was estimated as 0.054 Gtonnes CO_2-equivalent. Seventy-six per cent of this GWP-weighted amount was used for medical aerosols (0.041 Gtonnes CO_2-equivalent). Less than an estimated 10 per cent of all other medical aerosols use HFC propellants, with estimated HFC consumption of less than 1,000 tonnes per year. The majority of these would be for nasal inhalation, throat topical medication, and nitroglycerin sublingual application. This consumption is not likely to grow in the near future.

4.4.6 Sterilants

Sterilization is an important process in the provision of good quality healthcare services. It is also a process that requires strict application of the principles of quality management, reliability and long-term materials compatibility. Therefore, any alternative to the use of ozone-depleting substances needs to be well proven and tested to avoid putting the health of patients unnecessarily at risk. It is legal requirement in pharmaceutical and medical devices industries that any change in manufacturing processes, including sterilization, must be validated using appropriate guidelines before implementation.

There is a range of viable sterilization methods that can replace the use of ozone-depleting substances in this sector, including: 100 per cent ethylene oxide, aldehydes, heat (moist heat or dry heat), radiation, and oxidative processes (including hydrogen peroxide gas, liquid peracetic acid, and ozone gas). Further sterilization methods, based on these and other chemicals, are now available or are under investigation for commercialization. Many of these alternative technologies provided significant advances, such as better safety profiles and turn-around times, and reduced cost per cycle.

CFC-12 used in blends with ethylene oxide (EO) in the sterilization sector has been successfully phased out in non-Article 5 Parties, and in many Article 5 Parties. Although it is difficult to be certain, global use of CFCs for this application is believed to be zero.

EO/HCFC mixtures (10 per cent by weight EO in a mix of HCFC-124 and HCFC-22) are virtual drop-in replacements for the EO/CFC blends and were introduced as transitional products for sterilization in those countries that employed EO/CFC blends extensively. Estimated global use of HCFCs in sterilization is less than 500-700 metric tonnes, which amounts to less than 25 ODP tonnes worldwide. EO/HCFC use in Article 5 Parties is estimated to be less than 200-400 tonnes. EO/HCFC use has been significantly reduced by using less gas per sterilizer load, 100 per cent ethylene oxide, and by hospital conversion to other technologies. The complete phase-out of HCFCs in sterilization uses to meet the Montreal Protocol schedule is readily achievable. Hospital procurement should take the HCFC phase-out, and the coming redundancy of EO/HCFC sterilization equipment, into consideration in making future investment decisions.

4.5 Methyl Bromide Technical Options Committee (MBTOC)

4.5.1 Mandate and report structure

Under Decision XXIII/13 taken at the Twenty-Third Meeting of the Parties to the Protocol in 2011, the Parties requested the Assessment Panels to update their 2010 reports in 2014 and submit them to the Secretariat by 31 December 2014 for consideration by the Open-ended Working Group and by the Twenty Seventh Meeting of the Parties to the Montreal Protocol, in 2015.

As required under Decision XIII/13, the MBTOC 2014 Assessment reports on advances since 2010 to replace Methyl Bromide (MB) 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 with specific reference to challenges associated to the phase-out and its sustainability. It also reports on QPS uses, which are presently exempt from controls under the Montreal Protocol. It reports on technically and economically feasible alternatives for non-QPS and QPS uses of MB and gives actual examples of their successful commercial adoption around the world. It shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of MB to the atmosphere, and strategies to reduce those emissions.

4.5.2 The Methyl bromide TOC

As at December 2014, MBTOC had 29 members: 12 (41%) from Article 5 parties and 17 (59%) from non-Article 5 parties. Members came from 7 Article 5 and 9 non-Article 5 countries. After the renomination process in 2014 MBTOC numbers have reduced to has twenty members in 2015, 10 from Article 5 and 10 from non-Article 5 Parties.

4.5.3 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 also led countries to impose severe restrictions on methyl bromide use including 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 of concern.

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 submitted nearly 150 applications for 18,700 tonnes for ‘critical uses’ after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol. By 2014 the number had declined to three applications for 267 tonnes for use in 2016. Use of methyl bromide under the ‘Critical Use’ provisions is available to ‘Article 5 countries after 2015 and accordingly in 2014 three Article 5 Parties submitted six nominations for use of 500 tonnes in 2015.

Although QPS uses must be officially reported under Article 7 of the Protocol they continue to be exempt from controls under Article 2H.

4.5.4 Production and consumption trends

At the time of writing this report, all Parties had submitted data to the Ozone Secretariat for controlled uses in 2013. Although a few cases of data gaps remain from past years, reported data is much more complete than in the past. All tonnages are given in metric tonnes in this report.

In 2013, global *production* for the methyl bromide uses controlled under the Protocol was 2,493 tonnes, which represented 9% of the 1991 reported production data (66,430 tonnes). Less than 0.5% of production occurred in Article 5 countries.

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 8,148 tonnes in 2009 and declined to about 2,953 tonnes in 2013. Historically, in non-Article 5 regions, about 91% of methyl bromide was used for pre-plant soil fumigation 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), non-Article 5 consumption had been reduced to 11,470 tonnes, representing 21% of the baseline. Many non-Article 5 countries achieved complete phase out for controlled uses before 2009 (New Zealand, Switzerland and countries of European Community), the two latter Parties for all uses by 2011. Israel and Japan phased out for controlled uses in 2011 and 2012 respectively (for preplant soil uses). For the remaining uses phase-out or substantial reductions have occurred in most sectors; the USA, which was the largest non QPS user of MB historically, has indicated that 2016 will be the last year of MB for its remaining preplant soil use in the strawberry fruit sector. Many Article 5 Parties previously included among the largest users now report complete phase-out (i.e. Brazil, Turkey, Lebanon, Zimbabwe, Morocco). Other Article 5 Parties have made very significant reductions in their consumption since 2005 and aggregate consumption is now at 14% of the baseline (86% has been replaced).

In 2014, the Meetings of the Parties approved CUEs of 485.589 tonnes for use in 2016 in three non-Article 5 Parties and 333.257 tonnes for 2015 in Article 5 Parties.

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 2013 permitted levels of consumption (for CUEs) in these four Parties was 2.2%, 0% and 0% and 3.3% of their respective baselines, although in 2014 Japan reached total phase out.

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 baseline years. Total Article 5 consumption reduced to 2,276 tonnes in 2013, which is 14% of the baseline. A MBTOC survey of ozone offices, regional networks and national experts in 2014 provided information on the breakdown of methyl bromide uses in major methyl bromide-consuming countries. In 2013, an estimated 93% was used for soil and 7% for commodities/structures, not including QPS, in Article 5 regions. 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.

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. Fifty-six Article 5 parties (38%) have never used MB or reported zero MB consumption since 1991. The total number of Article 5 parties that have consumed MB (currently or in the past) is 91, or 62% of the total 148 Article 5 parties. Of the 91 MB-user countries, 73 (80%) have phased out MB, and only 18 still reported consumption in 2013.

4.5.5 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 98% by mass of controlled uses in 2013.

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 may exist that limit the implementation of some key alternatives and this can affect the ability to completely phase-out methyl bromide in some countries.

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. 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.

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 for controlled uses with amounts used in 2013 falling 85% from about 57,400 tonnes in 1992 to less than 450 tonnes, in non-Article 5 Parties and about 2,210 tonnes in Article 5 Parties.

The main crops for which methyl bromide is still being used in non-Article 5 countries are strawberry fruit, and strawberry runners. Some uses previously considered under the CUN process have been partially reclassified as QPS (e.g. forest nurseries). Crops still using methyl bromide in 2013 in Article

5 Parties included cucurbits, strawberry fruit, ginger, nurseries (strawberry and raspberry runners) tomatoes and other vegetables.

Since the 2010 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, metham sodium) and new fumigants (i.e., dimethyl disulfide), but also due to increased uptake of non-chemical alternatives i.e. grafted plants on resistant rootstocks, improved steaming methods, substrate production, biofumigation.

In 2008, a one to one replacement to MB, iodomethane (methyl iodide) was registered in several countries (USA, New Zealand), however the manufacture of this fumigant was withdrawn in 2012. Dimethyl disulfide (DMDS) is now registered in the USA (not California) and other countries. The world has seen an increase in regulations on alternatives, with tighter regulations on all fumigants particularly in the EU.

Chemical alternatives

The following fumigants are currently available in many regions and are the main alternatives that have been adopted as alternatives for MB.

- 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.

- 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, for this reason it is often combined in mixed formulations with chloropicrin. 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, metham sodium and metham 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.

- Isothiocyanates (ITCs) are sulfur-containing compounds produced by many members of *Brassicaceae* plant family, showing insecticidal and herbicidal activity. Research has demonstrated that they can be used as a pre-plant soil fumigant alternative for broad-spectrum control of weed seeds, nematodes and diseases. Allyl isothiocyanate (AITC) was registered in the USA in September 2013 (but not in California) for many types of vegetables and turf. Its small buffer zone requirement gives it an advantage over other fumigants. AITC is expected to be registered in the near future in other countries including Mexico, Canada, Italy, Spain, Turkey, Morocco, Japan and Israel.

- Sulfuryl fluoride (SF) is an insecticide fumigant gas, widely used for insect and rodent control in post-harvest commodities and structures. SF was registered in China as a nematicide fumigant for cucumber in 2014. This fumigant has a shorter plant-back time than other fumigants including MB and can be applied when soil temperatures are low. These features give this fumigant a significant advantage over other soil fumigants.

- Trials with other chemicals such as abamectin, fluensulfone and certain fungicides are also providing promising options for soilborne pest and disease management in several countries.

The future of soil disinfestation lies in combining available fumigants with other methods, or other fumigants and non-chemical fumigants to obtain acceptable performance. Combined fumigant treatments can expand the pest control spectrum and lead to performance levels that match and even surpass those of MB. Examples include 1,3-D/Pic, 1,3-D or 1,3-D/Pic and MITC, DMDS + Pic and others.

Lack of registration of some MB alternatives as well as regulatory constraints have hampered MB phase-out in some countries where MB is still being used under a critical use exemption.

Non-chemical alternatives

- Grafting, resistant rootstocks and resistant varieties are increasingly 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. Recent studies focus on improving the tolerance of vegetables to abiotic stresses including soil salinity, drought, heavy metals, organic pollutants and low and high temperatures.

- 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. This growing system can be used in combination with other options, for example compost, grafted plants and/ or biocontrol agents, providing very good results.

- Steam disinfestation is an increasingly attractive strategy to control soilborne pathogens and weeds both in greenhouses and field crops. New developments of steam application methods are aimed at reducing costs and extend its use on crops grown outdoors. Development of more efficient and economic steam application equipment, currently in progress, suggests that steam is approaching wider commercial feasibility.

- Solarisation is now increasingly combined with biofumigation or low doses of fumigants, as part of IPM programs to replace MB for controlling soilborne pathogens and weeds in many crops including vegetables and ornamentals with excellent results.

- Anaerobic soil disinfestation (ASD) is a biologically based, non-fumigant, pre-plant soil treatment developed to control a wide range of soilborne plant pathogens and nematodes in numerous crop production systems used for example in Japan, The Netherlands and the USA. Commercial use of ASD is currently limited by cost and uncertainty about its effectiveness for controlling different pathogens across a range of environments. Its feasibility is largely impacted by moisture and availability of appropriate carbon sources. However, active research is underway to adjust this promising option.

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.

The efficacy of grafted plants for example, can be greatly enhanced by combining it with solarisation and biofumigation, green manures, and chemicals such as MITC generators, 1,3-D and non- fumigant nematicides. Combinations of fumigant alternatives (1,3-D/Pic, MNa/Pic) with LPBF or relevant herbicides have been shown to be effective for nutsedge (*Cyperus* spp.). Finding alternatives for nursery industries has proven more difficult as growers are uncertain of the risk of spread of diseases provided by the alternative products. Further, regulators often lack the data to determine if alternatives meet the quality standards (e.g. certification requirements).

Crop specific strategies implemented in non-Article 5 and Article 5 regions are discussed in detail in the 2014 Assessment Report. These include alternatives used for the key sectors where it was necessary to phase-out methyl bromide in specific climates, soil types and locations, as well as application methods and other considerations.

Alternatives for strawberry runners

In 2014, MB is still used in three non-A5 Parties either as a critical use (Australia, Canada) or under a QPS exemption (USA). Mexico is continuing use in 2015 and under a critical use exemption, but trials with alternative fumigants (1,3-D/Pic, metham sodium) are giving encouraging results.

In Australia, the northern production region fully transitioned in 2009 to mixtures of 1,3-D/Pic and Pic alone, however in the cooler southern regions in heavy soil types these alternatives are phytotoxic causing losses of up to 40%, or are ineffective and no alternatives have been adopted except for the use of substrate production of foundation stock. The industry does, however, produce its early generations of runners using soil less culture, which reduces the need for disinfestation with MB/Pic. This system is not economically feasible for later generations.

In Canada in 2008, several regions transitioned to alternatives mainly Pic alone, however owing to its lack of registration in Prince Edward Island the request for a critical use continues.

In the EU (France, Italy, Poland, Spain), growers are using improved application techniques for old fumigants, such as metham sodium and dazomet to grow runner plants.In some countries where MB has been phased-out, there have been market shifts where growers may produce their own plants or where industries import runners produced in other countries.

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

Parties and scientists around the world continue to conduct research aimed at identifying and adopting alternatives to MB for controlling pests causing problems in the structures and commodities sectors. However, as of 2015, all postharvest uses of MB have been phased out in non-A5 Parties and no CUNs have been submitted for these uses for 2016. Some small usage for structures (flour mills), grain and dried foodstuffs remained in Article 5 Parties in 2013.

The main alternatives to the disinfestation of flourmills 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. Although phosphine is the fumigant of choice to replace MB in many postharvest treatments, some problems with its use need attention, particularly the possible development of resistance in the pests to be controlled.

Treatment of commodities with sulfuryl fluoride has also expanded. The fumigant is used for the treatment of grain, cotton and timber. The substance is also used for disinfestation of museums in the

USA. SF is in use for disinfestations of museums (structures) against insect pests in Japan. SF is now intensely used for disinfestation of bulk grain in Australia, also for resistance management of phosphine. China has three factories producing SF for local use and export.

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 registration of chemicals for pest control, including MB, is however under continuous review in many countries.

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.

Update on progress in research into methyl bromide alternatives

Many avenues of research have been pursued in the attempt to find realistic alternatives to MB for the remaining commodity and structural treatments conducted worldwide, as well as and in quarantine or preshipment. These include studies on alternative fumigants such as phosphine, sulphuryl fluoride and ozone, on controlled atmospheres with elevated temperature or raised pressure, on microwave, radio frequency or ionizing radiation, or on heat. Carbon dioxide and ethyl formate is also considered as an alternative chemical for disinfestation.

Producing dates is now considered resolved. Phosphine fumigation, supplied by tablet formulations or a phosphine generator has largely replaced post harvest MB fumigation in Algeria, Tunisia, Egypt, Jordan, UAE, KSA and other countries.

Dry cure pork product in SE USA – the remaining MB critical use in non-A5 Parties

Natural pork products are subject to pest infestation, in part because of the lengthy storage time required for flavour development. The pests most commonly reported are red-legged ham beetles *Necrobia rufipes* and ham mites *Tyrophagus putrescentiae.* Although pest control is being achieved without MB in many countries producing cured ham products, particular conditions present in the USA have made this use very difficult to replace.

