Halons Technical Options Committee

2018 Assessment Report

Volume 1

Montreal Protocol on Substances that Deplete the Ozone Layer

UN environment
United Nations Environment Programme
Ozone Secretariat

MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

REPORT OF THE
HALONS TECHNICAL OPTIONS COMMITTEE

DECEMBER 2018

VOLUME 1

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Dedication

Since the last Assessment Report, a former member of the Halons Technical Options Committee has passed away. This report is dedicated to the memory of:

Thomas A. Bush

Acknowledgements

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The opinions expressed are those of the Committee and do not necessarily reflect the views of any sponsoring or supporting organizations.

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1 Executive Summary

Impact of the Kigali Amendment

1. Following the Kigali Amendment to the Montreal Protocol, the role of the Halons Technical Options Committee (HTOC) has broadened in that it now has to cover alternatives to high-Global Warming Potential (GWP) hydrofluorocarbons (HFCs) as well as halons and hydrochlorofluorocarbons (HCFCs) and their alternatives. This has a number of consequences for the HTOC:

   a) Each of the chapters in this report has been revised to cover this expanded scope

   b) All Supplementary Reports and Technical Notes have been revised to cover this expanded scope

2. The initial Kigali production phase down of 10% in non-Article 5 parties is unlikely to have a significant impact on the availability of HFCs for fire protection.

Alternatives to Halons, HFCs and HCFCs

1. Halons are remarkably good fire extinguishants. Following their production phase-out, only 25% of system applications were replaced with “in-kind” solutions (vaporizing liquids that left no residue and acceptable toxicity), the other 75% being various other “not-in-kind” solutions (e.g., sprinklers, water mist, foam, dry chemical, CO_2). For portable extinguishers, the split is approximately 20% “in-kind” and 80% “not-in-kind”.

2. Since the 2014 Assessment Report, no substantial progress on potential alternatives has been reported. A hydrochlorofluoro-olefin, HCFO-1233zd(E) ($HClC=CHCF_3$), was proposed but has subsequently been withdrawn. More recently, the manufacturer has proposed a blend of this agent with the fluoroketone FK-5-1-12 ($CF_3CF_2COCF(CF_3)_2$). A recent interest has been growing for trifluoroiodomethane (CF_3I) as a total flooding agent in aviation-related normally unoccupied spaces such as Engine/ auxiliary power units (APU) applications.

3. Nevertheless, the HTOC is of the opinion that although research to identify potential new fire protection agents continues, it could be several years before a viable agent could possibly have significant impact on the fire protection sector. This could be as little as five years if the agent has undergone some development (e.g. CF_3I) or as much as ten years if the agent is only in the research and development phase.

Civil Aviation

1. The fire extinguishant 2-bromo-3,3,3-trifluoroprop-1-ene, $CH_2=CBrCF_3$, (2-BTP) is now commercialized and qualified for civil aviation use to replace halon 1211. Although it does contain a bromine atom, it degrades in the troposphere, meaning that it has a short atmospheric lifetime and thus a low GWP and Ozone Depletion Potential (ODP). It is the closest to a “drop-in” replacement for halon 1211 in portable extinguisher applications. Two companies now offer portable extinguishers containing 2-BTP and have started supplying major aircraft

manufacturers on a platform-by-platform basis. The transition to 2-BTP for newly produced aircraft is ongoing.

2. Despite over 20 years of research, the civil aviation industry has failed to find any replacements for halon 1301 that they deem to be acceptable from an efficiency perspective (i.e., space and weight), a toxicity perspective or both. Given the anticipated 25–40-year lifespan or more of a newly produced civil aircraft, halon 1301 dependency is likely to continue beyond the time when recycled halon is readily available.

3. Although the HTOC has previously reported that this situation might result in civil aviation submitting an Essential Use Nomination (EUN), the impact could be broader. Since most other enduring users of halon 1301 do not have long-term, dedicated stockpiles, they are also vying for the same halon supplies that civil aviation is reliant on. The timeframe when halon is no longer available to civil aviation could also be the timeframe when halon is no longer available to other users that do not have dedicated, long-term stockpiles, who might then also feel the need to submit an EUN(s).

4. To determine the potential availability of halon 1301 to support civil aviation and other enduring users, a model using various scenarios was developed to estimate halon 1301 resources needed to service the existing aviation fleet, account for aviation growth through 2060, and to also service continuing non-aviation applications. Based on the results of this analysis, the estimated available halon 1301 supplies for replacing halon emitted from most existing active fire protection systems in aviation and non-aviation applications (e.g., oil and gas facilities, nuclear facilities, and military installed/reserves) as well as new aviation demand are projected to run out by years 2032 to 2054, depending on estimates of the initial total worldwide supply in 2018 and annual emission rates used in the model. It should be noted that organizations that have long term, dedicated stockpiles such as certain militaries may be capable of providing support for their specific applications well beyond this timeframe.

   Work is ongoing in the Halon Alternatives for Aircraft Propulsion Systems (HAAPS) Industry Consortium, whose aim is to define common non-halon fire extinguishing solution(s) for use in engine nacelles and APUs. The industry Cargo Compartment Halon Replacement Advisory Group is conducting a technical assessment on alternatives and will report to ICAO next year.

5. A recent Technology and Economic Assessment Panel (TEAP) Working Group Report concluded that there was some likelihood that there might be Aircraft Rescue and Firefighting (ARFF) applications that would continue to need clean agents (i.e., those that vaporize and leave no residue) in the 2020 - 2030 timeframe that currently can only be met through the supply of halon 1211 or HCFC Blend B (mostly HCFC-123, with PFC-14[1] and argon). The most recent estimate is that between 120 and 450 tonnes of HCFC Blend B will be required per year. FK-5-1-12 has recently been evaluated in ARFF vehicle applications but the results have not been published at the time of writing this report.

6. In November 2018, the parties to the Montreal Protocol agreed to adjust the Protocol and adopted a corresponding Decision XXX/2 to allow the use of newly produced HCFCs for the

[1] PFC-14 is an extremely stable compound with an estimated atmospheric life time of 50,000 years and a GWP of 7,390(AR4) / 6,630 (AR5)

servicing of niche applications such as fire suppression and fire protection equipment existing on 1 January 2020 for the period 2020-2029 for non-A5 parties and also on existing equipment in 1 January 2030 for the period 2030-2039 for A5 parties.

Military Applications

1. Military fire protection systems are unique in that besides protecting against 'peacetime' fires from routine use, they must protect personnel and platforms from the consequences of combat damage. These fires are generally very fast-growing and relatively large and military fire protection systems must counter these threats and, in many cases, while allowing occupants to remain in the affected spaces.

2. Alternatives have been adopted where they have been found to be technically and economically feasible. For new designs, there are virtually no applications where a halon must be used although there are many applications where the only alternative is a high GWP HFC, i.e., there are no low-GWP alternatives for those applications. In legacy (existing) designs, there are several applications where neither suitable halon nor HFC alternatives exist. Therefore, in these applications halons and high-GWP HFCs are the only viable fire and explosion protection solutions that maintain parties' levels of national security and safety of their military personnel and equipment. This will, in all likelihood, continue to be the case for both new designs and legacy systems for the foreseeable future.

Oil & Gas Operations

1. Generally speaking, halon 1301 is only required to support enduring legacy facilities for the foreseeable future and all new facilities are halon-free but depending upon the climate (i.e., low temperature), might require HFC-23 which is a very high GWP (12,400 in Intergovernmental Panel on Climate Change Assessment Report 5).

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

Telecommunications and Computer Rooms

1. In the early 1990s, the HTOC estimated that telecommunications and computer rooms accounted for about 65% of the annual use of halon 1301. Since then a wide range of "in-kind" and "not-in-kind" alternatives have been adopted for new applications. Only a portion of the halon replacement went to high GWP HFCs, mainly HFC-227ea and lesser amounts of HFC-125.

2. There is significant geographical variation in the type of alternatives being employed; in some regions the HFCs are the market leader, whereas in others inert gas systems predominate. The fluoroketone FK-5-1-12 is also a significant alternative.

Merchant Shipping

1. Under International Maritime Organization (IMO) resolution MSC.27(61), halon 1301 ceased being installed in merchant shipping at the end of 1993. It has been estimated that the total

halon 1301 installed at that time was 3,775 metric tonnes. As the ships with halon 1301 installed come to the end of their lives, they are decommissioned and some fraction of that halon 1301 becomes available for other applications, but this fraction is not known. Depending on the assumed lives of the ships containing halon 1301, this limited supply is estimated to continue to be available through 2023 (assuming 30-year lives) to 2033 (assuming 40-year lives).

Global Estimates of Halons and HFC Fire Extinguishing Agent Quantities

1. The estimated size of the global halon banks at the end of 2018 are: halon 1301 - 37,750 metric tonnes; halon 1211 - 24,000 metric tonnes; and halon 2402 - 6,750 metric tonnes. Although regional disparities in the distribution of a halon itself does not necessarily constitute a regional imbalance, it is anticipated that imbalances may result in shortages in one country or region with excesses in other countries or regions.

2. The rates of halon 1301 emissions based on atmospheric measurements of halon 1301 concentrations are generally similar to the emission rates based on the HTOC model. However, emissions based on atmospheric measurements appear to have been higher for short periods of time. This suggests additional emissions but HTOC is unaware of any singular current fire protection use that could account for the higher levels of emissions as they are at least an order of magnitude higher than the largest single fire protection systems known to exist. One potential source of emissions is from shipbreaking activities. Additionally, halon 1301 continues to be produced as a feedstock for the pesticide Fipronil, whose emissions are not be accounted for in the HTOC model but are included in the emission estimates based on atmospheric measurements.

3. A possible consequence of this discrepancy is that the overall size of the halon 1301 bank might be up to ~25% smaller and the global emissions higher than estimated through the HTOC model. As halon 1301 stocks continue to be depleted this difference becomes even more significant. The combination of a potential higher emission rate than assumed by the HTOC and a smaller bank of halon 1301 could also imply that there is going to be significantly less halon 1301 available to support on-going needs in civil aviation, oil and gas, militaries, etc., which could result in a much sooner “run-out date” of 2032 to 2054 as discussed in the Civil Aviation section.

4. The rates of halon 1211 emissions based on atmospheric measurements of halon 1211 concentrations were generally similar to the rates of emissions based on the HTOC model up to approximately 2002. Thereafter the emissions estimated by the two techniques diverge, with emissions based on atmospheric measurements being higher.

5. HTOC is aware that in some places in the world, large amounts of halon 1211 were not allowed to be re-used so there was no economic reason to prevent emissions. As the HTOC model is based on the best handling practices over time, the lack of handling by professional servicers makes the estimation of emission factors difficult at best. Therefore, HTOC believes that it is certainly possible that the emissions are higher than the HTOC model predicts. The HTOC model might come back into closer agreement with emissions estimated from atmospheric

measurements once the non-professionally managed halon 1211 is emitted and emission rates are more predictable.

6. The HTOC estimates that the majority of halon 2402 remains in the former Countries with Economies in Transition. The HTOC model's emissions estimates are generally higher than those based on atmospheric measurements but are within the range of uncertainty of the atmospheric data.

7. A model was developed to estimate HFC-227ea (the main HFC used to replace halon 1301) emissions from fire protection and the size of the bank. As of the end of 2018, the total estimated emissions from fire protection applications is about 3,400 metric tonnes. Assuming a global average annual emission rate of 2.5%, the global HFC-227ea fire protection bank at the end of 2018 is estimated to be about 130,000 metric tonnes. While there is insufficient information available to estimate the emissions and banks of the other HFCs used in fire protection, the HTOC believes that they are much smaller than the HFC-227ea emissions and bank.

8. Many parties have halon banking programs that are fully operational, but more parties have implemented only partial programs, or none at all, and may not be aware of the increasing need to establish a means of meeting the long-term needs for their remaining users. Those parties who have established banking programmes have a distinct advantage in that it is a straightforward step to expand those programs, practices, and processes to include HCFCs and HFCs. Use of HCFCs in fire protection is much smaller than the use of HFCs and as of now recovery of HCFCs is somewhat limited. The banking of HCFCs is in its infancy. Recovery of HFCs in fire protection is meeting as much as 75% of servicing requirements for existing fire protection equipment. Some banking of HFCs is occurring, primarily in parties who have well-established halon banking programs such as Australia, Japan, and the U.S.

9. The HTOC has a continuing concern regarding the historical knowledge that has been lost due to the length of time over which the Montreal Protocol activities have been implemented. A significant number of individuals are new to the Protocol, finding themselves now responsible for fire extinguishing agent management but not being familiar with the issues surrounding halocarbon use, recycling, and banking. The HTOC notes that this is becoming more and more challenging as it works with various parties and organizations on issues related to acquiring halons to meet their continuing needs. Parties may wish to consider addressing awareness programmes to re-establish this apparent loss in institutional memory.

Recycling, Emission Reduction Strategies and Destruction

1. Many, if not all, of the recommended practices for recycling or reclaiming halons will also apply to other halogenated gaseous fire extinguishing agents. Quality testing of blended agents is needed to determine whether recycling or reclamation processes will need to be applied to return them back to their original quality specifications. Where agents are made up of halogenated blends, recycling will reduce physical contaminants like acidity, water content, particulate matter and nitrogen (if the agents have been pressurized). On the other hand, reclamation procedures involving a form of distillation may be required to separate the blended components and rectify their respective purities before they are re-blended in order to meet the

overall purity requirements of the agent. From time to time, depending on the agent's overall quality, it may need to be subjected to both recycling and distillation. Virtually all of the recommended halon emission reduction strategies will also apply to other halogenated gaseous fire extinguishing agents.

2. Owing to the continued global demand in applications such as civil aviation, oil and gas, and militaries, the HTOC continues to recommend that destruction as a final disposition option should be considered only if the halons are contaminated and cannot be reclaimed to an acceptable purity. The HTOC recommends extending this same practice to all halogenated fire extinguishants.

3. Destruction of halons presents some unique considerations. Therefore, technologies that are recommended for CFC and HCFC destruction, but have not been tested for halon destruction, are described as only being potential technologies for halon destruction. As there is nothing particularly different with the HFC fire extinguishants, much less concern with their destruction is anticipated. The one exception to this general principle is HFC-23, which was considered by the Task Force on Destruction Technologies to be in a separate category from the other HFCs, as it is more thermally stable.

2 Introduction

2.1 Structure of this Report

The 2010 Halons Technical Options Committee (HTOC) Assessment report was a long and somewhat unwieldy document, with a high proportion of static or unchanged data. The HTOC felt that placing these data in two Supplementary Reports and five Technical Notes would improve the readability of the 2014 Assessment Report. As a result, the 2014 Assessment report was substantially shorter than the 2010 report. However, subsequent feedback indicated the 2014 Assessment report was too brief and did not contain enough information. Therefore, the HTOC 2018 Assessment Report contains more detail (key background information and any significant updates), with additional reference material remaining in the revised (2018) Technical Notes and Supplementary Reports, produced by the Halons Technical Options Committee (HTOC), as follows

Supplementary Report #1, Volume 2 - *Civil Aviation*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_supplement_report1_2018.pdf

Supplementary Report #2, Volume 3 - *Global Halon, HCFC, and HFC Banking*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_supplement_report2_2018.pdf

Technical Note #1, Revision 5 - *Fire Protection Alternatives to Halons, HCFCs and HFCs*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note1_2018.pdf

Technical Note #2, Revision 3 - *Emission Reduction Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note2_2018.pdf

Technical Note #3, Revision 3 - *Explosion Protection: Halon Use and Alternatives*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note3_2018.pdf

Technical Note #4, Revision 2 - *Recommended Practices for Recycling Halons and Other Halogenated Gaseous Fire Extinguishing Agents*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note4_2018.pdf

Technical Note #5, Revision 2 – *Destruction Technologies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents*
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note5_2018.pdf

Additionally, to improve readability and improve the logical flow, some of the 2014 Assessment Report Chapters have been merged together in this Assessment report.

2.2 Background

Halons are compounds consisting of carbon, bromine and other halogens, such as fluorine and chlorine used almost exclusively as fire extinguishants. Halon 1301 (bromotrifluoromethane) was developed in 1954 in a joint venture between the United Sates (U.S.) Army and the DuPont company for use in portable fire extinguishers in ground combat vehicles and was later expanded for use in fixed gaseous-agent fire suppression systems. Halon 1301 has a normal boiling point of -57.7 °C. Halon 1301, when dispersed into and throughout a protected enclosure (a method called "total flooding") at a concentration of 5 vol. % in air, rapidly extinguishes flames of ordinary combustibles. Further, halon 1301 at 5 vol. % in air is safe to breathe in the event that it is discharged accidentally and without warning into an occupied space. In many applications, halon 1301 was a substitute for carbon dioxide, which is lethal at fire extinguishing concentrations. Additionally, the quantities of toxic decomposition products produced from halon 1301 in the course of extinguishing a fire are low enough to protect occupied spaces in military vehicles, where prompt egress under combat conditions may not be feasible, i.e., require longer exposure times than in other occupied uses. Further, the economics of using halon 1301 were frequently favorable with the result that it was widely adopted in many land-based, marine, and aerospace applications.

Halon 1211 (bromochlorodifluoromethane) was introduced as an effective fire suppression agent in the mid-1960s. It has a boiling point of -3.7 °C making it volatile enough for use as a total-flooding agent, but it is not safe to breathe at effective total-flooding use concentrations. However, halon 1211 was found to be extremely effective as a "streaming" agent where it was applied directly on or about burning materials. The toxicity of halon 1211 is low enough that, under normal use by trained personnel, inhalation of diluted vapors in air is safe. Nearly all commercial aircraft carry halon 1211 handheld fire extinguishers. Only in 2017 did the first in-kind, non-halon 1211 handheld extinguisher units begin to be installed in commercial aircraft.

Other compounds designated as halons, in particular halon 2402 (1,2-dibromotetrafluoroethane), have been used as fire extinguishants but are too toxic for use in occupied enclosed spaces. On November 8, 2008, a fire extinguishing system on a submarine charged with halon 2402 was accidentally released, resulting in the deaths of 20 people.[2]

The effectiveness of halons as fire extinguishants derives from the ease with which the bromine atom (Br) is released from the molecule upon exposure to flames. Bromine atoms act to suppress heat release from flames through a complex series of elementary chemical reactions that lead to the reduction in the concentration of free radicals, which, in turn, are responsible for the stepwise conversion of fuel species (e.g., hydrocarbons, cellulosic materials and plastics, to name only a few) to carbon dioxide and water. The concentration of free radicals in a flame is temperature dependent and is relatively high at temperatures above about 1600 K (1323 °C). Any inert gas added to air can act as a fire suppression agent as it causes a reduction of a flame's temperature and lowering of the free radical concentration. Consider dilution of 100 L of air by addition of 47.5 L of nitrogen. The mixture, consisting of 32.2 vol % added nitrogen, will extinguish heptane flames in the cup-burner test.[3] Halon 1301 achieves the same result at a concentration in air of only 3.3 vol %, Ford (1975). The mechanism by which nitrogen extinguishes flames is its absorption of heat (thermal effect)

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[2] See https://en.wikipedia.org/wiki/2008_Russian_submarine_K-152_Nerpa_accident
[3] The cup-burnet test procedure is described in ISO 14520-1, Annex B.

thereby lowering the flame temperature and, thereby, the concentration of free radicals. Nitrogen, argon, carbon dioxide, and mixtures of these gases extinguish flames at concentrations that are inversely proportional to their heat capacity, Senecal (2005). Displacement or depletion of oxygen also plays a role in the extinguishing mechanism of inert gases.

The mechanism by which halons extinguish flames also involves a thermal effect, however, the dominant extinguishing mechanism is the action of bromine atoms that efficiently convert highly reactive free radicals to chemical species that are much less chemically reactive (chemical-kinetic effect), which, in turn, leads to prompt flame extinguishment. The relative importance of chemical-kinetic vs. thermal effects in halons is about 80/20, Sheinson (1989).

Compounds of volatile substances containing bromine, chlorine, and iodine deplete stratospheric ozone. The potency of an ozone-depleting substance (ODS) is characterized by its ozone depletion potential (ODP). In 1974, it was suggested that atmospheric chlorine was responsible for destruction of atmospheric ozone, Rowland and Molina (1974). This discovery led eventually to the Montreal Protocol on Substances that Deplete the Ozone Layer, promulgated in 1987 and the banning of the production of potent ODSs, including halons, over a period of several years through stepwise production reductions.

2.2.1 Impact of the Montreal Protocol on the Fire Protection Sector

Since the implementation of the Montreal Protocol and the halt or reduction in the production of ODSs, the reduction in the use of halons in new fire extinguishing applications has been remarkable. Even though halons used in fixed systems (primarily halon 1301) and halons used in portable extinguishers (primarily halon 1211) have similar adverse effects on the environment, their employment as fire extinguishing agents is very different. Although halon 1301 has been used in a few portable extinguisher applications, its primary use is in total flooding systems. Halon 1211 is used primarily in portable extinguishers for local application. So, it is necessary to treat the two quite separately in this report.

2.2.1.1 Fixed Extinguishing Systems

Halon 1301 used in fixed fire extinguishing systems is no longer necessary in most (>95%) new installations that would have used halons in pre-Montreal Protocol times. The remaining new installations still using halon1301 are principally in commercial aircraft for which an effective alternative for certain applications has yet to be found.

According to the Intergovernmental Panel on Climate Change (IPCC), IPCC/Technology and Economic Panel (TEAP) (2005), seventy five percent of original halon used in fixed systems has been shifted to agents with no climate impact as shown in Figure 2.1. Less than four percent of the original halon applications continue to employ halons. The remaining twenty-one percent plus has been shifted to hydrofluorocarbons (HFCs), which have climate impacts, inert gases (IGs) and one fluoroketone (FK).

Hydrochlorofluorocarbons (HCFCs) and perfluorocarbons (PFCs) are no longer needed for new fixed systems.

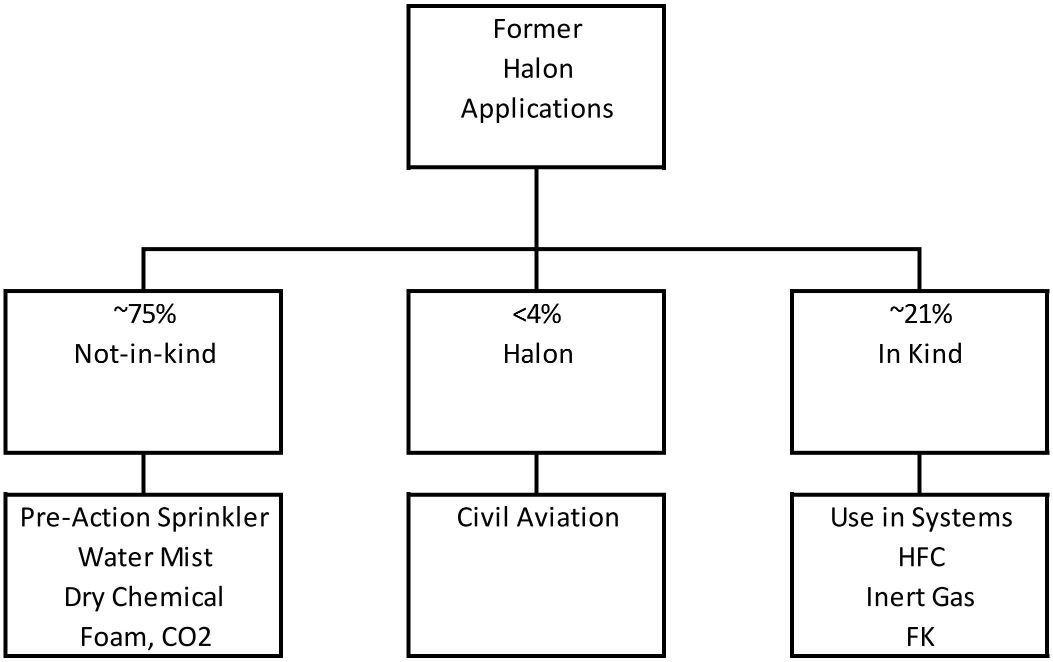

Figure 2.1: Migration of Former Halon 1301 System Applications to Other Types

2.2.1.2 Portable Extinguishing Systems

At least one portable system uses a PFC as a propellant, referred to as HCFC Blend B on the U.S. Environmental Protection Agency (EPA), Significant New Alternatives Policy (SNAP) List. This blend mainly comprises HCFC-123 (>95%).

Even so, according to the IPCC (2005), most (approximately 80%) portable extinguisher applications have gone to not-in-kind alternatives such as water, foam, carbon dioxide and dry powder. Only a very small portion of applications originally using halon 1211 has transitioned to HCFCs, HFCs or FK as shown in Figure 2.2. Recently, a low-Global Warming Potential (GWP), low ODP hydrobromofluoro-olefin (HBFO), specifically 2-bromotrifluoropropene or 2-BTP, has been commercialized for aviation (see section 4.1.4.3 on handheld extinguishers for civil aviation) that will replace halon 1211 and bypass the need for HCFCs and HFCs in this application.

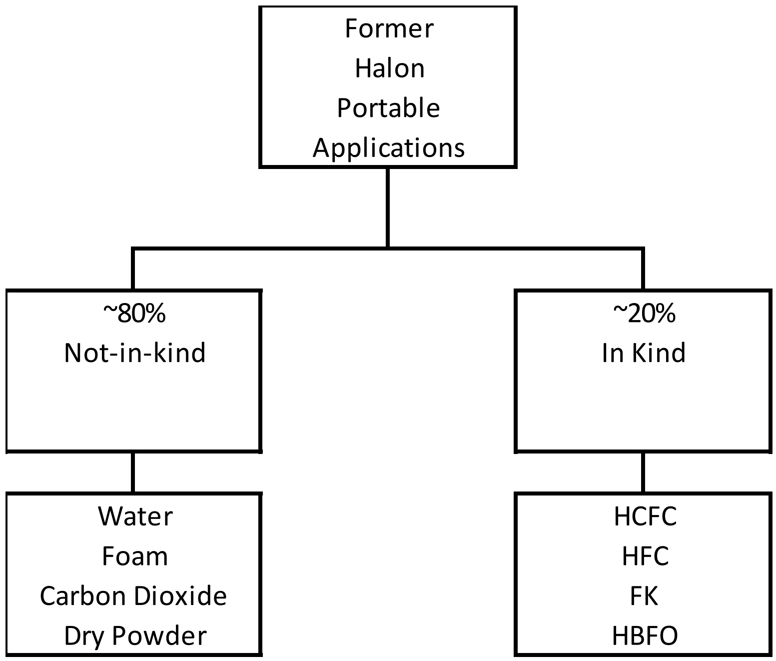

Figure 2.2: Migration of Former Halon 1211 Portable Extinguishers to Other Types

2.3 References

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3 Fire Protection Alternatives to Halons, HCFCs, and HFCs

3.1 Halons

Before discussing alternatives to halons, HCFCs and HFCs, it is helpful to add some historical context explaining the evolution of gaseous fire extinguishing systems.

3.1.1 The Success of Halons in Fixed Systems

The success of the halons was based on two things:

1. First was the awareness of the need for the protection of "essential electronics centers" after numerous catastrophic fires, the most highly publicized being the fire that destroyed the computer facilities in the U.S. Department of Defense at its Pentagon Headquarters.

2. The second driver was system cost where to the surprise of many it became obvious that halon systems cost less than carbon dioxide systems, therefore the lowest cost offering in gaseous extinguishing systems.

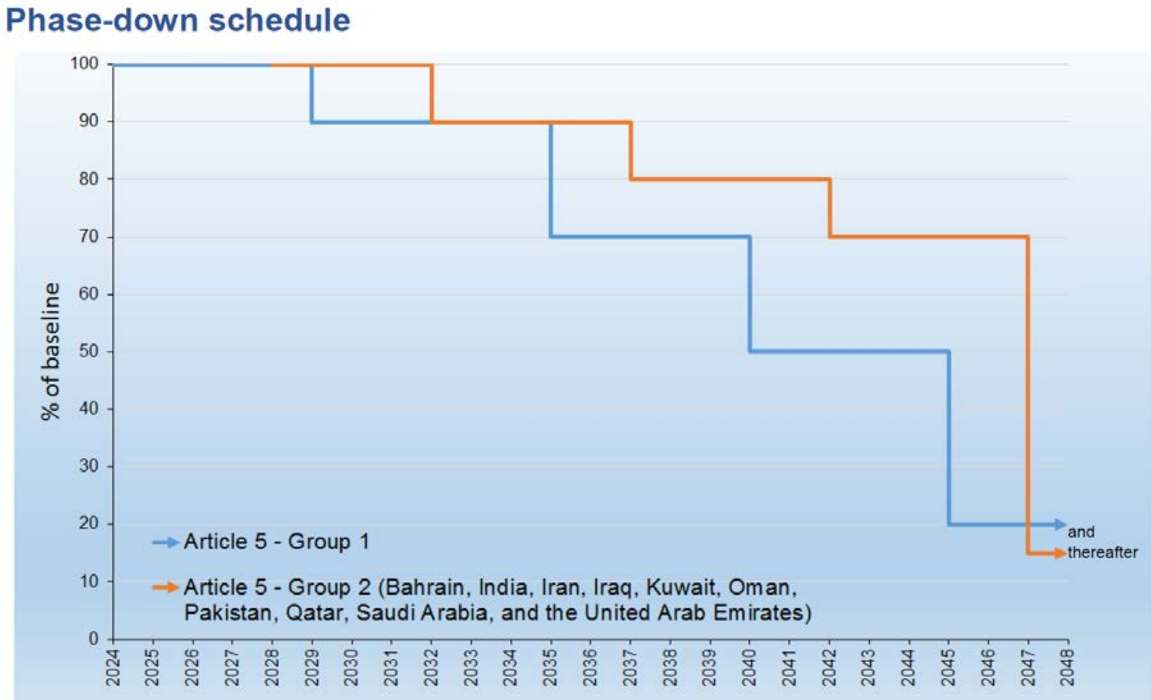
In the beginning of the migration of former halon applications to other fire protection methods, it became obvious that the search for equal cost, equal effectiveness, equal safety and environmentally acceptable alternatives to the halons was an unachievable task. That awareness drove users to not-in-kind alternatives including pre-action water sprinklers, water mist, dry chemical, foam and carbon dioxide. With the halt of production of the halons, the use of carbon dioxide systems increased significantly, especially in the protection of machinery spaces on merchant ships.

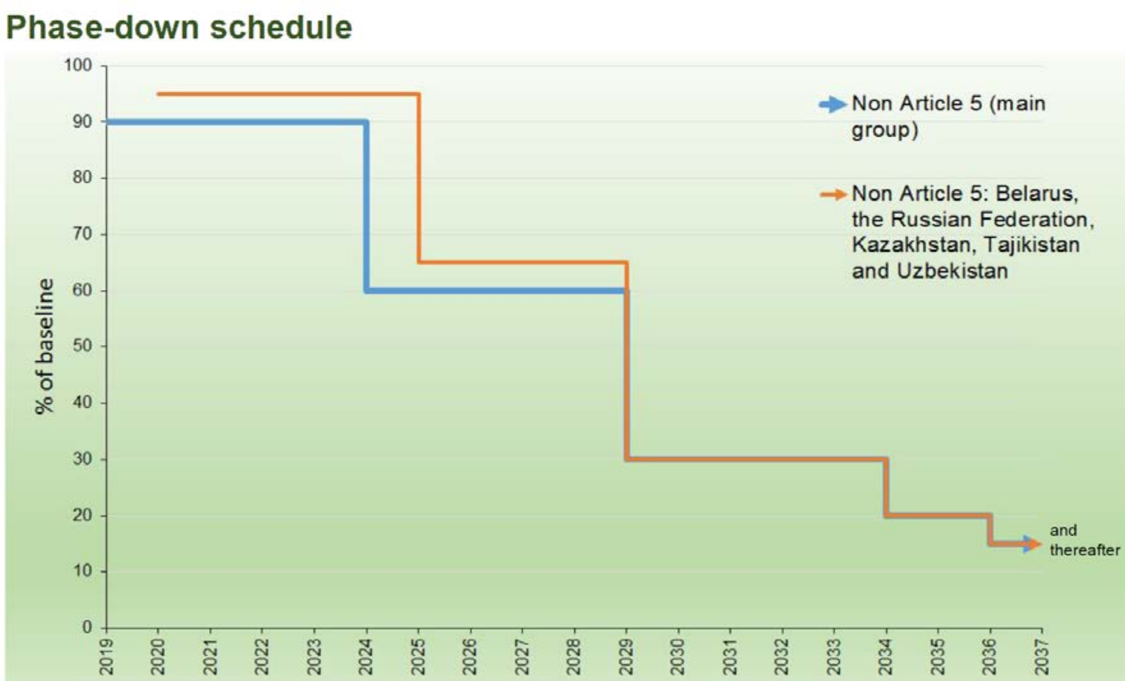
The movement of 75 % of those who had chosen halons for their applications in the past to not-in-kind systems was driven for the most part by the cost of the in-kind alternatives. The fire protection sector is extremely cost driven. Further, end users are generally not skilled in selecting and purchasing fire extinguishing systems. When one cannot differentiate on other system features, including very important ones such as fire performance and environmental characteristics, the tendency is to make purchasing decisions based on cost.

3.2 Impacts of the Kigali Amendment on the fire protection sector

In October 2016, at the 28th Meeting of the parties in Kigali, Rwanda, Decision XXVIII/1 contained an amendment to add HFCs to the Montreal Protocol and slowly phase down their production and consumption. Unlike the controls on ozone-depleting substances (ODSs) that require a complete phase-out of production and consumption of controlled uses, the controls on HFCs are intended to only significantly reduce production (on a carbon dioxide equivalent basis), but not eliminate it. Under the Kigali Amendment, the production phase down would begin in most non-Article 5 (non-A5) parties with a 10% reduction in 2019 and end with an 85% reduction in 2036. Some non-A5 parties have already begun their HFC phase-down according to National or regional regulations. For most A5 parties, the phase down would begin with a production freeze in 2024 and end with an 80% reduction in 2045. The amendment provides for a slight delay in the phase down schedules for a group of parties in Eastern Europe and a group of parties with high ambient temperatures.

Figure 3.1: Graphical Representation of the HFC Phasedown following the Kigali amendment to the Montreal Protocol – (a) A5 parties and (b) non-A5 parties[4]





[4] Taken from http://multimedia.3m.com/mws/media/1365924O/unep-fact-sheet-kigali-amendment-to-mp.pdf

Based on the factors outlined below, the initial Kigali phase down step of a 10% reduction in non-A5 parties is unlikely to have a significant impact on the availability of HFCs for fire protection.

- The use of HFCs for fire protection is extremely small in comparison to all uses of HFCs, with emissions of HFCs from fire protection being estimated at less than 1% of total HFC emissions from all sources.
- Sales of HFCs are flat in North America and declining in Europe.
- The HFCs used for fire protection are manufactured by multiple companies worldwide.

As in any situation where supply is artificially restricted, there is the potential for increases in the cost of HFCs, especially if demand remains high. The HFCs used for fire protection have high GWPs as compared to most HFCs used in refrigeration and other sectors, so this could also have an impact on price, especially where HFCs are regulated through an allowance allocation system based on GWP.

Many parties including those of the European Union (EU), Canada, and Japan have implemented regulations to phase down the production of HFCs that follow or are being adjusted to the Kigali amendment schedule. Parties such as the United Kingdom (UK), Canada and Australia have implemented through legislation a quota system for imports of HFCs as bulk gas ahead of the first Kigali phasedown date of 1 January 2019. In the EU, a quota has been required since 1 January 2015 for those producers and importers that place at least 100 tonnes of CO_2 equivalent of HFCs in bulk on the market in a calendar year. Since 2017, HFC pre-charged in equipment must be covered under the quota system as well. Different regulations include controls on specific HFCs in specific sectors in addition to the production phasedown. For example, the EU regulations include a ban on the use of HFC-23 in fire protection applications as of 2016. Regulations in Australia, Canada and Japan do not currently include any controls on HFCs used in fire protection.

It is impossible at this time to predict the potential impact of the more significant 45% reduction that will take place in 2024 in non-A5 parties or the freeze that will occur in 2024 in most A5 parties. The impact is likely to depend on a number of factors including the market penetration of current low/zero-GWP HFC alternatives and the development of new low/zero-GWP HFC alternatives in all sectors. The HTOC will continue to evaluate the impact of the 2019 reductions and provide future assessments on the impacts of the 2024 reductions in future assessment reports.

3.3 Lack of New Alternatives

Before discussing fire extinguishant alternatives to halons, HCFCs and HFCs it is helpful to review the recent developments in new halogenated fire extinguishant research and development. Since the withdrawal of hydrochlorofluoro-olefin (HCFO) -1233zd(E) for consideration as a total flooding alternative fire protection agent for halon 1301, HFC-227ea, HFC-125 or HFC-23 in the major standards bodies in the U.S. and in ISO in 2017, no substantial progress on potential alternatives has been reported. More recently, the manufacturer has proposed a blend of this agent with the fluoroketone FK-5-1-12. The HTOC is of the opinion that although research to identify potential new fire protection agents continues, it could be five to ten years before a viable agent could possibly have significant impact on the fire protection sector. This timescale is consistent with the 2005 assessment in the Fire Protection Chapter (Chapter 9) of the IPCC / TEAP Special Report, IPCC/TEAP (2005), that due to the lengthy process of testing, approval / certification and market acceptance of new fire protection equipment types and agents, no additional agents were likely to be available in time to have appreciable impact by 2015 (i.e., ten years in the future at the time of writing). This is also broadly consistent with the 2015 recommendation of the civil aviation working group on cargo bay halon alternatives, that the earliest possible date to set a mandate for non-halon systems in new aircraft designs was 2024 (i.e., nine years in the future from when the recommendation was made). However, there is also no assurance that any additional viable agents will be introduced at that time since the most promising chemical groups have already been thoroughly evaluated. Thus, for the foreseeable future, the fire protection industry will have to manage with the currently-available fire suppression agents and will need to re-evaluate agents and technologies that were initially rejected in the hopes of finding other alternatives with better properties, such as CF_3I and inert gas systems.

3.4 Initial Substitutes in the Former Halon Sector

3.4.1 General

Research to find substitutes for halons initially began after the announcement of the Montreal Protocol. Many substances can be used to extinguish flames. However, preferred halon substitutes would have to satisfy important performance criteria, namely, they would have to have ODP values of zero, be effective extinguishants, and have sufficiently low toxicity that under normal use the discharge of agent in occupied spaces would not harm people. Other important preferred features include being electrically non-conductive, and “clean,” meaning leaving no non-volatile residue in protected spaces.

In the U.S., the EPA, under its SNAP Program assumed responsibility for the assessment of certain performance criteria of prospective substitutes for ODS, including fire extinguishants. The EPA reviewed substitutes on the basis of environmental and health risks, including factors such as ODP, GWP, toxicity, flammability, and exposure potential. The EPA maintains lists (referred to as “SNAP” lists) of substitutes that are deemed acceptable, acceptable with use restrictions, or unacceptable for use in total flooding and streaming applications. The SNAP lists are shown in Annex A (total flooding agents) and Annex B (streaming agents) of Technical Note #1. For any agent to be recognized by NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems, NFPA (2018), or ISO 14520 Gaseous Fire Extinguishing Systems – Physical Properties and System Design, ISO (2015), it must first be evaluated in a manner equivalent to the process used by the U.S. EPA SNAP Program or other internationally recognized fire extinguishant approval institutions. Many materials are included in the SNAP lists for total flooding and streaming use, which parties may investigate for suitability to applications of interest. Note, however, that inclusion of an agent on the SNAP list does not necessarily mean it is an appropriate choice and additional listings or inclusions in the aforementioned internationally recognized fire standards are typically also required.

3.4.2 Alternatives in General Use

In-kind agents that satisfy the zero-ODP, toxicity, and cleanliness requirements have been introduced to the marketplace for use in fixed systems for total-flooding applications and for use in portable equipment as streaming agents. There are several total-flooding agent alternatives that are

SNAP-approved for use in occupied spaces, and that are included in ISO 14520 and NFPA 2001, as follows:

Inert gas agents: IG-01, IG-100, IG-55, IG-541
Chemical agents: FK-5-1-12, HFC-23, HFC-125, HFC-227ea

Fewer in-kind agent options have been identified as substitutes for halon 1211, as discussed in section 3.4.5.

3.4.3 CF_3I

CF_3I was evaluated in the late 1990's, but following some adverse toxicity testing, attention was focused elsewhere. Specifically, its cardiotoxic No Observed Adverse Effect Level (NOAEL) and Lowest Observed Adverse Effect Level (LOAEL) are 0.5 volume% and 1.0 volume% respectively. This precludes this agent's use in normally occupied space, although it is approved for non-occupied spaces under the US SNAP program. CF_3I is closest to a "drop-in" replacement agent for halon 1301. This is because iodine can undergo the same catalytic radical recombination reactions as bromine, which makes it is a very efficient fire extinguishing agent. The HTOC is aware that the Civil Aviation industry is refocusing on CF_3I as an engine nacelle / APU fire extinguishing agent. For more information on CF_3I and possible aviation applications refer to section 4.1.4.4 and to Volume 2 of this report, HTOC (2018). It is possible that this agent may be used in other applications which are not normally-occupied.

3.4.4 Agent Alternatives for Fixed Systems

There are several in-kind alternatives to halons. These started with HCFCs and PFCs, followed closely by HFCs and inert gases, and more recently by a FK. The HCFCs and PFCs are no longer used in new total flooding fire extinguishing systems and their use is limited to supporting existing systems. Today, for all practical purposes, there are three types of in-kind alternatives to the ozone-depleting fire extinguishants (halons and HCFCs) used in new fire extinguishing systems - these are HFCs, IGs and an FK. The FK and inert gases also represent low-GWP and no-GWP alternatives to the high-GWP HFCs.

Of the HFCs, the most widely used continues to be HFC-227ea. HFC-125 is used in many applications served by HFC-227ea but in nearly insignificant quantities. HFC-125 does have a very significant application as the extinguishing agent in some military aircraft engine nacelles due to its higher volatility. HFC-23 has found limited use, generally in applications involving low temperature where the agent's low boiling point allows rapid vaporization of the agent. For many of these low temperature applications, HFC-23 or halon 1301 are the only viable fire extinguishing options.

For inert gases, there are four different agents used in fire extinguishing systems. Listed in descending order of effectiveness (according to heptane cup burner testing results reported in the ISO 14520 series of standards) these agents are:

- IG-100 (100 % nitrogen)
- IG-541 (52 % nitrogen +40 % argon + 8 % carbon dioxide)

- IG-55 (50 % nitrogen + 50 % argon)
- IG-01 (100 % argon)

Until the introduction of the agent FK-5-1-12 to the market in the early 2000s, HFCs (most notably HFC-227ea) and inert gas systems as a group had achieved some degree of equilibrium in the fixed system market. More recently, the FK agent has been trending upwards at the expense of the HFCs, most notably HFC-227ea. With the chemical agents, without taking into consideration the relatively small quantities of HFC-125 and HFC-23, anecdotal information has suggested the split in market share is 55 % HFC-227ea and 45 % FK-5-1-12 when measured in terms of agent weight sold in systems.

There are regional differences in the use of chemical agent in-kind gaseous extinguishing systems versus those using inert gases. Generally speaking, the Americas more often use chemical agents (most notably HFC-227ea) whereas Europe, the Middle East, and Asia show a preference for inert gas systems including all four types. In the Americas, the split is estimated at 80 % chemical agent systems versus 20 % inert gas systems on a system-by-system basis. In Europe, the Middle East and Asia, the reverse is the case with an estimated 80 % of new systems based on inert gases and 20 % containing halogenated agents. On a worldwide basis, the market share in terms of cost of the systems sold appears to be evenly split between the chemical agent systems and inert gas systems as shown in Figure 3.2.

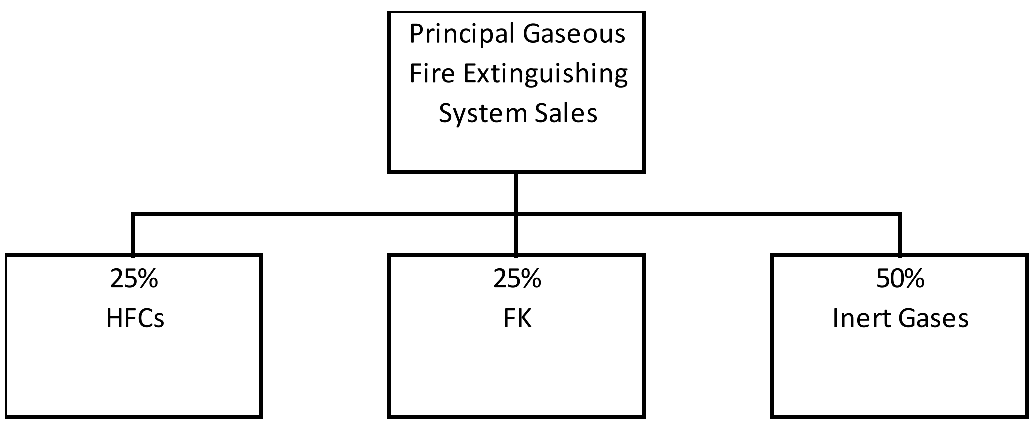


Figure 3.2: Approximate Market Share by System Cost

3.4.4.1 Chemical versus Inert Gas Agents

The chemical agent alternatives (e.g., HFCs and FK), like halon 1301, are stored in nitrogen-pressurized system cylinders either as a liquefied compressed gas (HFCs) or as a liquid below its boiling point (FK-5-1-12). These facts result in high agent in-cylinder storage density, up to about 1200 kg/m^3. Inert gas agents are stored in high-pressure cylinders, typically at 200 or 300 bar pressure, which results in cylinder agent storage densities of about 220 to 400 kg/m^3. Thus, inert gas systems require more cylinder volume per kilogram of agent than for the chemical agents. The early inert gas systems were limited to a maximum cylinder size of 83 litres pressurized to 200 bar. More recent versions are pressurized to 300 bar, representing a 38 % increase in stored agent mass per cylinder.[5] High-pressure cylinders of 166 litres capacity are now available. The increased storage pressure (200 to 300 bar) and the increased cylinder capacity (83 to 166 litres) has brought the inert gas systems to a cost level that is more competitive with the chemical agent systems.

It is a common practice, when discussing agent requirements, to invoke the required agent concentration in terms of volume percent. This approach can be misleading when considering agent quantity, cylinder count, and the floor space required. Table 3.1 illustrates how differences in agent properties relate to minimum mass quantities required to protect a typical ordinary Class A fire hazard. Understanding the quantities required of the several available agents, and the storage capacities of the available steel cylinders, is central to assessing the direct economic and facility floor space requirements on decision making.

Table 3.1: Minimum agent design concentration and agent quantity for ordinary combustible applications (at 20 °C)

Reference ISO 14520 Subpart	**Agent**	**Minimum design concentration, vol. %**	**Minimum agent quantity, kg/m^3[(6)]**
2	CF_3I	4.6	0.390[(7)]
5	FK-5-1-12	5.3	0.779
8	HFC-125	11.2	0.642
9	HFC-227ea	7.9	0.623
12	IG-01	41.9	0.901
13	IG-100	40.3	0.598
14	IG-55	40.3	0.726
15	IG-541	39.9	0.720

Decomposition of any of the chemical agents in the fire extinguishing process produces by-products (mostly HF and COF_2) that are both toxic and corrosive. The amount of these decomposition products formed is directly related to the size of the fire and the time needed to establish the extinguishing concentration in the protected space. Applications where large, fast developing fires are likely, such as in flammable liquid hazards, produce life safety challenges (toxicity) to those entering a space after extinguishment but before it has been purged with air. There is the additional risk of corrosive effects of acid-gas deposition on sensitive contents (e.g., electronics).

Both the U.S. Army and the U.S. Navy have developed mitigation techniques to limit HF and COF_2 generation in some of their systems that use HFC-227ea. The Army has successfully tested and fielded HFC-227ea systems with a 5 to 10 percent addition by weight of sodium bicarbonate powder for the protection of crew compartments in their armoured combat vehicles. The powder exits the extinguisher before the HFC-227ea, thus knocking down flaming before the HFC-227ea

[5] An increase in storage pressure from 200 to 300 bar results in an increase of stored inert gas density of only about 38 %, not 50 % as a simple pressure ratio would suggest. This is due to an increase in the gas compressibility factor at the higher pressure.
[6] Agent quantities were calculated in accordance with ISO 14520-1, sections 1.6.2 for halocarbon agents, and 1.6.3 inert gas agents.
[7] CF_3I is approved for non-occupied spaces only

arrives to complete the extinguishment. The U.S. Navy has a somewhat similar technique that simultaneously discharges water mist and HFC-227ea systems. The water mist cools the very hot combustion gases in the protected space thereby reducing chemical agent hydrolysis, the process that forms acid gases. FK-5-1-12 has not been demonstrated to be able to mitigate the HF and COF_2 generation in similar manners. However, this type of system is not widely used. Typical Navy shipboard systems are HFC-227 only and rely on design concentrations that are much higher than their commercial counterparts to more rapidly extinguish fires and reduce toxic decomposition products. This is practical because personnel are instructed to activate these systems as they exit the space. In addition, there is an approximate 30 second delay after an alarm before the system discharges. The delay is mainly to allow ventilation shutdown, but it also allows any remaining personnel to exit the space before the discharge. In addition, HFC-236fa has been widely used as a halon replacement.

3.4.4.2 Comparison of HFC, FK and Inert Gas Systems

When considering employing a system with HFC-227ea, or its potential in-kind alternatives – FK-5-1-12, or one of the inert gases - end users must consider several factors including system cost, environmental impact, performance at low application temperatures, and impact of agent decomposition products (mainly HF and COF_2). Often, users with numerous systems throughout their operation facilities will standardize on a particular system type in order to simplify maintenance complexities. Table 3.2 indicates some of the reasons why HFC-227ea continues to appeal to some end users.

Table 3.2: The Positives and Negatives of Alternative Agents for Systems

System Type	Positive	Negative
HFC-227ea	• Smallest agent quantity • Least expensive • HF and COF_2 mitigation techniques developed • Acceptable volatility at low application temperatures	• High GWP (3350) • Decomposition in flames produces HF and COF_2 • Potentially impacted by the HFC phase-down under Kigali Amendment to the Protocol
FK-5-1-12	• Negligible GWP (<1) • Not affected by HFC phase-down	• ~24 % more agent by weight required than HFC-227ea • Higher cost than HFC-227ea • Decomposition in flames produces HF and COF_2 • Relatively low vapor pressure imposes design limitations with respect to low-temperature applications
HFC-125	• High volatility at low application temperatures (e.g. aircraft engine nacelles)	• High GWP (3170) • Decomposition produces HF and COF_2 • Potentially impacted by the HFC phase-down under Kigali Amendment to the Protocol
HFC-23	• Very high volatility makes this the only practical choice in some low-temperature applications.	• Very high GWP (12400) • Decomposition in flames produces HF and COF_2 • Potentially impacted by the HFC phase-down under Kigali Amendment to the Protocol
Inert Gas	• Cost ~ FK-5-1-12 • No decomposition products • No environmental impact	• Cost greater than for HFC-227ea • High cylinder storage space and weight

3.4.5 Agent Alternatives in Portable Extinguishers

There have been several in-kind alternatives to halon 1211 for use as streaming agents starting with HCFC blends and PFCs, followed closely by HFCs and more recently by FK-5-1-12. For HFCs, the most notable alternative is HFC-236fa. According to IPCC (2005), only a very limited amount of the original halon market had gone to in-kind alternatives and this is based mainly on cost. In addition to cost being a barrier, the fire extinguishing performance of HCFC Blend B (mainly HCFC-123), HFC-236fa, and FK-5-1-12 do not have the fire extinguishing performance of halon 1211, meaning that greater quantities of agent (and larger extinguisher units) are required to achieve an equivalent extinguisher rating. All three produce high levels of HF and COF_2 when applied to flames, especially flammable liquid type fires. In a very specialized portable system application, the U.S. Army has developed a mixture of HFC-227ea and very finely ground sodium bicarbonate to replace halon 1301 portable extinguishers used in cockpits and other manned spaces of their helicopters.

When considering buying a new portable extinguisher, an end user has a choice between in-kind, which depending on local regulations can include halon 1211, HCFC Blend B, HFC-236fa, FK-5-1-12; and not-in-kind alternatives such as dry chemical, water/foams and carbon dioxide. Prior to the phase-out of halon 1211 production it was common for end users to pay a cost multiple over 7 times to get a clean agent halon 1211 unit versus an extinguisher using a dry chemical agent. Where powder contamination is not allowed, use of a dry chemical extinguisher would be avoided. With today's halogenated in-kind alternatives to halon (HCFC Blend B, HFC-236fa and FK-5-1-12) that cost multiple is in the range of 13 to 16 and it is obvious in the market place that most users are just not willing to pay that premium. Industry consensus is that the market for HCFC/HFC/FK type clean agent extinguishers is approximately 20% of the previous halon 1211 market size. The other 80% of the unit demand is being filled primarily by (1) dry chemical extinguishers where a clean agent is not required, or (2) by carbon dioxide units where a clean agent is required.

HCFC Blend B, with its modest ODP and GWP, has been and continues to be an important alternative to halon 1211. HCFC Blend B is certainly more attractive than its non-ODS alternative HFC-236fa from an environmental standpoint due to HFC-236fa's very high GWP. Indeed, some believe that HCFC Blend B should be preferred to HFC-236fa. The low GWP, non-ODS in-kind alternatives FK-5-1-12 and carbon dioxide are also HFC-236fa alternatives.

In addition, a new agent has been approved for use in portable extinguishers on civil aircraft, 2-bromo-3,3,3-trifluoroprope-1-ene (2-BTP), whose effectiveness is similar to halon 1211 and it appears to be a promising alternative to halon 1211 in that aircraft application. However, in the U.S., it is currently restricted to only that application and aircraft propulsion fire extinguishing under the U.S. SNAP program and the Toxic Substances Control Act. Therefore, it is unclear what further impact this agent could have as a wider halon, HCFC and HFC alternative.

3.4.6 Paths Forward

3.4.6.1 Fixed Systems

For fixed systems, in the absence of a new clean agent with greater appeal and fewer negatives than those shown in Table 3.2 for the existing agents, it is likely that HFC-227ea and FK-5-1-12 have reached equilibrium. However, the recent development of fixed systems employing higher pressure and bulk storage can significantly reduce hardware and installation cost for systems designed with FK-5-1-12.

Also, for fixed systems, as the inert gas systems' agent storage hardware becomes more efficient and thus less expensive, their total market share will likely continue to trend upwards at the expense of the share now held by both HFC-227ea and FK-5-1-12.

Post Kigali, it is likely that the market share of both inert gas and FK systems will grow at the expense of HFC systems. The balance will be determined according to the users' perceived importance of the positives and negatives described in Table 3.2 and any further cost reductions in the inert gas systems due to further improvements in storage efficiency.

3.4.6.2 Portable Extinguishers

For portable extinguishers, prospects for new agents with improved fire performance are low and it appears the market place will have to settle for the HCFC Blend B, HFC-236 fa and FK-5-1-12 agent extinguisher offerings as far as can be seen into the future, unless 2-BTP receives additional approvals. Testing of FK-5-1-12 in additional applications is ongoing with the possibility of expanding its role as both an HCFC and HFC replacement. For example, the U.S. Federal Aviation Administration (FAA) is testing FK-5-1-12 in civil aviation rescue and firefighting vehicles as a potential replacement for HCFC blend B, which would also avoid the need to try to use HFC-236fa in that application (i.e., serve as an HFC alternative).

3.4.7 New and emerging technologies entering commercial use

1. 2-BTP, CAS 1514-82-5, is SNAP-approved for use only in handheld extinguishers in aircraft and aircraft propulsion fire extinguishing. While 2-BTP does contain bromine, this chemical has a very short atmospheric lifetime (about 7 days), an ODP of 0.0028 and a 100-year GWP of 0.23-0.26. In 2017, the aerospace industry began installation of handheld units on commercial aircraft using this agent.

2. Hybrid water-mist systems use water mist combined with an inert gas, usually nitrogen, to gain extinguishing benefits of both inert gas and water mist. At least three companies manufacture and install hybrid water mist systems. One water mist-nitrogen system recently passed (2017) all the criteria of the International Aircraft Systems Fire Protection Working Group Minimum Performance Standard (MPS) for cargo bays.

3. HFC-227ea and FK-5-1-12 have also achieved Underwriters Laboratories Inc. (UL) listings, UL-2129 (UL, 2017), as streaming agents in certain equipment types.

Detailed discussion of substitutes for halons, HCFCs and high GWP HFCs is given in HTOC Technical Note #1, *Fire Protection Alternatives to Halons and other Halocarbon Fire Extinguishing Agents*, which can be found on the Ozone Secretariat website at: https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note1_2018.pdf

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4 <u>Long Term Halon, HCFC, and HFC Uses</u>

4.1 Civil Aviation

4.1.1 Introduction

Engine/APU and cargo compartment civil aviation fire protection needs are among the most demanding uses of halon 1301, requiring its high fire suppression effectiveness and acceptable level of toxicity, particularly for cargo compartments. However, despite over 20 years of research, the civil aviation industry has failed to find any replacements that they deem are acceptable from an efficiency perspective (i.e., space and weight). Given the anticipated 25-40-year lifespan or more of a newly produced civil aircraft, halon 1301 dependency is likely to continue beyond the time when recycled halon is readily available. A separate report on the status of halons and their alternatives in use in civil aviation was produced, HTOC Supplementary Report #1, Volume 2: *Civil Aviation*, and is summarized below.

4.1.2 Estimated Halon Installed Base and Emissions

4.1.2.1 Halon 1301 and Halon 1211 Installed Base

The halon 1301 installed base estimates for civil aviation were updated from the Decision XXVI/7 estimates using activity data and new fleet estimates, ICF (2018). The total worldwide fleet of mainline, regional, business jet and turboprop aircraft for 2018 is estimated to be approximately 52,500 rising to 82,250 by 2036. To estimate the halon installed base, the same activity data for engine nacelles, cargo compartments, APUs, and lavatory trash receptacle extinguishing systems from previous analyses were used, as well as feedback from airframe manufacturers. It is estimated that for 2018, there are approximately 2,700 metric tonnes of halon 1301, and approximately 270 metric tonnes of halon 1211 installed across the mainline and regional fleet. For halon 1301 this is projected to rise to 4,900 metric tonnes in 2036. For halon 1211, the projection for 2036 is to fall to 110 metric tonnes if the International Civil Aviation Organization (ICAO) requirements are fully followed, discussed below, but to rise to as much as 500 metric tonnes if the ICAO requirements are not followed at all. Since 2-BTP has begun to replace halon 1211 for newly-produced aircraft it is likely that the halon 1211 installed base will stay approximately level or begin to fall. HTOC Supplementary Report #1, Vol.2: *Civil Aviation*, details the calculations used for these estimates and also provides estimates for additional years.

4.1.2.2 Estimated Civil Aviation Emissions

One of the main goals of the ICAO efforts under Decision XXIX/8 on the future availability of halons and their alternatives, was to obtain information on the difference between the amount of halon that comes into civil aviation halon 1301 service provider facilities in cylinders for servicing (recovered) and the amount that goes out of the facility in serviced cylinders (filled) as a way of estimating the size and rate of emissions. Unfortunately, many facilities do not keep these exact records and many facilities did not provide complete data, so it was not possible to make this type of determination. For the 10 facilities that did provide some data in this area, the difference between the amount of recovered halon and the amount filled ranged from 4% to 50%, with an average of about 14%. While it is not possible from these limited data to determine the relationship between the 14% data point and the actual emission rate, it does provide additional anecdotal information on top of that contained in the 2014 FAA Halon Aviation Rulemaking Committee report, FAA (2014) that the aviation emissions rate for halon 1301 may be significantly higher than the global industry average of 3-4%.

In reviewing the surveys, it was determined that a number of major aviation service companies have not responded and some that did provided data only from the facility that received the survey and not from all of the company's facilities. Seven of the survey respondents that do not service halon 1301 systems themselves provided information on the companies that they contract with to do the service. ICAO is following up with these companies and those that did not respond in an attempt to obtain additional and more complete survey responses.

4.1.3 Estimates of When Halon 1301 Might Run Out

4.1.3.1 Introduction

At present, the halon demands of civil aviation and most other existing uses of halons (e.g., oil and gas, military, etc.) are being met by recycling agent being withdrawn from applications in other industries and decommissioned aircraft. As reported to parties in the Decision XXVI/7 and the XXIX/8 reports, the HTOC expresses concern that this source of supply will be dramatically reduced or completely exhausted long before the aircraft now being built and fitted (and potentially still designed) with halon systems are retired. Although HTOC has previously reported that this might result in civil aviation submitting an Essential Use Nomination (EUN), the impact could be broader. Since most other existing users do not have long-term, dedicated stockpiles, they are also vying for the same halon supplies that civil aviation does. The timeframe when halon is no longer available to civil aviation could also be the timeframe when halon is no longer available to other users that do not have dedicated, long-term stockpiles, who might then also feel the need to submit an EUN(s). The analysis below projects when this could happen based on varying use and emission scenarios.

4.1.3.2 Estimated Halon 1301 Supplies

The 2018 HTOC model estimates the remaining worldwide bank of halon 1301 to be approximately 37,750 metric tonnes at the end of 2018 (See Chapter 5). This remaining bank of halon 1301 is assumed to be currently installed in fire suppression equipment (e.g., in aviation, computer facilities, oil and gas, military, maritime, etc.), as well as in available stockpiles.

Of the estimated 37,750 metric tonnes of halon 1301 globally, approximately 16,250 metric tonnes are maintained by Japan and are not expected to be available to support other continuing uses (including aviation needs) of halon outside of Japan. The remaining 21,500 metric tonnes of halon 1301 is comprised of the following estimated global uses and stockpiles in 2018:

- Military applications are estimated to have 4,500 metric tonnes in the installed base and reserves.
- Oil and gas facilities are estimated to have 1,500 metric tonnes.

- Nuclear facilities are estimated to have 200 metric tonnes
- The global aviation bank (100 metric tonnes) and installed base are estimated to be a total of 2,800 metric tonnes.
- Marine (non-military) applications are estimated to be 1,500 metric tonnes, assuming each ship has an average 30-year lifetime, ICF (2015), which means this source of supply is projected to run out in approximately 2023.
- Electronics facilities, such as computer rooms and communications rooms, are estimated to be 11,000 metric tonnes.

The stockpiles and installed base for the military, oil and gas facilities, and nuclear facilities (i.e., a total of about 6,200 metric tonnes) are assumed not to be available to meet continuing uses of aviation needs. Furthermore, the amount of halon currently installed in aviation applications is accounted for in the worldwide supply, but also is not assumed to be available for future aviation needs, as it is already in use (i.e., an additional 2,700 metric tonnes in 2018 rising to 4,900 in 2036). This leaves about 12,500 metric tonnes of halon 1301 that could become available to support civil aviation if all of it went only to civil aviation. However, many other on-going uses of halon 1301 will also need to share in this available supply to meet their ongoing needs to refill discharged systems and/or leaks.

To determine the potential availability of halon 1301 to support civil aviation, eight scenarios were developed to estimate halon 1301 resources needed to service the existing aviation fleet, account for aviation growth through 2060, and to also service continuing non-aviation applications. Each scenario assumes various annual emission rates from all halon 1301 aviation applications (i.e., 2.3%-2.8%, 5%, 7.6%, or 15%) and varying emission rates for non-aviation sources (i.e., between 0.1% and 5%), which were reevaluated and refined for this update. The highest annual aviation emission rate (i.e., 15%) was estimated using the global average annual halon emission rate of about 4% from Vollmer et al., (2016) and the proportion of halon emissions from the aviation sector. In addition, the HTOC is aware of anecdotal information that supports this potentially high emission rate.

The eight scenarios model +/- 10% of the initial total available worldwide supply of halon 1301 as of the end of 2018 at 12,500 metric tonnes (i.e., a low and a high of approximately 11,500 and 13,750 metric tonnes respectively). The general assumptions for all scenarios modeled and the years in which the available halon 1301 is expected to be sufficient to meet demand in each scenario are summarized in Table 4.1. The best-case and worst-case scenarios are highlighted in yellow.