Mites are acknowledged to be very difficult to kill with phosphine, and in tests of the effectiveness of SF in 2008, control of the ham mites required three times the US legal limits of SF. Extensive research is under way indicating that the active ingredients that show the most promise as potential methyl bromide alternatives are propylene glycol, butylated hydroxytoluene (BHT), and lard. Propylene glycol (PG) is likely the most feasible food-grade ingredient that could be used to control ham mites but is relatively expensive. Currently, no fully effective treatment has been found which controlled the target pests at commercial scale for Southern cured pork production. MBTOC's review and analysis indicates merit for further research and refinement by pest control fumigators, and in particular for improving the efficacy of SF fumigations as methyl bromide replacements.

Special review on controlling pest eggs with sulfuryl fluoride

Fumigation with SF is one of the pest control methods adopted by some parties as the principal alternative to methyl bromide in some major postharvest and structural uses. The lack of full effectiveness of SF against eggs of pests is mentioned in several critical use nominations. MBTOC collated available data on the fumigation of eggs of stored product insects and especially those occurring in rice and flourmills, the situations of particular concern where SF is a potential or actual methyl bromide replacement. Summaries of published mortality data and lethal responses of eggs of 28 economically important insects and mites following fumigation with sulfuryl fluoride at 20°C are included. Pest species are sorted into groups that are probably, possibly or unlikely to be controlled at

1,500 g h m^{-3} at 26.7°C (80°F) and 24 h exposure. This ct-product is the maximum rate that is allowed under the registration of SF as a pesticide ('label' rate) for control of all developmental stages of stored product pest, such as specified in the 'Fumiguide', a proprietary guide to the use of SF as a postharvest and structural fumigant.

Other alternatives

Research on the use of propylene oxide and ethyl formate as methyl bromide continues and these chemicals are being adopted in several countries. Other chemical options include methyl iodide, MITC and CO_2, ozone, nitric oxide, and carbonyl sulfide (COS).

Adoption of Controlled Atmospheres (CA) and Modified Atmospheres (MA) as a means to control pests in stored commodities continues to increase. CA and MA treatments offer large commercial and small packing houses, even farmers, effective postharvest pest control options useful for most durable commodities (and even non-food commodities such as museum and historical artifacts), under a very wide range of circumstances, without using chemical fumigants. The CA treatment is based on creating a low-oxygen environment within a structure causing death of pests.

The use of irradiation as a phytosanitary treatment has increased with an undetermined part of this volume directly replacing methyl bromide fumigation. In 2013, about 5,800 tonnes of fresh fruit were irradiated for import into the US.

In Europe - especially in Germany - and in the US, parasitic wasps and predators now comprise a significant parts of pest management programs for facilities and stored products. Heat, cold and essential oils, are further options being researched and for which adoption has occurred around the world.

Integrated Pest Management

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. A reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners. Modern strategies concentrate on approaches where the infestation itself is limited at an early stage to prevent later mass growth and necessities for acute and immediate control. Biological control addresses the need of finding ways to attack the first intruders into a storage system.

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

Article 2H exempts methyl bromide used for QPS treatments from phase-out 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.

QPS uses are usually for commodities in trade, but one Party has classified some preplant soils uses of methyl bromide as quarantine uses. Similar uses by other Parties have remained under controls of the Montreal Protocol and have or are being phased out. Alternatives to these uses are discussed in detail in Chapter 5 on alternatives for pre-plant soil fumigation.

Quarantine treatments are generally approved on a pest and product specific basis, and following bilateral negotiations, which may require years to complete. This process helps ensure safety against the incursion of harmful pests.. For this and other reasons, replacing methyl bromide quarantine treatments can be a complex issue. Many non-methyl bromide treatments are, however, published in quarantine regulations, but they are often not the treatment of choice. Nevertheless, partial or complete adoption of alternatives to methyl bromide for QPS has occurred since the 2010 MBTOC Assessment Report. 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. In response to Decisions XX/6 and XXI/10 MBTOC estimated that between 31 and 47% of the MB used for QPS purposes could be replaced with immediately available alternatives.

Global production of methyl bromide for QPS purposes in 2013 was 9,915 tonnes, increasing by about 12% from the previous year. Production occurs in four parties, USA, Israel, Japan and to a much lesser extent, China. 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.

QPS consumption has remained relatively constant over the last decade. In 2009 the QPS use exceeded non-QPS for the first time, being 46% higher. This was partly due to the continued decrease in the non-QPS uses, as well as recategorisation by some Parties of uses previously considered non QPS to QPS. For example since 2003 an amount of methyl bromide included in the initial baseline estimates for controlled MB uses, between 1400 to 1850 t, has been recategorised to QPS MB use for the preplant soil treatment of propagation material. In 2013, reported QPS consumption was over three times larger than controlled consumption.

In 2013, QPS consumption in A5 Parties (5,521 tonnes) represented 56% of global consumption; non-A5 Party consumption, at 4,307 tonnes was 46%. Overall, consumption in Article-5 Parties has trended upward over the past 15 years, whereas consumption in non-A5 Parties. Global consumption averaged 10,850 tonnes over the period 1999 to 2013 and in 2013 (9,830 tonnes) remained close to the average.

On a regional basis, consumption in the Latin America & Caribbean, Africa and Eastern Europe regions has remained much lower since 1999 than in Asia and North America. In 2013, an analysis of global consumption (including both A5 and non-A5 Parties in the regions where appropriate), Asia accounted for 47% of global QPS consumption.

While there remain some data gaps and uncertainties, information supplied by the Parties allowed MBTOC to estimate that four uses consumed more than 80% 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; 4) Logs; and 5) Fresh fruit and vegetables. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, MBTOC calculated that about 31% of global consumption.

Because it is approved by IPPC for compliance to ISPM-15, the main adopted alternative to methyl bromide for wood packaging material is heat (now including dielectric heating); non-wooden pallets provide an additional option. Alternatives for logs include phosphine, sulfuryl fluoride, EDN (cyanogen) and other alternative fumigants; heat, irradiation and water soaking (immersion) and debarking provide further options. Methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants (phosphine, sulfuryl fluoride), by controlled atmospheres or by temperature treatments (heat or freezing). Preshipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems. For pre-plant soil treatments, alternative fumigants are available, provided the alternatives meet certification standards; substrates may be used at least partially in the propagation systems.

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. In 2013, about 5,800 tonnes of fresh fruit were irradiated for import into the US, representing a dramatic increase of 6,500% over usage of this technique in 2007.

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. In the absence of regulatory or economic incentives to adopt alternatives and assuming methyl bromide is in most cases the lowest cost effective system at present, an alternative would not be voluntarily adopted unless it performed as well or better at the same market cost. Technically feasible alternatives will have limited market acceptance if they are more costly – and in the world of bulk commodities, it is difficult to entice end buyers to pay a higher price for goods treated with alternatives.

4.5.7 Progress in phasing-out methyl bromide in Article 5 parties

Progress made in phasing out controlled uses of methyl bromide in Article 5 countries is addressed in view of the phase-out date of 1st January 2015. Challenges and factors that could potentially put the sustainability of the phase-out at risk are analysed together with the major technologies implemented and the factors that have assisted MB phase-out in MLF projects and other efforts to replace MB.

By end of 2013 (the last date for which official data were available at the time of writing this report), about 86% of the controlled uses of MB in Article 5 Parties had been phased out. This was primarily achieved through MLF-funded projects implemented by the agencies of the Montreal Protocol, and has taken place at different rates in different regions. This chapter includes a list of the main types and objectives of such projects together with the main alternatives successfully replacing MB in different countries and regions.

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.

By December 2014 the Multilateral Fund (MLF) had approved a total of 398 methyl bromide projects in more than 80 Article 5 Parties. This included 44 demonstration projects for evaluating and customising alternatives; 130 initiatives for the preparation of new projects, awareness raising, data collection, policy development and others; 95 technical assistance and training projects; and 129 investment projects for phasing-out methyl bromide.

MLF projects approved by December 2013 were scheduled to eliminate a total of 13,939 metric tonnes of MB in Article 5 countries. The total phase-out achieved by MLF projects by December 2013 was 12,165 tonnes (Table 7-3), which is 87% of the total due to be phased out by the projects, a figure which is higher than in previous years.

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.

The projects showed that very large MB reductions are feasible over periods of 4 – 5 years, especially in cases where governments and MB users make constructive efforts to register, transfer and adopt existing alternatives, and where a full range of key stakeholders were involved. 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.

Hurdles faced by Article 5 Parties include factors that go beyond the technical and economic feasibility of the alternatives including market drivers (ability to meet specific market windows), consumer issues, sufficient installed capacity to develop and implement an alternative and regulatory factors.

Challenges that may put the sustainability of the phase-out at risk include the continued unrestricted supply of MB in light of the exemption for QPS uses and the long term viability of some alternatives (for example when pests become resistant to an alternative or when regulations restrict the use of an alternative). Lack of registration of some alternatives are also an obstacle.

In accordance with Montreal Protocol controls, four Article 5 Parties have submitted CUNs for exemptions in 2015 and 2016.

4.5.8 Emissions from methyl bromide use and their reduction

Montreal Protocol restrictions on the use of MB are having greater impact on atmospheric MB than thought possible 10 years previously. The current understanding of the global annual budget (sources and sinks) for MB indicates that the global MB budget is not balanced and that there is potential for current identified sinks to exceed current identified sources by approximately 30 k tonnes. This implies that there may have been either large under reporting of MB production and consumption or that there are unidentified MB sources. Some of these may come from industrial processes, for example the production of purified tetraphthalic acid (PTA) or may be from unidentified natural sources. Resolving the current global budget imbalance requires a better understanding of the oceanic sources and sinks, industrial sources and natural vegetative sources of MB.

Overall total (natural and anthropogenic) MB emissions have declined from in excess of 120 k tonnes per year in 1995-1998 to 85 k tonnes in 2012, driven almost entirely by the declining consumption of non-QPS MB.

In 1995-1998, manufactured MB used in fumigation (48 k tonnes/year) accounted for about 40% of all identified MB sources; by 2012, thanks to countries taking steps to reduce the use of MB for non-QPS purposes, fumigation use had declined to just over 10% (10 ktonnes) of all identified sources, with QPS use accounting for about 8% of all identified sources. The total fumigation use of MB has declined by 80% over this period and the non-QPS fumigation use has declined by over 90%. The impact of the relatively recent and currently limited MB recapture on the global MB budget is likely to be small (less than 200 tonnes recaptured globally per annum (MBTOC estimate).

Owing to the short atmospheric half-life of MB (0.7 years) in the stratosphere, changes in emission of MB at ground level are rapidly reflected in changes in tropospheric and stratospheric MB concentrations.

The latest WMO scenarios suggest that further reductions in atmospheric concentrations are possible over the next few years, but will only occur if the remaining non-QPS uses in developing countries (A5 Parties) and the few non-Article 5 and Article 5 critical uses are phased out, and if emissions or use of MB for QPS are reduced significantly. In 2014, the use of MB for QPS was at least three times the total used for non-QPS in non-Article 5 and Article 5 countries.

Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 41 – 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 67 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 77%.

Best estimates of annual MB emissions from fumigation use in 2013 of 8781 tonnes were 52% lower than in 2009, which totalled 17,041 tonnes.

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.

Parties have been urged to minimise emissions of MB in situations where they still use MB and are unable to adopt non-ozone depleting alternatives. This includes both QPS treatments and fumigations carried out under CUEs (Decisions VII/7(c), IX/6). 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.

Worldwide many fumigations continue to be conducted in poorly sealed enclosures, leading to high rates of leakage and gas loss. QPS treatments with MB could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment. For the 7,456 tonnes used for commodity and structural treatments, principally for QPS use, at 70% recapturable, 5,219tonnes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment.

At this time, there remain no processes for MB approved as a destruction process under Decision XV/9 and listed in any updates to annex II of the report of MOP-15 that listed approved destruction processes by source and destruction method. However, the situation is currently under review (Decision XXII/10).

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 or liquid scrubbing with nucleophilic reagents. 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.

4.5.9 Economic criteria

During CUN evaluations, MBTOC assesses the financial feasibility of alternatives available to the Party (Decision IX/6), because an alternative may be considered technically feasible, but may not be economically feasible. Measurement of the economic implications of the use of methyl bromide or an alternative can in most cases be done satisfactorily by means of a partial budget analysis, a practical tool to compare alternative production practices.

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

4.6.1 Refrigerants

The chapter discusses and provides tabular summaries for identifiers as well as physical, safety, and environmental data for refrigerants and includes brief descriptions of refrigerants treated in this report.

Whatever refrigerant is chosen will always have to be a balance between several factors, the availability and cost of the refrigerant (and the associated equipment), the system energy efficiency, the safety and convenience of applicability, environmental issues and many more.

The perfect refrigerant does not exist, and is unlikely to come into existence. Choices will therefore include existing very low GWP refrigerants (e.g. R-717, R-744 or HCs) and the newly applied or developed chemicals. Many new alternatives are proposed which create a challenge of finding the right refrigerant for each application. In some cases this may be as simple as changing the refrigerant, while in most cases this will require redesign of the system or even change of system topology. The search is a trade-off between cost, safety, energy efficiency, and limiting the need for redesign. One of the important aspects is that refrigerants with low direct impact on climate change are often flammable to some extent.

So far 21 refrigerants obtained standardized designations and safety classifications since the 2010 RTOC assessment report. One new molecule HCFC-1233zd(E) is in this group of new refrigerants and is an unsaturated HCFC (also referred to as HCFO) with potential to replace HCFC-123. Approximately one quarter of the new refrigerants are blends which are replacements for HCFC-22. Of the new refrigerants twelve are blends of saturated HFCs and unsaturated HFCs (HFOs) of which seven blends are with class 2L flammability.

The new refrigerants address climate concerns, and ozone depletion concerns with replacement refrigerants for ozone-depleting substances.

4.6.2 Domestic appliances

Under the domestic appliance category, the domestic refrigeration sub-sector is the major component and comprises appliances that are broadly used domestically, such as refrigerators, freezers and combined refrigerator/freezer products. Small beverage dispensing machines are similar products and are commonly included in domestic refrigeration, but represent a small fraction of total units.

Globally, new refrigerator production conversion from the use of ODS was essentially completed by 2008. HC-600a or HFC-134a continue to be the refrigerant options for new production. No other new refrigerant has matured to become an energy-efficient and cost-competitive alternative. Refrigerant migration from HFC-134a to HC-600a is expected to continue, driven either by local regulations on HFCs or by the desire for reduced global warming impact from potential emissions. Excluding any influence from regulatory interventions, it is still projected that by 2020 about 75% of new refrigerator production will use HC-600a (possibly with a small share by unsaturated HFC refrigerants) and the rest will use HFC-134a.

According to some industrial sources, initial developments to assess the use of HFC-1234yf in domestic refrigeration have begun, but it is not being pursued with high priority, as in automotive applications. Given the cost disadvantage, flammability and investment requirements for product development, HFC-1234yf suffers significant disadvantages. With the lack of activity by manufacturers, HFC-1234yf is not likely to displace HC-600a or HFC-134a in the foreseeable future.

Alternative refrigeration technologies for domestic refrigeration continue to be pursued for applications with unique drivers such as very low noise, portability or no access to the electrical energy distribution network. In the absence of unique drivers, no identified technology is cost or efficiency competitive with conventional vapour-compression technology for mass-produced domestic refrigerators.

The other domestic appliance covered in this chapter is the heat pump clothe (laundry) dryer (HPCD). It is included in this chapter for the first time and the title has been accordingly modified as “Domestic Appliances” instead of “Domestic Refrigerators” used earlier. The market for HPCD is fast growing in the EU with manufacturers from both the EU and Japan. The current market share of HPCDs in Article 5 countries is insignificant. These dryers mostly use HFC-134a as a refrigerant and refrigerant charge amounts vary from 200 to 400 g. HPCDs using R-407C and HC-290 have also been just introduced. Alternative low GWP refrigerant solutions are being explored, including R-744, HC-600a and low GWP HFCs.

Non-Article 5 countries completed conversions of new equipment production to non-ozone depleting substances (ODSs) more than 15 years ago. Later, a few Article 5 countries also completed their conversion, e.g., India by 2003. Therefore, most products containing ozone depleting refrigerants are now approaching the end of their life cycle. Field conversion to non-ODS refrigerants has significantly lagged original equipment conversion. The distributed and individual proprietor character of the service industry is a barrier to co-ordinated efforts to convert from ODS refrigerants. Field service procedures typically use originally specified refrigerants. Refrigerant blends developed specifically for use as drop-in service alternatives have had limited success.

Both mandatory and voluntary energy efficiency regulation programs catalysed industry product efficiency development efforts. A number of improved energy efficiency design options are fully mature, and future improvements of these options are expected to be evolutionary. Extension of these to an all-global domestic market would yield significant benefit, but is generally constrained by availability of capital funds and related product cost implications.

4.6.3 Commercial refrigeration

Commercial refrigeration can be broadly classified as three different groups of systems: centralised systems (refrigerant is field charged) installed in supermarkets, condensing units (refrigerant is field charged) installed mainly in small shops and restaurants, and self-contained or stand-alone units (refrigerant is factory charged). On a global basis, HCFC-22 continues to represent a large refrigerant bank in commercial refrigeration and is used at all temperature levels. The most widely used HFC is R-404A and this for all temperature levels. Over the last decade, HCs --for low refrigerant charge systems-- and CO_2 --for supermarkets-- have taken significant market share, especially in Europe. In parallel, progress has been made to improve energy efficiency and leak tightness especially for centralized systems. The progressive phase-out of HCFC-22 in developing countries requires making informed choices on the best replacement options.

Stand-alone Equipment: Even if they have very different GWPs, HFC-134a and R-404A can be expected to be phased-out progressively in developed countries. Lower GWP HFC and HFC blends, hydrocarbons and CO_2 are replacing R-404A and HFC-134a in new stand-alone equipment. Minimum energy standards have been issued or updated in many countries making a new competition between manufacturers in order to reach higher energy efficiency in stand-alone systems.

Condensing Units: Condensing units are designed for several capacities and are standardized equipment; their cooling capacities vary from 5 to 20 kW with a refrigerant charge varying from 1 to 5 kg. HCFC-22 is still the most used refrigerant in all Article 5 countries. For new systems, R-404A is still the leading choice, and intermediate blends such as R-407A or R-407F are proposed as immediate options to replace R-404A. Global companies are now offering hydrocarbon condensing units for smaller capacities.

Supermarket systems: The size of centralised systems can vary from refrigerating capacities of about 20 kW to more than 1 MW relative to the size of the supermarket. Refrigerant charges range from 40 up to 3000 kg per installation. In Article 5 countries, HCFC-22 is still the dominant refrigerant used in centralised systems. In Europe, new systems have been mainly charged with R-404A; R-744 is now taking a significant market share with improved energy efficiency by using two-stage systems, options well known from industrial refrigeration. For small and medium size supermarkets, the so-called "booster system" has been designed to use CO_2 at the low and the medium temperature levels. For large supermarkets, the cascade system is preferred with CO_2 at the low temperature level and CO_2 or HFC-134a at the medium temperature level. Distributed systems are also quite common, gaining market share with improved energy efficiency, lower charge levels and lower emission rates. Indirect systems are also popular in order to limit the refrigerant content by more than 50% and to drastically lower refrigerant emission levels. For developing countries, the important issue remains the replacement of

HCFC-22, either for retrofit or for new installations. Blends such as R-407A or R-407F constitute options offering significantly lower GWP than R-404A and R-507A.

4.6.4 Industrial systems

The majority of large industrial systems use R-717 as the refrigerant. When R-717 is not acceptable in direct systems in these countries, options include R-744 or glycol in secondary systems or HCFCs or HFCs in direct systems. In countries where R-717 has not been the preferred solution, or in market segments with smaller systems, the transition from HCFC-22 is not straightforward. It requires acceptance of higher cost fluorocarbons in systems similar to the types used with R-22 or the adoption of more expensive systems with the cheaper refrigerants R-717 and R-744. This transition is slow and is constrained by a lack of trained personnel and lack of experience of the local end-users. It has been facilitated by corporate policy from multinational food and beverage manufacturers. The process of moving from HCFCs to zero ODP, low GWP alternatives would be accelerated by a concerted education and training programme including operational experience and lessons learned from existing systems. This conclusion has been reinforced by several recent fatal accidents in Article 5 countries. These accidents appear to be caused by the acceptance of low standards of safety that would not be acceptable in more mature markets. Suitable safety standards already exist, for example those published by the International Organisation for Standardization (ISO).

In markets where R-717 is accepted as the preferred refrigerant there is no indication of any likelihood of new refrigerants gaining any significant market share. It is self-evident that if the current range of HFC fluids that could be used in these applications are being avoided due to concerns about refrigerant price and long term availability in bulk quantities then new fluids, which are expected to be even more expensive than current HFCs will not be any more successful. There are a few exceptions to this general rule. For example, HFC-1234ze(E) has been demonstrated in large district heating systems as a possible replacement for HFC-134a, however its performance is not any better than HFC-134a which is already limited in application and efficiency compared for example with R-717. HFC-1234ze(E) has also been demonstrated in centrifugal chillers which could be used in process cooling or in district cooling installations. This may be a key player in addressing the challenge of rapid market growth in the Gulf Co-operation Countries over the next twenty years.

The industrial sectors covered by this chapter are too diverse to facilitate the level of development expenditure required to bring a new fluid to market. It therefore follows that if any new development gains market share in industrial systems, it will be a fluid developed for some other purpose, either as a refrigerant in smaller mass-market systems or as a foam-blowing agent, solvent or other specialty chemical. Apart from absorption systems there is no significant growth of other not-in-kind cooling or heating solutions.

4.6.5 Transport refrigeration

Transport refrigeration is a small segment comprising delivery of chilled or frozen products by means of trucks, trailers, vans, intermodal containers and boxes. It also includes the use of refrigeration and air conditioning on merchant, naval and fishing vessels above 100 gross tonnes (GT) (over about 24 m in length).

Since 2010, most development has taken place in the intermodal container industry. Although many of the lessons are applicable to road transport, differences between containers and road vehicles should not be neglected, and may lead to different system solutions and (possibly) to different refrigerant choices.

For new systems, hydrocarbons offer high energy efficiency, but the safety risks in transport refrigeration applications appear significant and must be mitigated. On the other hand, R-744 has been tested in the field since 2011. Its non-flammable characteristics make R-744 attractive, but the gap in efficiency in high ambient temperatures and the limited component supply base are limiting its penetration into the market.

Recently there has been an initiative to consider the design and service best practices for flammable and high pressure refrigerants which it is hoped will lead to a fast track ISO standard on how these refrigerants can be applied to intermodal container refrigeration. The framework of this initiative has not yet been set.

In the case of a regulation banning the use of refrigerants above a certain GWP level (as in the EU), HFC blends are likely to play a role as a retrofit to R-404A and (possibly) HFC-134a systems: their GWP is significantly lower than R-404A and performances are relatively close. Candidates include but are not limited to R-407A, R-407F, R-448A, R-449A and R-452A.

One also sees “non-conventional” solutions such as open loop systems or eutectic systems. These solutions offer specific advantages in some transport routes, furthermore, the fact that vehicles are HFC free and that the supporting installation can be HFC free will continue making them attractive.

New information about vessel type and existing refrigerant charge is provided based on the 2012 IMO study. It appears that the differences in type are large and that segmentation will be needed in future. The designers must factor in specific safety requirements, space and reliability, but in general, they closely follow developments in industrial and air-conditioning systems.

Based on research, the road vehicle fleet size previously estimated at 4 million --in the 2006 and 2010 RTOC Assessment Reports-- has been downsized to 2 million. This changes the overall picture in that the refrigerant banks in vessels almost double the banks in other transport sub-segments.

The bottom line is that while CFCs and HCFCs can still be found in older equipment, virtually all new transport refrigeration systems continue to utilize HFCs, with a prevalence of HFC-134a and R-404A. Some systems aboard vessels utilize HCFC-22 in both non-Article 5 and Article 5 countries.

4.6.6 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 primarily from 2.0 kW to 35 kW (although in some cases up to over 750 kW) comprise a significant segment of the air conditioning market. Nearly all air conditioners and heat pumps manufactured prior to 2000 used HCFC-22. Most Article 5 countries continue to utilise HCFC-22 as the predominant refrigerant in air conditioning applications, although several major producing countries within Asia, Middle East and South America are now initiating HCFC Phase-out Management Plans (HPMPs) to introduce non-ODS alternatives.

R-410A is the dominant alternative to HCFC-22 in air-conditioners and is being used in manufacturing in most non-Article 5 and several Article 5 countries. This particularly is the case in China, where there is a large export market satisfying demand in non-Article 5 countries. However, R-410A units are not widely sold in the domestic market because of their higher cost. Whilst the use of R-407C in new product designs was common early on because it required minimal design changes, it is currently decreasing although it is still preferred in for regions with high ambient temperatures. The other main alternatives under consideration are HC-290, HFC-32, R-744, HFC-161 and a number of blends of HFCs and unsaturated HFCs such as R-444B, R-446A and R-447A (but also many currently without R-number designations).

Except for R-744, all of the medium and low GWP alternatives are flammable and should be applied in accordance with appropriate regulations and/or safety standards (that are continuously under development), considering refrigerant charge amount, risk measures and other special construction requirements. Some safety standards limit the system charge quantity of any refrigerant within occupied spaces; in some countries the application of such guidelines are voluntary although in some they are mandatory, whilst flammable gas regulations take precedence. Where national regulations place controls on the use of flammable substances, they normally require a risk-based approach and do not impose arbitrary charge size limits (e.g., EU Atex directive). Most manufacturers apply the safety standards. Some countries are introducing bans on imports of HFC-containing air conditioners.

HC-290 and HC-1270 are mainly considered for systems with smaller charge sizes, whilst the operating pressures and capacities are similar to HCFC-22 and the efficiency is higher than HCFC-22. Split air conditioning systems using HC-290 have been available in Europe and Australia, are in production in India and HCFC-22 equipment production capacity is being converted to HC-290 in China (however, with limited output at present). R-744 is considered to have limited applicability for air conditioning appliances in Article 5 countries, due to the reduced efficiency when the ambient temperature approaches or exceeds about 31°C. There is continuing research on cycle enhancements and circuit components, which can help improve the efficiency under such conditions, although they can be detrimental to system cost. HFC-161 is currently under evaluation for systems with smaller charge sizes due to flammability. The operating pressure and capacity is similar to HCFC-22 and the efficiency is at least as high as HCFC-22, although there is concern over its stability. HFC-32 is currently on the market for various types of air conditioners and has recently been applied in split units in several countries and some OEMs are also considering it for other types of systems. The operating pressure and capacity are similar to R-410A and its efficiency is similar or better than that of R-410A. There are various proprietary mixtures targeted for air conditioning applications, which comprise, amongst others, HFC-32, HFC-125, HFC-134a, HFC-152a, HFC-161, HFC-1234yf, HFC-1234ze, HC-600a, HC-600, H-1270 and HC-290. Some mixtures have been assigned R-numbers, such as R-444B, R-446A and R-447A, whilst most are still under development. These mixtures tend to have operating pressures and capacities similar to HCFC-22 or R-410A, with GWPs ranging from 150 to around 1000 and flammability class 1 (for higher GWPs) and class 2L (medium GWPs). Currently, most of these mixtures are not commercially available on a broad scale and adequate technical data is not yet in the public domain. Other low GWP single component HFCs, such as HFC-1234yf and HFC-152a, are unlikely to be used extensively as a replacement for HCFC-22 in air conditioners principally because of their low volumetric refrigerating capacity.

A major concern in some regions is the efficacy of the various alternatives to HCFC-22 in high ambient conditions (particularly R-410A). Whilst this problem for R-410A can be addressed through design and selection, work has fairly recently been carried out on a number of other alternatives, such as HC-290 and some of the new blends of HFCs and unsaturated HFCs, that show that performance degradation with higher ambient temperatures is similar to or not notably worse than with HCFC-22. Another issue is the possible impact on required refrigerant charge, where hotter regions can imply greater heat loads, larger system capacity and thus larger refrigerant charge; limits on refrigerant charge may be approached at smaller capacities, where additional (safety) measures would then have to be applied to the equipment. Systems using low-GWP refrigerants are not currently available for large capacity systems in high ambient temperature regions.

4.6.7 Water heating heat pumps

Within the category of water heating heat pumps there are heat pump water heaters, space heating heat pumps and combined space and hot water heat pumps. The required warm water temperature affects the selection of refrigerant. Heat pump systems are more efficient at lower sink temperatures, but each product must fulfil the required operating temperature. The main use of heat pumps is to replace fossil fuel water heating systems. This is done with the purpose of reducing life time cost and/or to reduce the impact of greenhouse gas emissions. To compete with fossil fuel water heating systems, cost and energy efficiency are the most important factors and have direct impacts on the selection of the refrigerant.

Most heat pumps commercialised today make use of non-ODS refrigerants. Refrigerants used are R-410A, HFC-134a, R-407C, HC-290, HC-600a, R-717 and R-744. The majority of new equipment uses R-410A. In some Article 5 countries, HCFC-22 is being used due to its favourable thermodynamic properties and high efficiency. There are no technical barriers in replacing HCFC-22 by a non-ODS. The technical and process changes related to pressure, lubrication and contamination control are well known. Replacements are commercially available, technically proven and energy efficient. All replacements have a similar or lower environmental impact. R-410A has a slightly higher GWP but the required charge is less than HCFC-22. The issue of high ambient temperature conditions is of minor or no importance for water heating heat pumps. The main parameters to select the alternatives and the main issue to switch over from HFCF-22 are efficiency, cost effectiveness, economic impact, safe use and easiness of use. Replacements such as HFC-32 and other low-GWP HFC blends are under way to become commercially available.

HFC-134a, R-744 and HFC blends R-407C, R-417A and R-410A are commercially available solutions that have the highest grade of safety and easiness to use. R-410A is most cost effective for small and medium size systems, while for large systems HFC-134a is most efficient. R-407C and R-417A are the easiest alternatives for HCFC-22 from a design point of view, but cannot compete with the other HFC-solutions.

4.6.8 Chillers

Chillers have low emission rates and low direct global warming impact. The issue, then, is to determine which of the new refrigerants has high energy efficiency in chillers while being safe to use and having acceptable application costs. Though most HFCs in use today are considered to have relatively high GWPs, this is not a governing factor for chillers because emissions are minimal.

The required global phase-out of HCFCs and the need to manage the lifetime operation of HCFC-based equipment, coupled with concerns to reduce global warming, continue to drive the transition from ozone depleting substance (ODS) refrigerants. The refrigerants that were used in the transition generally were HFCs with global warming potentials (GWPs) that are sufficiently high to cause environmental concerns, so a second transition has begun. Major efforts have been launched to propose and test new, lower GWP refrigerants to replace higher GWP refrigerants. A number of candidates have been proposed and are in the early stages of testing as possible replacements for higher-GWP HFCs.

The new candidates generally are unsaturated HFCs or blends which may contain HFCs, HCs, and/or unsaturated HFCs. A number of the new candidates have an A2L safety rating which is associated with flammability. They have a low flame velocity, distinguishing them from more flammable chemicals such as propane (HC-290). It is too early to tell which lower-GWP refrigerants will be successful as replacements for the higher GWP HFCs now in use. The parameters to be sorted out require balancing energy efficiency, flammability (including application standards and regulations), GWP values, cost, worldwide availability, retrofit considerations, and level of system design complexity that is required to use the new candidates successfully.