These scenarios do not model uptake of halon 1301 alternatives for engine nacelles, cargo compartments, or APUs in existing systems and newly manufactured aircraft, nor are retrofits included. Although ICAO requires new aircraft designs to use halon alternatives in engine and APU applications beginning on December 31, 2014 and for cargo bays beginning in 2024 (dates for the EU are even earlier), there are no aircraft designs currently available to meet that requirement. Starting in 2010, newly manufactured mainline aircraft are assumed to no longer use halon lavatory trash receptacle systems, while a constant portion of the fleet still contains halon lavatory trash receptacle systems (i.e., in aircraft manufactured before 2010).

Based on the results of this analysis, the estimated available halon 1301 supply for replacing emissions from most existing active fire protection systems in aviation and non-aviation applications (i.e., oil and gas facilities, nuclear facilities, and military installed/reserves) as well as new aviation demand are projected to run out by years 2032 to 2054, depending on the initial total worldwide supply in 2018 and annual emission rates.

Table 4.1. Assumptions and Results for Eight Drawing Down Halon 1301 Scenarios

Scenario	Total Available Worldwide Supply in 2018	Annual Emission Rate (Aviation)	Annual Emission Rate (non-Aviation)	Global Overall Emission Rate	Year Available Supply Runs Out
1	11,250	2.3 – 2.8%	0.1 – 3%	1.6%	2048
2	11,250	7.6%	0.1 – 3%	1.9%	2038
3	11,250	5.0%	1 – 5%	2.3%	2040
4	11,250	15.0%	1 – 5%	3.9%	2032
5	13,750	2.3 – 2.8%	0.1 – 3%	1.6%	2054
6	13,750	7.6%	0.1 – 3%	2.0%	2042
7	13,750	5.0%	1 – 5%	2.3%	2045
8	13,750	15.0%	1 – 5%	3.8%	2034

The analysis shows the importance of the effect of the civil aviation emission rate. The high rate of 15% reduces the run-out date significantly, with all scenarios falling within 2032-2035, thus confirming the need for the ICAO informal working group to continue to try to firm up the emissions data. Figures 4.1-4.4 present the run-out date results graphically for the worst-case scenario (i.e., Scenario 4) and best-case scenario (i.e., Scenario 5), respectively. The graphs also show "demand deficit," which represents the amount of halon that would be needed for newly manufactured aircraft and to service existing systems.

4.1.3.3 Potential for Smaller Global Halon 1301 Bank

The above assessment was based on the estimated halon 1301 global bank in the HTOC 2018 model. Atmospheric concentration-based emission estimates in the updated mean data through mid-2017 provide cumulative emissions of 118,000 metric tonnes (Vollmer et al., (2016); this emission rate is more than was estimated previously in the 2014 HTOC Assessment Report, HTOC (2014). The global total cumulative production data provided by HTOC and the emission data calculated by Vollmer et al. (2016) results in a remaining bank of only 30,000 metric tonnes versus the HTOC model estimate of approximately 109,000 metric tonnes of cumulative emissions and a remaining bank of 39,000 metric tonnes. Using the average of the two bank sizes, the difference in remaining banks is nearly 25%. This difference is becoming significant as the global bank (i.e., the amount halon that is available to support fire protection uses) becomes smaller over time. The updated Vollmer et al. (2016) data, provide a much higher mean annual emission rate for 2016/2017 of about 4% of the bank/year than the approximately 2.5% composite rate used by the HTOC. The combination of a potential higher emission rate than assumed by the HTOC and a smaller bank of halon 1301 could also imply that there is going to be significantly less halon 1301 available to support civil aviation and others needs than estimated above. As the supply of halons gets further reduced the likelihood of a significant disruption in supply increases dramatically. If civil aviation

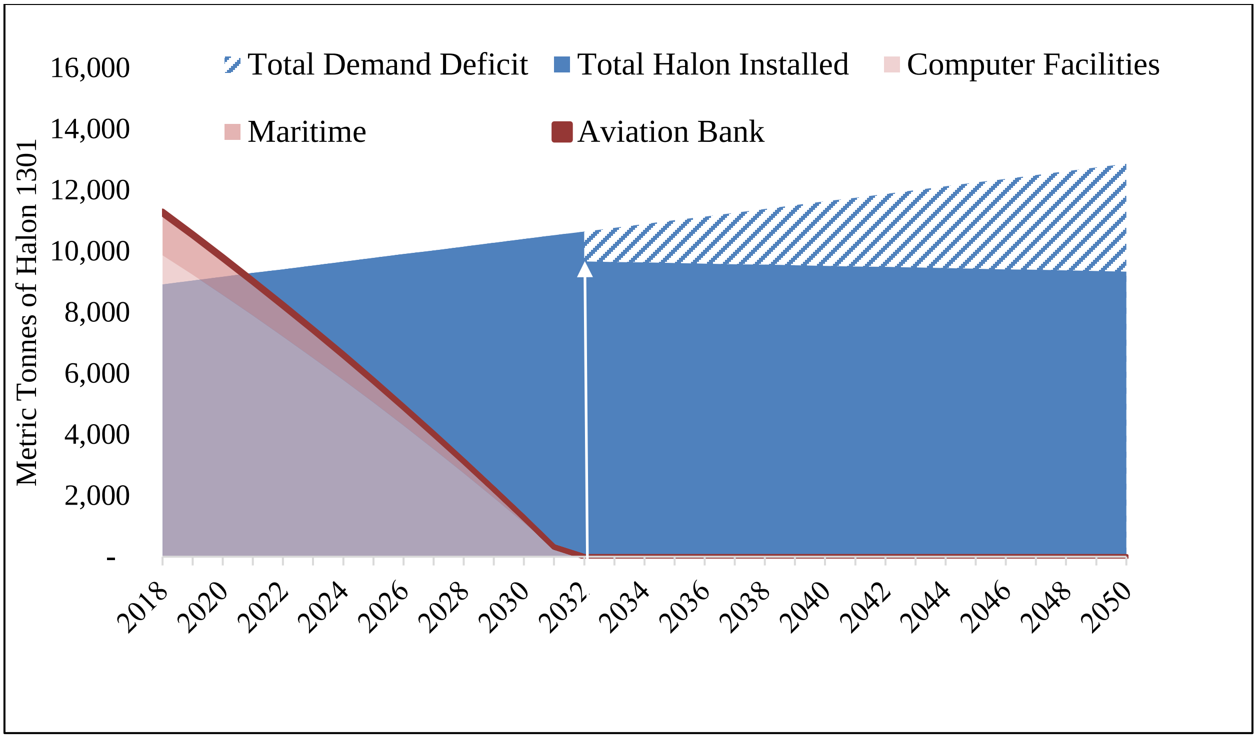

Figure 4.1 - Scenario 4: Drawing Down Halon 1301 Showing the **Entire Available Supply** (**3.9%** Overall Emission Rate; **11,250** metric tonnes of Available Supply)

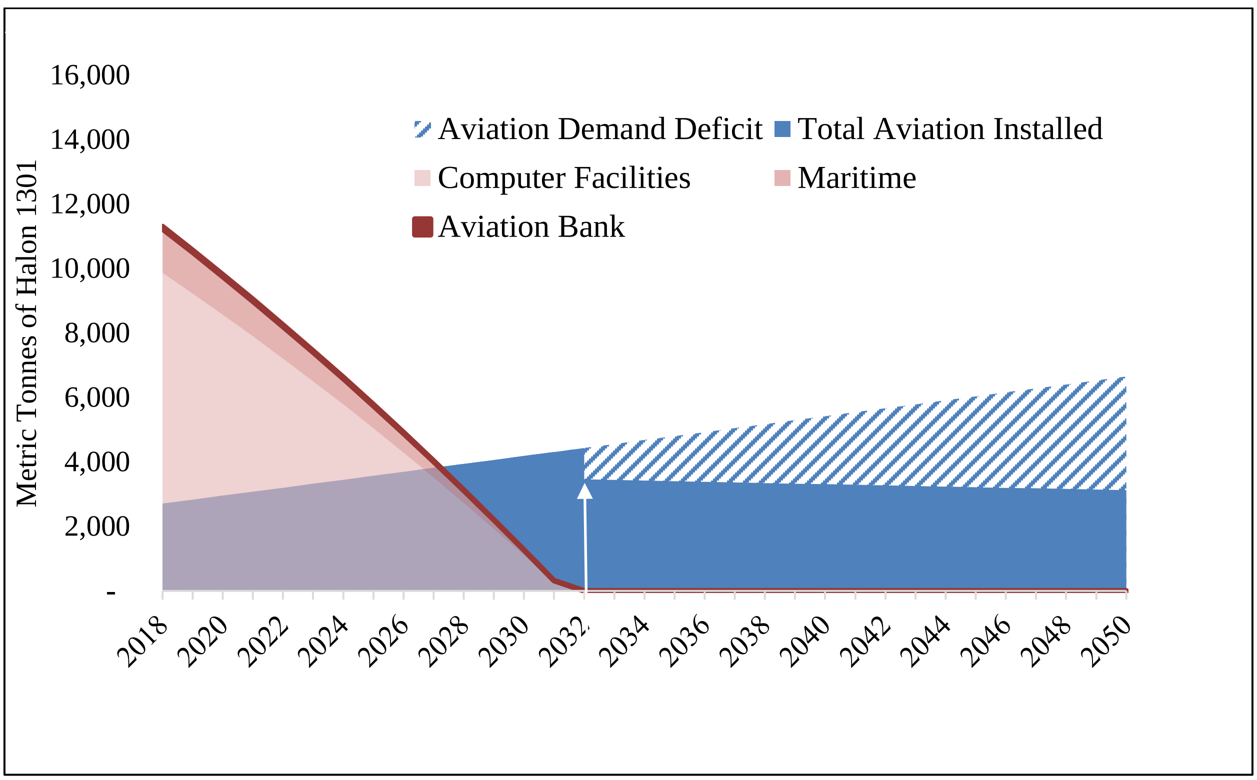

Figure 4.2 - Scenario 4: Drawing Down Halon 1301 Showing the **Available Supply and Civil Aviation Bank** (**3.9%** Overall Emission Rate; **11,250** metric tonnes of Available Supply)

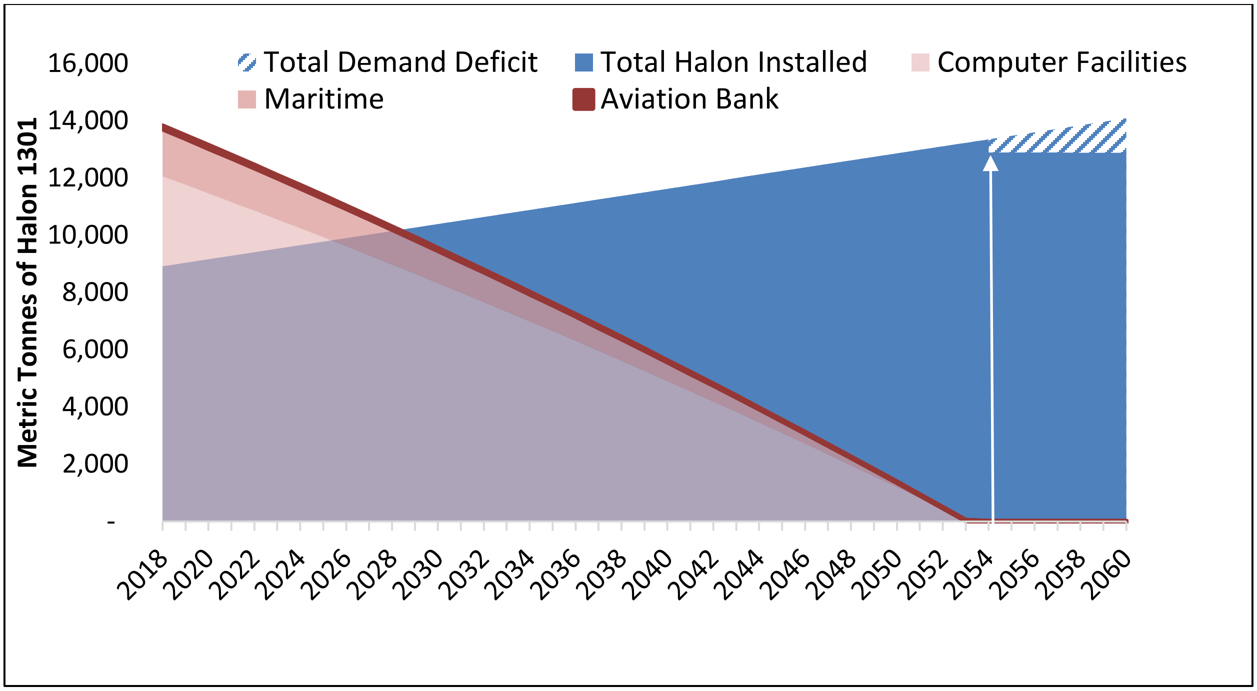

Figure 4.3 - Scenario 5: Drawing Down Halon 1301 Showing the **Entire Available Supply** (**1.6%** Overall Emission Rate; **13,750** metric tonnes of Available Supply)

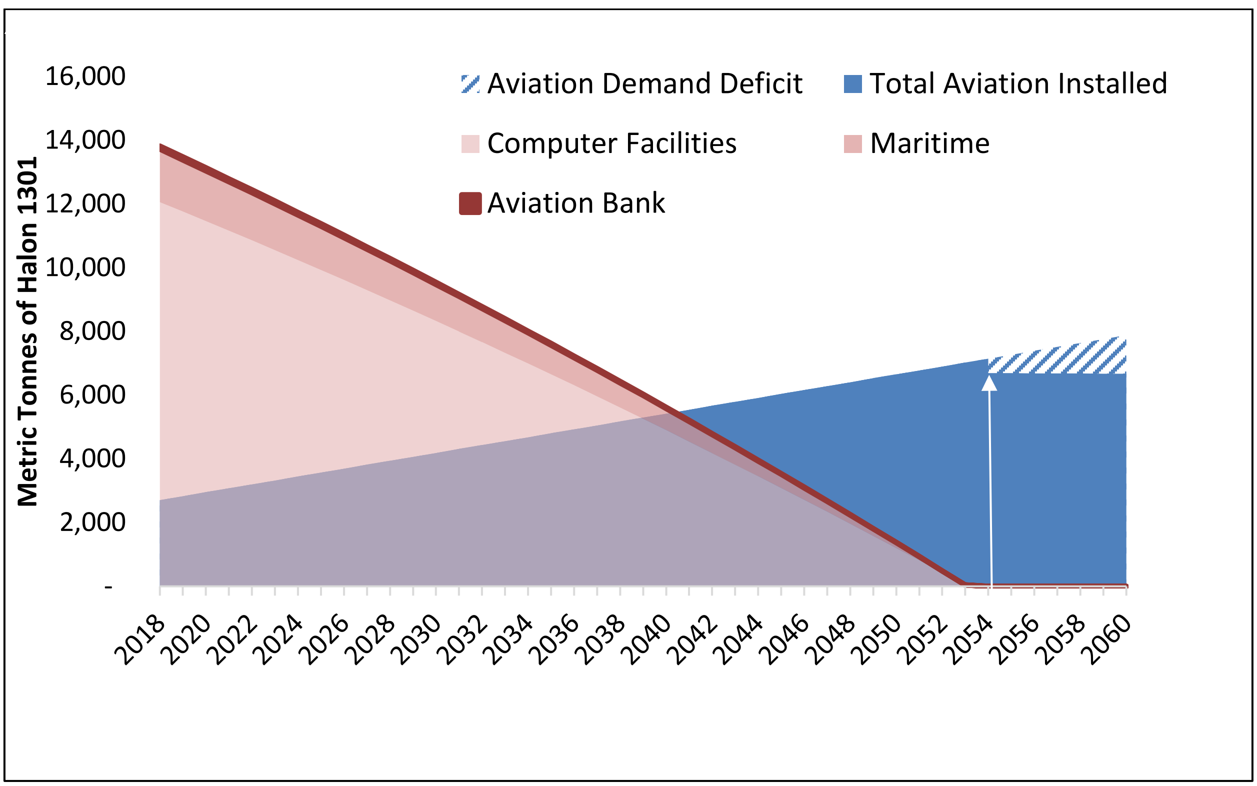

Figure 4.4 - Scenario 5: Drawing Down Halon 1301 Showing the **Available Supply and Civil Aviation Bank** (**1.6%** Overall Emission Rate; **13,750** metric tonnes of Available Supply)

does not stop producing new aircraft using halon 1301, they soon will be, and likely are, already producing and potentially designing new aircraft that cannot be sustained over their economic lifetimes with existing supplies of recycled halon 1301.

4.1.4 Status of Halon Replacement Options

4.1.4.1 Introduction

Civil aviation has only instituted a halon 1301 replacement for its smallest use, lavatory trash receptacle extinguishing systems, estimated to be less than 0.5% of its total installed base on aircraft. Its two largest uses, engine nacelles/APUs and cargo compartments, continue to have no alternatives available to be approved by aviation authorities.

4.1.4.2 Lavatory Trash Receptacle Systems

As previously reported in the 2014 Assessment Report, research and testing has shown that there are suitable halon alternative lavatory trash receptacle suppression systems using HFC-227ea or HFC-236fa. It is reported that now, virtually all current production aircraft lavatory trash receptacles are fitted with halon replacement agents albeit with these high GWP HFCs. Many older legacy platforms have not transitioned to the replacement agents, and to do so would require Type Certification / Aircraft Manuals to be updated. In some cases, this is happening; in others it is not. In addition, several airlines are replacing existing halon 1301 lavatory trash receptacle systems with these halon-free alternatives during scheduled maintenance operations. There are no approved low-GWP alternatives for this application to replace the HFC-227ea, HFC-236fa or halon 1301, and the HTOC is not aware of any research to develop one at this time.

4.1.4.3 Handheld Extinguishers

Despite three halon alternatives, HFC-227ea, HFC-236fa and HCFC Blend B, having completed all of the required handheld UL and Minimum Performance Standard (MPS) tests and having been commercially available since 2003, airframe manufacturers chose not to pursue qualification and installation certification for these alternatives. This was reported as being due to the fact that all three alternatives have increased space and weight characteristics over halon 1211 and there are environmental concerns that the two HFCs are high-GWP greenhouse gases and the HCFC already had production phase-out dates under the Montreal Protocol. In short, the airframe manufacturers were waiting for an agent without most of these adverse characteristics. The fire extinguishant 2-BTP is now commercialized and qualified for civil aviation use. It is the closest to a “drop-in” replacement for halon 1211. Two companies now offer portable extinguishers containing 2-BTP and have started supplying major aircraft manufacturers on a platform-by-platform basis. The transition to 2-BTP for newly produced aircraft is currently ongoing.

4.1.4.4 Engine and APU Compartment

HFC-125 could be an effective halon 1301 replacement but has increased space and weight characteristics over halon 1301 that reportedly present installation and environmental concerns to the airframe manufacturers. Although, some military aircraft have been fitted with HFC-125 systems, airframe manufacturers have chosen not to pursue qualification and installation certification for HFC-125 in civil aviation engines/APUs.

A recent interest has been growing for trifluoroiodomethane (CF_3I) as a total flooding agent in aviation-related normally unoccupied spaces such as Engine/APU applications. This agent was evaluated in the late 1990's but following some adverse toxicity testing attention was focused elsewhere. As iodine shares the catalytic radical recombination reactions with bromine, it is a very efficient fire extinguishing agent. It is very close to a "drop-in" replacement for halon 1301 in terms of volume and has a small weight penalty. Following evaluation by the U.S. FAA, a certification concentration of 7.1% has been defined, equivalent to halon 1301 at 6%, Ingerson (2007). Refer to Chapter 3 for more information on CF_3I.

The civil aviation industry decided in 2013 to define common non-halon fire extinguishing solution(s) and formed the Engine/APU Halon Alternatives Research Industry Consortium. In 2015, this was renamed the Halon Alternatives for Aircraft Propulsion Systems (HAAPS) consortium. The consortium consists of aircraft original equipment manufacturers (OEMs) Airbus, Boeing, Bombardier, Embraer, Textron, and the Ohio Aerospace Institute acting as administrator. Engagement with fire extinguishing suppliers and distributors, chemical companies, airline operators, engine manufacturers, universities, consultants and other stakeholders is planned. The consortium has mapped out a three phase multi-year approach for alternatives development and has recently completed Phase I (administrative start-up), with a signed Joint Collaboration Agreement in place. Phase II (formal creation of Technical and Non-Technical Task Teams) has commenced and has completed the initial FAA Engagement and drafts for a technical requirements document and a Request for Information. Work in-progress includes definition of high level solution(s) strategy, design requirements, performance validation, down selection criteria, regulatory requirements, certification path proposals and formation of the non-technical task team to develop supplier engagement documentation. The consortium projects that Phase II is expected to be complete no later than the end of October 2019 with agent down selection. Phase III will then establish supplier agreements for in-depth agent evaluation and testing. The HTOC notes that the progress of this consortium is slower than was originally forecast by the consortium and reported in the 2014 HTOC Assessment Report. The consortium is of the opinion that the benefits of industry-wide solution(s) will pool resources for testing and development, support more timely agency approvals, and leverage supply chain readiness for more economically viable implementations. Except for the customized approval for use of phosphorous tri-bromide in one private jet, the only approved agents for use in civil aviation engine nacelles/APUs remains halon 1301 and HFC-125 on a military derivative of a large commercial aircraft (Boeing 767; military derivative KC-46).

4.1.4.5 Cargo Compartments

To date, there have been no cases of halon 1301 replacement with an alternative agent in cargo compartments of civil aircraft. Part of the approval process is a test involving a simulated exploding aerosol can and all chemical fire extinguishing agents (apart from halon 1301) that have undergone this exploding aerosol can test have been shown to cause an undesired increase in the test compartment pressure if discharged at a concentration below which the agent will suppress a fire or deflagration event. In other words, it can make the event worse than if there was no fire extinguishant at all. The cargo MPS now requires that pressure increase not occur upon application of the fire extinguishant in a quantity less than that needed to suppress a fire or deflagration event. On this basis, all chemical fire extinguishants tested so far have been found to be unacceptable.

Currently there are two approaches being developed by industry. Data have been presented to a U.S. FAA fire protection forum by one fire suppression system manufacturer showing that inert gas alone is capable of passing the MPS. The FAA recently presented data showing a combination of water mist and nitrogen (IG-100) can pass the current MPS and a challenge test focused on lithium ion batteries. Commercial development of both the inert-gas-only and the water mist/nitrogen cargo fire suppression systems continues.

As previously reported in the 2014 Assessment report, the International Coordinating Council of Aerospace Industries (ICCAIA) formed the Cargo Compartment Halon Replacement Working Group (CCHRWG) in 2013 to coordinate a single industry effort to effort to promote and assess alternatives to halon 1301 in cargo compartments. This group recommended to ICAO the end of 2024 as the time by which a cargo compartment fire suppression system containing a replacement agent, system or concept could be developed and a Type Certificate applied for. The group (renamed as the Cargo Compartment Halon Replacement Advisory Group, CCHRAG) is currently conducting a technical assessment of nine potential halon replacements, including inert gases, chemicals, and other not-in kind technologies. A report summarizing the status will be presented at the 2019 ICAO General Assembly and available for the 31st Meeting of the Parties.

4.1.4.6 Regulatory Timelines

At the 39th General Assembly meeting, ICAO accepted the recommendation from the CCHRWG (Amendment 106 to Annex 8) and adopted as Resolution A39/13, the date of 2024. This now means that all halon applications on civil aircraft have dates by which new designs (an application for a Type Certificate in aircraft certification terminology) or aircraft currently in production require halon alternatives be used as follows:

- in lavatory fire extinguishing systems used in aircraft produced after December 31, 2011;
- in hand-held fire extinguishers used in aircraft produced after December 31, 2018[8];
- in engine and auxiliary power unit fire extinguishing systems used in aircraft for which application for Type Certification will be submitted after December 31, 2014 (current designs are allowed to continue to use halon for production of new aircraft); and
- in cargo compartment fire suppression systems used in aircraft for which application for Type Certification will be submitted on or after 28 November 2024 (current designs are allowed to continue to use halon for production of new aircraft).

However, these are not necessarily requirements that Member States must follow. Instead, States can, and some have filed “differences” indicating that they will not meet these standards and will continue to use halons or allow the use of halons past these dates.

Within the EU, all current on-board uses of halons in aviation are listed as critical uses in the current Annex VI to Regulation (EC) No. 1005/2009. Annex VI was revised in 2010 as per Commission Regulation (EU) No 744/2010 of 18 August 2010 and contains “cut-off dates” for the use of halons in new designs of equipment or facilities (including aircraft) and “end dates” when all

[8] Amendment 41 to ICAO Annex 6 modified the date from December 31/2016 to December 31/2018

halon systems or extinguishers in a particular application must be decommissioned. Table 4.2 provides a comparison of the ICAO and EU dates.

Table 4.2 – Comparison of EU and ICAO halon Phase-out Requirements

	Requirement	Lavatory	Handheld Extinguisher	Engine / APU	Cargo
New Design Aircraft	EC Cutoff Date	2011	2014	2014	2018
	ICAO	2011	2018	2014	2024
Current Production Aircraft	EC End Date (includes retrofit)	2020	2025	2040	2040
	ICAO	2011	2018	NA	NA

Additionally, the European Aviation Safety Agency (EASA), as the Regulatory Aviation Agency for the EU, has included provisions (as part of the airworthiness standards for the issue of type certificates - EASA CS-25) for the use of alternative fire-extinguishing agents. The time scale for the Halon replacement is in line with the dates given in the Commission Regulation (EU) No 744/2010.

4.1.5 New Generation Aircraft

The civil aviation regulatory authorities should closely monitor and ensure that the testing and approval of alternatives for engine nacelle and cargo compartment applications is completed in the near-term for new airframe designs. New airframe designs should take into account these tested and approved alternative fire extinguishants and systems. However, this is not happening to date. The timing of the inclusion of the available alternatives in new aircraft designs remains uncertain, and unless the processes of designing, conforming, qualifying and certifying new extinguishing systems on civil aircraft are made a priority by the airframe manufacturers and approval authorities – and expedited accordingly – these are significant barriers to the transition away from halons and will continue to use up the diminishing supplies of halon 1301 leading to shortages in the future.

The HTOC continues to report that it remains markedly disappointing that, given the extensive research and testing efforts that have been expended on aviation applications since 1993, alternatives are used only in the lavatory fire extinguishing systems of new Airbus, Boeing and Embraer aircraft systems and hand-held extinguisher applications. This leaves unaddressed the engine/APU and cargo bay applications, which are by far the largest civil aviation uses of halon 1301.

4.1.6 Crash Rescue Vehicles

In addition to on-board civil aircraft applications, halon 1211 is used in some Aircraft Rescue and Fire Fighting (ARFF) or Crash Rescue vehicles on airport ramps. Since 1995, a significant number of airports in the U.S. have used HCFC Blend B as an alternative to halon 1211 for this application. However, because HCFC Blend B is an ODS, national regulations may limit its use for this application in other countries. A recent TEAP Working Group Report, TEAP (2018), concluded that there was some likelihood that there might be ARFF applications that would continue to need clean agents in the 2020 - 2030 timeframe that currently can only be met through the supply of halon 1211 or HCFC Blend B. Originally the report estimated that up to 900 metric tonnes per annum of HCFC Blend B might be required, but more recent information from the U.S. indicated that the quantity likely to be needed could be reduced to between 120 and 450 tonnes per year. The fluoroketone FK-5-1-12 has recently been evaluated in ARFF vehicle applications but the results have not been published at the time of writing this report.

In November 2018, the parties to the Montreal Protocol agreed to adjust the Protocol and adopted a corresponding Decision XXX/2 to allow the use of newly produced HCFCs for the servicing of niche applications such as fire suppression and fire protection equipment existing on 1 January 2020 for the period 2020-2029 for non-A5 parties and also on existing equipment in 1 January 2030 for the period 2030-2039 for A5 parties.

4.2 Military Applications

The parties' defence ministries and military organisations continue to carefully manage their limited supplies of halons for future uses where alternatives cannot be implemented. These reserves are critical to the sustainment strategies of weapon systems for the remainder of their service lives or until alternatives can be fitted. Although prices of recycled halons continue to rise, at this point**,** supplies appear to be sufficient to support most anticipated future military needs. The HTOC is not aware of any reports of shortages other than those of individual parties whose national regulations restrict the imports or exports of halons.

Due to a lack of priority, much of today's fielded weapon systems and support equipment will remain in service, and their mission-critical halon fire protection systems will need to be supported until 2050 and potentially beyond. However, the EU requires phase-out of halons in military uses as shown in Table 4.3 (Commission Regulation EU, 2017/605), where the cut-off date is the date after which halons must not be used for fire extinguishers or fire protection systems in new equipment and new facilities for the application concerned and the end date is the date after which halons shall not be used for the application concerned and by which date the fire extinguishers or fire protection systems containing halons shall be decommissioned.

Given that the last end date for halon in these military critical use applications is 2040, the replacement process would have to be initiated years ahead of these legislated phase-out dates.

Military fire protection systems are unique in that, besides protecting against 'peacetime' fires from routine use, they must protect military personnel and platforms from the consequences of combat damage. Fires due to combat events are generally very fast-growing and relatively large and military fire protection systems are required to counter these threats, often while allowing occupants to remain in the affected spaces.

There are no universal fire protection requirements for military applications. For example, some navies rely on halons as a key element of their fire protection strategy for submarines while others prohibit this use due to concerns regarding the potential hazards from combustion by-products (for example, acid gases including hydrogen fluoride (HF), hydrogen bromide (HBr), and/or hydrogen chloride (HCl) as well as carbonyl species such as carbonyl fluoride (COF_2) and carbonyl chloride ($COCl_2$, phosgene), depending on the particular halon used) that are inevitably generated at some levels by thermal breakdown of the agent during the fire suppression process. Similarly, combustion by-products are a key consideration for agent selection in ground vehicle crew compartment fire extinguishing systems for some militaries while others have not established limits for these potentially toxic compounds. These examples illustrate the fact that a suitable alternative for one party may not be acceptable to another.

Table 4.3: Phase-out dates for military applications within EU

CRITICAL USES OF HALONS					
Category of equipment or facility	Purpose/Applications	Type of extinguisher	Type of halon	Cut-off date (31 December of stated year)	End date (31 December of stated year)
1. On military ground vehicles	1.1. For the protection of engine compartments	Fixed system	1301 1211 2402	**2010**	**2035**
	1.2. For the protection of crew compartments	Fixed system	1301 2402	**2011**	**2040**
	1.3. For the protection of crew compartments	Portable extinguisher	1301 1211	**2011**	**2020**
2. On military surface ships	2.1. For the protection of normally occupied machinery spaces	Fixed system	1301 2402	**2010**	**2040**
	2.2. For the protection of normally unoccupied engine spaces	Fixed system	1301 1211 2402	**2010**	**2035**
	2.3. For the protection of normally unoccupied electrical compartments	Fixed system	1301 1211	**2010**	**2030**
	2.4. For the protection of command centres	Fixed system	1301	**2010**	**2030**
	2.5. For the protection of fuel pump rooms	Fixed system	1301	**2010**	**2030**
	2.6. For the protection of flammable liquid storage compartments	Fixed system	1301 1211 2402	**2010**	**2030**
	2.7. For the protection of aircraft in hangars and maintenance areas	Portable extinguisher	1301 1211	**2010**	**2016**
3. On military submarines	3.1. For the protection of machinery spaces	Fixed system	1301	**2010**	**2040**
	3.2. For the protection of command centres	Fixed system	1301	**2010**	**2040**
	3.3. For the protection of diesel generator spaces	Fixed system	1301	**2010**	**2040**
	3.4. For the protection of electrical compartments	Fixed system	1301	**2010**	**2040**
7. In land-based command and communications facilities essential to national security	7.1. For the protection of normally occupied spaces	Fixed system	1301 2402	**2010**	**2025**
	7.2. For the protection of normally occupied spaces	Portable extinguisher	1211	**2010**	**2013**
	7.3. For the protection of normally unoccupied spaces	Fixed system	1301 2402	**2010**	**2020**

4.2.1 Military Ground Vehicle Applications

Parties continue to make progress to reduce dependence on halons for vehicle fire protection and in some cases avoid the use of high GWP HFCs. For example, several parties have initiated conversion programs to replace halon 1301 in crew and/or engine protection systems with a more environmentally friendly agent based upon an HFC-227ea/powder blend, HFC-236fa, or FK-5-1-12. Additionally, the UK has converted the engine compartment fire protection systems of all its in-service armoured fighting vehicles to HFC alternatives (HFC-227ea and HFC-236fa) and replaced halon portable extinguishers in the vehicle crew compartments. Carbon dioxide extinguishers have also replaced halon portable extinguishers on all Swedish military vehicles.