4.6.9 Vehicle air conditioning

In spite of existing regulations in the US (supporting the use of low-GWP refrigerants) and legislation in Europe (banning the use of refrigerants with GWP > 150), the overwhelming majority at present (year 2014) of the newly sold passenger cars and light trucks worldwide are still equipped with air conditioning systems, which use HFC-134a as refrigerant.

At the end of 2014 it looks likely that more than one refrigerant will be used in the coming years for car and light truck air conditioning: HFC-134a will remain largely adopted worldwide, HFC-1234yf will continue its growth in new models at least in the near future, other new low GWP synthetic refrigerants or refrigerant blends (e.g. R-445A) may be implemented and R-744 is expected to be implemented by 2017. All options have GWPs below the EU threshold and can achieve fuel efficiencies comparable to modern HFC-134a systems. Currently it cannot be forecast whether or not all these refrigerants will see parallel use in the market for a long period of time. It is also unclear whether the bus and train sector will follow these trends.

The global warming impact is almost identical for the above mentioned refrigerant options when considered on a global basis and in comparison to the CO_2 tailpipe emissions. 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. Here, especially safety, cost, and system reliability are important concerns, but also other aspects have to be taken into account, like regulatory approval, heat pump capability, suitability for hybrid electric vehicles, servicing, and risk of illegal use of high-GWP refrigerants in systems designed for low-GWP refrigerants. In the year 2012, HFC-1234yf seemed to be the worldwide accepted alternative to HFC-134a. However, based on new findings regarding the on-the-road flammability of HFC-1234yf (classified as A2L) most German OEMs abandoned this option and decided to further develop and eventually use R-744 in their future air conditioning systems. Further, one Japanese OEM decided to not use HFC-1234yf on the European market. Similar to the 2012 acceptance of HFC-1234yf, these decisions are subject to change as the OEMs continue their pursuit of alternative refrigerants to meet regulatory requirements and other concerns mentioned above.

Owing to safety concerns hydrocarbons and their blends are not considered as viable refrigerant options by OEMs. Although HFC-1234yf is also flammable, it has a lower heat of combustion, burning velocity and minimum ignition energy compared to hydrocarbons, and has been the subject of several safety assessments by OEMs and other research bodies. Today, some OEMs use HFC-1234yf as refrigerant in some of their car models.

OEMs and suppliers do also work on future not-in-kind refrigeration concepts. However, the development status of such refrigeration technologies, like sorption, thermoelectric or magneto caloric systems, are still far away from serial production and presently show very poor price competitiveness and poor system performance and efficiency. These concepts are briefly discussed in Annex C of this report.

The increasingly rapid evolution of hybrid electric vehicles and electric vehicles with reversible air conditioning and heat pump cycles, which use semi hermetic electrically driven compressors introduces new challenges for any new alternative refrigerant.

At present, no regulations exists that control 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, as well as developments in the stationary heat pump market, will influence the choice of refrigerant for air conditioning systems in buses and trains.

4.6.10 Sustainable refrigeration

Refrigeration, air conditioning, and heat pump equipment are vital means for sustainability to address the fundamental needs of humans in areas such as food conservation, food security, healthcare, water heating, and thermal comfort worldwide. There are, however, a number of negative environmental impacts from the use of this equipment that need to be minimized through careful consideration of design, operation, and end of life aspects of these equipment and the refrigerants they use.

The most relevant environmental impacts can be minimized by:

a. The use of assessment tools enabling manufacturers to plan for continual improvement of the design and operation of their equipment. A number of available assessment tools are referenced in this chapter.
b. The careful choice of refrigerants with lower environmental impact, both direct (due to chemical composition) and indirect (such as use of energy and materials). The wide range

of gases already available in the market, as well as those in the development process, stresses the need of conveying updated, unbiased information to both product designers, service technicians, and users through initiatives fostered by local governments and industry associations.

c. The proper management of the selected refrigerants in response to growing environmental, regulatory, and economic concerns associated with refrigerant emissions, through:
    - Charge minimization through simple measures such as checking the amount of refrigerant being charged, or by innovative technologies such as cascade systems and secondary loops;
    - Improved design for leak tightness;
    - Care taken during manufacturing, installation, service, and maintenance;
    - Refrigerant conservation, using commercially available equipment for recovery, recycling and recovery, as well as destruction of refrigerants at the end of life.

d. The reduction of CO_2 emissions from energy use, achievable through:
    - Minimum energy efficiency performance standards applied through national regulation;
    - The use of renewable energy sources; and
    - Better energy management related to smart grid technologies, waste energy analysis, heat recovery, and anti-cyclical storage.

e. The adoption and enforcement of responsible national and regional policies, legal requirements, and voluntary initiatives aiming to reduce refrigerant emissions through ban on venting and other measures.

f. Environmentally sound end-of-life procedures in response to the growing demand of national and regional regulations.

5 Special Reports prepared in Response to Decisions from the Parties

5.1 TEAP Organisation and Operational Procedures; Responses to Decisions XXIII/10, XXIV/8 and XXV/6

5.1.1 Executive Summary XXIII/10 Task Force report: Updating the Nomination and Operational Processes of the Technology and Economic Assessment Panel and Its Subsidiary Bodies

Decision XXIII/10 requested TEAP to,

> "1… compose its technical options committees and its temporary subsidiary bodies to reflect a balance of appropriate expertise so that their reports and information are comprehensive, objective, and policy neutral and to provide a description in reports by temporary subsidiary bodies on how their composition was determined;
>
> "2… update its matrix of needed capabilities calling for expertise on the Panel, its technical options committees and its temporary subsidiary bodies twice a year and to publish the matrix on the Secretariat website and in the Panel's annual progress reports; this matrix should include the need for geographic and expertise balance;
>
> "3… ensure that the information in the matrix is clear and sufficient to allow a full understanding of needed expertise and that information on the nomination process, the selection process, the Panel's terms of reference and the operation of the Panel and its subsidiary bodies is published on the Secretariat website in an easily accessible format;
>
> "4… standardize the information required from potential experts for all nominations to the Panel, its technical options committees and its temporary subsidiary bodies in line with section 9.5.4 of the (TEAP) 2011 progress report, and to prepare a draft nomination form for consideration by the OEWG at its thirty-second meeting;
>
> "5…. ensure that all nominations for appointments to the Panel, including co-chairs of the technical options committee, are agreed to by the national focal points of the relevant party;
>
> "6… ensure that all nominations to its technical options committees and its temporary subsidiary bodies have been made in full consultation with the national focal points of the relevant party;
>
> "16… ensure that all new technical options committee members are properly informed of the Panel's terms of reference, its code of conduct contained in the Panel's terms of reference, relevant decisions of the parties and Panel operational procedures and are requested to abide by that guidance;
>
> "17… revise its draft guidelines on recusal, taking into account similar guidelines in other multilateral forums, and provide them to the Open-ended Working Group at its thirty-second meeting for consideration by the Parties;
>
> "18… prepare guidelines, for the appointment of the co-chairs of the Panel and to provide them to Open-ended Working Group at its thirty-second meeting for consideration by the Parties;
>
> "19… consider the number of members of each of its subsidiary bodies to ensure that their membership is consistent with each of the subsidiary bodies' workload and to propose revision

to their numbers to the Open-ended Working Group at its thirty-second meeting for the consideration of the Parties, taking into account the need for geographical balance in accordance with decision VII/34;

"20… update its terms of reference in accordance with this decision and submit it to the Open-ended Working Group at its thirty-second meeting for consideration by the Parties;

and,

"21… not to apply the guidelines mentioned in paragraphs 17 and 18 until they are approved by the Parties;

Decision XXIII/10 anticipated changes to TEAP procedures and the report provide information requested by Parties to inform any decisions. In preparing this response to Decision XXIII/10, TEAP has found cause to reflect on the fact that there have been a number of changes in its working environment over its twenty-three year existence. Some of the changes have been abrupt, but a number have been gradual and might even have passed unrecognized at the time. As the Montreal Protocol has matured in its implementation, there have been changes in both emphasis and focus, particularly over the last ten years. The shift from a mix of transition activities by Non-Article 5 and Article 5 Parties to transition activities predominantly by Article 5 Parties has had a particular bearing on the issues that TEAP has been asked to address. In order to meet the continuing needs of the Parties, there is a growing need to refresh TEAP and TOC memberships as old issues have been resolved and new ones have emerged. TEAP will need to continue to address the same challenges in the near term and welcomed the opportunity provided by Decision XXIII/10 to address some of the procedures required to respond to this changing environment.

In responding to the specific requests of Decision XXIII/10, TEAP identified additional operating procedures that could benefit from being better defined. This is particularly the case where TEAP and some TOC memberships have become more focused around the assessment of technology solutions for developing countries or are otherwise concentrated on the remaining issues being dealt with under the Protocol. This then places additional pressures on, for example, the disclosure and management of interests of members in the review of CUEs and EUEs, the clarification and enforcement of recusal and the rules for submission of minority views. There is also a need to take advantage of new communication technologies that can reduce the cost of TEAP, TOC, and Task Force operations, but this requires accompanying procedural innovation. Where these issues have not been addressed directly in the response to Decision XXIII/10, they were nonetheless noted in the report.

During the 32nd OEWG a contact group was formed to address Decision XXIII/10. In the course of its deliberations, the contact group requested TEAP to provide the following additional information to support discussions of these issues at the 24th MOP:

1. Harmonised matrices of present expertise. The TF already provided matrices of present and needed expertise, however a comment was made that it would be helpful to standardise or harmonise the information presented in these matrices.

2. Reorganisation proposal for each of the TOCs including their size, workload, geographical balance, expertise needed, and others. Operating procedures in place for each TOC if available.

3. Possible configuration and functions of the Conflict Resolution Body (referred to as the Ethics Advisory Body in our report).

In response, the Task Force provided an Addendum (October 2012) to the above report that included the following:

1. Revised matrices of current and needed TOC expertise, reflecting comments heard in the contact group and follow-on discussions;

2. Clarification and additional information behind the proposal for a conflict resolution body. A brief discussion paper providing the context and outlining considerations for Parties is provided.

With regard to reorganization plans and operating procedures, the very limited time did not allow sufficient, thoughtful consideration within each of the TOCs to be able to provide fully considered proposals to the Parties at that time. The Task Force offered to continue working on reorganisation plans based on membership and anticipated work load as a priority focus for TEAP over the next year, and sought the support of the Parties for TEAP to be able to present more complete plans in the near future.

5.1.2 Executive Summary XXIV/8 report: Terms of Reference, Code of Conduct and Disclosure and Conflict of Interest Guidelines for the Technology and Economic Assessment Panel and its Technical Options Committees and Temporary Subsidiary Bodies

Decision XXIV/8 requested the TEAP to,

"…make recommendations on the future configuration of its technical options committees to the Open-Ended Working Group at its thirty-third meeting, bearing in mind anticipated workloads;"

Further, it requests the TEAP and its TOCs to,

"…make available to the parties their standard operating procedures;"

The history of the Montreal Protocol, its success as a global environmental treaty as well the challenges Parties face in its implementation over 25 years, is inextricably linked to the history of the TEAP and its TOCs. Since their creation in 1989, TEAP and its TOCs have provided advice that has mostly been proven both accurate and timely: innovation and emerging technologies have received objective review, EUNs and CUNs have been reviewed and approved after thorough evaluation, and nominations have decreased from year to year.

Historical membership in TOCs show spikes in numbers of members reflecting critical decision periods of the Parties (i.e., amendments under the Protocol) but have remained essentially unchanged since 2006. Currently, over 150 experts serve on the TEAP, its six TOCs, and Temporary Subsidiary Bodies (TSBs). Since its creation, over 900 experts from about 65 countries have participated in the assessment process. With expertise being the priority consideration in its membership, TOCs have generally been successful in recruiting and retaining the balance of expertise needed to address the issues facing Parties. Co-chairs of each TOC continually strive to maintain and strengthen the relevant expertise within its membership while making every effort to also reach the goals of geographical distribution, A5/non-A5 and gender balance.

Over this period, TEAP and the TOCs invariably faced the challenge of retaining the needed expertise and balance as its working environment has changed. As noted in the previous Decision XXIII/10 report, as the Montreal Protocol has matured in its implementation, there have been changes in both emphasis and focus, particularly over the past ten years. The shift from a mix of transition activities in Non-Article 5 and Article 5 Parties to transition activities predominantly by Article 5 Parties has had a particular bearing on the issues that TEAP and its TOCs have been asked to address. However that shift has not been reflected in the TEAP and its TOCs, as membership of needed expertise from Article 5 Parties remains a challenge for TOC co-chairs seeking qualified new members with required expertise for balance.

In Decision XXIV/8, TEAP considered the near- and long-term issues related to the on-going transition under the Protocol and recommended a re-configuration of its TOCs to support Parties' deliberations and decisions on these issues. The recommendations were as follows:

- For the period 2013-2014, TEAP suggests that the TOCs membership generally remain at their current numbers to meet the need for required expertise, and because 2014 is an Assessment year; regional and A5/non-A5 balance has been achieved by some TOCs but still challenging to the majority of TOCs; gender balance remains a significant, continuing challenge to all TOCs;
- For the period 2014-2018, the TOCs membership numbers are anticipated to remain the same or decrease from the 2013-2104 period due to anticipated attrition during the 2014 reappointment process and some anticipated decrease in workload in this period; the exception is RTOC which is likely to retain its previous membership numbers based on anticipated, continuing work on issues related to transition in its sectors of use; and
- For the period beyond 2018, there is significant uncertainty in the likely TOC membership numbers, although significant reductions are anticipated for CTOC and MTOC based on the anticipated workload after 2018; that the need for retention of the necessary expertise from these committees beyond this date must be considered.

TEAP noted that these recommendations for TOC configurations were made under the current Protocol phase out and that any significant changes to that would necessitate a re-evaluation of the recommendations. The challenge remains in ensuring that the TOCs are structured in size and expertise to continue supporting the future efforts of the Parties.

As requested by the decision, TEAP also provided in its report its operating procedures, including organization and logistics and the process of achieving consensus.

5.1.3 Executive Summary of the XXV/6 report on TOC appointment processes, future configurations and the streamlining of annual (progress) reports

Decision XXV/6 reads:

….. To encourage the Technology and Economic Assessment Panel to continue its implementation of the revised terms of reference as approved by the parties in decision XXIV/8;

…. To request the Technology and Economic Assessment Panel to provide the following information in its 2014 progress report:

a) An update on its processes for the nomination of members to its technical options committees, taking into account section 2.2.2 of its terms of reference;
b) Its proposed configuration of the technical options committees from 1 January 2015 (for example, the combination or division of the existing technical options committees, or maintaining the status quo thereof);
c) Options, if considered appropriate, to streamline the Panel's annual technology updates to the parties;

In response to Decision XXV/6, TEAP assigned a working group amongst its members, including one representative from each TOC, to address the pending tasks. The recommendations for TOC configurations were made based on the current Protocol phase out and priorities. TEAP noted that any significant changes to that would necessitate a re-evaluation of these recommendations with the challenge remaining to ensure that the TOCs are structured in size and expertise to continue supporting the future efforts of the Parties. The table below from the report summarizes the proposed TOCs configurations as of 1 January 2015:

Table 4-1 Summary of current and estimated future TOCs membership

	2014 Assessment	**2015-2018 (2018 Assessment Period)**	**Post-2018 (Assumed 2022 Assessment Period)**
CTOC	14	~17	~15
FTOC	18	18-24*	12-18**
HTOC	21	~18	~15
MTOC	26	~15***	~15
MBTOC	29	20-25	20-25
RTOC	39	33-38	35-38

* One third Corresponding Members
** Two thirds Corresponding Members
*** 3-4 corresponding sterilants members, 10-12 metered dose inhalers (MDI) members, mostly corresponding, unless issues emerge

5.2 Reports on alternatives to ODS; responses to Decisions XXIV/7 and XXV/5

5.2.1 Executive Summary XXIV/7 Task Force report

Introduction

This Final Report builds on the Draft Report on Decision XXIV/7 presented to the 33rd meeting of the Open Ended Working Group in June 2013 and has sought to accommodate the helpful comments provided by Parties and other stakeholders at that meeting. It has been substantially restructured to separate out the consideration of ‘what could have been avoided’ (now Chapter 3), a substantial and updated review of alternatives as required by Clause 1 of the Decision (now Chapters 4, 5, 6 and 7) and also a summary of ‘what could be avoided’ between now and 2020 (now Chapter 8). As directed, the Task Force has sought to focus its additional efforts on further analysis of the current situation and future opportunities.