The following discussion of the agent selection process for crew compartments of ground combat vehicles by the militaries of several parties illustrates how different approaches could be taken and different agent selections could be made for the same military application.

4.2.1.1 United States

The U.S. Army conducted live-fire testing of ground vehicle crew automatic fire extinguishing systems (AFES) to evaluate several potential halon 1301 replacements, including the high GWP HFC alternatives, with and without sodium bicarbonate ($NaHCO_3$) dry chemical, HFC-227ea, HFC-236fa, and HFC-125, and the zero-GWP water with freeze-point additives, and $NaHCO_3$ alone (referred to as neat). HFC-227ea and HFC-236fa mixed with $NaHCO_3$, and a proprietary aqueous agent, demonstrated acceptable performance. The HFC-227ea/$NaHCO_3$ combination and aqueous system were down-selected. The HFC-236 based blend also met requirements but was not chosen because of its higher GWP compared to HFC-227ea. The HFC-227ea/$NaHCO_3$ mix was subsequently SNAP-listed by the U.S. EPA as HFC 227-BC and is the only halon alternative agent deployed to protect the crew compartments of U.S. Army ground vehicles (McCormick et al., 2000; McCormick et al., 2006; Hodges, 2006).

The evaluation method involved fuel-spray live-fire tests engineered to simulate the blast overpressure and fireball development that follows a ballistic penetration of the vehicle armour and fuel tank. The test vehicle was instrumented so that results could be judged against the casualty criteria developed by the U.S. Army medical community (Ripple and Mundie, 1989). These criteria were derived to allow vehicle occupants to remain in the compartment for at least five minutes during and following a fire suppression event without being subject to incapacitation (immediate or delayed). Key elements of the criteria are summarized in Table 4.4.

In a follow-on effort, lower GWP extinguishing agents were evaluated as part of ongoing vehicle modernization efforts. Several agents were investigated, including FK-5-1-12, FK-5-1-12 with dry chemical, water with additives, and neat dry chemicals, using several extinguisher technologies. The basic conclusion (Hodges and McCormick, 2010 and 2013) was that no low-GWP alternate agent was available at that time which could be considered to be a drop-in replacement for halon 1301 or HFC227-BC for this application.[9] The U.S. Army continues to research low- and zero-

[9] An interesting observation made during this study was that the byproducts from FK-5-1-12 evolved quite differently than those from halon 1301 or HFC-227; specifically, FK-5-1-12 produced hazardous levels of hydrogen fluoride (HF) and carbonyl fluoride (COF_2) simultaneously, whereas halon 1301 and HFC-227 generally produced lower levels of COF_2 initially which then decayed into HF. The result was that the dose of byproducts from FK-5-1-12 were

GWP potential alternatives but has not yet found anything to replace HFCs that meets the performance requirements listed in Table 4.4.

Table 4.4: Select Crew Casualty Criteria

Parameter	Requirement
Fire Suppression	Extinguish all flames without reflash
Skin Burns	Less than second degree burns Thermal, 10 sec dose ≤ 1316°C-sec (2400°F-sec) and flux ≤ 3.9 cal/cm²
Overpressure	Lung damage < 0.8 bar (11.6 psi) Ear damage ≤ 0.28 bar (4 psi)
Agent Concentration	Not to exceed LOAEL (per applicable NFPA standard)
Toxic Gases	Acid and Carbonyl Gases, 5 min dose HF + HBr + 2·COF_2 < 746 ppm-min Other gases (e.g., CO_2, CO, NO_X, HCN) are also measured
Oxygen Levels	Not below 16%

4.2.1.2 Sweden

In the mid-1990s, Sweden joined forces with Germany to take the lead in Europe to evaluate alternate agents and systems for crew and engine compartments on military vehicles. Several live-fire test programs were carried out over years that involved fuel-spray live-fire tests developed to simulate the blast overpressure that follows a ballistic penetration of the armour and fuel tank (in conformity with Level 4 of STANAG 4317, NATO (2017)). The crew casualty criteria used are similar to those in Table 4.4, apart from overpressure where the Swedish/German criteria allow a maximum of 5.5 psi (0.38 bar) as shown in Table 4.5.

consistently well above the U.S. Army casualty criteria limit, while byproducts from HFC227-BC and halon 1301 were below the limit (Hodges and McCormick, 2010; Hodges and McCormick, 2013). It should also be noted that measuring the total averaged fluorine levels is not an adequate method to determine incapacitation due to inhalation of these toxic gases. Overall, this points to the fact that chemicals that are designed to be more reactive, thus yielding shorter atmospheric lifetimes and therefore lower GWPs, generate much higher byproduct levels during the fire suppression process than more stable, and thus likely higher GWP, compounds.

Table 4.5: Swedish key elements of crew casualty criteria (Schepers, 1999; Schepers, 2000)

Parameter	**Requirement**
Fire Suppression	Extinguish all flames without reflash
Skin Burns	Less than second degree burns Thermal, 10 sec dose ≤ 1316°C-sec (2400°F-sec) and flux ≤ 3.9 cal/cm²
Overpressure	Lung damage < 0.38 bar (5.5 psi) Ear damage ≤ 0.28 bar (4 psi)
Agent Concentration	Not to exceed LOAL (per applicable NFPA standard) Min. 10% vol; Max 15% vol HFC236fa
Toxic Gases	Acid and Carbonyl Gases, 10 min dose HF + HBr + 2 COF_2 < 300 ppm-min Other gases (e.g., CO_2, CO, NO_x, HCN) are also measured
Oxygen Level	Not below 16%

The agents selected for initial testing were

- HFC-227ea,
- HFC-236fa,
- HFC-125,
- HCFC Blend B and HFC Blend B (HFC-134a (CH_2FCF_3), HFC-125 and carbon dioxide),
- Water mist with additives,
- HFC-227ea mixes with $NaHCO_3$,
- FK-5-1-12, and
- FK-5-1-12 with $NaHCO_3$[10]

As a result of the tests, HFC-236fa and water mist were shortlisted for crew compartment applications. After additional evaluations, Sweden and Germany selected HFC-236fa which fulfilled all Swedish casualty criteria for this application. As of today, it is the only agent apart from halon 1301 approved for use in their vehicle crew compartments. Although it has a lower GWP and atmospheric lifetime, HFC-227ea was not selected because of the smaller margin between its design concentration and its human exposure limits compared to HFC-236fa, while HFC227-BC was not selected because of short-term visibility reduction and powder residue left in the vehicle.
Overall, on main battle tanks, armoured and light armoured vehicles, halon 1301 has either been replaced or is scheduled to be replaced when the vehicles go through modification or maintenance. Sweden, Germany, and many other European armies (Denmark, Finland, Norway, the Netherlands, Belgium, Austria, Poland, Czech Republic, Greece, Spain, and Portugal) are now using HFC-236fa for all new and retrofit engine and crew compartment applications for ground vehicles.

[10] It should be noted that this blend is not stable as the two materials are reactive.

4.2.1.3 Brazil

Brazil has deployed FK-5-1-12 in its crew AFES on its Guarani medium wheeled personnel carriers U.S. Army/MOD Brazil (2018). Using test methods and performance criteria similar to the U.S. Army, testing verified that

- fires were extinguished in less than 250 ms without reflash,
- temperatures at crew locations were less than the threshold of 2nd degree burns,
- overpressures did not exceed the threshold for lung damage, and
- oxygen levels of 16% or greater were maintained

However, it should be noted that combustion byproducts were not addressed during the reported verification process, which potential users should consider for occupied applications.

4.2.2 Military Aviation Applications[11]

Halon replacement can only be achieved when there are technically and economically feasible alternatives available. To date, many military aviation applications have continued to rely on halons as the only viable option. As an example, the A400M military cargo aircraft has been ordered by eight European and Asian countries (Germany, France, Spain, UK, Turkey, Belgium, Luxembourg, and Malaysia) and entered service in late 2013 using halon 1301 for its engine nacelle fire extinguishing system. The extinguishers are installed at the rear of each engine nacelle using the very limited space available. Halon 1301 is used due to its fire extinguishing capability under the wide range of operating conditions that are likely to be experienced. The A400M and its halon 1301 extinguishing system are expected to have a minimum service life of 30 years. A retrofittable alternative is unlikely to be available for the foreseeable future due to the complex technical issues associated with the current aircraft design.

On the other hand, HFC-125 has been used successfully as an alternative to halon for engine fire protection and APUs on U.S. military fighters and helicopters developed since the early 1990s. In addition, HFC-125 is currently being specified for use on a military derivative of a large commercial aircraft currently under development (Boeing 767; military derivative KC-46), Robin (2014). The aircraft is designed to have a minimum service life of 30 years so support for the current system will be required beyond 2040; it is not likely this system could be converted to a lower-GWP agent in the foreseeable future.

As stated in the civil aviation section, in 2013, the U.S. Army announced the development of a drop-in replacement for its halon 1301 handheld fire extinguishers used in aviation applications that is based on HFC-227ea in combination with very finely ground sodium bicarbonate powder. Military specifications (MIL-DTL-32412, 2012) have been developed and procurement has been initiated for these units.

In the U.S., there has been success in replacing the standard 150 lb halon 1211 wheeled units employed on military flight lines with similar size units containing either HCFC Blend B or FK-5-1-12 at facilities operated by the military inside and outside the U.S. These units are UL

[11] This section should be read in conjunction with Supplementary Report #1 on Civil Aviation.

listed and have somewhat lower ratings than the 150 lb. halon 1211 unit employed (with the distinctive yellow/green colour) for more than 20 years at U.S. DOD sites.

4.2.3 Military Naval Applications

For the most part, halons are no longer being installed in new designs of naval vessels. However, they continue to be used in critical legacy applications, including on some submarines and in certain ship areas.

In naval vessels, a wide range of agents that include both high-GWP and low/zero-GWP fire suppressants - which serve as both halon and HFC alternatives - are being used for the main machinery and other spaces of new vessels operated by some parties. These include HFC-227ea, fine water spray, hybrid HFC-227ea/water spray, FK-5-1-12, foam and carbon dioxide systems. However, carbon dioxide systems are prohibited in all spaces on all new U.S. naval vessels due to crew safety considerations based on the toxicity of carbon dioxide at concentrations needed to extinguish fires. Militaries that use carbon dioxide systems rely on warnings, established egress procedures, and training for safe usage.

On Norwegian naval vessels, mainly halon and HFC alternatives are used. This includes IG-541 in electrical compartments, and water sprinklers and water mist with and without aqueous film forming foam (AFFF) additives for machinery spaces and other similar compartments. FK-5-1-12 is also an option for new vessels (SDMO, 2018).

On existing naval vessels operated by some militaries, conversion programs continue for normally-unoccupied spaces such as paint lockers and diesel or gas turbine modules. In these applications, both carbon dioxide and HFC extinguishants have been found to be acceptable. Australia and Germany have also converted some main machinery space halon systems to HFC-227ea and carbon dioxide, respectively. The Italian Department of the Navy has qualified the halon and HFC alternative FK-5-1-12 for local explosion suppression on board its military ships, based on the result of live-fire tests performed using a fuel-spray fire inside a trial room representing a ship's machinery space. In these tests, an explosion was considered successfully suppressed when these criteria were met Bona and Pallant (2006); Grimaldi and Aceto (2009):

- Extinction time ≤ 300 ms;
- Temperature integral ≤ 1300°C-sec
- HF produced < 1000 ppm-min

In Sweden, most naval vessels have been converted and the rest will be converted when the upcoming midlife modifications are due within a few years. They have mainly been converted to the halon and HFC alternative FK-5-1-12 for occupied and normally unoccupied spaces but also some carbon dioxide systems for normally unoccupied spaces and a small number of inert gas systems have been installed.

In Denmark, where HFCs are not acceptable because of national legislation, inert gas systems have been installed to protect the engine compartments of some surface ships. When considering inert gas systems for naval vessels, the weight and space occupied by the system must be taken into account. For example, inert gas systems require over three times the cylinder weight and deck space of an equivalent HFC-227ea system.

A point to consider when choosing an extinguishing agent for shipboard compartments that are normally occupied (e.g., command centers) is to decide if the enclosure must stay operational during combat operations or can be evacuated. Requirements can then be established similar to crew compartments on ground vehicles where evacuation is not always an option or can be addressed more like a commercial application.

4.2.4 Military Applications Summary

As the introduction of potentially viable new alternatives being developed and marketed by industry slows, so too does the research and development that can be executed by the parties' militaries. Most, if not all, commercially available extinguishing agents have been assessed against the range of unique military fire protection requirements. Alternatives have been adopted where they have been found to be technically and economically feasible. For new designs, there are virtually no applications where a halon must be used although there are many applications that the only alternative is a high-GWP HFC, i.e., there are no low-GWP alternatives for those applications. In legacy (existing) designs, there are several applications where both no suitable halon or HFC alternatives exist. Therefore, in these applications halons and several of the high-GWP HFCs are the only viable fire and explosion protection solutions to maintain parties' levels of national security and the safety of their military personnel and equipment. This will, in all likelihood, continue to be the case for both new designs and legacy systems for the foreseeable future.

Historically, in general, where halon replacement programmes have not been implemented, it was likely due to several possible reasons, including:

- Uncertainties related to the ultimate availability and costs of the high-GWP HFC, which is now less uncertain with the Kigali Amendment.
- An HFC or other alternative system generally requires more space and is heavier than the halon system it is to replace.
- Potentially unacceptable levels of toxic combustion byproducts may result from systems utilizing fluorinated alternatives.
- Converting a fielded platform to a new extinguishing system can be very expensive and demand considerable resources for a significant period.

It is clear that without major progress in the development of more suitable alternatives, there will continue to be a need for recycled halons and high-GWP HFCs for a substantial number of military applications including vehicle crew compartments, aviation engine nacelles, naval machinery spaces and submarines, at least until, if not well past, the middle of the century. However, the military sector has incorporated alternatives to halons on many of its newer platforms, reducing its future demand for the diminishing supplies of the halons while at the same time limiting the use of high-GWP agents where feasible.

4.3 Pipelines / Oil and Gas

The use of halon 1301 and halon 2402 systems in this industry for explosion prevention (inerting) and fire protection has been focused on inhospitable locations such as the Alaskan North Slope in the U.S., the North Sea in Europe, and parts of the former Soviet Union, where facilities have had to be enclosed due to the harsh climatic conditions. The process areas in the production modules and the oil and gas pumping stations live under constant threat of methane gas and crude oil leaks that can lead to potential explosive atmospheres sometimes in close proximity to personnel housing facilities. Halon 1301 was the agent of choice for mitigating this threat in the U.S. and Europe, and halon 2402 in the Russian Federation and Ukraine. When reviewing the reliance on existing halon banks, there are two distinct cases to consider, existing facilities and new facilities. Existing facilities will likely remain protected by halon while new facilities will adopt alternatives based on the specific risks and agent functionality in the given ambient environment.

4.3.1 Existing Facilities

In most cases, existing facilities in cold climates were designed and constructed with halon fixed systems as an integral part of the safety system design as well as the physical layout of the facility. As with civil aviation, after extensive research, it has been determined that in some cases, the replacement of such systems with currently available alternatives is economically impossible, and that current research is unlikely to lead to an economic solution. Thus, these facilities will likely rely on existing halon banks for their operating lifetimes. However, in order to reduce the impact on the halon banks, measures have been taken to reduce emissions through either of two methodologies, which can be summarized as follows:

1) Reassess the hazards and evaluate whether the potential for an explosion still exists.
   In some aging offshore platforms, process pressures have declined such that an accidental gas or crude oil release could not result in an explosive cloud. In others, advantage can be taken of the high winds that prevail in the area to assist in the exhausting of any gas accumulation from a hydrocarbon release. In both cases, the result may be a fire hazard but not an explosion hazard and so the original fixed halon 1301 system can often be decommissioned, the halon recycled, and an alternative fire suppression system installed.

2) Contain the halon and avoid spurious releases.
   Typically, if an inerting system has been required then it is also used for fire suppression in the same facility. Thus, in looking at methods to avoid spurious emissions, focus has been on upgrading both the fire and the gas detection systems to utilize modern technologies. Such systems are immune to common false alarms such as hot carbon dioxide emissions, reflections from flare radiation, black body radiation, hot work such as welding, and other problems that affect older technology detectors.

For offshore platforms, physical space and weight constraints create a barrier to the replacement of legacy systems. Systems that have not already been removed or replaced with an alternative will likely remain in service for the life of the facility unless a cost effective “drop-in” alternative is discovered, or the capital cost of the necessary infrastructure expansions required to accommodate replacement with current agents becomes significantly less than the predicted management costs of legacy systems.

A5 parties in the Asia Pacific region, including India, installed halon 1301 systems in refineries, gas pumping stations and offshore oil platforms. Oil pumping stations are gradually switching over to dry powders and HFC-227ea, FK-5-1-12, and inert gas systems are being installed in refineries where it is technically feasible given space and weight concerns. Nevertheless, for many oil and gas industry applications in this region, halon and high-GWP HFC requirements still exist. Halon supply is typically met by local sources of recovered halon, which are used to refill existing cylinders. However, there is no halon recycling, banking or quality testing facility for such recovered halon in much of Asia and therefore the quality and effectiveness of the halon supply in this region is currently a major concern. Both newly produced and recycled high- GWP HFCs are available. In land-based halon 1301 systems, where a clean agent is important, some companies are hesitating to switch over to HFCs because of their high GWP as they do not want to switch over twice. It is reported that HFC-23 has never been used in this region by the oil industry unlike in cold climates.

Halon 1301 is also used for fire extinguishing systems and hydrocarbon inerting systems that protect offshore oil exploration platforms in tropical regions of Asia.

Due to the adoption of alternatives in new facilities, this sector on a whole is reducing the reliance as a percent of protected facilities on halons. However, enduring uses related to existing halon and HFC systems will continue indefinitely.

4.3.2 New Facilities

For new facilities, the oil and gas industry companies appear to be adopting an Inherently Safer Design approach (including enhanced isolation capabilities to minimize potential volume/exposure and/or process blow-down, gas detection, and ventilation) to mitigate risk within their facilities. This approach focuses on minimizing the probability of a release of hydrocarbons, the available quantity of flammable or explosive materials, and the potential for ignition such as by through use of explosion proof equipment or by diluting explosive hydrocarbon vapour concentrations. Only when all such measures have been considered, and a residual risk of the hazard still remains, are other risk reducing measures considered such as hydrocarbon inerting systems.

In most cases, robust hydrocarbon gas detection systems are employed to shut-down, isolate, blow-down process inventory, and/or turn on high rate ventilation systems rather than closing-up the space and trying to inert it with a total flooding inerting agent. An unintended consequence of high rate ventilation in an Arctic climate is that the protected, enclosed process module may be at or near ambient outside winter time temperatures during hydrocarbon gas release and subsequent hydrocarbon inerting system discharge events. The potential extreme low temperature can require the use of an agent with very high volatility such as HFC-23. In some specific instances, temperatures permitting, total flooding FK-5-1-12 systems and fine water mist systems have been employed for fire extinguishment only, to replace the need for high GWP HFCs.

4.4 Telecommunications and Computer Rooms (Electronics)

In the early 1990s, the HTOC estimated that telecommunications and computer rooms accounted for about 65% of the annual use of halon 1301. In its 1993 Assessment, the HTOC indicated that by then a wide range of suitable non-ODS alternatives including both traditional and new technologies existed for new applications. The HTOC finds the same true today for alternatives in this sector, consistent with the general finding on the fire protection sector. Only a portion of the halon replacement went to high GWP HFCs-125 and -227ea.

The following halon alternatives are reported as used in electronics sector, with non-HFCs (1st seven in the list) also representing HCFC and HFC alternatives.

- Double interlock water spray systems (Fine spray)
- Water Mist systems
- Early warning detection systems with smoke evacuation
- Smoke evacuation systems
- FK-5-1-12
- Inert Gas Systems
- Carbon Dioxide systems (very limited)
- HFC-227ea
- HFC-125

On a regional basis, it is reported that in some of the European countries (in particular, Hungary, Bulgaria, Turkey, Greece) HFC-125 and HFC-227ea extinguishing systems are utilized while in Italy, mainly inert gas systems and a small percentage of FK-5-1-12 systems are used.

It has been reported that Japan used IG-100 and high-GWP HFCs as the main alternatives to halon but halon is still installed in significant quantities in this sector. The installation rates from 2006 to date in Japan are shown in Figure 4.5 below:

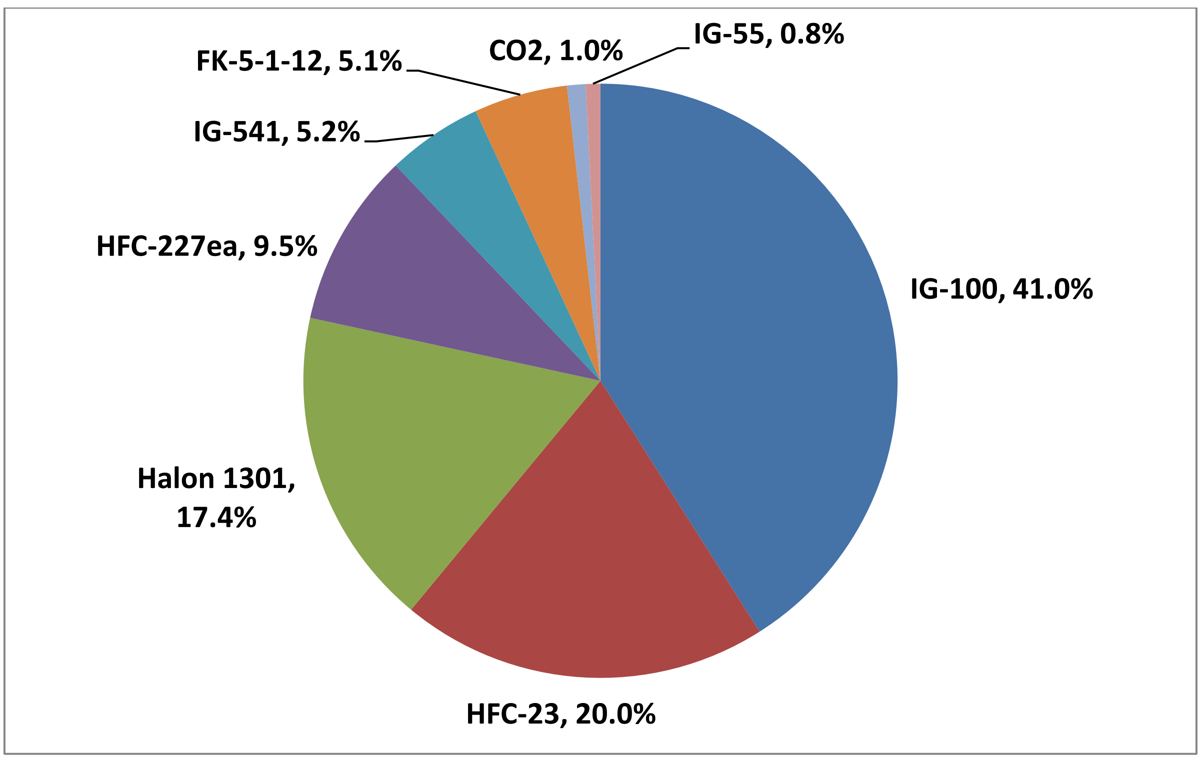

Figure 4.5: Installation Rates of Fire Protection Agents in Telecommunications and Computer Rooms in Japan from 2006 to date.

In Australia, it is estimated that the inert gas agents and HFC-227ea were introduced and widely installed, along with a very small number of HCFC Blend A (HCFC-22, HCFC-124, HCFC-125 and d-limonene) installations. FK-5-1-12 has also been promoted over the last several years. Aerosol agents and water mist have been proposed but are not-in-kind alternatives and have found very little application in this sector.

In Egypt, the majority of the Telecommunications and Computer Rooms have switched to using HFC-227ea, at about 85%, with the remainder going to inert gas, at about 10%, water mist about 5% and FK-5-1-12, currently at less than 1%.

In India, fire protection for Telecommunications and Computer Rooms is estimated as follows: FK-5-1-12 at about 60%, HFC-227ea at about 30% and carbon dioxide at about 10%. Carbon dioxide systems are no longer being used for new installations and HFC-236fa is being used in server racks.

In Sweden, it is estimated that HFC-227ea makes up about 60% of the systems, IG-541 and -55 about 15% and water mist systems about 5%. The remaining 20% are not using in-kind alternatives but choosing rather to employ alternative risk management strategies such as enhanced detection coupled with fire services quick response.

4.5 Merchant Ships

4.5.1 Background

In the mid-1970s passenger ships and tankers switched from carbon dioxide to halon 1301 as it was more cost effective. When the International Maritime Organization (IMO) banned the use of halons in new constructions in 1992 (IMO, 1992), carbon dioxide once again became the agent-of-choice for these types of ships. However, from 1975 – 1993 (the last year that halon was allowed to be used under IMO rules), a significant amount of halon 1301 was installed in this sector. Decision XXVI/7 on the availability of recovered, recycled or reclaimed halons requested the HTOC to try to estimate the amount of halon 1301 and 1211 that could that could come onto the market from the breaking of ships. Below is the information contained in the Decision XXVI/7 report.

4.5.2 Estimated Halon 1301 Installed on Merchant Ships

In order to estimate the amount of halon 1301 that may still be installed in merchant shipping, five questions need to be answered:

1) What types of ships had halon 1301 installed?
2) Over what time period was the halon installed?
3) How much halon would be installed per ship?
4) How many ships were built during the time period?
5) What is the average lifetime of those ships?

For the first two questions the HTOC could provide answers based on direct experience or other information available. Halon1301 was primarily used for the protection of machinery spaces on passenger ships and machinery spaces and cargo pump rooms on tankers. Data on quantities of halon 1301 by ship size, quantities of ships constructed during 1975 – 1993 and the average lifetime were still needed.

It had been hoped that the IMO would provide two of the missing pieces of information to the HTOC: 1) quantities of ships constructed during 1975 – 1993 and 2) year of ship breaking so that average lifetimes could be established. The Ozone Secretariat provided a point of contact at IMO who informed the HTOC that they were not allowed to provide such information owing to a contractual agreement with the ship registry company and that access to the data would need to be discussed with commercial providers. The Ozone Secretariat subsequently directed HTOC to a partially open access website, http://www.world-ships.com/, which contained information on year and sizes of ships constructed. Additional information on year of ship breaking was reported as being available through this registry but was not able to be obtained in time for this report. For the purposes of this report, the useful lifetime of all ships is estimated to be between 30 - 40 yrs.

Data on passenger ships and tankers were extracted from the World Shipping Register including ship name, ship type, deadweight tonnage (DWT), year built, and flag. The database constructed only includes ships that were built between 1975 and 1993. The database includes approximately 4,000 tankers (i.e., asphalt tankers, chemical/oil tankers, crude oil tankers, LNG tankers, LPG tankers, water tankers, and other tankers) and approximately 2,700 passenger ships (i.e., cruise ships, ferry ships, and other passenger ships).

The average charge size of halon 1301 systems on passenger ships and tankers was assumed to vary by the ship's DWT. These charge sizes are listed in Table 4.6 for each size range of passenger ships and tankers.

Table 4.6: Halon 1301 Charge Sizes for Passenger Ships and Tankers of Various Sizes (ICF, 2015)

Ship Type	Deadweight Tonnage (DWT)	Halon 1301 Charge Size (kg)
Passenger Ship	< 1,000	100
Passenger Ship	1,000 – 10,000	750
Passenger Ship	10,001 – 20,000	1,500
Passenger Ship	> 20,000	2,000
Tanker	< 1,000	100
Tanker	1,000 – 50,000	2,000
Tanker	50,001 – 100,000	2,500
Tanker	100,001 – 200,000	3,000
Tanker	200,001 – 300,000	7,000
Tanker	> 300,000	8,000

Figure 4.6 shows the number of passenger ships and tankers built between 1975 and 1993 and Figure 4.7 shows the estimated total residual amount of halon 1301 remaining in service for an assumed 30 year and 40-year lifetime. In 2014, approximately 2,628 metric tonnes is estimated to remain in service for a 30-year lifetime of ships.

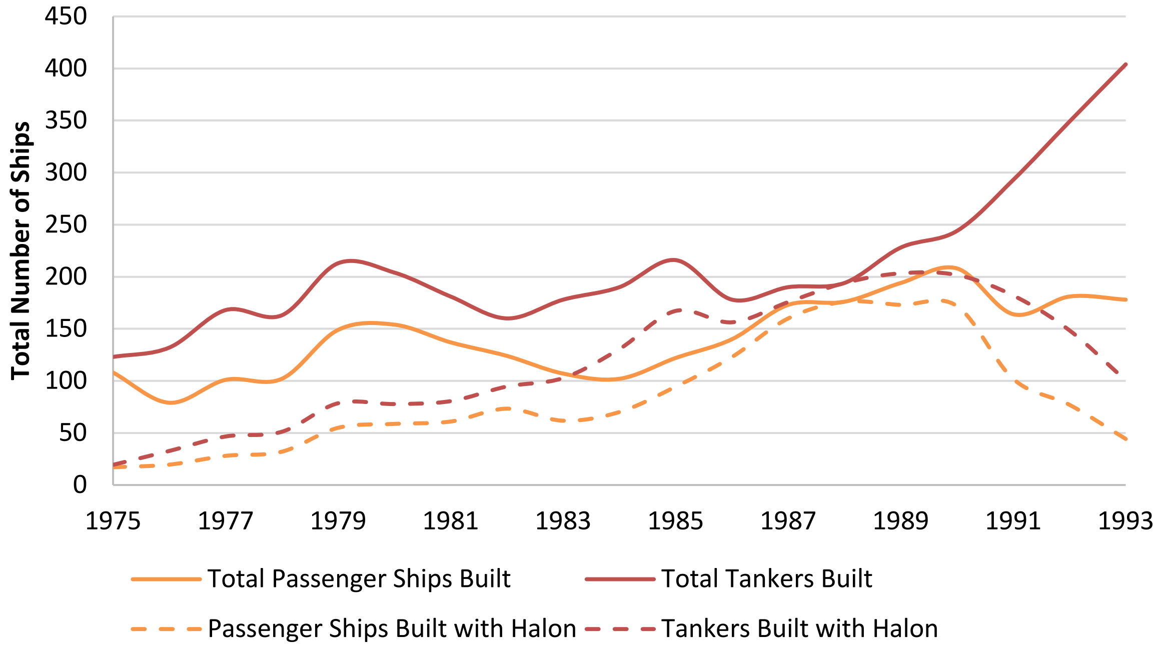

Figure 4.6: Number of Passenger Ships and Tankers Built Between 1975 and 1993, ICF (2015)

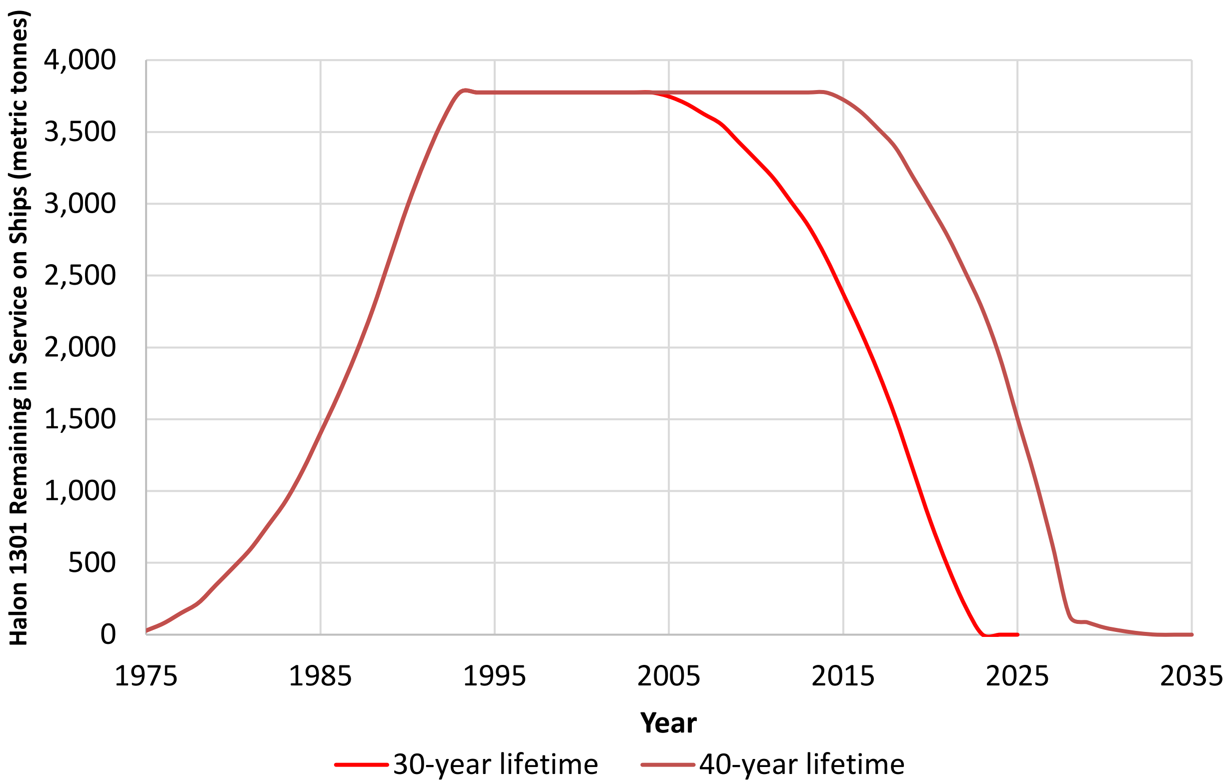

Figure 4.7: Total Residual Amount of Halon 1301 Remaining in Service, ICF (2015)

This amount would provide on average a little less than 300 metric tonnes annually through 2023. For a 40-year lifetime of ships, 3,775 metric tonnes of residual halon 1301 is estimated to remain in service in 2014. This would provide on average a little less than 200 metric tonnes annually through

2033. It is not known how much of this halon is actually being recovered and making its way into the recycled halon market.