In restructuring the Report, the Task Force has also sought to address some methodological deficiencies of the Draft Report. In particular, it has refined its interpretation of Technical Feasibility and Commercial Availability (e.g. by the introduction of Technical Readiness Levels) in such a way as to recognise more specifically the circumstances of high ambient temperatures and high urban population density, both of which were highlighted at the discussions that took place at the 33rd Open Ended Working Group meeting. Inclusions and changes of emphasis are summarised in Chapter 2.

Refrigeration and air conditioning

In Chapter 3, a number of considerations are given to ‘what could have been avoided’. Domestic refrigeration and mobile air conditioning are the subsectors highlighted; here the conversion away from ODSs has been completed and low GWP alternatives have been applied or considered for quite some time. This is continued in Chapter 8 with a determination of amounts ‘that could be avoided’ for the two main refrigeration and air conditioning subsectors cases where servicing plays an important role. In Chapter 4, an updated review of alternatives is given. Initially, the chapter provides generic information relating to selected **alternative substances**. This includes a description of five classes of alternatives:

- Ammonia (R-717)
- Carbon dioxide (R-744)
- Hydrocarbons (HC-290 and others)
- HFCs (medium and high GWP), and
- HFCs (low GWP)

For each alternative, general efficiency aspects, cost effectiveness and barriers and restrictions are given. Subsequently, additional information, including current trends, is presented in the sub-sector specific sections that follow, wherever applicable. For this report it was considered under the current circumstances to discuss a small number of currently unassigned refrigerant blends where it is anticipated that they are close to commercialisation and receiving R-number designations.

In **domestic refrigeration**, the main refrigerants used are hydrocarbon HC-600a (isobutane) and HFC-134a. More than 50% of current new production (globally) employs HC-600a, the remainder uses HFC-134a. HC-600a continues to be the main alternative to HFC-134a. Concerns in connection with the high flammability no longer exist for the low charges applied. No new alternative has matured to become energy-efficient and cost-competitive. Considering the product costs, HC-600a is less expensive than HFC-134a, but additional investment cost for HC-600a products are due to the larger size of compressors. Production cost for refrigerators can be higher due to the requirements for safety systems.

Initial developments to assess HFC-134a replacement with HFC-1234yf have begun, but is not being pursued as a high priority. Still HFC-1234yf has demonstrated the potential for comparable efficiency to HFC-134a. The lower flammability makes its application easier in countries with strong reservations about HC-600a. R-744 (CO_2) is also being evaluated, but its application implies additional costs.

In **commercial refrigeration** stand-alone equipment HFC-134a and R-404A are still the dominant refrigerants. HC-600a and HC-290 are used for small commercial equipment with refrigerant charges varying from 15 g to 1.5 kg. R-744 is mainly used in vending machines; the technology is operating well but it is a technical challenge and only one supplier is able to provide an efficient system. The small additional cost associated with safety in HC equipment is integrated in the price, and is not much different compared with HFC equipment. Where it concerns low GWP HFCs, HFC-1234yf can replace HFC-134a in any application. Due to its comparable energy-efficiency with HFC-134a, vending machines with HFC-1234yf have been introduced in countries such as Japan (two manufacturers). Currently a main barrier is still (the wide) availability of the chemical.

Regarding condensing units, some new R-744 based units are sold in northern Europe, but the penetration in the market is slow. Several indirect condensing units with HC-290 or HC-1270 are operating in Europe with typical refrigerant charges varying from 1 to 20 kg, with good energy efficiency. Costs for these HC based systems are typically 5 to 15% higher compared with HFC systems.

HFC-134a, R-404A, and, at a small level, R-410A are HFCs of choice for condensing units. As in all other commercial applications, high GWP HFCs are seen as short-term options.

The preferred option for large European commercial companies is HFC-134a at the medium-temperature level (-10 to -15°C) cascading with a R-744 direct system for the low temperature (-35 to -38°C) since it is a global option for all climates.

Ammonia is used in indirect centralised systems for large capacities; usually R-744 is used at the low-temperature level. Due to safety issues the number of installations so far is limited. For applying lower GWP options, HFC-134a can be replaced by HFC-1234yf or HFC-1234ze where the lower flammability of these refrigerants can be addressed during the design stage. For non-flammable options, small temperature-glide blends --such as N-13 and XP-10-- can also be used in existing facilities. For the non-low GWP refrigerants, R-404A is currently the dominant refrigerant, even if it is now replaced in new installations by HFC-134a at the medium-temperature level. R-407F is proposed as an intermediate option. There are also non-flammable options with lower GWP such as the HFC blends N-40 and DR-33. Two-stage R-744 systems for the medium-temperature level and the low-temperature level have taken a certain market share in Europe and are now installed in more than 1300 stores. R-744 trans-critical cycle developments are on-going to make the technology more energy-competitive under higher ambient conditions. The additional cost is limited to 10 to 15%.

The refrigerant of choice for **transport refrigeration** systems in non-Article 5 countries is HFCs. R-404A has become a preferred choice for practically all trailers and large trucks. HFC-134a is used in small trucks and vans as well as reefer containers. Testing of low-GWP HFC and non-HFC alternatives are in progress elsewhere, but not one option seems viable in the short term. The main issue is that the performance of R-404A is difficult to meet. Current and previous tests with trucks using R-744 suggest that introduction of R-744 will be possible when more efficient compressors with more than one compression stage, which are under development, will be commercially available. The use of hydrocarbons (mainly HC-290) in truck refrigeration units has been tested; they would be the preferred choice because they can provide lower energy consumption in the order of 20% or more. HFC-1234yf can be an interesting alternative to HFC-134a due to its lower discharge temperature.

On vessels, hydrocarbons are technically feasible, but the strict safety concerns currently do not favour application of flammable refrigerants aboard. Natural refrigerants have been commercialised to a small extent aboard marine vessels worldwide. For European fishing vessels highly efficient ammonia- CO_2-cascade systems are the systems of choice.

Over 90% of the large **industrial refrigeration** installations use R-717 whereas the market share of R-717 is only 5% (India and China) to 25% (Europe and Russia) for smaller industrial refrigeration systems. Energy efficiency is in general 15% better than HFCs systems. Hydrocarbons are not widely used, other than in situations where safety measures are already required, e.g. in a petrochemical plant or in compact chillers.

In Small Self-Contained (SSC) **air conditioners** R-744 is not widely considered for use. The main barriers for SSC air conditioners are related to efficiency and cost implications, such as due to its very high operating pressure. Due to efficiency implications, the use of cooling only R-744 systems is not really feasible. However, there are developments on units for specific purposes, where both cooling and heating is needed. HC-290 has been used in portable ACs for many years and several companies are producing them. Window units are also under development. HC-290 seems to be preferred over HC-1270 for smaller capacity systems.

R-410A is used in most SSC ACs, where HCFC-22 is not used. It is feasible to use HFC-32 in SSC ACs, for example, where R-410A is already used. HFC-32 energy efficiency is similar to or a few per cent higher than HCFC-22 and R-410A although its deterioration at high ambient temperatures is a few per cent worse than HCFC-22, but not as severe as R-410A.

R-410A is most popular refrigerant for mini-split air conditioners where R-22 is phased out. HC-290 has been used in split ACs for many years on a limited scale but now several companies are developing and beginning to produce them on a larger scale. Although HC-290 seems to be the preferred HC option, HC-1270 is under evaluation by some companies. HC-290 units are available from several companies. Currently, no split air conditioners are available using R-744 or HFC-1234yf, although some studies have been carried out. One manufacturer has started producing mini-split air conditioners with HFC-32 in 2012. Another company has produced proto-type units with “L-41”.

In hot **water heat pumps and space heating heat pumps**, R-410A is most common refrigerant. R-717 is used fairly widely in capacities from 250 kW to very large/industrial-scale (>1 MW). Such systems are located outside or in special machinery rooms in order to handle the higher toxicity characteristics. As with R-717 systems in general, the main barriers are related to the minimal capacity required for cost-effectiveness and certain national regulation controlling installation. A large number of manufacturers globally are producing domestic and small commercial sized hot water heating heat pumps using R-744. Generally, the efficiency that can be achieved by R-744 in hot water heaters is equivalent to or slightly higher than HFC refrigerants even at high temperature difference condition. It is feasible to use HFC-32 in hot water heat pumps, for example, where R-410A is already used. HCs, particularly HC-290, had been used widely in Europe for small (domestic) heat pumps, and at a minor level, there are also large commercial-sized heat pumps being marketed, which use HC-290 or HC-

1270. It is feasible to use HFC-32 and the L-20 blend in space heating heat pumps, but R-744 is not considered by some as a suitable refrigerant for space heating only heat pumps at the present time.

Considering the use of low-GWP refrigerants in reciprocating and screw **chillers** the following describes the current situation. R-717 is used fairly widely for process refrigeration, food storage facilities and air conditioning. The efficiency of R-717 is high for chillers in both medium and high temperature applications. The barriers for chillers are consistent with R-717 systems in general. R-744 is now used in reciprocating chillers by many manufacturers. As with other types of systems, the efficiency is compromised with increasing ambient temperatures. The main barrier for R-744 chillers is the poorer efficiency in climates with consistently higher ambient temperatures and high cost due to various reasons including its high operating pressure. Both HC-290 and HC-1270 units are produced by a number of manufacturers in Europe and some countries in other regions, although the total number is minor compared to conventional HFC technology. There are certain barriers in the case of HC applications, depending upon chiller configurations.

HFC-1234ze(E) is a refrigerant that can be used in existing HFC-134a technologies with minor modifications (compressor sizing), and it has been trialled in systems in Europe. When used in reciprocating, scroll or screw type of compressors, it produces efficiency levels comparable to HFC-134a. In centrifugal compressors, this refrigerant produces efficiency levels slightly better than HFC-134a. HCFC-1233zd(E) (a low-GWP HCFC) can replace HCFC-123 in low pressure centrifugal chillers with slightly better efficiency levels. In chiller applications, both HFC-1234ze(E) and HCFC-1233zd(E) should perform very well in warm climates, due to their high critical temperatures.

Both R-407C and R-410A are widely used in positive displacement chillers as is HFC-134a. HFC-134a is used widely in various capacities of centrifugal and screw chillers.

In **mobile air conditioning** systems), the preferred option is to shift from HFC-134a to HFC-1234yf when it is required as it is by the EU regulation, but the delayed introduction is related to several issues: global availability, flammability concerns, regulation and. Other future options are still being reconsidered by certain car manufacturers; in fact R-744, while staying with HFC-134a until R-744 would have been commercialised. R-744 has been demonstrated to be as efficient as the best in class HFC-134a system except under high ambient conditions (above 35°C). However, the main barriers for R-744 systems have been costs, reliability and servicing aspects.

In developed countries, the change from HFC-134a to HFC-1234yf seems to be the likely solution because the car industry favours global options for AC systems. HFC-134a is currently the only refrigerant in use except the refilling of existing AC systems with HFC and HC blends

In public transports, the two dominant refrigerants are currently HFC-134a and R-407C in developed countries and HFC-134a and HCFC-22 in developing countries. Future options to be considered includeHFC-1234yf, R-744, new blends, possibly the air cycle.

In order to calculate amounts that can be avoided, a certain BAU case has been developed using a number of assumptions:

- a certain consumption pattern during the period 1995-2012 for the subsectors
- a certain consumption pattern in separate Article 5 and non-Article 5 countries, which determines the specific starting point of 2012 (in tonnes for the various refrigerants in the various subsectors)
- a conservative servicing percentage (of the existing bank) of 15% per year
- an economic growth (and an extrapolated economic growth) taken from percentages over the period 2005-2012 (for separate countries or separate groups of countries)

The important subsectors considered are commercial refrigeration and stationary air conditioning.

Looking at the totals for 2020 it can be observed that

- stationary air conditioning is twice as large as commercial refrigeration in ktonnes
- stationary air conditioning is 30% larger than commercial refrigeration without the application of lower GWP alternatives, is about 50% larger with the application of lower GWP alternatives

All countries, stationary air conditioning

	Total consumption (ktonnes)				Total consumption (Mt CO_2-eq)			
Year/ Substance	HCFC	HFC	Alter-natives	Total	HCFC	HFC	Alter-natives	Total (no alternatives)*
2015	354.6	220.0	35.6	610.1	634.6	431.9	17.6	**1084.1 (1136.3)**
2020	255.8	249.9	132.1	637.9	457.9	492.0	65.3	**1015.3 (1113.9)**
Aggregated 2013-20	2600.6	1832.8	524.3	4957.8	4655	3601	259	**8515 (9288)**

All countries, commercial refrigeration

	Total consumption (ktonnes)				Total consumption (Mt CO_2--eq)			
Year/ Substance	HCFC	HFC	Alter-natives	Total	HCFC	HFC	Alter-natives	Total (no alternatives)
2015	157.3	90.2	18.8	266.3	281.7	268.1	3.6	**553.4 (653.4)**
2020	195.5	114.0	66.9	376.4	350.0	278.9	13.4	**642.3 (875.6)**
Aggregated 2013-20	1349.7	778.7	269.9	2398.3	2417	2170	53.0	**4640 (6245)**

All countries, commercial plus stationary AC

	Total consumption (ktonnes)				Total consumption (Mt CO_2-eq)			
Year/ Substance	HCFC	HFC	Alter-natives	Total	HCFC	HFC	Alter-natives	Total (no alternatives)
2015	511.8	310.2	54.3	876.3	916.3	700.0	21.2	**1637.5 (1740.7)**
2020	451.4	363.9	199.1	1014.3	807.9	770.9	78.7	**1657.6 (2085.7)**
Aggregated 2013-20	3950.3	2611.5	794.2	7356.0	7072	5771	312	**13155 (15533)**

* Note; the amounts given in parentheses are the ones without using (lower GWP) alternatives

Looking at the aggregated 2013-2020 values it can be observed that

- stationary air conditioning is about twice as large in ktonnes, about 50% larger in Mt CO_2-eq. if commercial refrigeration would apply HFCs
- stationary air conditioning would (again) be twice as large in Mt CO_2-eq. if a large amount of lower GWP alternatives would be used instead of the refrigerants R-404A and R-507.

In total, for all countries, for both new manufacture and servicing, 794 ktonnes can be avoided during the period 2013-2020, which is 11% of the total (7356 ktonnes). During that same period 2378 Mt CO_2-eq. can be avoided, which is more than 15% of the total.

It should be realised that these numbers are derived for 15% servicing. Should this percentage be substantially higher, the amounts that can be avoided calculated in percentages would decrease. This could be a subject for a more detailed scenario analysis.