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5 Global Estimates of Halons and HFC Fire Extinguishing Agent Quantities

5.1 Introduction

Beginning with the first HTOC Assessment report in 1989, the HTOC has included estimated historic and projected future uses and emissions of halons 1211 and 1301. This was initially based on the work of former HTOC co-chair, Mr. Gary Taylor, who developed a methodology and computer program to perform the initial work. The basic methodology is still in use today and relies on a simple mass balance approach. The total amount produced is summed year by year and the estimated annual emissions are subtracted year by year. The result is a yearly estimate of the total amount of halons available for existing and future uses. Since emissions patterns can be quite different for different parts of the world, the model was segmented into five regions: 1) North America, 2) Western Europe and Australia, 3) Japan, 4) former Countries with Economies in Transition (former Soviet bloc countries), and 5) Montreal Protocol "Article 5" countries, which are the remainder of the countries. Different practices that lead to emissions were separately identified for each of the regions and are periodically updated by the HTOC based on current best practices. Initially, emissions were based on training, discharge testing, fire and inadvertent discharges and loss during servicing. As practices changed, the percentage lost to each of these practices changed as well. For example, beginning in the 1970s, as part of cost cutting measures, it became more common to try to recover halon from partially filled systems instead of just venting it. With the advent of the Montreal Protocol, emissive practices were all changed, and emissions were greatly reduced. Beginning with the 2006 Assessment report, in addition to estimating emissions based on use and best practices, the models also took into account direct data on destruction, import and export, and where available, known quantities of inventories. In 2014, open literature information was found on production of halon 2402 in the former Soviet Union. Based on that information, and other estimates, the HTOC developed and reported on a model for halon 2402 similar to the halon 1211 and 1301 models.

For the 2018 Assessment, the HTOC is again providing the most current estimates of inventories for halon 1301, halon 1211 and halon 2402. These models have been updated to reflect all quantities that have been reported as destroyed and to account for imports and exports between the five modelled regions where data are available. No new information was found to warrant changing any of the emission pattern assumptions from the 2014 Assessment. Only some minor modelling updates have been made to round-out changes in assumptions to obtain smoother transition points. In general, this assessment is similar, but not identical, to the 2014 Assessment for all three halons.

The 2018 Assessment also includes quantitative information on estimates of the bank and annual emissions of HFC-227ea used in the total flooding sector as the main initial alternative to halon 1301. In addition, qualitative information on the other high- GWP alternatives to halon 1301 is also included to provide a sense of the relative size of the use, bank and emissions of these other HFCs from the fire protection sector.

5.2 Emissions and Inventories of Halons

5.2.1 Halon 1301

Table 5.1 summarizes the HTOC 2018 Assessment of estimates of total production, annual emissions, cumulative emissions and resulting inventories (bank) for halon 1301 in five-year increments from 2014 - 2049. Future projected detailed yearly estimates for 2019 – 2050 are provided in Table 5.2. Historic yearly detailed results from 1963 to 2018 are provided in Appendix C. *Note that in some instances the values do not add up exactly due to rounding errors.* Negative production values in the tables in this report are the result of either destruction or export out of the model region. Destruction results in a net loss of total cumulative production. Export is matched by an import to a different region so that there is no net change to total cumulative production. Positive values in the production columns after 1993 for non-A5 and after 2009 for A5 parties are the result of import of recycled halons and are not actual new production. The current emissions and bank for Japan are consistent with those independently reported by the Japanese Fire and Environment Protection Network through 2016. Using the methodology provided by O'Doherty et al., (2015), the emissions for North West (NW) Europe for the period 2000 – 2017 are consistent with the latest data, published in O'Doherty et al., (2018). To compare O'Doherty et al., (2018) with the HTOC model, the HTOC model emission estimates were scaled for NW Europe by using gross domestic product (GDP) as a proxy. This is done by taking the Europe and Australia results and dividing by 1.1 to remove the Australia region and then dividing that result further by 1.65 to scale down to the NW Europe countries included: Belgium, Denmark, France, Germany, Ireland, Luxembourg, The Netherlands and the UK. The NW Europe emissions for 2014 – 2017 are 125 metric tonnes, 120 metric tonnes, 115 metric tonnes and 111 metric tonnes, respectively, as compared to the O'Doherty et al. (2018) updated mean emission estimate of 115 metric tonnes, 128 metric tonnes, 107 metric tonnes and 105 metric tonnes, respectively. While the HTOC model tends to be higher for those years it is well within the uncertainty range of the O'Doherty et al. (2018) updated data. This implies that a significant amount of halon 1301 is still contained within NW Europe. This amount includes halon 1301 in the EU critical uses including civil aviation fleets operating in Europe.

Figure 5.1 provides graphically, the future projected regional distribution of the global inventory of halon 1301 and shows that at the end of 2019, the HTOC projects 45% of the total inventory of halon 1301 will be in Japan and 31% in North America. Although the regional disparity in the distribution of halon itself does not necessarily constitute a regional imbalance, it is anticipated that regional imbalances may result in shortages in one country or region with excesses in other countries and regions. Where information is available on import/export, it has been included in the HTOC model.

As shown in Figure 5.2, the HTOC model emissions and bank estimates compare well with the mean emissions derived from mixing ratios (atmospheric concentrations) from the latest data using the methodology of Vollmer et al. (2016) until the last few years where the HTOC model emissions are consistently lower than the mean. Taking into account the uncertainties in the updated Vollmer et al. (2016) data, as shown in Figure 5.2, the HTOC estimates generally fall within one sigma of the mean except for three periods, approximately 1986 – 1988, 2000 and 2011 – 2014, where the HTOC estimates are all lower than the 16th percentile value. For the period 2011 – 2014, the HTOC is unaware of any singular current fire protection use that could account for the higher level of emissions as they are at least an order of magnitude higher than the largest single fire protection systems known to exist. The only potential source from fire protection systems would be from ship breaking (decommissioning) activities but that is not anticipated, as recovered halon 1301 has a significant market value. Halon 1301 continues to be produced as a feedstock for the pesticide Fipronil, whose emissions would not be accounted for in the HTOC model but would be included in the Vollmer et al. (2016) estimates. None-the-less, as a result, the updated Vollmer et al. (2016) mean data through mid-2017 provide cumulative emissions of 118,000 (86,000 16th percentile – 151,000 84th percentile) metric tonnes, which is more than was estimated previously in the 2014 HTOC Assessment Report, HTOC (2014) and in this current HTOC assessment. Based on the global total cumulative production data from the HTOC, which are also used by Vollmer et al., the mean values of the updated Vollmer et al. (2016) data through mid-2017 provide a remaining bank of only 30,000 (0 – 62,000) metric tonnes versus the HTOC model estimate of approximately 109,000 metric tonnes of cumulative emissions and a remaining bank of 39,000 metric tonnes. Using the average of the two bank sizes, the difference in remaining banks is nearly 25%. This difference is becoming significant as the global bank (i.e., the amount of halon that is available to support fire protection uses) becomes smaller over time. The updated Vollmer et al. (2016) data also provide a much higher mean annual emission rate for 2016/2017 of nearly 4% of the bank/year (with a low of 1.3% and an upper emission rate of more than 6%) than the approximately 2.5% composite rate used by the HTOC. This assumes the smallest bank from known remaining amounts as provided in the Decision XXVI/7 Report, TEAP (2015) of approximately 25,000 metric tonnes. The combination of a potential higher emission rate than assumed by the HTOC and a smaller bank of halon 1301 could also imply that there is going to be significantly less halon 1301 available to support on-going needs in civil aviation, oil and gas, militaries, etc., which could result in a much earlier "run-out date" as already discussed in Section 4.1 Civil Aviation.

Table 5.1 HTOC Halon 1301 Model Summary (in metric tonnes)

	2014	2019	2024	2029	2034	2039	2044	2049
CUMMULATIVE PRODUCTION								
North America, Western Europe and Japan	135,423	135,365	135,365	135,365	135,365	135,365	135,365	135,365
former Countries with Economies in Transition	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	148,421	148,362	148,362	148,362	148,362	148,362	148,362	148,362
ANNUAL EMISSIONS								
North America	474	402	338	285	240	202	170	143
Western Europe and Australia	228	188	158	134	113	95	80	68
Japan	25	25	24	24	24	24	24	24
former Countries with Economies in Transition	69	56	45	36	29	23	19	15
Article 5	392	234	140	83	50	30	18	11
TOTAL ANNUAL EMISSIONS	1,187	903	705	562	456	374	311	260
CUMMULATIVE EMISSIONS								
North America	29,347	31,497	33,311	34,840	36,127	37,195	38,108	38,877
Western Europe and Australia	24,591	25,601	26,450	27,166	27,771	28,274	28,705	29,068
Japan	10,603	10,726	10,848	10,970	11,090	11,210	11,329	11,446
former Countries with Economies in Transition	6,613	6,917	7,161	7,358	7,516	7,641	7,743	7,826
Article 5	35,296	36,749	37,616	38,133	38,441	38,617	38,727	38,792
TOTAL CUMMULATIVE EMISSIONS	106,448	111,490	115,386	118,466	120,945	122,937	124,611	126,010
INVENTORY (BANK)								
North America	13,574	11,502	9,688	8,160	6,872	5,804	4,891	4,122
Western Europe and Australia	6,590	5,443	4,594	3,878	3,273	2,770	2,339	1,976
Japan	16,652	16,528	16,406	16,285	16,164	16,044	15,926	15,808
CEIT	1,556	1,252	1,008	811	653	528	425	343
Article 5	3,601	2,148	1,281	764	456	280	170	105
GLOBAL INVENTORY (BANK)	41,973	36,873	32,976	29,897	27,418	25,426	23,751	22,353

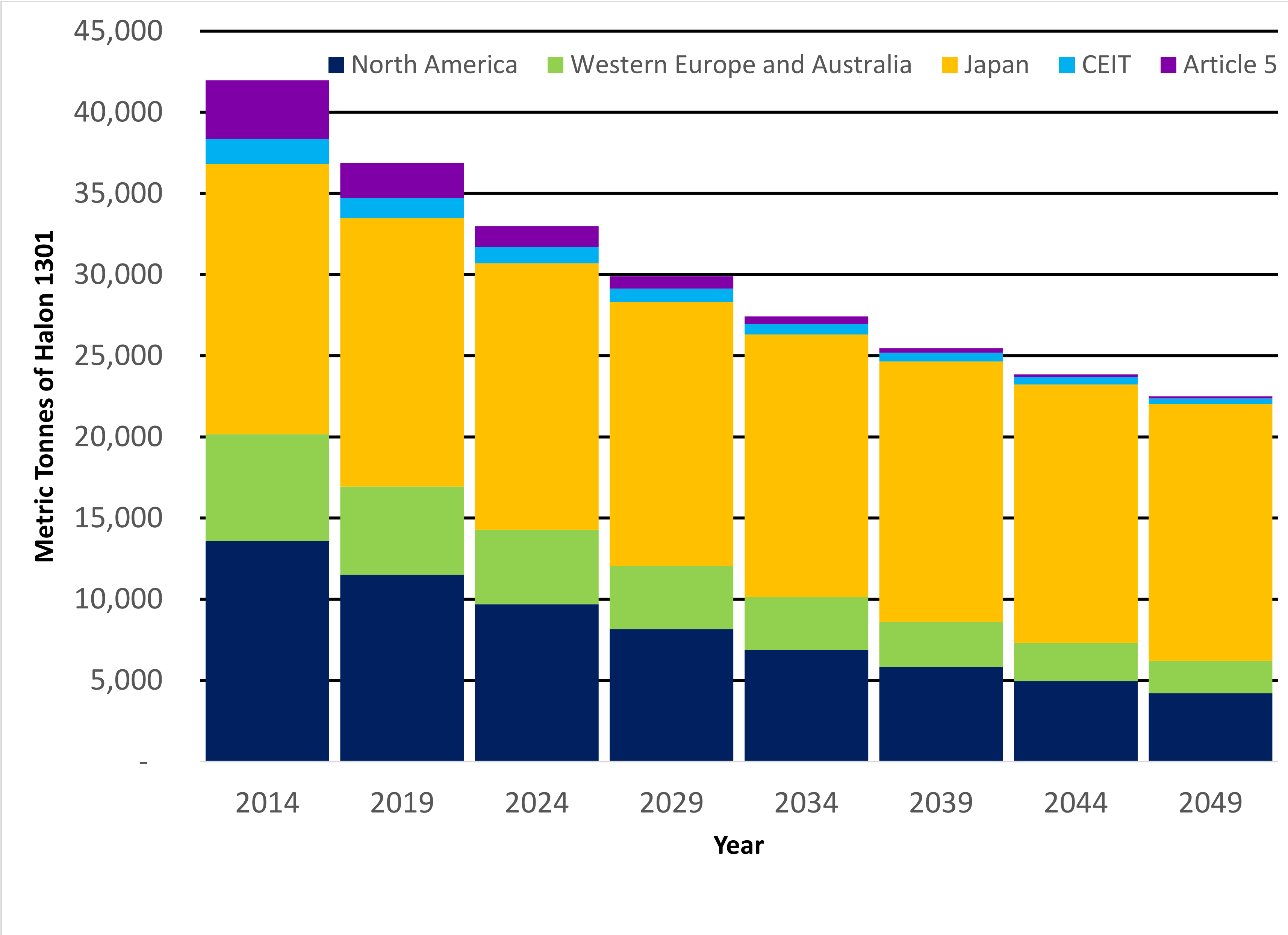

Figure 5.1: Forecast of future Regional Distribution of halon 1301 inventory

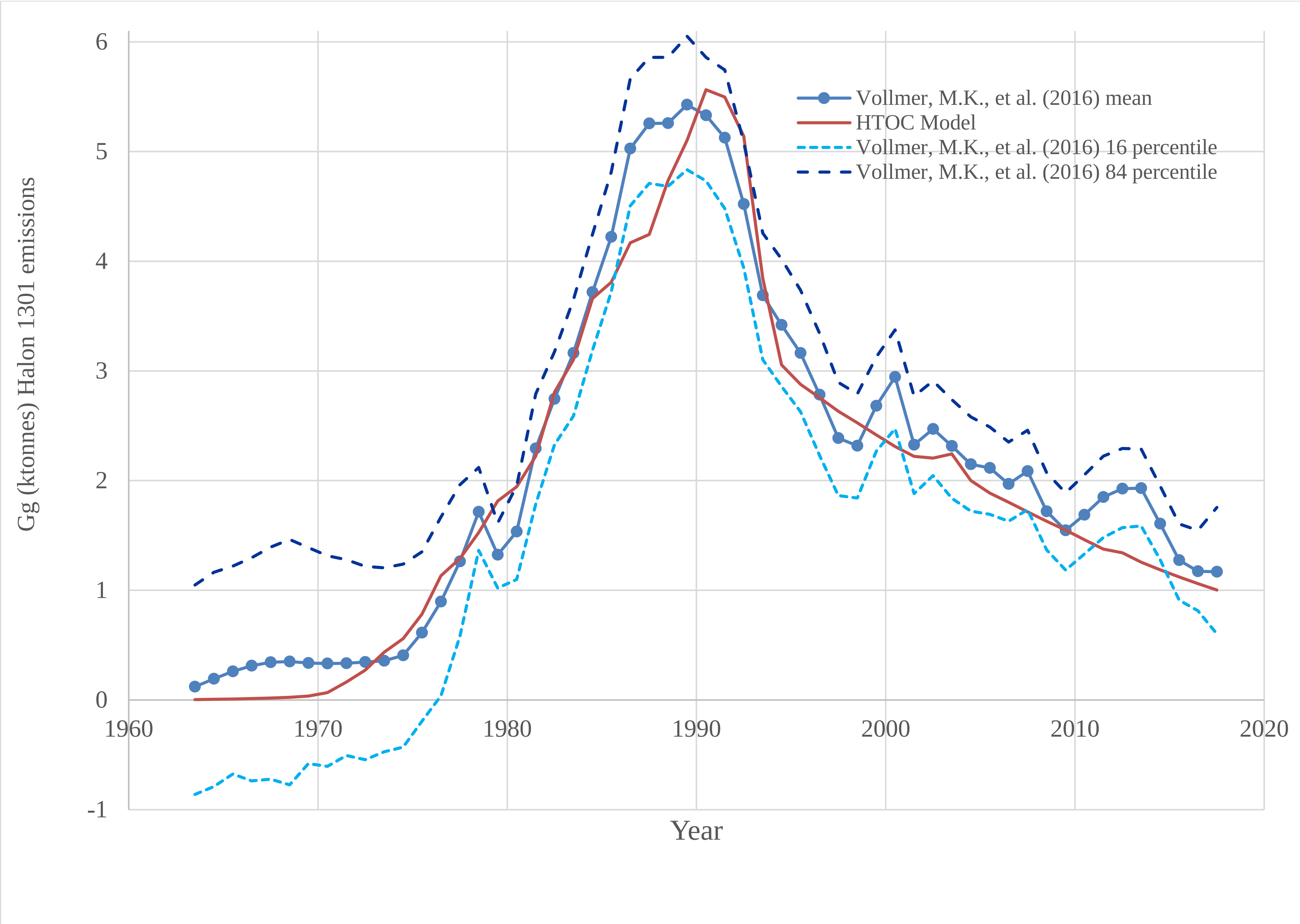

Figure 5.2: Comparison of halon 1301 emissions from updated Vollmer et al (2016) and the HTOC model

Table 5.2: Halon 1301 Summary (in metric tonnes)

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
ANNUAL PRODUCTION										
North America, Western Europe and Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	402	388	375	362	350	338	327	316	305	295
Western Europe and Australia	188	181	175	170	164	158	153	148	143	138
Japan	25	25	25	24	24	24	24	24	24	24
CEIT	56	53	51	49	47	45	43	41	39	38
Article 5	234	211	190	172	155	140	126	113	102	92
TOTAL ANNUAL EMISSIONS	903	858	816	777	740	705	673	643	614	587
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
CUMMULATIVE PRODUCTION ALLOCATION										
North America	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999
Western Europe and Australia	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169
Article 5	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363
CUMMULATIVE EMISSIONS										
North America	31,497	31,885	32,260	32,623	32,973	33,311	33,638	33,954	34,260	34,555
Western Europe and Australia	25,601	25,783	25,958	26,127	26,291	26,450	26,603	26,751	26,894	27,032
Japan	10,726	10,750	10,775	10,799	10,824	10,848	10,873	10,897	10,921	10,945
CEIT	6,917	6,970	7,021	7,069	7,116	7,161	7,204	7,245	7,284	7,322
Article 5	36,749	36,960	37,150	37,322	37,476	37,616	37,742	37,855	37,957	38,050
TOTAL CUMMULATIVE EMISSIONS	111,490	112,348	113,164	113,941	114,681	115,386	116,059	116,702	117,316	117,904
INVENTORY (BANK)										
North America	11,502	11,114	10,739	10,376	10,026	9,688	9,361	9,045	8,739	8,445
Western Europe and Australia	5,443	5,261	5,086	4,916	4,752	4,594	4,441	4,293	4,150	4,011
Japan	16,528	16,504	16,479	16,455	16,430	16,406	16,382	16,357	16,333	16,309
CEIT	1,252	1,199	1,148	1,099	1,052	1,008	965	924	885	847
Article 5	2,148	1,937	1,747	1,575	1,421	1,281	1,155	1,042	940	847
GLOBAL INVENTORY (BANK)	36,873	36,015	35,198	34,422	33,682	32,976	32,303	31,661	31,046	30,459

Year	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
ANNUAL PRODUCTION										
North America, Western Europe and Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	285	275	266	257	248	240	224	217	217	209
Western Europe and Australia	134	129	125	121	117	113	105	102	102	99
Japan	24	24	24	24	24	24	24	24	24	24
CEIT	36	34	33	32	30	29	27	25	25	24
Article 5	83	75	68	61	55	50	40	36	36	33
TOTAL ANNUAL EMISSIONS	562	538	516	495	475	456	420	404	404	389
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362

Year	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
CUMMULATIVE PRODUCTION ALLOCATION										
North America	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999
Western Europe and Australia	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169
Article 5	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363
CUMMULATIVE EMISSIONS										
North America	34,840	35,115	35,381	35,638	35,887	36,127	36,351	36,567	36,784	36,993
Western Europe and Australia	27,166	27,295	27,420	27,541	27,658	27,771	27,876	27,978	28,080	28,179
Japan	10,970	10,994	11,018	11,042	11,066	11,090	11,114	11,138	11,162	11,186
CEIT	7,358	7,392	7,425	7,457	7,487	7,516	7,542	7,568	7,593	7,618
Article 5	38,133	38,208	38,276	38,337	38,392	38,441	38,482	38,518	38,554	38,587
TOTAL CUMMULATIVE EMISSIONS	118,466	119,004	119,520	120,015	120,489	120,945	121,365	121,769	122,174	122,562
INVENTORY (BANK)										
North America	8,160	7,884	7,618	7,361	7,112	6,872	6,648	6,432	6,215	6,006
Western Europe and Australia	3,878	3,748	3,623	3,503	3,386	3,273	3,168	3,066	2,964	2,865
Japan	16,285	16,260	16,236	16,212	16,188	16,164	16,140	16,116	16,092	16,068
CEIT	811	777	744	712	682	653	626	601	575	551
Article 5	764	689	621	560	505	456	415	379	343	310
GLOBAL INVENTORY (BANK)	29,897	29,358	28,843	28,348	27,873	27,418	26,997	26,593	26,189	25,800

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
ANNUAL PRODUCTION												
North America, Western Europe and Japan	0	0	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION												
North America	0	0	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS												
North America	202	195	189	182	176	170	165	159	154	148	143	139
Western Europe and Australia	95	92	89	86	83	80	78	75	73	70	68	66
Japan	24	24	24	24	24	24	24	24	24	24	24	23
CEIT	23	22	21	20	20	19	18	17	16	16	15	14
Article 5	30	27	24	22	20	18	16	14	13	12	11	9
TOTAL ANNUAL EMISSIONS	374	360	347	334	322	311	300	289	279	270	260	252
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365	135,365
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362	148,362

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CUMMULATIVE PRODUCTION ALLOCATION												
North America	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999	42,999
Western Europe and Australia	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044	31,044
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169
Article 5	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897	38,897
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363	148,363
CUMMULATIVE EMISSIONS												
North America	37,195	37,391	37,579	37,762	37,938	38,108	38,273	38,432	38,585	38,734	38,877	39,016
Western Europe and Australia	28,274	28,366	28,455	28,541	28,624	28,705	28,782	28,857	28,930	29,000	29,068	29,134
Japan	11,210	11,234	11,257	11,281	11,305	11,329	11,352	11,376	11,399	11,423	11,446	11,470
CEIT	7,641	7,663	7,685	7,705	7,725	7,743	7,761	7,779	7,795	7,811	7,826	7,840
Article 5	38,617	38,644	38,668	38,689	38,709	38,727	38,742	38,757	38,770	38,781	38,792	38,801
TOTAL CUMMULATIVE EMISSIONS	122,937	123,297	123,644	123,978	124,301	124,611	124,911	125,201	125,480	125,749	126,010	126,261
INVENTORY (BANK)												
North America	5,804	5,608	5,420	5,237	5,061	4,891	4,726	4,567	4,414	4,265	4,122	3,983
Western Europe and Australia	2,770	2,678	2,589	2,503	2,420	2,339	2,261	2,186	2,114	2,043	1,976	1,910
Japan	16,044	16,021	15,997	15,973	15,949	15,926	15,902	15,878	15,855	15,831	15,808	15,784
CEIT	528	505	484	463	444	425	407	390	373	358	343	328
Article 5	280	253	229	208	188	170	155	140	127	116	105	96
GLOBAL INVENTORY (BANK)	25,426	25,066	24,719	24,384	24,062	23,751	23,451	23,162	22,883	22,613	22,353	22,101

5.2.2 Halon 1211

During the 2014 HTOC Assessment, the HTOC was concerned with the status of banking capabilities in some regions of the world and the handling of halon 1211. As a result, the HTOC had changed its assumptions on emissions as a percentage of the bank as it was believed that global emissions of halon 1211 were higher than previously proposed. HTOC expresses the same concerns in this assessment but does not have any additional quantitative information to justify any changes in emission factors. Table 5.3 summarizes the HTOC 2018 Assessment of estimates of total production, annual emissions, cumulative emissions and resulting inventories (bank) for halon 1211 in five-year increments from 2019 - 2049. Future projected detailed yearly estimates for 2019 – 2050 are provided in Table 5.4. Historic yearly detailed results from 1963 to 2018 are provided in Appendix D. Negative production values in the tables in this report are the result of destruction, which results in a net loss of total cumulative production. There are no known import / export data between regions for halon 1211.

Figure 5.3 provides graphically, the future projected regional distribution of the global inventory of halon 1211 and shows that at the end of 2019, the HTOC projects almost 80% to be equally divided between the North America, and Western Europe and Australia regions with about 20% estimated to remain in A5 parties. The estimate for A5 parties is significantly lower than the more than 50% projected in the 2010 Assessment, which again is a reflection of HTOC concerns with halon 1211 bank management. Although the regional disparity in the distribution of halon itself does not necessarily constitute a regional imbalance, it is anticipated that regional imbalances may result in shortages in one country or region with excesses in other countries and regions.

As shown in Figure 5.4, there is significantly more uncertainty in the updated Vollmer et al. (2014) halon 1211 data than there is for halon 1301. In part, this is due to the higher uncertainty in the halon 1211 lifetime but also its shorter lifetime (15.9 years as opposed to 73.7 years for halon 1301). Newland et al. (2013) showed that changing the atmospheric lifetime of halon 1211 from 16 years to 14 years would reduce their 2010 bank estimates from 37,000 metric tonnes to 10,000 metric tonnes. Conversely, increasing the atmospheric lifetime would reduce the amount of resulting emissions and would increase the size of the bank. The HTOC emission estimates for North America are consistent with 600 metric tonnes average from 2004 – 2006 estimated by Millet et al. (2009) using aircraft measurements. The emissions and bank for Japan are consistent with those reported by the Japanese Fire and Environment Protection Network annually.
Using the methodology provided by O’Doherty et al., (2015), the emissions for NW Europe for the period 2000 – 2017 are consistent with the latest data, published in O’Doherty et al., (2018). For example, the HTOC model emission estimates scaled for NW Europe for 2014 – 2017 are 278 metric tonnes, 266 metric tonnes, 257 metric tonnes, and 246 metric tonnes respectively, as compared to the O’Doherty et al. (2018) updated mean emission estimate of 147 metric tonnes, 138 metric tonnes, 144 metric tonnes and 158 metric tonnes, respectively. While the HTOC model is considerably higher for those years it is well within the uncertainty ranges over that period for the O’Doherty et al. (2018) updated data. While perhaps not as much as the HTOC model estimates, this implies that a significant amount of halon 1211 is still contained within NW Europe and likely Europe overall. This amount includes halon 1211 in the EU critical uses including civil aviation fleets operating in Europe.

As shown in Figure 5.4, the estimates of emissions from the updated Vollmer et al. (2016) data and the HTOC model have compared fairly well within uncertainty until about 2002, thereafter, the HTOC model emissions are consistently lower and below the 16th percentile until the end of the record. HTOC is aware that in some places in the world, large amounts of halon 1211 were not allowed to be re-used so there was no longer any economic reason to prevent emissions. As the HTOC model is based on the best handling practices over time, the lack of handling by professional servicers makes the prediction or estimation of emission factors for that amount of halon difficult at best. HTOC believes that it is certainly possible that the emissions are higher than the HTOC model predicts because of the inability to reliably estimate emissions from "unwanted" halon 1211. As halon 1211 is still managed carefully in other parts of the world, the HTOC model may come back into closer agreement once the non-professionally managed halon 1211 is emitted and emission rates are more predictable. As indicated above, HTOC does not have any quantitative basis to make specific changes to the current assumptions on emission factors at this time.

The updated Vollmer et al. (2016) data estimates mean cumulative emissions through mid-2017 of 311,000 metric tonnes (190,000 – 431,000) and a remaining bank of only 1,500 metric tonnes (0 – 122,500) versus the HTOC model estimate of 286,000 metric tonnes of cumulative emissions and a remaining bank of 26,000 metric tonnes.

Table 5.3: HTOC Halon 1211 Model Summary (in metric tonnes)

	2014	2019	2024	2029	2034	2039	2044	2049
CUMMULATIVE PRODUCTION								
North America, Western Europe and Japan	195,596	195,583	195,583	195,583	195,583	195,583	195,583	195,583
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	312,453	312,440	312,440	312,440	312,440	312,440	312,440	312,440
ANNUAL EMISSIONS								
North America	457	375	308	253	207	170	140	115
Western Europe and Australia	505	409	347	282	242	197	150	114
Japan	12	10	8	6	5	4	3	3
CEIT	61	41	27	18	12	8	6	4
Article 5	1,024	582	331	189	107	61	33	19
TOTAL ANNUAL EMISSIONS	2,059	1,417	1,021	748	574	441	331	254
CUMMULATIVE EMISSIONS								
North America	47,774	49,808	51,477	52,847	53,971	54,894	55,651	56,272
Western Europe and Australia	73,824	76,055	77,881	79,402	80,647	81,730	82,570	83,208
Japan	1,700	1,754	1,798	1,833	1,861	1,883	1,900	1,915
CEIT	10,163	10,403	10,564	10,672	10,745	10,793	10,826	10,848
Article 5	146,654	150,350	152,453	153,649	154,329	154,717	154,931	155,052
TOTAL CUMMULATIVE EMISSIONS	280,116	288,371	294,173	298,402	301,553	304,017	305,878	307,295
INVENTORY								
North America	11,342	9,308	7,639	6,270	5,145	4,223	3,466	2,844
Western Europe and Australia	11,421	9,177	7,352	5,831	4,586	3,502	2,663	2,025
Japan	259	207	165	132	105	84	67	54
CEIT	674	452	304	204	137	92	62	41
Article 5	7,659	4,357	2,479	1,410	802	457	267	158
TOTAL INVENTORY	30,422	22,750	17,315	13,335	10,351	8,007	6,248	4,903

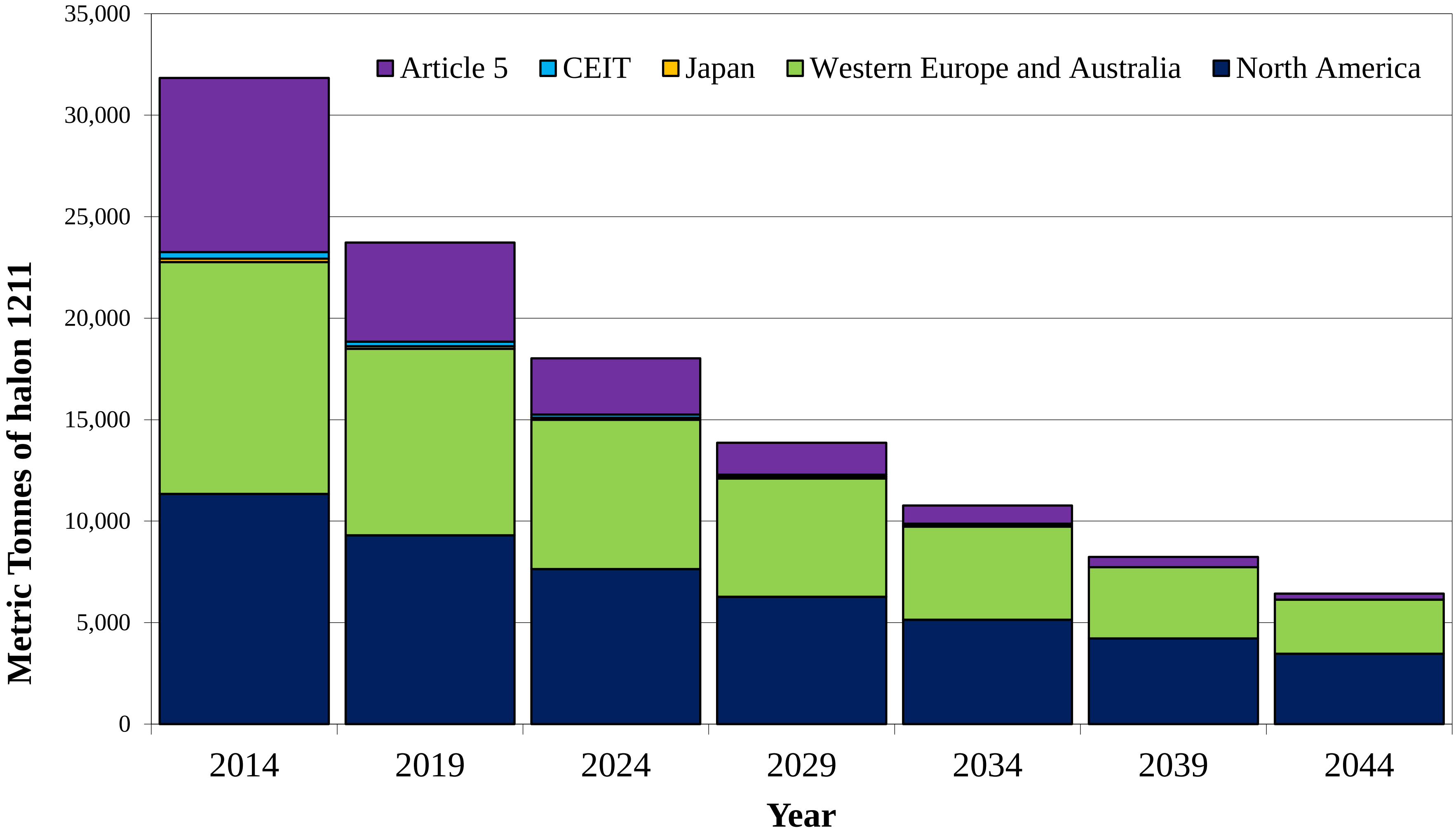

Figure 5.3: Forecast of future Regional Distribution of halon 1211 inventory

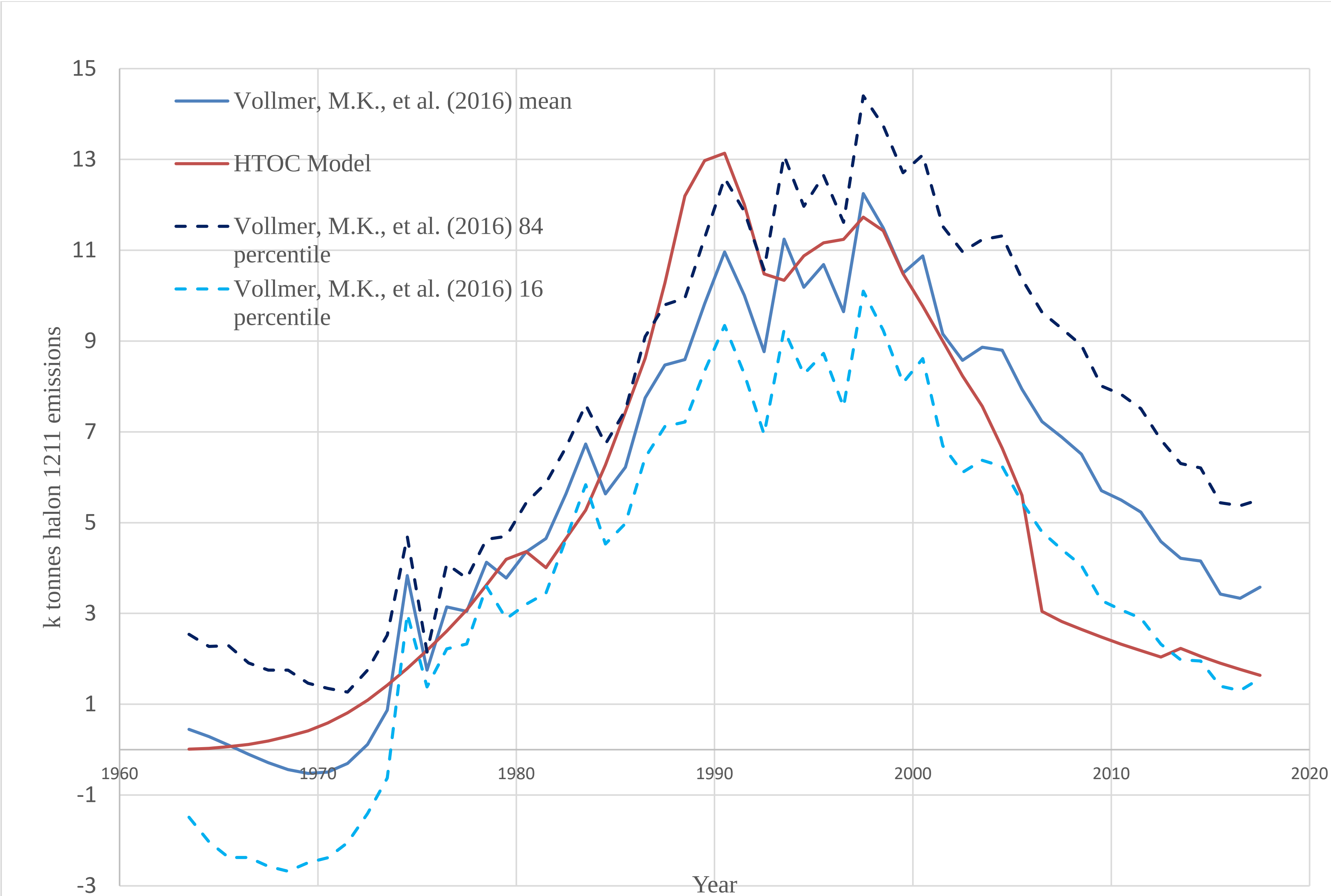

Figure 5.4: Comparison of halon 1211 emissions from one sigma of updated Vollmer et al (2016) and the HTOC model

Table 5.4: Halon 1211 Summary (in metric tonnes)

Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	375	361	347	333	320	308	296	285	274	263
Western Europe and Australia	409	391	379	362	346	347	328	313	299	299
Japan	10	10	9	9	8	8	8	7	7	7
CEIT	41	38	35	32	30	27	25	23	21	20
Article 5	582	520	465	415	371	331	296	264	236	211
TOTAL ANNUAL EMISSIONS	1,417	1,319	1,235	1,151	1,076	1,021	953	893	837	799
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440

YEAR	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233
Japan	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893
Article 5	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
CUMMULATIVE EMISSIONS										
North America	49,808	50,169	50,516	50,849	51,169	51,477	51,773	52,058	52,331	52,594
Western Europe and Australia	76,055	76,446	76,826	77,188	77,534	77,881	78,209	78,522	78,821	79,120
Japan	1,754	1,764	1,773	1,782	1,790	1,798	1,806	1,813	1,820	1,826
CEIT	10,403	10,440	10,475	10,507	10,537	10,564	10,589	10,612	10,634	10,654
Article 5	150,350	150,870	151,335	151,750	152,121	152,453	152,749	153,013	153,249	153,460
TOTAL CUMMULATIVE EMISSIONS	288,371	289,690	290,925	292,076	293,151	294,173	295,125	296,018	296,855	297,654
INVENTORY										
North America	9,308	8,948	8,601	8,268	7,947	7,639	7,343	7,059	6,785	6,522
Western Europe and Australia	9,177	8,786	8,407	8,045	7,698	7,352	7,024	6,711	6,411	6,113
Japan	207	198	189	181	173	165	158	151	144	138
CEIT	452	418	386	356	329	304	280	259	239	221
Article 5	4,357	3,893	3,477	3,107	2,775	2,479	2,215	1,978	1,767	1,579
TOTAL INVENTORY	22,750	21,516	20,364	19,289	18,267	17,315	16,422	15,585	14,786	14,038

YEAR	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	253	243	234	224	216	207	199	192	184	177
Western Europe and Australia	282	269	256	245	233	242	225	232	220	208
Japan	6	6	6	6	5	5	5	5	4	4
CEIT	18	17	16	14	13	12	11	10	10	9
Article 5	189	168	150	134	120	107	96	86	76	68
TOTAL ANNUAL EMISSIONS	748	703	662	623	588	574	537	524	495	467
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440

YEAR	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233
Japan	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893
Article 5	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440

YEAR	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
CUMMULATIVE EMISSIONS										
North America	52,847	53,090	53,323	53,548	53,764	53,971	54,170	54,362	54,546	54,723
Western Europe and Australia	79,402	79,671	79,927	80,172	80,405	80,647	80,872	81,104	81,324	81,533
Japan	1,833	1,839	1,845	1,850	1,855	1,861	1,865	1,870	1,874	1,879
CEIT	10,672	10,689	10,705	10,719	10,732	10,745	10,756	10,766	10,776	10,785
Article 5	153,649	153,817	153,968	154,102	154,222	154,329	154,425	154,511	154,587	154,656
TOTAL CUMMULATIVE EMISSIONS	298,402	299,105	299,767	300,391	300,979	301,553	302,089	302,614	303,109	303,576
INVENTORY										
North America	6,270	6,027	5,793	5,569	5,353	5,145	4,946	4,754	4,570	4,393
Western Europe and Australia	5,831	5,562	5,306	5,061	4,828	4,586	4,360	4,128	3,908	3,700
Japan	132	126	120	115	110	105	101	96	92	88
CEIT	204	188	174	160	148	137	126	117	108	99
Article 5	1,410	1,260	1,126	1,006	898	802	717	640	572	511
TOTAL INVENTORY	13,335	12,673	12,049	11,462	10,888	10,351	9,826	9,331	8,864	8,424

YEAR	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION												
North America	0	0	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS												
North America	170	164	157	151	145	140	134	129	124	119	115	110
Western Europe and Australia	197	187	177	167	158	150	142	134	127	120	114	108
Japan	4	4	4	4	3	3	3	3	3	3	3	2
CEIT	8	8	7	6	6	6	5	5	4	4	4	3
Article 5	61	55	49	44	34	33	30	27	24	22	19	18
TOTAL ANNUAL EMISSIONS	441	416	394	372	348	331	314	298	283	268	254	242
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583	195,583
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440

YEAR	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233	85,233
Japan	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893
Article 5	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
CUMMULATIVE EMISSIONS												
North America	54,894	55,057	55,215	55,366	55,511	55,651	55,785	55,914	56,038	56,158	56,272	56,382
Western Europe and Australia	81,730	81,917	82,094	82,261	82,420	82,570	82,712	82,846	82,973	83,094	83,208	83,316
Japan	1,883	1,887	1,890	1,894	1,897	1,900	1,903	1,906	1,909	1,912	1,915	1,917
CEIT	10,793	10,801	10,808	10,814	10,820	10,826	10,831	10,836	10,840	10,844	10,848	10,851
Article 5	154,717	154,771	154,820	154,863	154,898	154,931	154,961	154,987	155,011	155,033	155,052	155,070
TOTAL CUMMULATIVE EMISSIONS	304,017	304,433	304,827	305,199	305,546	305,878	306,192	306,490	306,773	307,041	307,295	307,537
INVENTORY												
North America	4,223	4,059	3,902	3,751	3,605	3,466	3,331	3,202	3,078	2,959	2,844	2,734
Western Europe and Australia	3,502	3,316	3,139	2,971	2,813	2,663	2,521	2,386	2,259	2,139	2,025	1,917
Japan	84	80	77	73	70	67	64	61	59	56	54	51
CEIT	92	85	78	72	67	62	57	53	49	45	41	38
Article 5	457	408	364	330	297	267	240	216	195	175	158	142
TOTAL INVENTORY	8,007	7,614	7,241	6,894	6,562	6,248	5,950	5,668	5,399	5,145	4,903	4,674

5.2.3 Halon 2402

In 2014, the HTOC estimated cumulative production of halon 2402 based on data from Kopylov et al. 2003, (in Russian) and by making a series of assumptions about halon 2402 production based on available data. It was assumed that the difference between total Article 7 production data for all halons in non-A5 parties and the halon 1211 and 1301 quantities used in the HTOC models represents additional halon 2402 production outside of the former Soviet Union from the years 1986 - 2010. The Soviet Union's production represented 7% of the total quantity of halons produced over that period. To estimate the 1963 – 1985 production, the 7% factor was applied to the halon 1211 and 1301 production quantities per year. No changes have been made to the model initially provided in the 2014 Assessment.

Table 5.5 provides a summary of HTOC 2018 Assessment of estimates of cumulative production, annual emissions, cumulative emissions and resulting inventories (bank) for halon 2402 in five-year increments from 2014 - 2049. There is little information available on import / export of halon 2402. Future projected detailed yearly estimates for 2019 – 2050 are provided in Table 5.6. Historic yearly detailed results from 1963 to 2018 are provided in Appendix E.

Figure 5.5 provides the regional distribution of the global inventory of halon 2402 based on the HTOC model. The HTOC estimates that the majority of halon 2402 remains in the former CEIT countries but also with significant quantities remaining in Europe. However, the emissions for Europe from the HTOC model are much higher than estimates using the methodology provided by O'Doherty et al., (2015) in O'Doherty et al., (2018) for NW Europe for the period 2014 – 2017. The HTOC model emission estimates scaled for NW Europe for 2014 – 2017 are 74 metric tonnes, 69 metric tonnes, 64 metric tonnes, and 60 metric tonnes, respectively, as compared to the O'Doherty et al. (2018) updated mean emission estimate of 33 metric tonnes, 28 metric tonnes, 13 metric tonnes and 17 metric tonnes, respectively. The HTOC model is over predicting the emissions and is outside of the range of uncertainly in the O'Doherty et al. (2018) updated data. While there is still halon 2402 in Europe, it is likely less than predicted by the HTOC model.

As shown in Figure 5.6, the HTOC estimate of emissions is generally higher than the mean estimate of emissions from the updated Vollmer et al. (2016) data since about 1980 and above even the 84th percentile estimate of emissions starting about 1983. The updated Vollmer et al. (2016) data provide a mean cumulative emissions through mid-2017 of 43,000 metric tonnes (27,000 – 58,000) and a remaining mean bank of 16,000 metric tonnes (500 – 31,500) versus the HTOC estimate of 52,000 metric tonnes of cumulative emissions and a remaining bank of about 7,000 metric tonnes. This places the HTOC model emissions and bank estimate within the range of uncertainty of the updated Vollmer et al. (2016) data

Table 5.5: HTOC Halon 2402 Model Summary (in metric tonnes)

	2014	2019	2024	2029	2034	2039	2044	2049
CUMMULATIVE PRODUCTION								
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	-	-	-	-	-	-	-	-
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
ANNUAL EMISSIONS								
North America	57	42	31	23	17	12	9	7
Western Europe and Australia	134	94	66	47	33	23	16	11
Japan	12	10	8	7	6	5	4	3
CEIT	391	275	193	136	96	67	47	33
Article 5	45	30	21	14	10	6	4	3
TOTAL ANNUAL EMISSIONS	639	452	319	226	160	114	81	57
CUMMULATIVE EMISSIONS								
North America	4,930	5,168	5,344	5,473	5,568	5,638	5,690	5,728
Western Europe and Australia	8,662	9,208	9,591	9,861	10,050	10,184	10,278	10,344
Japan	860	915	959	996	1,026	1,051	1,072	1,088
CEIT	30,202	31,792	32,909	33,696	34,248	34,637	34,910	35,103
Article 5	5,278	5,456	5,577	5,659	5,715	5,753	5,779	5,796
TOTAL CUMMULATIVE EMISSIONS	49,932	52,538	54,381	55,685	56,608	57,263	57,728	58,058
INVENTORY								
North America	903	665	489	360	265	195	143	106
Western Europe and Australia	1,838	1,292	909	639	449	316	222	156
Japan	306	252	207	171	140	116	95	78
CEIT	5,356	3,766	2,649	1,862	1,310	921	648	455
Article 5	556	377	256	174	118	80	54	37
TOTAL INVENTORY	8,959	6,353	4,510	3,206	2,282	1,628	1,163	832

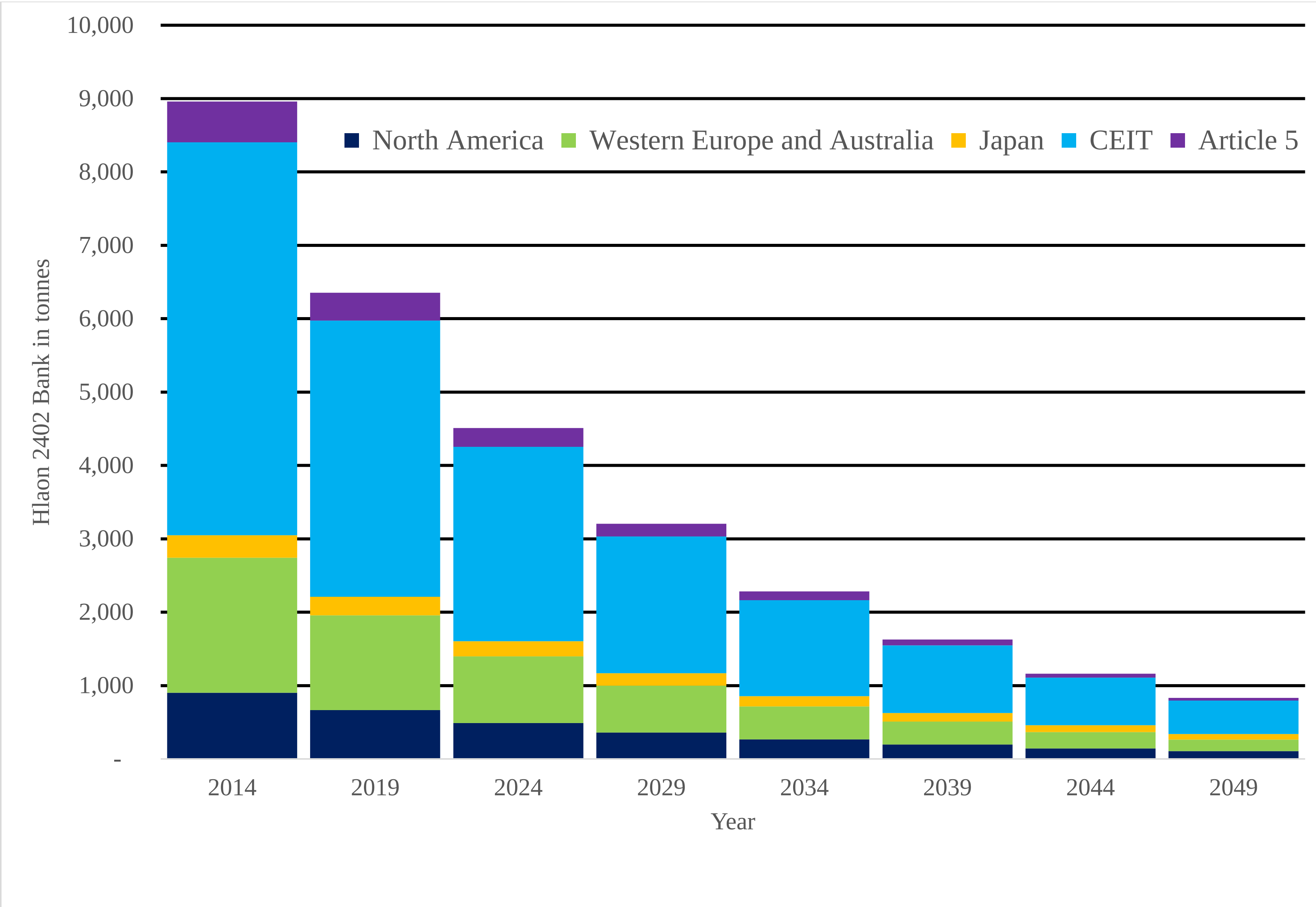

Figure 5.5: Forecast of future Regional Distribution of halon 2402 inventory

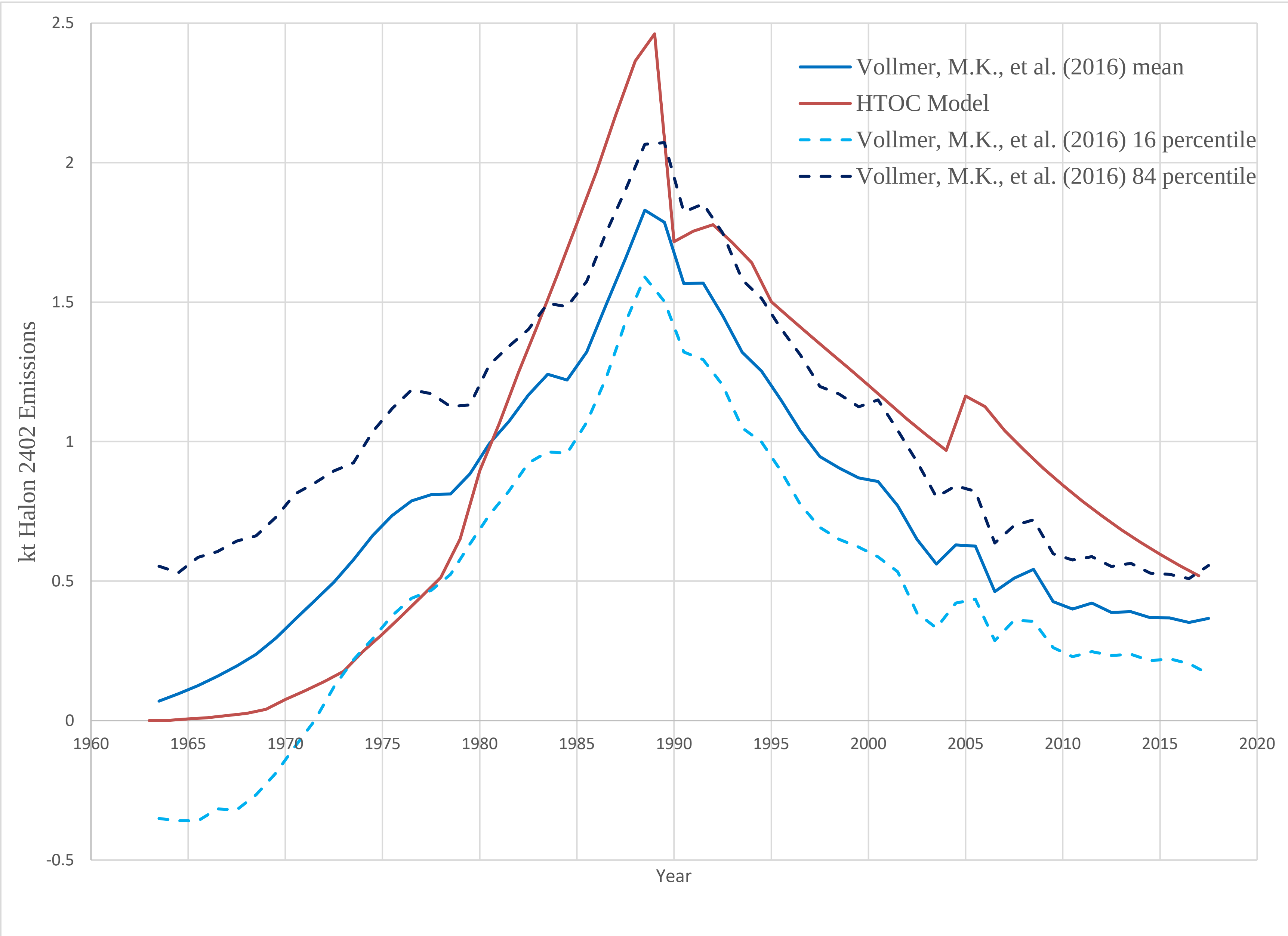

Figure 5.6: Comparison of halon 2402 emissions from one sigma of updated Vollmer et al (2016) and the HTOC model

Table 5.6: Halon 2402 Summary (in metric tonnes)

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	42	40	37	35	33	31	29	27	26	24
Western Europe and Australia	94	88	82	76	71	66	62	58	54	50
Japan	10	10	9	9	9	8	8	8	7	7
CEIT	275	256	239	222	207	193	180	168	156	146
Article 5	30	28	26	24	22	21	19	18	16	15
TOTAL ANNUAL EMISSIONS	452	421	393	367	342	319	298	278	260	242
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

YEAR	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

YEAR	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
CUMMULATIVE EMISSIONS										
North America	5,168	5,208	5,245	5,280	5,313	5,344	5,373	5,400	5,426	5,450
Western Europe and Australia	9,208	9,295	9,377	9,454	9,525	9,591	9,653	9,711	9,764	9,814
Japan	915	924	934	942	951	959	967	975	982	989
CEIT	31,792	32,048	32,286	32,509	32,716	32,909	33,090	33,257	33,414	33,560
Article 5	5,456	5,484	5,510	5,534	5,556	5,577	5,596	5,614	5,630	5,645
TOTAL CUMMULATIVE EMISSIONS	52,538	52,959	53,353	53,719	54,062	54,381	54,679	54,957	55,217	55,459
INVENTORY										
North America	665	625	588	553	520	489	460	433	407	383
Western Europe and Australia	1,292	1,204	1,122	1,046	975	909	847	789	736	686
Japan	252	242	233	224	216	207	199	192	184	177
CEIT	3,766	3,510	3,272	3,049	2,842	2,649	2,468	2,301	2,144	1,998
Article 5	377	349	323	299	277	256	237	219	203	188
TOTAL INVENTORY	6,353	5,931	5,538	5,172	4,829	4,510	4,212	3,934	3,674	3,432

YEAR	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	23	21	20	19	18	17	16	15	14	13
Western Europe and Australia	47	43	40	38	35	33	31	28	27	25
Japan	7	7	6	6	6	6	5	5	5	5
CEIT	136	127	118	110	103	96	89	83	77	72
Article 5	14	13	12	11	10	10	9	8	8	7
TOTAL ANNUAL EMISSIONS	226	211	197	184	172	160	150	140	130	122
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

YEAR	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
CUMMULATIVE EMISSIONS										
North America	5,473	5,495	5,515	5,534	5,552	5,568	5,584	5,599	5,613	5,626
Western Europe and Australia	9,861	9,904	9,945	9,983	10,018	10,050	10,081	10,109	10,136	10,161
Japan	996	1,003	1,009	1,015	1,021	1,026	1,032	1,037	1,042	1,047
CEIT	33,696	33,822	33,940	34,050	34,153	34,248	34,337	34,420	34,498	34,570
Article 5	5,659	5,672	5,684	5,695	5,706	5,715	5,724	5,732	5,740	5,747
TOTAL CUMMULATIVE EMISSIONS	55,685	55,896	56,093	56,277	56,448	56,608	56,758	56,898	57,028	57,150
INVENTORY										
North America	360	339	318	299	282	265	249	234	220	207
Western Europe and Australia	639	596	555	517	482	449	419	390	364	339
Japan	171	164	158	152	146	140	135	130	125	120
CEIT	1,862	1,736	1,618	1,508	1,405	1,310	1,221	1,138	1,060	988
Article 5	174	161	149	138	128	118	109	101	94	87
TOTAL INVENTORY	3,206	2,995	2,798	2,614	2,443	2,282	2,133	1,993	1,863	1,741

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION												
North America	0	0	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS												
North America	12	12	11	10	10	9	9	8	8	7	7	6
Western Europe and Australia	23	21	20	19	17	16	15	14	13	12	11	11
Japan	5	4	4	4	4	4	4	3	3	3	3	3
CEIT	67	63	58	54	51	47	44	41	38	36	33	31
Article 5	6	6	6	5	5	4	4	4	3	3	3	3
TOTAL ANNUAL EMISSIONS	114	106	99	93	86	81	75	70	66	61	57	54
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
CUMMULATIVE EMISSIONS												
North America	5,638	5,650	5,661	5,671	5,681	5,690	5,698	5,706	5,714	5,721	5,728	5,734
Western Europe and Australia	10,184	10,205	10,225	10,244	10,261	10,278	10,293	10,307	10,320	10,332	10,344	10,354
Japan	1,051	1,056	1,060	1,064	1,068	1,072	1,075	1,079	1,082	1,085	1,088	1,091
CEIT	34,637	34,700	34,758	34,812	34,863	34,910	34,954	34,995	35,034	35,069	35,103	35,134
Article 5	5,753	5,759	5,765	5,770	5,774	5,779	5,783	5,787	5,790	5,793	5,796	5,799
TOTAL CUMMULATIVE EMISSIONS	57,263	57,369	57,468	57,561	57,647	57,728	57,803	57,874	57,940	58,001	58,058	58,112
INVENTORY												
North America	195	183	172	162	153	143	135	127	119	112	106	99
Western Europe and Australia	316	294	274	256	238	222	207	193	180	168	156	146
Japan	116	111	107	103	99	95	91	88	85	81	78	75
CEIT	921	858	800	746	695	648	604	563	524	489	455	424
Article 5	80	74	69	64	59	54	50	47	43	40	37	34
TOTAL INVENTORY	1,628	1,521	1,422	1,330	1,243	1,163	1,087	1,017	951	890	832	779

5.3 HFC Estimates

5.3.1 HFC-227ea Estimates

Unlike halons, the majority of which were exclusively used for fire protection, HFC-227ea is also used in Metered Dose Inhalers (MDIs) and in foam blowing. Therefore, in order to estimate the amount of the global emissions that are from the fire protection sector, it was necessary to create a model that can separate the annual emissions into those three categories of use. It is also known that HFC-227ea is used in some refrigerant blends, but that use is considered small at this time. If information on annual refrigerant use and emissions becomes available, it will be included in the future. Any use as a refrigerant would both reduce the amount that went into fire protection applications and the amount emitted from fire protection, so it is a conservative estimate in that it would overestimate the amount of emissions from fire protection. The model was developed in coordination with a Medical and Chemicals (MC) TOC co-chair and a Rigid and Flexible Foams (F)TOC co-chair. It is a top-down model using best estimates of annual global production capacity of HFC-227ea beginning in 1993 and carried out until 2018, Walter-Terrinoni (2018). This is a much more simplified model than the halon model and does not try to predict regional variations or reasons for the emissions, i.e., does not try to predict service losses, inadvertent discharges, fires, etc. The estimated annual use and therefore emissions from MDIs is from the work of Noakes (2018). The amount that was used for production of foam was provided by Walter-Terrinoni (2018), who also provided the estimated annual emissions from both the production and use of foams. The amount that went into fire protection applications was taken to be the remainder of the production capacity, which would also serve, as was the case for not including HFC-227ea use as a refrigerant, to increase the amount that went into the fire protection sector. The fire protection emission factors come from expert opinion based on the experience of the HTOC halon models. The annual emission rates used are as follows.

- MDIs – 100%
- Foams – Production – 25%
- Foams annual from installed base – 1%
- Fire protection – starting at 25% in 1993 (initially significant quantities were discharged for development testing and certification), quickly dropping to 4% by 1998 (as much less developmental testing was performed and as best practices for reducing emissions were adopted from halon 1301 lessons learned, gradually reducing to 2.5% (the same as the HTOC estimates for current halon systems) by 2011 and remaining at 2.5% thereafter.