Aggregated for the period 2013-2020, for all countries, both non-Article 5 and Article 5, 184 ktonnes of refrigerants (with higher GWP) can be avoided from a total of 1304 ktonnes, which equals 14%. Expressed in Mt CO_2-eq. for that same period, 247 Mt CO_2-eq. can be avoided from a total of 1791 Mt

CO_2-eq., which equals 13.8% (the numbers should be more or less the same, since it only concerns amounts of HFC-134a that can be avoided, by a mix of low GWP alternatives, which give a very small contribution in Mt CO_2 eq.). It should be emphasised here that the percentage of the amount that can be avoided for non-Article 5 countries would be higher than for Article 5 countries (17% vs. about 10%, in Mt CO_2-eq., aggregated over 2013-2020).

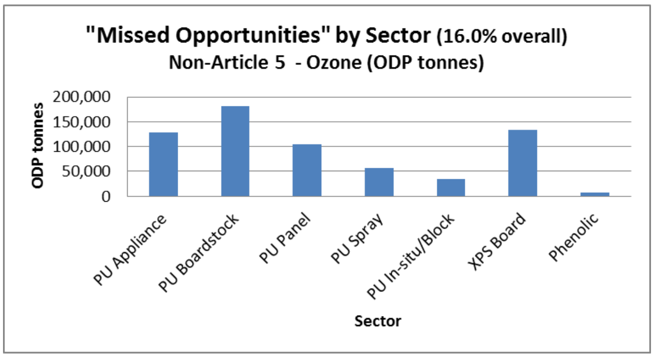
Foams

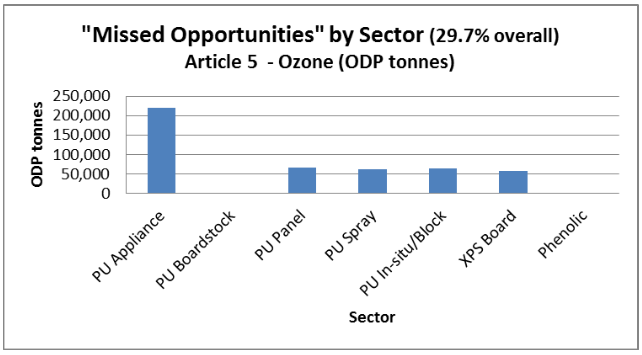
The foams sector has made transitions from its CFC baseline, through HCFCs in some cases, to either high-GWP or low-GWP non-ozone depleting solutions. As of 2013, the residual reliance on HCFC use in Article 5 regions rests to some extent in polyurethane appliance foams, but mostly in PU Spray and XPS Board.

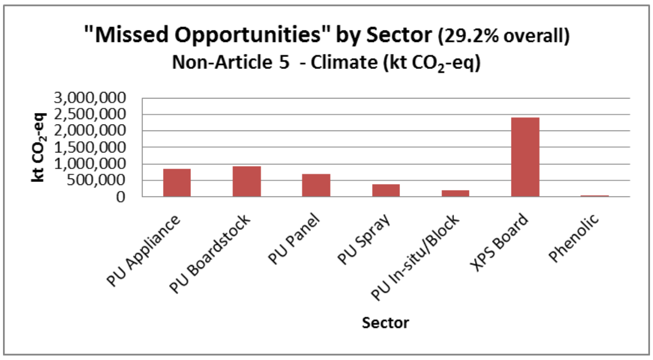
It is important to note that, of the 5.6 million ODP baseline footprint[5] of the foam sector between 1990 and 2012, over 80% of the footprint was avoided. Similarly, for a cumulative baseline climate footprint of 26.3 billion tonnes CO_2-eq over 66% has been avoided. This assessment has taken the rather stringent approach of not correcting for the 10 year grace period given to Article 5 Parties, so the avoided baseline percentages against regulatory requirements are considerably higher. A similarly stringent approach has been taken with respect to the availability of non-ozone depleting alternatives and low-GWP solutions.

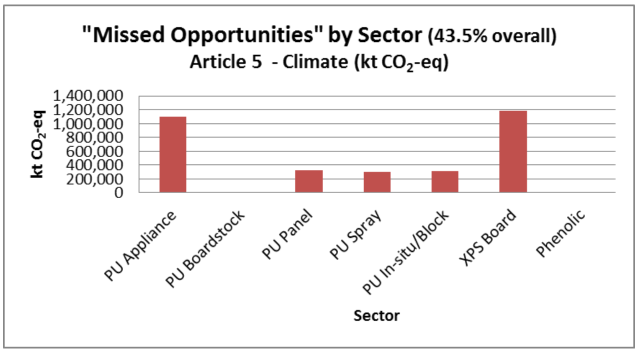
It has effectively been assumed that these were available throughout the period of analysis and thereby the analysis over-estimates the ‘missed opportunities’ in order to place a worst case perspective to the data generated and avoid subjective scenarios. The following graphs illustrate the missed opportunities analysed in this way for both ozone and climate:

[5] That which would have occurred if not action had been taken on ozone depleting substances.





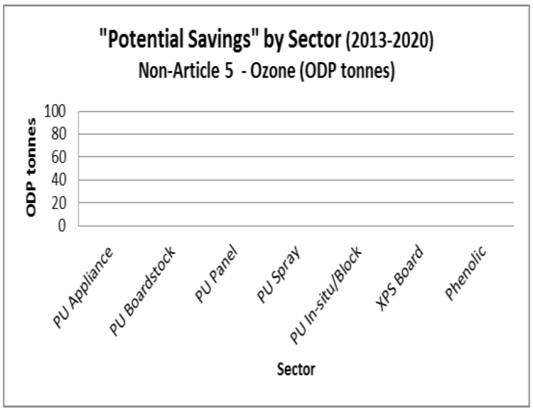




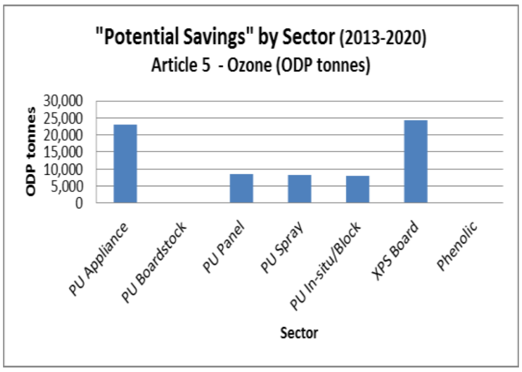
The reasons for these 'missed opportunities', especially for the XPS board sector, are fully explained in Chapters 3 & 5. It remains difficult to identify significant areas where the transition process could have been accelerated substantially given the constraints faced. It should also be noted that the effect of changes in thermal performance have not been factored into the climate assessment in view of the complex and non-determinable usage patterns to which most building insulation foams are subject.

As of 2013, the proportion of blowing agent being consumed by sector that can be considered as high-GWP is shown in the following table. It can be seen that some sectors have virtually completed their phase-out while others still have major hurdles to overcome. Particular examples are the PU Spray Foam and XPS Board sectors, where major product and processes challenges remain. In general, the remaining challenges are greater in Article 5 Parties where there is often less to be gained from economies of scale.

Many of these sectors are still reliant on the emergence of a new generation of alternatives which can display the performance associated with their high-GWP counterparts while delivering limited direct global warming impact. In particular, unsaturated HFCs (HFOs) are likely to have a strong role to play, with other emerging blowing agents, such as methyl formate, meeting some of the more specific niche applications. Drivers in non-Article 5 Parties will be market and regulatory pressure, while the main driver in Article 5 Parties will be the phase-out of HCFCs under the Montreal Protocol through the implementation of HCFC HPMPs.

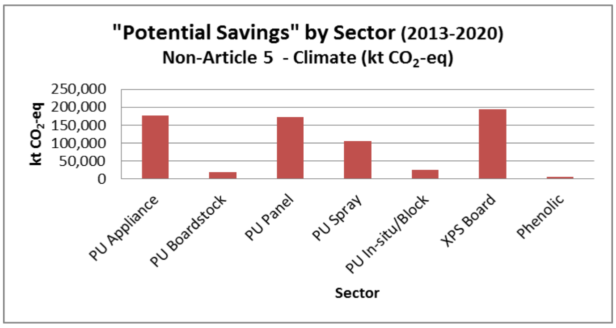


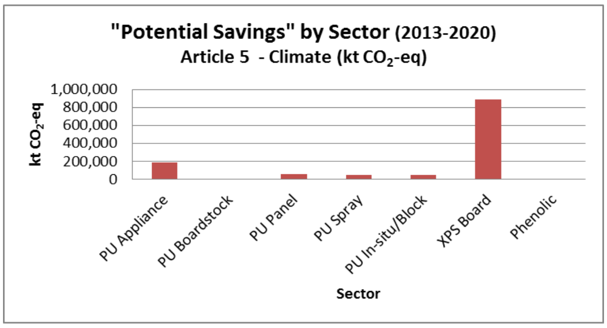
	non-A5	A5
PU Appliance	41.34%	41.34%
PU Boardstock	2.48%	0.00%
PU Panel	44.68%	78.60%
PU Spray	99.63%	100.00%
PU In-situ/Block	36.08%	99.64%
XPS Board	81.84%	99.98%
Phenolic	15.98%	32.51%
Total	***35.61%***	***48.37%***



Moving forward to assess the potential for further avoided consumption, the period of assessment has been limited to 2013-2020 in view of the uncertainties surrounding market growth in the foam sector beyond that date. However, it should be noted that the potential savings will be under-estimated by taking this relatively cautious approach. The following four charts show the potential savings available assuming an immediate transition in 2013. While recognizing that this is not possible in most cases, it does compensate to some extent for the relatively short assessment period:

Again, it should be noted that, although these savings are assumed to remove all of the remaining ozone and climate impacts for the period 2013-2020, the ozone-related savings represent only 2.3% of the footprint that would have existed without the Montreal Protocol. Similarly, the removal of the remaining climate impacts only represents 13.3% of the climate footprint that would have existed without the Montreal Protocol.





With HCFC Phase-out Management Plans now well into their first phase, it is clear that most of the significant sectors identified in Article 5 Parties are already being addressed. However, this is not necessarily the case in non-Article 5 Parties where the drivers for further transition need to come from the climate agenda, bearing in mind that the phase-out of ozone-depleting substances is already complete. Apart from the market and regulatory intervention mentioned earlier, one of the key drivers may ultimately be the improvement in thermal efficiency offered by low-GWP substitutes such as unsaturated HFCs, unsaturated HCFCs or blends containing them.

It is clear that the timing of further transitions is less critical to the environment than was the case for CFC phase-out, where delay had substantial consequences. There are still some difficult transitions to address (e.g. in the XPS sector) and it may be that waiting for the maturing of emerging technologies will offer better long-term solutions than forcing the transition too soon. Where this is unavoidable because of ODS phase-out commitments, it may still be better to consider a low-cost interim solution in order allow for a subsequent transition.

Having reviewed the potential for avoided consumption, this Report has also sought to make some assessment of the percentage reduction of cumulative consumption that might be realistically achieved in the 2013-2020 period. The following table illustrates those outputs:

	Cumulative High-GWP Consumption to 2020				***Est. % Avoidance***		***Estimated Avoided Consumption to 2020***			
	Non-Article 5		Article 5		Non-A5	A5	Non-Article 5		Article 5	
	tonnes	*ktCO2-eq*	*tonnes*	*ktCO2-eq*			*tonnes*	*ktCO2-eq*	*tonnes*	*ktCO2-eq*
PU Appliance	159,132	176,652	225,420	189,564	55%	75%	87,523	97,158	169,065	142,173
PU Boardstock	17,054	19,747	-	8	50%	50%	8,527	9,874	-	4
PU Panel	148,542	172,550	77,374	54,710	50%	40%	74,271	86,275	30,950	21,884
PU Spray	103,966	105,824	75,895	53,582	25%	25%	25,992	26,456	18,974	13,395
PU In-situ/Block	26,881	25,910	71,839	50,711	25%	25%	6,720	6,478	17,960	12,678
XPS Board	202,705	192,878	457,667	891,499	10%	25%	20,271	19,288	114,417	222,875
Phenolic	5,196	4,978	408	282	50%	50%	2,598	2,489	204	141
Total	***663,476***	***698,539***	***908,603***	***1,240,356***			***225,901***	***248,017***	***351,569***	***413,150***
							34.05%	*35.51%*	*38.69%*	*33.31%*

In summary, the foam sector might be expected to deliver a further 575,000 tonnes of avoided high-GWP blowing agent consumption yielding approximately 660,000 ktCO_2-eq of additional climate benefit beyond business-as-usual by 2020, with further benefits to accrue thereafter.

Fire protection

Ozone depleting substances (ODS) used as fire extinguishants possess unique efficacy and safety properties that serve as a basis of fire protection systems where the application of water (by hose stream or sprinkler heads), dry chemical agents, or aqueous salt solutions is problematic. This is especially true in high-value, commercial electronics environments and in military systems, to name only two of many applications where such systems had many serious technical disadvantages.

Commercially available, technically proven alternatives to ODS for Fire Protection have been developed and include: halocarbon agents, e.g., HFCs and a fluoroketone (FK); inert gases, e.g., nitrogen and argon and their blends; carbon dioxide; water mist technologies; inert gas generators; fine solid particles (powders); dry chemicals; and aqueous film-forming foam. Several environmentally sound alternatives to ODS fire extinguishing agents for both total flooding and local applications uses have been introduced to the market. If an environmentally sound alternative agent works in any specific application, there is no barrier to its adoption other than economic considerations. Additional environmentally sound alternatives are presently under development that may increase the number of applications where environmentally sound alternatives are technically viable but it is too soon to make any realistic assessments.

The production of PFCs and HFCs for use in fire extinguishing systems and portable fire extinguishers as well as the production of alternatives (without negative environmental impacts) to these agents for uses in the same applications is performed by very few manufacturers, all of whom treat the information on their historical, present and projected production as proprietary. Without a clear understanding of these production levels for the alternatives without negative environmental impacts, and also for the PFCs and HFCs, there is no basis for making a sound judgment about the overall utility of any alternatives in replacing PFCs and HFCs in the fire protection sector.

Nevertheless, we can say that the fire protection community has acted responsibly in dealing with what have turned out to be unsuitable alternatives from an environmental impact perspective. The availability of several HFCs that collectively could perform as well as the PFCs in certain applications, and at the same time present a more favourable environmental impact, led to the collapse of the use of PFCs in those applications.

However, the need for chemical agents remains as inert gases, water mist and other agents are not suitable for many fire protection applications that had previously used halon. HFCs have filled that role and, since about 2005, a fluoroketone (FK) has increasingly become more accepted. The fire protection industry is still evaluating alternatives that have low environmental impacts. In addition, the Halons Technical Options Committee is assessing regional biases in fire protection agent, systems and costs across the spectrum of available choices.

The use of HCFCs in fire protection is declining, with the only total flood agent being provided for the maintenance of legacy systems that are themselves phasing out. Only HCFC-123 is used in any quantity in portable extinguishers. However, if the development of 2-Bromo-3,3,3-trifluoropropene proves to be commercially successful, owing to its fire extinguishing characteristics being closer to halon 1211 and it having a low environmental impact, means that it would be the natural replacement for HCFC-123 and halon 1211 – particularly in the aviation industry.

Solvents

The HCFC solvents currently used are HCFC-141b and HCFC-225ca/cb with ODP of 0.11 and 0.025/0.033 and GWP-100yr of 713 and 120/586, respectively. The elimination of HCFCs from solvent applications still leaves many options available. Many alternative solvents and technologies developed so far since 1980s are the candidates for HCFC alternatives, which include, not- in kind technologies such as aqueous cleaning, semi-aqueous cleanings, hydrocarbon and alcoholic solvents, and in-kind solvents such as chlorinated solvents, a brominated solvent, and fluorinated solvents with various levels of acceptance. However, no single option seems well suited to replace HCFCs completely.

Recently unsaturated fluorochemical HFOs (hydrofluoroolefins) with zero ODP and HCFOs (hydrochlorofluoroolefins) with negligibly small ODP are said to be under development. They have ultra low GWP (<10) and are expected to replace high GWP-HFC and low or moderate GWP HFE solvents. Among them, HCFOs are unique in their balanced solvency due to the presence of chlorine and fluorine atom in the molecule. If HCFOs with appropriate boiling points, low toxicity and enough stability to the practical use be on market, they may replace HCFCs totally in the future.

5.2.2 Executive Summary TEAP XXV/5 Task Force report

Overview

Decision XXV/5 is the first in a series of Decisions on alternatives to ozone depleting substances to request TEAP to develop and assess the impact of specific mitigation scenarios as part of its reporting back to the Parties. In responding to this mandate, TEAP has sought to draw from its earlier evaluations of alternatives (Decisions XXIII/9 and XXIV/7) in order to provide a grounded basis for such mitigation scenarios. The information has been updated where appropriate, although the changes have generally been minor because of the short time period between the finalisation of the TEAP Report on XXIV/7 (September 2013) and the publication of this Report (May-October 2014).

It should be noted that quantitative information is only available for the refrigeration, air conditioning foam, and to a lesser extent, medical use sectors. Therefore, discussion on fire protection and solvents has remained qualitative, with the latter being added to the scope of such reports for the first time (Chapter 9). Nevertheless, for each of these sectors, efforts have still been made to address the three major inputs requested of TEAP in Decision XXV/5 – namely:

- An update on alternatives available, highlighting significant differences between non-Article 5 and Article 5 regions (Element 1(a))
- A (qualitative/quantitative) discussion of future demand for alternatives to ozone depleting substances (Element 1(b))
- A (qualitative/quantitative) discussion on the costs and environmental benefits of various mitigation scenarios (Element 1(c))

Where quantitative information has been available, it has become self-evident that the Refrigeration and Air Conditioning (RAC) sector is the dominant factor in the climate impact assessment even when existing regulatory measures are considered as part of the BAU scenario (see Figure ES-1)

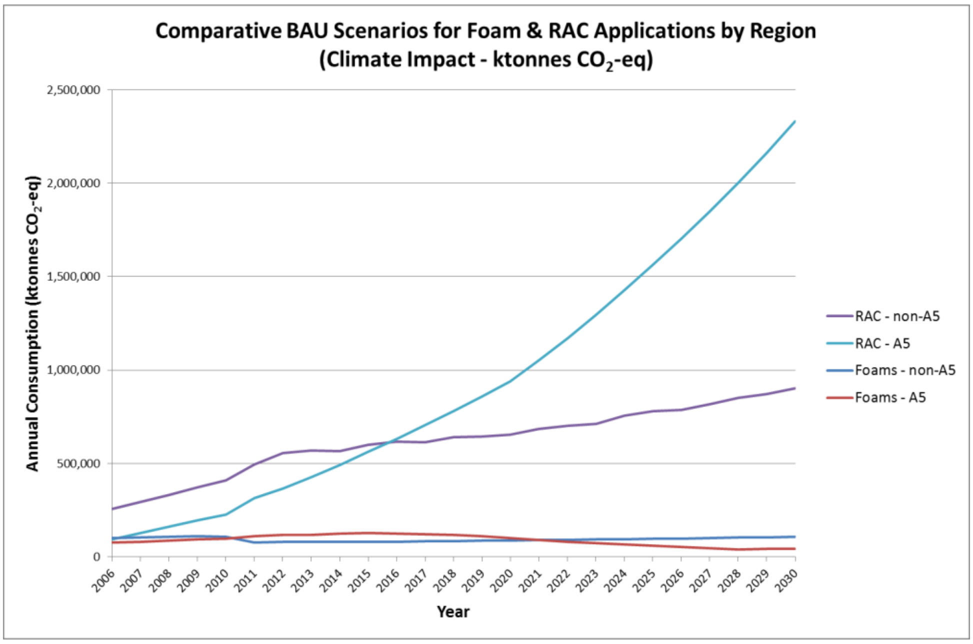


Figure ES-1 Projection of Business-as-Usual Climate Impact to 2030 for RAC and foams

Business-as-Usual Scenario

The make-up of the Business-as-Usual scenario for RAC is shown in Figures ES-2 and ES-3 below:

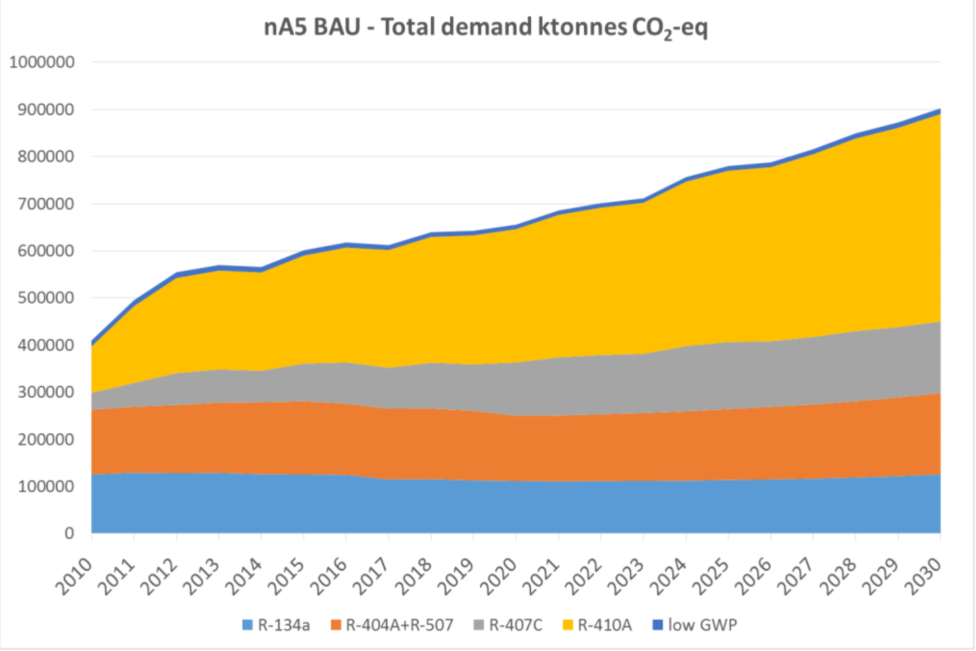


Figure ES-2 Actual and projected BAU demand of refrigerants in non-Article 5 regions

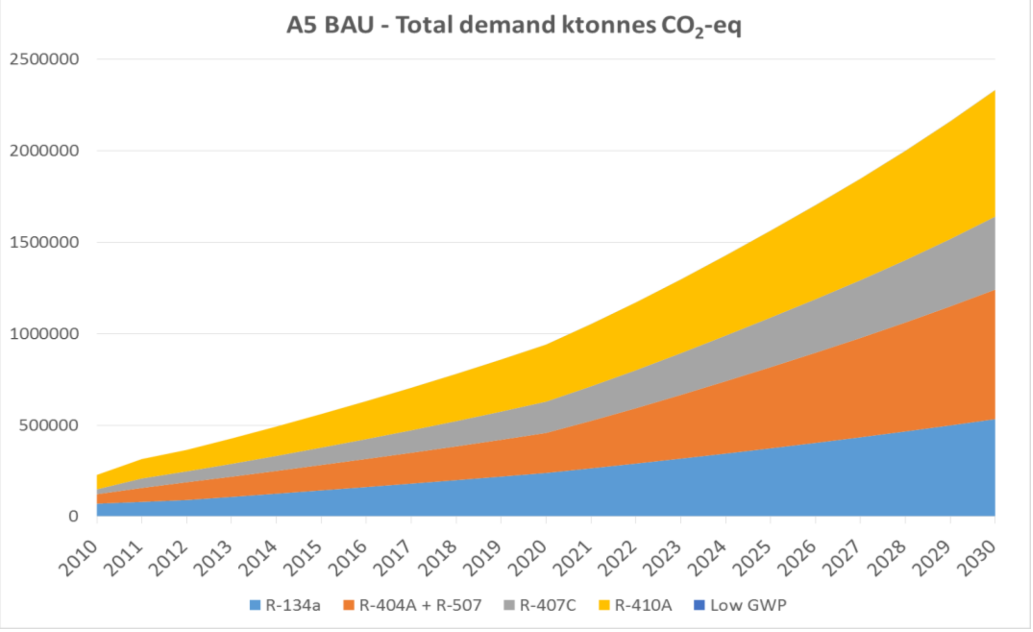


Figure ES-3 Actual and projected BAU demand of refrigerants in Article 5 regions

Mitigation Scenarios

Understandably, the grounding of the mitigation scenarios for such large consuming sectors becomes critical to the outcome of the response to Element 1(c) of Decision XXV/5 and a large part of this report addresses the technical capability and economic capacity of the RAC sector to respond. Two mitigation scenarios have been identified. One (MIT-1) is believed to be a relatively achievable scenario based on current technology options and potential trends. The other (MIT-2) is a more progressive "what if" assessment and is believed to be at the limit of what could be achievable in the period to 2030. The following two graphs illustrate the impact for non-Article 5 regions:

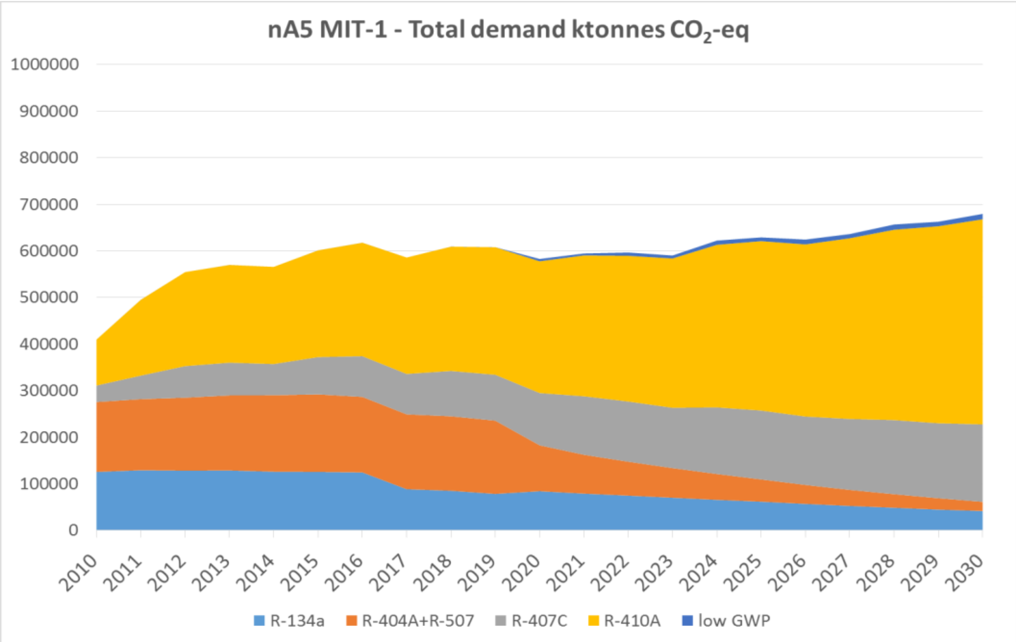


Figure ES-4 The climate impact of Mitigation Scenario 1 for RAC in non-Article 5 regions

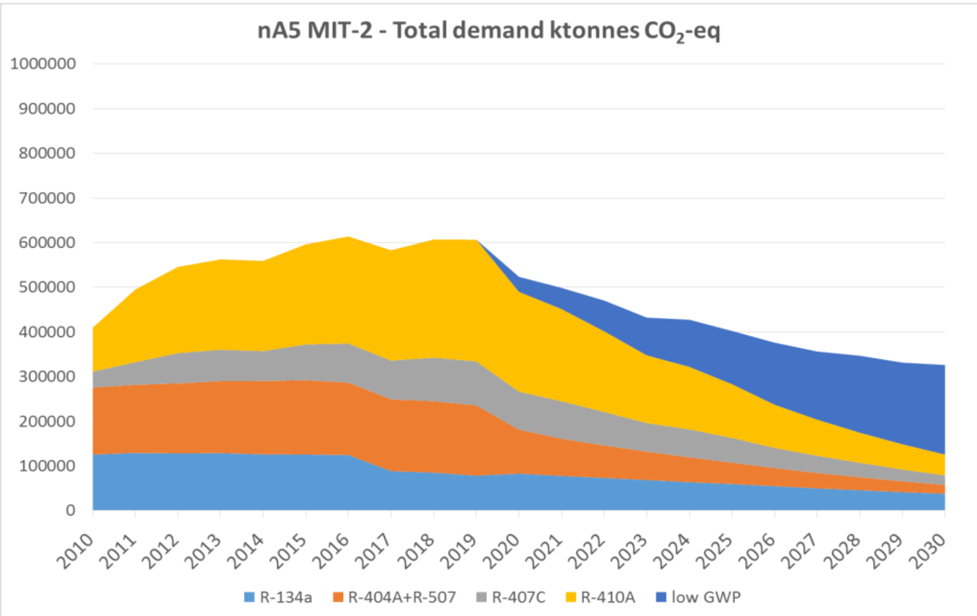


Figure ES-5 The climate impact of Mitigation Scenario 2 for RAC in non-Article 5 regions

It is clear from both graphs that the impact of measures on low-GWP alternatives is unlikely to be felt in non-Article 5 regions until after 2020. This acknowledges the fact that additional regulatory measures, such as the revised F-Gas Regulation will be necessary to trigger transitions.

For the Article 5 "case", the incursion of low-GWP alternatives is evident from the year 2000 onwards. However, the importance of guiding investment into low-GWP solutions wherever possible is clear in view of the anticipated rate of growth of the RAC sector in the period through to 2030. Figure ES-7 is particularly revealing in that the opportunity to major inroads exists beyond 2020.