Updated data from Montzka, et al., (2015) were obtained on the global emissions of HFC-227ea through mid-year 2017 and are in excellent agreement with the simplified HTOC model, as shown in Figure 5.7. The HTOC simplified model is generally between the 16th and 84th percentile estimates, except for the period from 2008 – 2014. Even then, it is very close to the 16th percentile estimate. It is important to note that the input values for the model were not adjusted to try to get the two estimation techniques to agree.

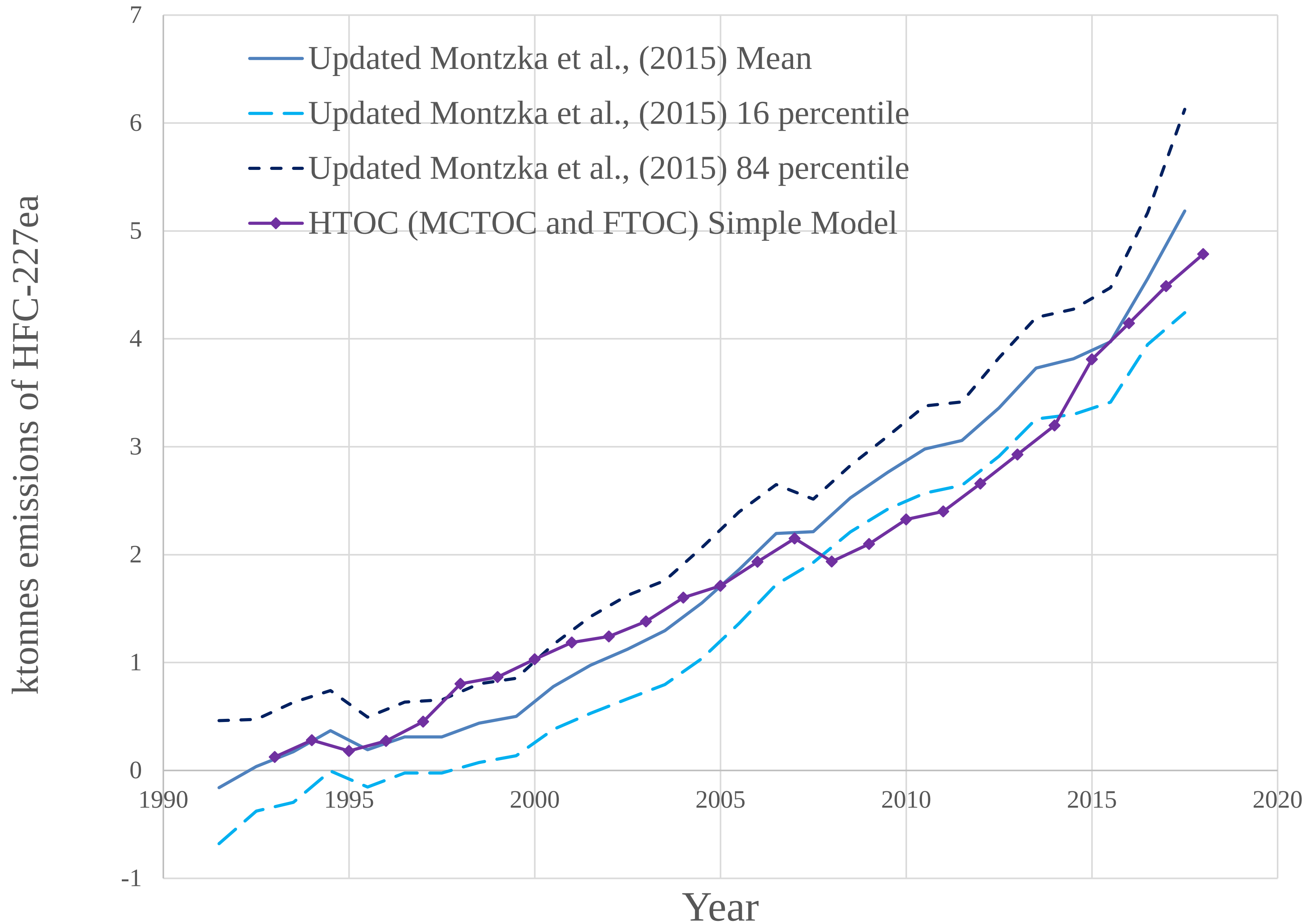

Figure 5.7: Comparison of updated Montzka et al. (2015) HFC-227ea estimated global emissions with the simplified HTOC model

All of the input data of the model was based directly on the expert opinion of the HTOC, MCTOC and FTOC co-chairs who provided data and expert opinion. Only small differences in the model assumptions would be needed to get the two to agree but having done so would eliminate the independence of the two methods. If there becomes additional independent information available or data in the future such as refrigerant use and emissions of HFC-227ea, the model would be updated at that time. For now, the very good agreement from the two independent methods is felt as sufficient to use the HTOC simplified model to estimate the size of the fire protection bank of HFC-227ea and the amount of the overall global emissions that comes from fire protection applications. Based on the estimated emissions of 3,381 metric tonnes in 2018 and a 2.5% annual emission rate, the global HFC-227ea fire protection bank is estimated to be 128,500 metric tonnes at the end of 2018.

To put that amount into context, the largest that the global halon 1301 bank was projected to be in the HTOC model was 77,000 metric tonnes in 1991. An initial impression is this might make the HFC-227ea bank seem too high. However, if one considers that although halon 1301 was commercialized and used as early as 1963, it was not really until the mid-1970s that halon 1301 really began to see significant market penetration, with less than a 20-year run before the Montreal Protocol began to decrease its production. HFC-227ea has about the same length of time now in the market place. Further, well above 50% more HFC-227ea is required over halon 1301 to protect against the same fire threat. Therefore, to protect the same spaces being protected by the 77,000 metric tonnes of halon 1301 would require about the 128,500 metric tonnes now projected to be in the HFC-227ea fire protection bank. Lastly, the bank of HFC-227ea is not emitted at nearly the same rate that was common for halons up until the Montreal Protocol, meaning that the bank continues to grow steadily.

Regionally, U.S. HFC-227ea emissions have been estimated from 2008 – 2014 by Hu et al., (2017). In 2008, emissions were about 280+/- 110 metric tonnes rising to 600+/-100 metric tonnes in 2014, the last year of the data set. While no data have been found on U.S. use and emissions of HFC-227ea for foams and MDIs, some assumptions on percentages of use in the U.S. ranging from no use in foams and MDIs to their global average, provide an estimate that the U.S. emissions of HFC-227ea from the fire protection sector are about 15 to 25% of the global emissions from the fire protection sector. All anecdotal information available to the HTOC would indicate that this range is reasonable, which would provide further support to the HFC-227ea model estimates in Figure 5.7.

5.3.2 HFC-125 Estimates

There are several known applications of HFC-125 in fire protection including some military uses but these are estimated to be quite small. Since the largest use of HFC-125 is as a blend in several refrigerants, it is not possible to estimate the amount of HFC-125 used in or emitted from fire protection systems using atmospheric measurements alone. It would be necessary to be able to separate out the amounts of agent sold into fire protection and make assumptions similar to those for the HFC-227ea model. At this time, the HTOC does not have the necessary information to perform such modelling.

5.3.3 HFC-23 Estimates

Unlike HFC-227ea, which is purposely produced, HFC-23 is a byproduct of HCFC-22 manufacturing. As a result, it is not possible to estimate the amount of HFC-23 used in fire protection from atmospheric measurements. HFC-23 is typically limited to use in cold temperature applications, as discussed in the sections 3.4.4 on alternatives, and 4.3.1 on oil and gas production. Only limited information on actual amounts of HFC-23 used in fire protection is available and indicates that it is typically small compared to HFC-227ea. In one case, where more precise information is available, its use is higher than typical at around 20% - 25% of HFC-227ea, Yagi (2018). However, this is limited to a region where inert gases dominate this sector and therefore is not illustrative of the overall percentage globally. The HFC-227ea use in this case is less than 0.5% of the global HFC-227ea fire protection use whereas this region's need for fire protection would be much higher at around 6% of the total demand in this sector. The 6% estimate is based on GDP, IMF (2018), using the correlation shown in Verdonik (2004). If this region was using the average amount of HFC-227ea at 6% of the global total, its HFC-227ea installed base (bank) would be over 7,000 metric tonnes in 2018. Under the assumption that HFC-23 would not be used in applications that would be suitable to inert gases, taking the actual HFC-23 used in this region and dividing by the theoretical 7,000 metric tonnes of HFC-227ea provides an estimate of the global amount of HFC-23 used as a percentage of HFC-227ea, which is about 1%. This is consistent with expert opinion that the global percentage of HFC-23 use in fire protection is small.

5.3.4 HFC-236fa Estimates

As was the case for HFC-227ea, there are other non-fire protection uses of HFC-236fa. However, unlike HFC-227ea, there is little information available on the relative take-up of HFC-236fa in the fire protection market. There are portable extinguishers that have been commercialized to replace halon 1211. HFC-236fa is widely used in European military vehicle applications and there is also one other known small use for fire protection in U.S. auto racing, National Association for Stock Car Auto Racing, known as NASCAR. At this time, there is not sufficient information to estimate HFC-236fa installed quantities or emissions in the fire protection sector.

5.4 Global Halon, HCFC, and HFC Banking

5.4.1 Introduction

A bank is defined as all agent contained in fire extinguishing cylinders and storage cylinders within any organization, country, or region. Likewise, the 'global bank' is all agent presently contained in fire equipment plus all agent stored at recycling centres, at fire equipment companies, at users' premises, etc., i.e., it is all agent that has been produced but has yet to be emitted or destroyed. The collection, reclamation, storage, and redistribution of fire extinguishing agents is referred to as "Banking". These same concepts and terminologies apply to HCFCs and HFCs.

Many parties have halon banking programs that are fully operational, but more parties have implemented only partial programs and may not be aware of the increasing need to establish a means of meeting the long-term needs for their remaining users. Those parties who have established banking programmes have a distinct advantage in that it is a straightforward step to expand those programs, practices, and processes to include all halocarbons (preferably all halogenated gaseous fire extinguishing agents).

HTOC has a continuing concern regarding the historical knowledge that has been lost due to the length of time over which the Montreal Protocol activities have been implemented. A significant number of individuals are new to the Protocol, finding themselves now responsible for halon management but not being familiar with the issues surrounding halon (and halocarbon) use, recycling, and banking. HTOC notes that this is becoming more and more challenging as it works with various parties and organizations on issues related to acquiring halons to meet their continuing needs. Parties may wish to address awareness programmes to re-establish this apparent loss in institutional memory.

5.4.2 HCFC and HFC Banking

Like halons, HFC and HCFC fire extinguishing agents can be recovered from decommissioned fire protection systems and extinguishers and reused. For HFCs, this practice is fairly common in non-A5 parties that have an established halon recycling industry. Unlike halons, where recovered agent is used in both new fire protection equipment and to service existing fire protection equipment, recovered HFCs are used mostly to service existing equipment and are not commonly used in new fire protection systems or extinguishers. This may change in the future as the phasedown of HFC production and consumption proceeds. HFC recycling is performed by the primary halon recycling companies. The U.S. Defense Logistics Agency recycles HFCs for military uses. In addition, recovery and reuse of HFCs occurs at the distributor level. Data from the Halon Alternatives Research Corporation's HFC Emission Estimating Program shows that in recent years about 75% of the HFCs used to service existing fire protection equipment in the U.S. comes from recycling as opposed to new production. Recovery of HCFCs from fire extinguishers is occurring, however, reclamation is complicated by proprietary agent composition restrictions.

The use of HCFCs in fire protection is much smaller than the use of HFCs and more regionally specific, and as of now recovery of HCFCs from fire protection equipment is somewhat limited. This may change as the phase-out of HCFC production and consumption proceeds.

The banking of HCFCs is in its infancy and is discussed in the TEAP Working Group Report on Decision XXIX/9, TEAP (2018a). Likewise, there have been no reports of HFC banking with the exception of the few non-A5 parties who already have well-established halon banking programs such as Australia, Japan, and the U.S.

The HTOC Supplemental Report #3 on Global Banking has some country-specific information on HFC and HCFC banking for most regions globally. The following are two examples:

India: A regulation was passed in India in 2014 banning the import of HCFCs and limiting their use in many applications. India now has a bank management plan in place to address the phase-out of HCFCs. Multi-lateral Fund support was provided in 2017 to assist India in moving forward the phase-out dates for HCFCs from 2040 to 2025.

Egypt: The Egyptian Environmental Affairs Agency (EEAA) with UNIDO conducted workshops in August and November to discuss the feasibility of establishing recycling facilities. Such operations are not expected to be on-line before the year 2022.

It is the conclusion of the HTOC that parties who have not implemented halon management programmes (or organized recycling) are unlikely to be recycling or managing other halogenated fire extinguishing agents. In all of those cases, there are no reported activities for HFCs and HCFCs.

Countries/regions who have more recently begun working on halon banking have indicated awareness of the need to bank HFCs and HCFCs and are at various levels in the planning stages.

Parties with well-established halon bank management programmes and who are in most cases the largest remaining users have already incorporated HFCs into their bank management operations.

5.4.3 Halon 1211 and 1301 Banking

Halon banking programmes are well established in non-A5 parties that need them such as Australia, Japan, and the U.S.

China's Foreign Economic Cooperation Office (FECO) recently signed a contract with an office under the Ministry of Public Security to function as the national halon management office and to maintain a database on halon 1211 and 1301 installed, collected, and stored in China. This office is essentially the halon bank programme office and they are in the process of setting up a halon recycling website. A survey on halon installed in fire extinguishing systems and portable fire extinguishers and collected by fire equipment companies and fire brigades covering several provinces, was competed in in 2016. While conducting this survey, some recycling companies were identified. One of the companies, located in Shanghai, has been active in the collection of halons from fire extinguishing systems on-board ships. No other details are available on the aforementioned recycling companies. All of the identified recycling activities are now part of the national halon management programme. A former producer of halon 1211 has a large enough stock available to meet the commercial aviation and military needs for numerous decades. This surplus is a result of continued halon production through 2010. An unfortunate consequence of the surplus is that it seems to be inhibiting banking and recycling efforts. As of 2018, the regulatory issue of halon being classified as a hazardous waste in China has been resolved, and the halon banking and recycling activities have restarted. FECO signed a contract with a company who set up a halon 1301 recycling centre. The company has a small stock of halon 1301, which is now also managed under the national halon management activities.

India has an active halon bank management program. The Indian Air Force utilizes halon 1211 and halon 1301, and in 2016 is reported to have procured the quantities needed to support their remaining applications.

South American countries continue in their efforts to eliminate the use of the halons in fire protection applications, where feasible, such as communications, banks, transportation, and marine vessels. Meanwhile civil aviation and military branches still use halons in their equipment. Legislation was passed prior to 2014 in most Latin American countries to prohibit the import and export of halons (including recycled). This has created difficulties for some companies who provide servicing to the remaining users such as aviation and military.

Many A5 parties have indicated an interest in getting support in various aspects of banking such as collecting data on remaining users, recycling, navigating import/exports of halons, and transitioning to long-term acceptable alternative (e.g., non- or low-GWP) solutions for their fire protection applications. Parties may wish to consider projects aimed at providing such support, particularly at the regional level.

5.4.4 Halon 2402 Banking

Halon 2402 had been produced nearly exclusively in the former USSR, and production was continued by the Russian Federation after 1991 until the end of 2000. The bank of halon 2402 was very small at the time of production phase-out and therefore, through Decision VIII/9, from 1996 through 2000 production was continued under the Essential Use Exemption procedure approved by the parties to the Montreal Protocol, the objective being to build a bank of halon 2402 that existing applications could rely on for the remaining useful lives of their equipment.

However, as reported in the 2006 HTOC Assessment Report, the inventory of this bank was significantly reduced owing to the use of halon 2402 as a process agent in the chemical industry during the period 2002-2003, when the average price of halon 2402 was low. (This release of halon 2402 is not yet included in the HTOC model.) More recently, halon 2402 was commercialized for the Russian market as an encapsulated component of a flame-retardant material, which can be used as a painting or coating, further reducing the inventory for existing uses.

Equipment associated with halon 2402 systems was almost exclusively manufactured in the USSR until its dissolution in 1991, and in the Russian Federation and the Ukraine thereafter. In other countries of the former Eastern Bloc (e.g., Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, and Slovakia) use of halon 2402 was associated with the use of Russian military equipment and civilian aircraft. However, now many of these are no longer in use. Halon 2402 based fire protection equipment was also exported to some Asian countries together with Russian products, mostly for use in military vehicles, ships, and aircraft.

Countries that still use halon 2402 as a fire protection agent can be grouped as follows:

- Russian Federation, Ukraine, Belarus;
- Other former USSR and other countries of the former Eastern Bloc: Caucasus: Armenia, Azerbaijan, Georgia; Central Asia: Kazakhstan, Kyrgyzstan, Tadzhikistan, Turkmenistan, Uzbekistan; Non-EU states of East-South Europe: e.g., former Yugoslavia; EU member states: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia; and
- South-East and East Asia: India, Vietnam, Japan.

Some military and aviation equipment employing halon 2402 may still be in use in countries that purchased equipment from the USSR, and later from Russia, e.g., Afghanistan, Algeria, China, Cuba, Egypt, Libya, Mongolia and Syria.

The needs of some parties for halon 2402 cannot be estimated due to the unavailability of market information, but it should be assumed that a demand for halon 2402 for the servicing of operating equipment exists and that halon from outside sources will be required, as banking and recycling facilities do not exist. While there is no apparent shortage of halon 2402 on a global basis, in the absence of bank management plans and, given the prevalence of low quantity installed bases spread over large geographical areas, there may be regional shortages in the near future that parties may wish to address with increased awareness programmes, particularly on the need to prevent venting. The HTOC believes that it remains essential to maintain a readily viable path for transfer of decommissioned halons, or destruction of contaminated halons when necessary.

Italy reports no halon 2402. O'Doherty et al., (2018) data indicates the presence of halon 2402 in NW Europe but the HTOC has not been able to ascertain where. Halon 2402 is still being used in Russia, central Asia, and Japan. Russia is the largest user of halon 2402 with an estimated installed base of approximately 920 tonnes, annual emissions of 3 tonnes, and an average of 30 tonnes available for the global market. The next two largest users are Japan (159 tonnes) and the Ukraine (128 tonnes). The 'market' appears to be balanced. Most critical uses are in the military sector, except in Japan where the majority of uses are non-military. Data show no increase in demand and no increases are expected in the future. Contaminated agent and mixtures, such as that with ethyl bromide, continue to enter the market and may represent an increasing proportion of the remaining stock as the overall global bank diminishes. While there is no direct data at this time showing this trend, it is a possibility that should be taken into consideration when forecasting and planning for future remaining needs.

5.4.5 Conclusions

Some countries have classified halons as hazardous wastes, which is hampering movement. The HTOC has a concern that the transboundary movement of halons (which would facilitate movement of halons to where they are needed) is not possible due to legislation in some countries. An example of a national restriction is one country's policy on transferring halon out of their country; they will not allow halons to be moved unless the halon goes to another country operating under the Basel Convention.

The HTOC has similar concerns for halon 1211 and halon 1301, as previously cited for halon 2402, that geographical dispersion of smaller quantities of installed halons and lack of awareness, or challenges to recycling, may result in venting. Regardless of the quantities or locations of halons, the HTOC believes that it is essential that a readily viable path for transfer or destruction of all decommissioned or contaminated halons is made available. The committee further believes that during decommissioning and transfer, it is imperative the collected halons be recycled/reclaimed (and certified to international standards) using industry recognized Codes of Practice in the handling, storage, and transport. Refer to Chapter 6 of this report, HTOC Technical Note #2, and HTOC Technical Note #4 for best practices.

HTOC Technical Note #2 can be found at https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note2_2018.pdf

and

https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note4_2018.pdf

respectively.

The subject of global halon banking was addressed at length in earlier editions of the HTOC Assessment Reports. For the 2014 Assessment Report, the HTOC elected to move the contents of this chapter to Supplementary Report #2, Volume 3: *Global Halon 1211, 1301, and 2402 Banking*, where it could be continuously updated as necessary.

Supplementary Report #2- Volume 3: renamed *Global Halon, HCFC, and HFC Banking* (2018) has been updated to include specific reference to all halogenated fire extinguishing agents. This chapter is only a summary of the latest version of HTOC Supplementary Report #2, Volume 3 which can be found on the Ozone Secretariat website at: https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_supplement_report2_2018.pdf

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6 Recommended Practices for Recycling Halons and Other Halogenated Gaseous Fire Extinguishing Agents.

With the halt in production, halons from fire suppression systems and units removed from service have been recycled/reclaimed and become the sole replenishment source for the recharge of these units. While production of HFCs is ongoing, there are increasing amounts of recycled agent being used in lieu of new production. The HTOC sees this trend continuing for all halogenated gaseous fire extinguishing agents as the preferred source to recharge systems and extinguishers. Poor recovery, recycling and reclamation processes can inadvertently compromise the purity and quality of the agents by the introduction of contaminants rendering the agents not fit for purpose.

The most common halogenated gaseous fire extinguishing agents in use today are:

- Halon 1301
- Halon 1211
- Halon 2402
- HCFC-123 (in appropriate blends only)
- HFC-23
- HFC-125
- HFC-227ea
- HFC-236fa
- FK-5-1-12

In the fire protection industry, there are several terms used to describe the treatments of halons and other gaseous halogenated fire extinguishants to prepare them for possible redeployment:

- **Reuse**: To remove an agent cylinder or extinguisher from one application and re-install in another application.
- **Recover**: To remove agent in any condition from an extinguisher or extinguishing system cylinder and store it in an external container without necessarily testing or processing it in any way.
- **Recycle**: To clean recovered agent without meeting all the requirements for reclamation. In general, recycled agent has its pressurizing nitrogen removed in addition to being processed to only reduce moisture and particulate matter.
- **Reclaim**: To reprocess agent to a purity specified in applicable standards and to use a certified laboratory to verify this purity using the analytical methodology as prescribed in those standards. Reclamation is the preferred method to achieve the highest level of purity. Reclamation requires specialized machinery usually not available at a servicing company.

Faced with this high reliance on recycled and reclaimed agents for the replenishment of systems, it is essential that recovered agents be properly processed to remove impurities and to return the agents' purity levels to be consistent with newly manufactured agent and/or the applicable purity standards.

It has been shown that it is important to meet all of the quality assurance requirements throughout the recovery, recycling, reclamation and testing phases, in order for there to be a credible gaseous halogenated fire extinguishant resupply industry.

Contamination mitigation strategies by the key players involved in the supply chain offering recycled agent for replenishment can also play an important role. These key players include the recycling companies, the accredited testing laboratories, the servicing companies and the end users. All have a role to play in employing robust quality assurance processes throughout each of their operations to ensure processed agent is returned to the correct quality specifications.

Many, if not all of the recommended practices for recycling or reclaiming halons will apply to other halogenated gaseous fire extinguishing agents. Quality testing of halogenated gaseous fire extinguishing agents made up of blends will determine whether recycling or reclamation processes will need to be applied to return these types of agent back to their quality specifications. Where agents are made up of halogenated blends, recycling will reduce physical contaminants like acidity, water content, particulate matter and nitrogen if the agents have been pressurized. Reclamation practices involving a form of distillation on the other hand, may be required to separate the blend components out, rectify their respective purities and then re-blend to achieve the overall purity requirement of the agent. From time to time, depending on the overall quality of the agent, it may need to be subject to both recycling and reclamation processes.

Guidance on the practices for recycling halon was addressed in earlier editions of the HTOC Assessment Reports. For the 2014 Assessment Report the HTOC elected to move the contents of this chapter to Technical Note #4: *Recommended Practices for Recycling Halons*, where it could be continuously updated as necessary.

Technical Note #4, Revision 2: renamed *Recommended Practices for Recycling Halons and Other Halogenated Gaseous Fire Extinguishing Agents (2018)* has been updated to include specific reference to all halogenated gaseous fire extinguishing agents. This chapter is only a summary of the latest version of HTOC Technical Note #4 which can be found on the Ozone Secretariat website at: https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note4_2018.pdf

7 Emission Reduction Strategies

Releasing fire extinguishing agents into the atmosphere is fundamental to the process of flame extinction and enclosed space inerting. Historically, less than 5% of all halon emissions have been a result of using halons to extinguish fires. While most (it is presumed all) parties have discontinued system discharge testing and discharge of extinguishers for training purposes, additional significant reductions of emissions can be realized by improving maintenance procedures, detection, and control devices, recovery and recycling, recordkeeping, proper training, and utilizing standardized procedures for agent transfers and storage.

There are a number of non-technical actions that could be taken which have been shown to be equally important to the aforementioned technical actions. Non-technical steps include development of codes of conduct, implementing awareness campaigns, workshops and training, policies, and legislating regulations and ensuring enforcement. *Emissions Reduction Strate*gies are a combination of "responsible use" and political regulatory action.

Emission reduction strategies are grouped into the following ten areas (refer to HTOC Technical Note #2 for more coverage of each area):

1. **Alternative Fire Protection Strategies:** Do not use ODS or high-GWP halogenated gaseous fire extinguishants in new fire protection applications or new designs of equipment where feasible. Alternatives are available for virtually all applications with very few exceptions, e.g., some aircraft and military applications, low temperature applications, etc. Clearly, emissions can be reduced if the agent is no longer employed as the fire protection agent. Other active fire extinguishing systems, which perform the same function as gaseous halogenated fire extinguishant systems, should not be considered as the only alternative to halon, HCFC or HFC systems. A combination of prevention, inherently safe design, minimization of personnel exposure, passive protection, equipment duplication, detection, and manual intervention should be considered.

2. **Halogenated Gaseous Fire Extinguishant Use Minimization:** When protection using halogenated gaseous fire extinguishants against fire or explosion hazards is considered vital, practices such as local application and zoned systems should be considered to minimize the use of agent quantities, and thus reduce emissions potential.

3. **Maintenance Programs:** Attention to maintenance programs can add years to a bank of agent by reduced emissions. This represents money saved in two ways. It minimizes the need to purchase recycled agents, and it prolongs the useful life of the existing fire protection system.

4. **Detection Systems:** Automatic systems go hand in hand with sensitive detection systems. Poor design and improper maintenance of detection systems can result in significant unwanted releases, i.e., emissions.

5. **Hazard and Enclosure Review:** Monitor and control the hazard. Check for enclosure modifications or changes to the configuration of the protected space. Check with local/national fire regulations and manufacturers' recommendations

for specific requirements or in their absence support the development or adoption thereof.

6. **Personnel Training and Documentation:** It is recommended that the personnel performing on-site maintenance as well as the user be trained and competent in the maintenance and proper operation of the system/unit and aware of activities that could result in an unwanted discharge. It is recommended that both groups should be educated on ozone depletion and climate change issues and the impact of halogenated gaseous fire extinguishant releases, as well as the restrictions on future supplies.

7. **Agent Transfers and Storage:** The component emissions related to agent transfers can be substantially reduced by the use of approved filling rigs. Recovery rigs should be operated to avoid contaminating agent supplies. By recovering all on-site agent that is not in use for fire protection purposes, the risk of accidental discharge or agent leakage is minimized. The agent can be recovered into large storage tanks, if the quality can be verified, and the tanks monitored for leaks. Where testing of agent quality (followed with recycling/reclamation if needed) is not feasible, the agent should be stored in separate appropriate-for-use containers in a common area and monitored for leaks.

8. **Agent Discharging:** The discharging of halogenated gaseous fire extinguishing agent systems and portable fire extinguishers for testing, training, and other non-fire related procedures can be a cause of unnecessary emissions and should be avoided. Training with substitute agents should be considered where possible. With the increase in awareness of the environmental problems associated with halons, HCFCs and high-GWP HFCs, many users are switching to the not-in-kind agents or fire protection strategies discussed in Chapter 3.

9. **Awareness Campaigns and Policies:** Non-technical actions for emission reduction strategies can include:

    - **Policies, Regulations, and Enforcement:** Each National Ozone Unit (NOU) has been tasked with the responsibility for implementing policies, programs, and regulations in support of those obligations under the articles of the Montreal Protocol specific to their country. Some parties have elected to utilize a Steering Group to formulate plans for ODS phase-out, to draft policies and regulations, and to provide periodic oversight. This is especially effective where resources are limited, and actions might otherwise be delayed. It also serves to involve those entities directly affected by the phase-out such as the following.
        - Public fire services
        - Fire equipment trade associations
        - Insurance companies
        - End users (civil aviation, military, telecommunications, etc.)
        - Environmental advocacy groups (NGOs)
        - Environment Ministry
        - Customs officials
        - Defence Ministry

Without the support of the NOU, decommissioned halons within the country may be lost rather than banked for the parties' critical needs. A proactive approach has the benefit of also managing the other fire extinguishing agents regulated under the Montreal Protocol, i.e., HCFCs and HFCs.

- **Awareness Campaigns:** Emission Reductions can be achieved by implementing a comprehensive awareness campaign which can include workshops, training, brochures, television commercials, website, newsletters directly or through fire protection equipment/service providers, fire protection and trade publications, etc. Involve the stakeholders, who may include the NOU delegate, Ministry of Environment, fire protection users, code enforcing authority, military branches, maritime and airline industries, research and testing laboratories, and others in the fire protection community.
- **Standards and Code of Practice:** The fire protection community could adopt or develop technical standards on the design, installation, testing, and maintenance of extinguishers and fire suppression systems both for halons and other halogenated fire extinguishing agents. Additionally, many countries have developed or adopted a Voluntary Code of Practice that is intended to focus the industry's efforts on minimizing emissions of gaseous fire protection agents.
- **Record keeping:** Record keeping can be an integral part of managing these agents from the system user to any national or commercial banks.

10. **Decommissioning, Transportation, and Destruction:** Decommissioning is the process of removing a system from service. This must be done in order to recover the agent, so it can be made available for other uses. It is important to develop procedures and ensure they are properly followed so that the agent is handled, transported, and stored in such a way that it is not emitted, and its physical property value is not degraded. Destruction of these agents is a final disposition option that should be considered **only** if they are contaminated and cannot be reclaimed to an acceptable purity.

The subject of halon emission reduction strategies was addressed at length in earlier editions of the HTOC Assessment Reports. For the 2014 Assessment Report the HTOC elected to move the contents of this chapter to Technical Note #2: *Halon Emission Reduction Strategies*, where it could be continuously updated as necessary.

Technical Note #2, Revision 3: renamed, *Halons and Other Halogenated Gaseous Fire Extinguishing Agents Emission Reduction Strategies* (2018) has been updated to include specific reference to all halogenated fire extinguishing agents. This chapter is only a summary of the latest version of HTOC Technical Note #2 which can be found on the Ozone Secretariat website at:
https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note2_2018.pdf

8 Destruction Technologies

With the worldwide end of halon production for fire protection uses at the end of 2009, and the imminent phase-out of HCFCs and phase-down of HFCs, including as fire suppressants, global inventory management and responsible disposal practices become important considerations to prevent emissions during a critical period of global environmental protection. The options for avoiding emissions of unwanted stockpiles of fire extinguishants include destruction and transformation (also referred to as conversion) to useful and more environmentally friendly chemical products. Halogenated gaseous fire extinguishants, more than some of the other ODSs and HFCs, are readily accessible for collection, storage, and disposal or reuse. Owing to the continued global demand in applications such as aviation, the HTOC has previously recommended that destruction as a final disposition option should be considered only if the halons are contaminated and cannot be reclaimed to an acceptable purity. The HTOC recommends extending that to all halogenated gaseous fire extinguishants. Approved ODS destruction technologies and facilities can be found in many countries and those are often applicable to HCFCs and HFCs.

Destruction of halons presents some unique considerations. A number of the technologies screened by the TEAP Task Force on Destruction Technologies (TFDT) satisfied the criteria for the destruction of chlorofluorocarbons (CFCs) and HCFCs but had not been tested for halon destruction. The TFDT, therefore, could not recommend such technologies for halon destruction since the presence of bromine in halons can significantly alter the process parameters. In particular, molecular bromine tends to be formed and is very difficult to remove from the exhaust gases. Technologies that are recommended for CFC and HCFC destruction, but have not been tested for halon destruction, are described as potential technologies for halon destruction. As there is nothing particularly different with the HFC fire extinguishants, much less concern with their destruction is anticipated. The one exception to this general principle is HFC-23, which was considered by the TFDT to be in a separate category from the other HFCs, as it is more thermally stable.