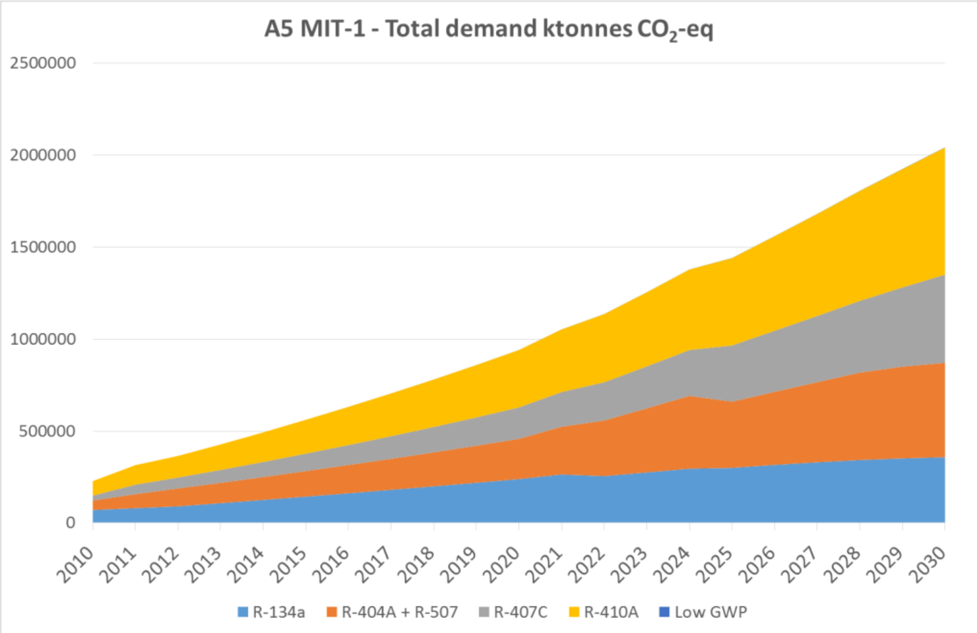


Figure ES-6 The climate impact of Mitigation Scenario 1 for RAC in Article 5 regions

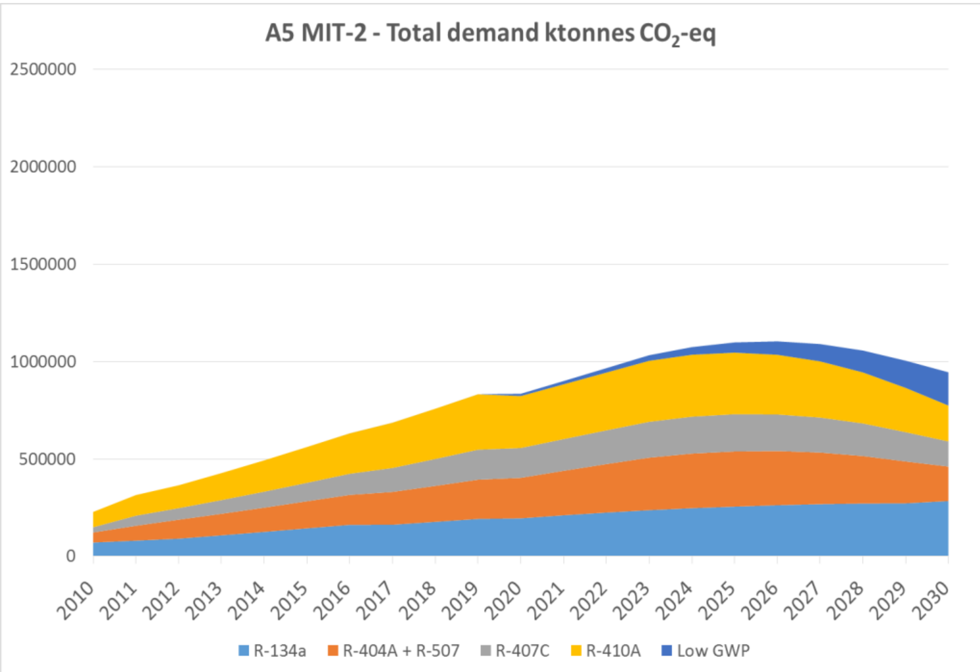


Figure ES-7 The climate impact of Mitigation Scenario 2 for RAC in Article 5 regions

The Task Force has also made efforts to quantify the potential cumulative climate impact arising from mitigation activities in both the foam and RAC sectors. Although the foam contribution is modest, it is still believed to be desirable, especially since any measures to reduce reliance on high-GWP blowing agents will have an enduring effect beyond 2030. The most notable benefits are likely to come from the XPS sector in the period beyond 2025.

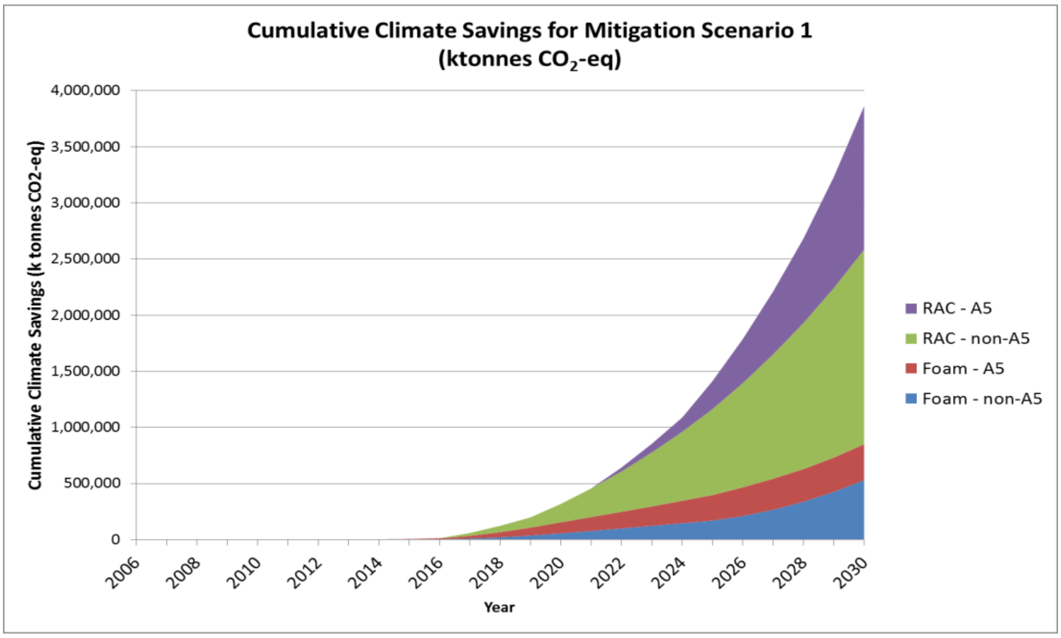


Figure ES-8 Cumulative Climate Savings compared with BAU from Mitigation Scenario 1

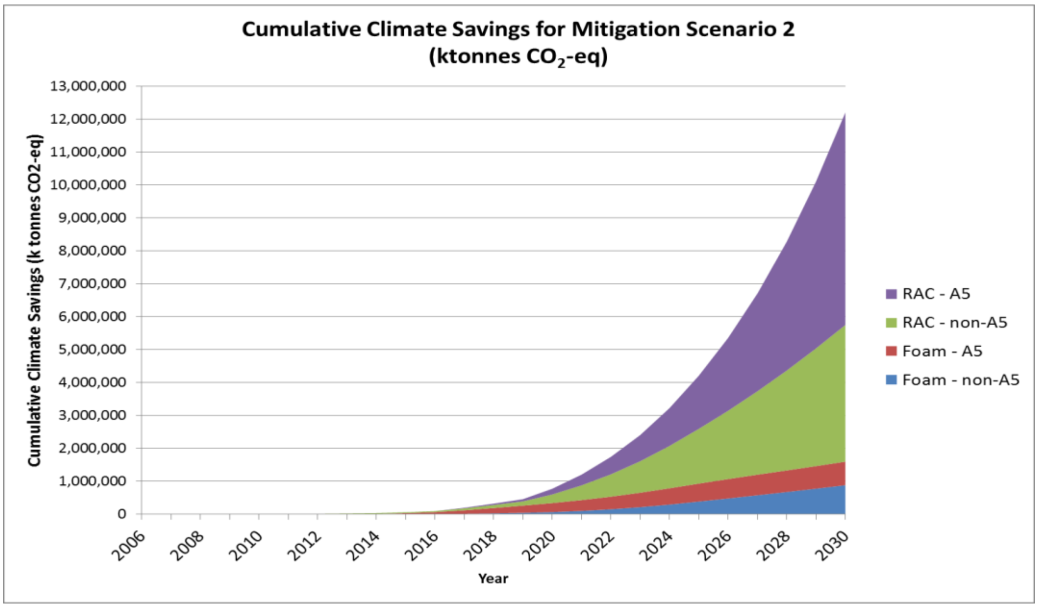


Figure ES-9 Cumulative Climate Savings compared with BAU from Mitigation Scenario 2

It can be seen that the cumulative savings by 2030 from Mitigation Scenario 1 are approximately 3.8 billion tonnes CO_2-eq, while the delivery from Mitigation Scenario 2 is in the region of 12 billion tonnes CO_2-eq.

Cost assessment

With respect to cost, the ranges are inevitably wide because the circumstances surrounding any future transitions have a major bearing. It is clear that technology transitions that can coincide with other process upgrades will be more cost-effective than those that are forced to be implemented independently because of specific regulatory measures. Most importantly, the costs will be least where new RAC and foam manufacturing capacity investment is directed away from high-GWP options at the outset. Hence, efforts should be focused on ensuring that low-GWP options are well proven at the earliest opportunity in order to inspire investment confidence.

Within the RAC sector, the costs for Mitigation Scenarios 1 and 2 in Article 5 regions have been estimated and the ranges are shown in the following two tables.

Sector	**Conversion to**	**Amount (tonnes)**	**Manufacturing conversion (tonnes)**	**Costs (US$ million)**
MAC	Low GWP	75,000	45,000	405-810
Refr.sectors	R-407A/C/F	90,000	54,000	54-162
Stationary AC		135,000		0
Total				**459-972**

Table ES-1 Costs for the MIT-1 scenario in Article 5 countries

Sector	**Conversion to**	**Amount (tonnes)**	**Manufacturing conversion (tonnes)**	**Costs (US$ million)**
MAC	Low GWP	75,000	45,000	270-810
Refr.sectors	Low GWP	90,000	54,000	324-972
Stationary AC	Low GWP	135,000	81,000	486-1458
Total				**1080-3240**

Table ES-2 Costs for the MIT-2 scenario in Article 5 countries

Although there is considerable further information available on climate abatement costs, the whole life costing approach used is not particularly helpful in that it typically offsets investment costs against future energy efficiency gains. Often these cost and benefits are attributed to different parties.

Qualitative Summaries

Whilst the quantification of costs and savings has not been as possible, or as detailed, for other sectors, it is important to note the following conclusions for fire protection, solvents and medical uses:

- The process for assessing and qualifying new fire protection agents for use is long and is also application specific. Whilst the phase-out of ODS in this sector is well underway, there will be some reliance of high-GWP solutions for the foreseeable future. Control of avoidable emissions continues to improve, thereby minimising impacts.
- In the solvents sector, there is still limited use of HCFC-141b and HCFC-225ca/cb. However, there is increased interest in a number of the emerging unsaturated halogenated substances, since the range of halogens (chlorine, fluorine and/or bromine) provide a range of solvating capabilities which should address any short-comings of currently available alternatives.
- Metered dose inhalers use HFC-134a and HFC-227ea, with cumulative emissions between 2014-2025; they are estimated to have a climate impact of 173,000 ktonnes CO_2 equivalent under a business-as-usual scenario. Completely avoiding high-GWP (HFC) alternatives in this sector is not yet technically or economically feasible. In the sterilants sector, where there is almost non-existent use of HFCs and a wide variety of alternatives available, the impact of avoiding HFCs would be minimal.

6 TEAP and TOC membership information

6.1 TEAP and TOC Membership Lists - Status January 2015

Technology and Economic Assessment Panel (TEAP)

TEAP Co-chairs	**Affiliation**	**Country**
Bella Maranion	US EPA	USA
Marta Pizano	Hortitecnia	Colombia
Ashley Woodcock	Wythenshawe Hospital Manchester	UK
Senior Expert Members	**Affiliation**	**Country**
Marco Gonzalez	Consultant	Costa Rica
Masaaki Yamabe	National Inst. Advanced Industrial Science and Technology	Japan
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
David Catchpole	Petrotechnical Resources Alaska	UK
Sergey Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
Lambert Kuijpers	A/genT consultancy (TUE University)	The Netherlands
Roberto de A. Peixoto	Maua Technological Institute, IMT, Sao Paulo	Brazil
Jose Pons Pons	Spray Quimica	Venezuela
Ian Porter	La Trobe University	Australia
Miguel Quintero	Consultant	Colombia
Helen Tope	Energy International Consultancy	Australia
Daniel Verdonik	Hughes Associates	USA
Jianjun Zhang	Sen Yat Sen University	PR China

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**
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Samir Arora	Urethanes	India
Roy Choudhury	Foam supplies	USA
Rick Duncan	Spray Foam Alliance	USA
Mike Jeffs	Ind Consultant	UK
Rajaran Joshi	Owens Corning	India
Ilhan Karaagac	Izocam AS	Turkey
Candido Lomba	Abripur	Brazil
Yehia Lotfi	Technocom	Egypt
Joseph Lynch	Arkema	USA
Simon Lee	Dow	USA
Christoph Meurer	Solvay	Germany
Sasha Rulhoff	Haltermann	Germany
Enshang Sheng	Huntsman Co	China
Kiochi Wada	JULL	Japan
Helen Walter-Terrinoni	Dupont	USA
Dave Williams	Honeywell	USA
Allen Zhang	Owens Corning	China

TEAP Halons Technical Options Committee (HTOC)

Co-chairs	**Affiliation**	**Country**
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AdamChattaway	UTC Aerospace Systems	UK
Michelle M. Collins	Consultant- EECO International	USA
Carlos Grandi	Embraer	Brazil
H. S. Kaprwan	Consultant – Retired	India
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
Filippo Tomasello	European Aviation Safety Agency	Italy
Robert T. Wickham	Consultant-Wickham Associates	USA
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan
Consulting Experts		
Thomas Cortina	Halon Alternatives Research Corporation	USA
Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan
Nikolai Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
David Liddy	United Kingdom Ministry of Defence	UK
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

TEAP Medical Technical Options Committee (MTOC)

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Helen Tope	Energy International Australia	Australia
Ashley Woodcock	University Hospital of South Manchester	UK
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Sidney Braman	Mount Sinai School of Medicine	USA
Hisbello Campos	Instituto Fernandes Figueira, FIOCRUZ, Ministry of Health	Brazil
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Christer Carling	Private Consultant	Sweden
Davide Dalle Fusine	Chiesi Farmaceutici	Italy
Eamonn Hoxey	Johnson & Johnson	UK
Javaid Khan	The Aga Khan University	Pakistan
Katharine Knobil	GlaxoSmithKline	USA
Suzanne Leung	3M	USA
Gerald McDonnell	STERIS	UK
Hideo Mori	Private Consultant	Japan
Tunde Otulana	Boehringer Ingelheim Pharmaceuticals Inc.	USA
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Rabbur Reza	Beximco Pharmaceuticals	Bangladesh
Raj Singh	The Chest Centre	India
Roland Stechert	Boehringer Ingelheim	Germany
Ping Wang	China Food and Drug Administration	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
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Marta Pizano	Consultant	Colombia
Ian Porter	La Trobe University	Australia
Members	**Affiliation**	**Country**
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Jonathan Banks	Consultant	Australia
Chris Bell*	Consultant	UK
Fred Bergwerff	Eco2, Netherlands	The Netherlands
Peter Caulkins*	Associate Director, Special Review& Reregistration Division US EPA	USA
Ricardo Deang*	Consultant	Philippines
Raquel Ghini	EMBRAPA	Brasil
Ken Glassey	Senior Advisor Operational Standards Biosecurity New Zealand, Ministery of Agriculture and Forestry Wellington	New Zealand
Alfredo Gonzalez	Fumigator	Philippines
Michelle Marcotte*	Consultant	Canada
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 (Fumigator)	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
Alejandro Valeiro	Department of Agriculture	Argentina
Ken Vick	Consultant	USA
Nick Vink	University of Stellenbosch	South Africa
Chris Watson*	Consultant	UK
Jim Wells*	Environmental Solutions Group	USA
Eduardo Willink	Ministerio de Agricultura	Argentina
Suat Yilmaz	BATEM Horticulture Research Station	Turkey

*retired from MBTOC on 31 December 2014

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

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Roberto de A. Peixoto	Maua Technological Institute, IMT, Sao Paulo	Brazil
Fabio Polonara	Universita delle Marche	Italy
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Dennis Dorman	Trane	USA
Basaam Elasaad	Consultant	Lebanon
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Samir Hamed	Petra Industries	Jordan
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Holger König	Ref-tech Engineering	Germany
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Petter Nekså	SINTEF Energy Research	Norway
Horace Nelson	Consultant	Jamaica
Carloandrea Malvicino	Fiat Ricerche	Italy
Tetsuji Okada	JRAIA	Japan
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Alexander C. Pachai	Johnson Controls	Denmark
Per Henrik Pedersen	Danish Technological Institute	Denmark
Rajan Rajendran	Emerson	USA
Giorgio Rusignuolo	Carrier Transicold	USA
Alessandro Silva	Bitzer	USA
Paulo Vodianitskaia	Consultant	Brazil
Asbjorn Vonsild	Danfoss	Denmark