Based on a further evaluation of destruction technologies by the TEAP in response to Decision XXII/10, the following technologies were approved by the parties (Decision XXIII/12 and Annex, UNEP/OzL.Pro.4/15) for the destruction of halons:

- Liquid injection incineration
- Chemical reaction with hydrogen and carbon dioxide
- Rotary kiln incineration
- Argon plasma arc
- Inductively coupled radio frequency plasma
- Thermal reaction with methane

These technologies are also approved for HFC and HCFC fire extinguishants.

In early April 2018, the TEAP TFDT published its Advance Report TEAP (2018b) in response to Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances. Based on the consideration of the chemical similarity of HFCs, HCFCs, CFCs and halons and including the practice of destroying them together, the TFDT performed an assessment of the destruction technologies with a view of confirming their applicability to HFCs and reviewed other technologies for possible inclusion in the list of approved destruction technologies in relation to those controlled substances.

A summary of the recommendations was set out in Appendix 3 of the Advance Report, including several cases where technologies were recommended as “high potential” or “unable to assess”.

Taking into account the new information that was submitted post the Advance Report, a Supplementary Report was produced and submitted to the 40th Open-ended Working Group. The Supplementary Report updates the assessment of destruction technologies approved under Decision XXIII/12. The assessment criteria remain unchanged from the April 2018 TFDT report.

The subject of halon destruction was addressed at length in earlier editions of the HTOC Assessment Reports. For the 2014 Assessment Report the HTOC elected to move the contents of this chapter to Technical Note #5: *Halon Destruction*, where it could be continuously updated as necessary.

Technical Note #5, Revision 2: renamed *Destruction Technologies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents* (2108) has been updated to include destruction considerations for HCFC and HFC fire extinguishants, in addition to halons, and can be found on the Ozone Secretariat website at: https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/technical_note5_2018.pdf

8.1 References

TEAP (2018b): Report of the Technology and Economic Assessment Panel, Volume 2, Decision XXIX/4 TEAP *Task Force on Destruction Technologies for Controlled Substances*, April 2018. http://conf.montreal-protocol.org/meeting/oewg/oewg-40/presession/Background-Documents/TEAP-DecXXIX4-TF-Report-April2018.pdf

Appendix A: List of Acronyms and Abbreviations

A5	Article 5 Party
AFES	Automatic Fire Extinguishing System
APU	Auxiliary Power Unit
ARFF	Aircraft Rescue and Fire Fighting
2-BTP	Bromotrifluoropropene (2-bromo-3,3,3-trifluoroprop-1-ene)
CCHRWG	Cargo Compartment Halon Replacement Working Group
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
DWT	Deadweight Tonnage
EASA	European Aviation Safety Agency
EC	European Commission
EPA	Environmental Protection Agency
EU	European Union
EUN	Essential Use Nomination
FAA	Federal Aviation Administration
FIC	Fluoroiodocarbon
FK	Fluoroketone
FK-5-1-12	Dodecafluro-2-methyl-pentane-3-one ($CF_3CF_2C(O)CF(CF_3)_2$)
GHG	Green House Gas
GWP	Global Warming Potential
HAAPS	Halon Alternatives for Aircraft Propulsion Systems
HBFO	Hydrobromofluoro-olefin
HBr	Hydrogen Bromide
HCFC	Hydrochlorofluorocarbon
HCFC-123	2,2-Dichloro-1,1,1-trifluoroethane (CF_3CHCl_2)
HCFO	Hydrochlorofluoro-olefin
HFC	Hydrofluorocarbon
HFC-23	Trifluoromethane (CHF_3)
HFC-125	Pentafluoroethane (CF_3CHF_2)
HFC-227ea	1,1,1,2,3,3,3-Heptafluoropropane (CF_3CHFCF_3)
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane ($CF_3CH_2CF_3$)
HTOC	Halons Technical Options Committee
IG	Inert Gas
IG01	ISO 14520 Code for the inert gas argon
IG541	ISO 14520 Code for a blend of 50% nitrogen, 42% argon and 8% CO2
IG55	ISO 14520 Code for a blend of 50% nitrogen, 50% argon
IG100	ISO 15420 Code for the inert gas nitrogen
ICAO	International Civil Aviation Organisation
ICCAIA	International Coordinating Council of Aerospace Industry Associations
IGG	Inert Gas Generator
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
kg	kilogramme
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MPS	Minimum Performance Standard
OBIGGS	On-board Inert Gas Generating System

ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEM	Original Equipment Manufacturer
PFC	Perfluorocarbon
PGA	Pyrotechnically Generated Aerosol
TEAP	Technology and Economic Assessment Panel
TFDT	Task Force on Destruction Technologies
UK	United Kingdom
UNEP	United Nations Environment Programme
US	United States

Appendix B: Definitions

Article 5 (A5) Parties: Parties to the Montreal Protocol whose annual calculated level of consumption is less than 0.3 kg per capita of the controlled substances in Annex A, and less than 0.2 kg per capita of the controlled substances in Annex B, on the date of the entry into force of the Montreal Protocol, or any time thereafter. These countries were permitted a ten year "grace period" compared to the Phase-out schedule in the Montreal Protocol for developed countries. The parties in this category are known as "countries operating under Article 5 of the Protocol”.

Atmospheric Lifetime: The total atmospheric lifetime or turnover time of a trace gas is the time required to remove or chemically transform approximately 63% (i.e., $1-1/e$) of its global atmospheric burden as a result of either being converted to another chemical compound or being taken out of the atmosphere by a sink.

Bank: A bank is all the fire extinguishing agent contained in fire extinguishing cylinders and storage cylinders within any organisation, country, or region.

Bank Management: A method of managing a supply of banked fire extinguishing agents. Bank management consists of keeping track of agent quantities at each stage: initial filling, installation, recycling, and storage. A major goal of a bank is to re-deploy agents from decommissioned systems. Banks can be managed by a clearinghouse, i.e., an office that facilitates contact between owners and buyers.

Clean Agent: An agent that is a gas or vaporizing liquid that leaves no residue after discharge.

Commission Regulation: *European Commission* (*EC*) is an institution of the *European Union*, responsible for proposing *legislation*, implementing decisions, upholding the *EU* treaties. A Commission regulation becomes law to all member states simultaneously

Consumption: Production plus imports minus exports minus destruction of controlled substances.

Controlled Substance: Any substance that is subject to control measures under the Montreal Protocol. Specifically, it refers to the ozone depleting substances listed in Annexes A, B, C or E or the global warming substances (HFCs) listed in Annex F of the Protocol, whether alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance.

Countries with Economies in Transition (CEITs): States of the former Soviet Union, and Central and Eastern Europe that have been undergoing a process of major structural, economic and social change, which has resulted in severe financial and administrative difficulties for both government and industry. These changes have affected most areas of community life, as well as implementation of international agreements such as the phase out of ODS in accordance with the Montreal Protocol. CEITs include both A5 and non-A5 countries.

Country Programme (CP) A national strategy prepared by an A5 country to implement the Montreal Protocol and phase out ODS. The Country Programme establishes a baseline survey on the use of the controlled substances in the country and draws up policy, strategies and a phase out plan for their replacement and control. It also identifies investment and non-investment projects for funding under the Multilateral Fund.

Decision: A documented decision or action taken by the parties to the Montreal Protocol on Substances that Deplete the Ozone Layer.

Decommissioning: Decommissioning is the physical process of removing a fire extinguishing system containing a substance regulated under the Montreal Protocol from service. This must be done to recover the substance so that it can be made available for other uses. Effective decommissioning requires knowledge of good practices related to technical procedures and safety measures.

Essential Use: In their Decision IV/25, the parties to the Montreal Protocol define an ODS use as "essential" only if: "(i) It is necessary for the health, safety or is critical for the functioning of society (encompassing cultural and intellectual aspects) and (ii) There are no available technically and economically feasible alternatives or substitutes that are acceptable from the standpoint of environment and health". Production and consumption of an ODS for essential uses is permitted only if: "(i) All economically feasible steps have been taken to minimise the essential use and any associated emission of the controlled substance; and (ii) The controlled substance is not available in sufficient quantity and quality from existing stocks of banked or recycled controlled substances, also bearing in mind the developing countries' need for controlled substances".

Essential Use Nomination (EUN): A party's request to obtain an Essential Use. Decision IV/25 of the 4^{th} Meeting of the parties to the Montreal Protocol set the criteria and process for assessment of essential use nominations.

Feedstock: A controlled substance that undergoes transformation in a process in which it is converted from its original composition except for insignificant trace emissions as allowed by Decision IV/12.

General Assembly: The Assembly is an Organization's sovereign body.

Global Warming Potential (GWP): Global warming potential is defined as a cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to CO_2. The TEAP has proposed the following classification: High >1000, Moderate 300 – 1000, and Low < 300, which has been used in this Assessment report.

Halocarbons: Halocarbons are compounds derived from hydrocarbons, where one or several of the hydrogen atoms are substituted with chlorine (Cl), fluorine (F), bromine (Br), and/or iodine (I). The ability of halocarbons to deplete ozone in the stratosphere is due to their content of chlorine, bromine, and/or iodine and their chemical stability. CFCs, HCFCs and HFCs are examples of halocarbons.

Halocarbon Fire Extinguishing Agents: Halogenated hydrocarbon chemicals, including HCFCs, HFCs, PFCs, and FICs, that are used for firefighting applications. Each of these chemicals is stored as a liquefied compressed gas at room temperature, is electrically non-conductive, and leaves no residue upon vaporisation.

Halon: The halon terminology system provides a convenient means to reference halogenated hydrocarbon fire extinguishants. Halogenated hydrocarbons are acyclic saturated hydrocarbons in which one or more of the hydrogen atoms have been replaced by atoms from the halogen series (that is, fluorine, chlorine, bromine, and iodine). By definition, the first digit of the halon numbering system represents the number of carbon atoms in the compound molecule; the second digit, the number of fluorine atoms; the third digit, the number of chlorine atoms; the fourth digit, the number of bromine atoms; and the fifth digit, the number of iodine atoms. Trailing zeros are not expressed. Unaccounted for valence requirements are assumed to be hydrogen atoms. For example, bromochlorodifluoromethane – CF_2BrCl - halon 1211. Halons exhibit exceptional firefighting effectiveness. They are used as fire extinguishing agents and as explosion suppressants.

Halon 1211: A halogenated hydrocarbon, bromochlorodifluoromethane (CF_2BrCl). It is also known as "BCF". Halon 1211 is a fire extinguishing agent that can be discharged in a liquid stream. It is primarily used in portable fire extinguishers. Halon1211 is an ozone depleting substance with an ODP of 3.0.

Halon 1301: A halogenated hydrocarbon, bromotrifluoromethane (CF_3Br). It is also known as "BTM". Halon 1301 is a fire extinguishing agent that can be discharged rapidly, mixing with air to create an extinguishing application. It is primarily used in total flooding fire protection systems. Halon 1301 is an ozone depleting substance with an ODP of 10.

Halon 2402: A halogenated hydrocarbon, dibromotetrafluoroethane ($C_2F_4Br_2$). Halon 2402 is a fire extinguishing agent that can be discharged in a liquid stream. It is primarily used in portable fire extinguishers or hand hose line equipment, and fire protection for specialized applications. Halon 2402 is an ozone depleting substance with an ODP of 6.0.

Halons Technical Options Committee (HTOC): An international body of experts established under the Technology and Economic Assessment Panel (TEAP) to regularly examine and report to the parties on the technical options and progress in phasing out halon and other halocarbon fire extinguishants (see TEAP).

Hydrochlorofluorocarbons (HCFCs): A family of chemicals related to CFCs that contains hydrogen, chlorine, fluorine, and carbon atoms. HCFCs are partly halogenated and have much lower ODP than the CFCs.

Hydrofluorocarbons (HFCs): A family of chemicals related to CFCs that contains one or more carbon atoms surrounded by fluorine and hydrogen atoms. Since no chlorine or bromine is present, HFCs do not deplete the ozone layer.

Inert Gases: Fire extinguishing agents containing one or more of the following gases: argon, carbon dioxide, and nitrogen. Inert gases have zero ODP and extinguish fires by reducing oxygen concentrations in the confined space thereby "starving" the fire.

Inert Gas Generator: A firefighting technology that uses a solid material that oxidises rapidly, producing large quantities of carbon dioxide and/or nitrogen. The use of this technology to date has been limited to specialized applications such as engine nacelles and dry bays on military aircraft.

Member States: A *member state* is a state that is a member of an international organization or of a federation or confederation.

Montreal Protocol (MP): An international agreement limiting the production and consumption of chemicals that deplete the stratospheric ozone layer, including CFCs, halons, HCFCs, HBFCs, methyl bromide and others. Signed in 1987, the Protocol commits parties to take measures to protect the ozone layer by freezing, reducing or ending production and consumption of controlled substances. This agreement is the protocol to the Vienna convention.

Multilateral Fund (MLF): Part of the financial mechanism under the Montreal Protocol. The Multilateral Fund for Implementation of the Montreal Protocol has been established by the parties to provide financial and technical assistance to A5 parties.

National Ozone Officer (NOO): NOOs lead the A5-party's NOU. Typically they have a dedicated team that includes an Assistant Ozone Officer and other staff. The NOO is the focal points for implementation issues related to the Montreal Protocol.

National Ozone Unit (NOU): The government unit in an A5 Party that is responsible for managing the national ODS phase-out strategy as specified in the Country Programme. NOUs are responsible for, inter alia, fulfilling data reporting obligations under the Montreal Protocol.

Non-Article 5 Parties: Parties to the Montreal Protocol that do not operate under Article 5 of the MP.

Ozone Depleting Substance (ODS): Any substance with an ODP greater than 0 that can deplete the stratospheric ozone layer. Most ODS are controlled under the Montreal Protocol and its amendments, and they include CFCs, HCFCs, halons and methyl bromide.

Ozone Depletion Potential (ODP): A relative index indicating the extent to which a chemical product destroys the stratospheric ozone layer. The reference level of 1 is the potential of CFC-11 to cause ozone depletion. If a product has an ozone depletion potential of 0.5, a given mass of emissions would, in time, deplete half the ozone that the same mass of emissions of CFC-11 would deplete. The ozone depletion potentials are calculated from mathematical models that take into account factors such as the stability of the product, the rate of diffusion, the quantity of depleting atoms per molecule, and the effect of ultraviolet light and other radiation on the molecules. The substances implicated generally contain chlorine, bromine and/or iodine.

Ozone Layer: An area of the stratosphere, approximately 15 to 60 kilometres (9 to 38 miles) above the earth, where ozone is found as a trace gas at higher concentrations than other parts of the atmosphere. This relatively high concentration of ozone filters most ultraviolet radiation, preventing it from reaching the earth.

Ozone Secretariat: The Secretariat to the Montreal Protocol and Vienna Convention, provided by UNEP and based in Nairobi, Kenya.

Party: A country that has ratified an international legal instrument (e.g., a protocol or an amendment to a protocol), indicating that it agrees to be bound by the rules set out therein. Parties to the Montreal Protocol are countries that have ratified the Protocol.

Perfluorocarbons (PFCs): A group of synthetically produced compounds in which the hydrogen atoms of a hydrocarbon are replaced with fluorine atoms. The compounds are characterized by extreme stability, non-flammability, low toxicity, zero ozone depleting potential, and high global warming potential.

Phase Down: The reduction of production and consumption of the HFCs following the Kigali Amendment to the Montreal Protocol.

Phase-out: The ending of all production and consumption of a chemical controlled under the Montreal Protocol.

Pre-Action Sprinkler: A sprinkler system whose pipes are normally dry and are charged with the extinguishing agent (e.g., water) only when the fire detection system actuates.

Production: The amount of controlled substances produced, minus the amount destroyed by technologies to be approved by the parties and minus the amount entirely used as feedstock in the manufacture of other chemicals. The amount recycled and reused is not to be considered as “production”.

Reclamation: To reprocess a fire extinguishing agent to a purity specified in applicable standards and to use a certified laboratory to verify this purity using the analytical methodology as prescribed in those standards. Reclamation is the preferred method to achieve the highest level of purity. Reclamation requires specialized equipment usually not available at a servicing company.

Recovery: To remove the fire extinguishing agent in any condition from an extinguisher or extinguishing system cylinder and store it in an external container without necessarily testing or processing it in any way.

Recycling: To extract the fire extinguishing agent from an extinguisher or system storage container and clean the agent for reuse without necessarily meeting all of the requirements for reclamation. In general, recycled agent has its super-pressurising nitrogen removed in addition to being processed to only reduce moisture and particulate matter.

Total Flooding System: A fire extinguishing system that protects a space by developing the required concentration of extinguishing agent throughout the protected volume.

Type Certificate: A type certificate is issued to signify the airworthiness of an *aircraft* manufacturing design or "type". The certificate reflects a determination made by the regulating body that the aircraft is manufactured according to an approved design and that the design ensures compliance with airworthiness requirements.

Water Mist: A firefighting agent that uses relatively small water droplet sprays to extinguish fires. These systems generate much smaller droplets than are produced by traditional water-spray systems or conventional sprinklers.

Appendix C: Historical Production, Emissions and Bank Values from 1963 – 2018 for Halon 1301

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
ANNUAL PRODUCTION												
North America, Western Europe and Japan	10	20	30	40	50	60	100	200	550	839	1,292	1,461
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5(1)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION	10	20	30	40	50	60	100	200	550	839	1,292	1,461
ANNUAL PRODUCTION ALLOCATION												
North America	3	6	9	12	15	18	30	60	165	252	388	438
Western Europe and Australia	3	5	8	10	13	15	25	50	138	210	323	365
Japan	2	4	6	8	10	12	20	40	110	168	258	292
CEIT	1	1	2	2	3	3	5	10	28	42	65	73
Article 5(1)	2	4	6	8	10	12	20	40	110	168	258	292
TOTAL ANNUAL PRODUCTION ALLOCATION	10	20	30	40	50	60	100	200	550	839	1,292	1,461
ANNUAL EMISSIONS												
North America	1	2	3	4	5	7	10	19	47	77	123	156
Western Europe and Australia	1	2	3	4	5	7	11	20	48	79	127	164
Japan	0	1	1	2	3	3	5	9	21	36	59	78
CEIT	0	0	1	1	1	1	2	4	10	16	25	32
Article 5(1)	1	2	2	3	4	6	9	16	38	63	102	131
TOTAL ANNUAL EMISSIONS	4	7	9	14	19	24	37	67	165	272	436	561
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	10	30	60	100	150	210	310	510	1,060	1,899	3,191	4,652
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5(1)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	10	30	60	100	150	210	310	510	1,060	1,899	3,191	4,652
Year	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**

CUMMULATIVE PRODUCTION ALLOCATION												
North America	3	9	18	30	45	63	93	153	318	570	957	1,396
Western Europe and Australia	3	8	15	25	38	53	78	128	265	475	798	1,163
Japan	2	6	12	20	30	42	62	102	212	380	638	930
CEIT	1	2	3	5	8	11	16	26	53	95	160	233
Article 5(1)	2	6	12	20	30	42	62	102	212	380	638	930
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	10	30	60	100	150	210	310	510	1,060	1,899	3,191	4,652
CUMMULATIVE EMISSIONS												
North America	1	3	6	10	15	22	32	51	98	176	299	454
Western Europe and Australia	1	3	6	10	15	22	33	53	100	180	307	471
Japan	0	1	2	4	7	10	15	24	46	82	141	219
CEIT	0	1	1	2	3	4	7	10	20	36	61	93
Article 5(1)	1	3	5	8	12	18	26	42	80	144	246	377
TOTAL CUMMULATIVE EMISSIONS	4	11	20	33	52	76	113	180	345	617	1,054	1,614
INVENTORY (BANK)												
North America	2	6	12	20	30	41	61	102	220	394	658	941
Western Europe and Australia	1	4	9	15	22	30	45	75	165	295	491	692
Japan	2	5	10	16	23	32	47	78	166	298	497	712
CEIT	0	1	2	3	4	6	9	15	33	59	99	139
Article 5(1)	1	3	7	12	18	24	36	60	132	236	392	554
GLOBAL INVENTORY (BANK)	6	19	40	67	98	134	197	330	715	1,282	2,137	3,038

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
ANNUAL PRODUCTION										
North America, Western Europe and Japan	2,019	3,172	3,550	4,015	4,718	4,877	5,694	7,565	7,386	8,692
CEIT	0	0	0	0	0	0	0	0	0	30
Article 5(1)	0	0	0	0	0	0	0	0	0	70
TOTAL ANNUAL PRODUCTION	2,019	3,172	3,550	4,015	4,718	4,877	5,694	7,565	7,386	8,792
ANNUAL PRODUCTION ALLOCATION										
North America	606	952	1,065	1,205	1,415	1,463	1,708	2,270	2,216	2,608
Western Europe and Australia	505	793	888	1,004	1,180	1,219	1,424	1,891	1,847	2,173
Japan	404	634	710	803	944	975	1,139	1,513	1,477	1,738
CEIT	101	159	178	201	236	244	285	378	369	465
Article 5(1)	404	634	710	803	944	975	1,139	1,513	1,477	1,808
TOTAL ANNUAL PRODUCTION ALLOCATION	2,019	3,172	3,550	4,015	4,718	4,877	5,694	7,565	7,386	8,792
ANNUAL EMISSIONS										
North America	217	330	378	443	520	493	512	649	736	869
Western Europe and Australia	228	312	372	429	495	567	672	848	926	1,083
Japan	109	148	179	209	260	280	335	420	469	550
CEIT	45	68	76	88	102	109	121	156	171	207
Article 5(1)	182	275	285	357	437	495	584	733	801	951
TOTAL ANNUAL EMISSIONS	782	1,133	1,289	1,527	1,814	1,944	2,223	2,807	3,102	3,661
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	6,671	9,843	13,393	17,408	22,126	27,003	32,697	40,262	47,648	56,340
CEIT	0	0	0	0	0	0	0	0	0	30
Article 5(1)	0	0	0	0	0	0	0	0	0	70
TOTAL CUMMULATIVE PRODUCTION	6,671	9,843	13,393	17,408	22,126	27,003	32,697	40,262	47,648	56,440

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
CUMMULATIVE PRODUCTION ALLOCATION										
North America	2,001	2,953	4,018	5,222	6,638	8,101	9,809	12,079	14,294	16,902
Western Europe and Australia	1,668	2,461	3,348	4,352	5,532	6,751	8,174	10,066	11,912	14,085
Japan	1,334	1,969	2,679	3,482	4,425	5,401	6,539	8,052	9,530	11,268
CEIT	334	492	670	870	1,106	1,350	1,635	2,013	2,382	2,847
Article 5(1)	1,334	1,969	2,679	3,482	4,425	5,401	6,539	8,052	9,530	11,338
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	6,671	9,843	13,393	17,408	22,126	27,003	32,697	40,262	47,648	56,440
CUMMULATIVE EMISSIONS										
North America	672	1,002	1,380	1,823	2,343	2,836	3,347	3,996	4,732	5,600
Western Europe and Australia	699	1,011	1,382	1,811	2,306	2,874	3,546	4,394	5,320	6,404
Japan	328	476	655	865	1,124	1,404	1,739	2,159	2,628	3,178
CEIT	139	207	283	371	474	583	704	860	1,031	1,238
Article 5(1)	559	834	1,119	1,476	1,913	2,408	2,991	3,724	4,525	5,476
TOTAL CUMMULATIVE EMISSIONS	2,396	3,530	4,819	6,346	8,160	10,103	12,327	15,133	18,236	21,896
INVENTORY (BANK)										
North America	1,329	1,951	2,638	3,400	4,295	5,265	6,462	8,082	9,563	11,302
Western Europe and Australia	969	1,450	1,966	2,541	3,225	3,877	4,628	5,671	6,592	7,681
Japan	1,006	1,492	2,023	2,617	3,301	3,997	4,801	5,894	6,902	8,090
CEIT	195	285	387	499	633	767	931	1,153	1,352	1,609
Article 5(1)	775	1,135	1,560	2,005	2,512	2,993	3,548	4,328	5,005	5,862
GLOBAL INVENTORY (BANK)	4,275	6,313	8,574	11,062	13,966	16,900	20,370	25,129	29,412	34,544

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
ANNUAL PRODUCTION										
North America, Western Europe and Japan	9,781	11,076	11,604	12,551	11,152	9,115	7,326	4,884	2,442	0
CEIT	30	30	35	30	30	1,100	50	50	0	0
Article 5(1)	94	127	193	214	227	360	572	511	738	700
TOTAL ANNUAL PRODUCTION	9,905	11,233	11,832	12,795	11,409	10,575	7,948	5,445	3,180	700
ANNUAL PRODUCTION ALLOCATION										
North America	2,934	3,323	3,481	3,765	3,346	2,735	2,198	1,465	733	0
Western Europe and Australia	2,445	2,769	2,901	3,138	2,788	2,279	1,832	1,221	611	0
Japan	1,956	2,215	2,321	2,510	2,230	1,823	1,465	977	488	0
CEIT	519	584	615	658	588	1,556	416	294	122	0
Article 5(1)	2,051	2,343	2,514	2,724	2,457	2,183	2,037	1,488	1,227	700
TOTAL ANNUAL PRODUCTION ALLOCATION	9,905	11,233	11,832	12,795	11,409	10,575	7,948	5,445	3,180	700
ANNUAL EMISSIONS										
North America	890	1,037	1,090	1,133	1,234	1,295	1,327	1,319	1,005	842
Western Europe and Australia	1,089	1,118	987	1,141	1,248	1,309	1,336	1,316	875	564
Japan	589	684	771	867	922	946	954	739	289	108
CEIT	239	274	305	337	329	570	379	309	254	189
Article 5(1)	1,001	1,055	1,091	1,255	1,369	1,445	1,501	1,456	1,421	1,352
TOTAL ANNUAL EMISSIONS	3,807	4,168	4,244	4,734	5,101	5,564	5,497	5,140	3,844	3,056
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	66,121	77,197	88,801	101,352	112,504	121,619	128,945	133,829	136,271	136,271
CEIT	60	90	125	155	185	1,285	1,335	1,385	1,385	1,385
Article 5(1)	164	292	485	699	926	1,286	1,857	2,368	3,107	3,807
TOTAL CUMMULATIVE PRODUCTION	66,345	77,579	89,411	102,206	113,615	124,190	132,137	137,582	140,763	141,463

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
CUMMULATIVE PRODUCTION ALLOCATION										
North America	19,836	23,159	26,640	30,406	33,751	36,486	38,684	40,149	40,881	40,881
Western Europe and Australia	16,530	19,299	22,200	25,338	28,126	30,405	32,236	33,457	34,068	34,068
Japan	13,224	15,439	17,760	20,270	22,501	24,324	25,789	26,766	27,254	27,254
CEIT	3,366	3,950	4,565	5,223	5,810	7,366	7,782	8,076	8,199	8,199
Article 5(1)	13,389	15,731	18,245	20,969	23,427	25,609	27,646	29,134	30,361	31,061
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	66,345	77,579	89,411	102,206	113,615	124,190	132,137	137,582	140,763	141,463
CUMMULATIVE EMISSIONS										
North America	6,490	7,527	8,617	9,750	10,985	12,279	13,607	14,926	15,931	16,773
Western Europe and Australia	7,492	8,610	9,597	10,739	11,986	13,295	14,631	15,947	16,821	17,386
Japan	3,767	4,451	5,222	6,090	7,011	7,958	8,912	9,651	9,941	10,049
CEIT	1,477	1,751	2,056	2,393	2,722	3,291	3,670	3,979	4,234	4,423
Article 5(1)	6,477	7,532	8,623	9,878	11,246	12,691	14,192	15,648	17,068	18,420
TOTAL CUMMULATIVE EMISSIONS	25,704	29,872	34,115	38,849	43,950	49,514	55,011	60,151	63,995	67,051
INVENTORY (BANK)										
North America	13,346	15,632	18,023	20,655	22,767	24,207	25,077	25,223	24,951	24,109
Western Europe and Australia	9,038	10,689	12,603	14,599	16,140	17,110	17,606	17,511	17,246	16,682
Japan	9,457	10,988	12,538	14,181	15,490	16,366	16,877	17,114	17,313	17,205
CEIT	1,889	2,199	2,509	2,829	3,089	4,075	4,112	4,097	3,965	3,776
Article 5(1)	6,911	8,199	9,622	11,091	12,180	12,918	13,455	13,487	13,293	12,641
GLOBAL INVENTORY (BANK)	40,642	47,707	55,295	63,356	69,665	74,676	77,127	77,432	76,768	74,412

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
ANNUAL PRODUCTION										
North America, Western Europe and Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	750	800	750	535	475	475	590	650	650	711
TOTAL ANNUAL PRODUCTION	750	800	746	531	446	425	568	632	408	415
ANNUAL PRODUCTION ALLOCATION										
North America	52	26	84	66	140	241	178	82	84	104
Western Europe and Australia	(52)	(26)	(89)	(71)	(169)	(291)	(200)	(100)	(326)	(400)
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	750	800	750	535	475	475	590	650	650	711
TOTAL ANNUAL PRODUCTION ALLOCATION	750	800	746	531	446	425	568	632	408	415
ANNUAL EMISSIONS										
North America	814	788	763	740	718	699	683	665	646	627
Western Europe and Australia	542	523	504	485	466	444	421	462	551	356
Japan	51	51	25	25	25	25	25	25	25	25
CEIT	179	153	146	140	134	128	123	118	113	108
Article 5(1)	1,291	1,242	1,195	1,137	1,074	1,015	970	936	908	887
TOTAL ANNUAL EMISSIONS	2,878	2,757	2,634	2,527	2,417	2,312	2,222	2,207	2,243	2,003
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	136,271	136,271	136,266	136,262	136,233	136,183	136,161	136,142	135,900	135,604
CEIT	1,385	1,385	1,385	1,385	1,385	1,385	1,385	1,385	1,385	1,385
Article 5(1)	4,557	5,357	6,107	6,642	7,117	7,592	8,182	8,832	9,482	10,193
TOTAL CUMMULATIVE PRODUCTION	142,213	143,013	143,758	144,289	144,735	145,160	145,728	146,359	146,767	147,182

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CUMMULATIVE PRODUCTION ALLOCATION										
North America	40,933	40,959	41,044	41,110	41,250	41,491	41,670	41,752	41,835	41,939
Western Europe and Australia	34,016	33,990	33,901	33,830	33,661	33,370	33,169	33,069	32,743	32,343
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,199	8,199	8,199	8,199	8,199	8,199	8,199	8,199	8,199	8,199
Article 5(1)	31,811	32,611	33,361	33,896	34,371	34,846	35,436	36,086	36,736	37,447
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	142,213	143,013	143,758	144,289	144,735	145,160	145,728	146,359	146,767	147,182
CUMMULATIVE EMISSIONS										
North America	17,587	18,375	19,138	19,878	20,596	21,296	21,979	22,644	23,290	23,917
Western Europe and Australia	17,927	18,450	18,954	19,439	19,905	20,349	20,771	21,233	21,784	22,140
Japan	10,100	10,151	10,177	10,202	10,227	10,252	10,278	10,303	10,328	10,353
CEIT	4,602	4,755	4,902	5,042	5,176	5,305	5,428	5,545	5,658	5,766
Article 5(1)	19,712	20,953	22,148	23,285	24,359	25,373	26,343	27,279	28,187	29,074
TOTAL CUMMULATIVE EMISSIONS	69,928	72,685	75,319	77,846	80,263	82,575	84,798	87,005	89,248	91,251
INVENTORY (BANK)										
North America	23,346	22,584	21,905	21,232	20,654	20,196	19,691	19,107	18,545	18,022
Western Europe and Australia	16,088	15,540	14,947	14,391	13,755	13,020	12,399	11,836	10,959	10,203
Japan	17,154	17,103	17,078	17,052	17,027	17,002	16,976	16,951	16,926	16,901
CEIT	3,596	3,443	3,297	3,157	3,022	2,894	2,771	2,653	2,541	2,433
Article 5(1)	12,099	11,658	11,213	10,611	10,012	9,473	9,093	8,807	8,549	8,373
GLOBAL INVENTORY (BANK)	72,284	70,328	68,439	66,443	64,472	62,584	60,930	59,355	57,519	55,931

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
ANNUAL PRODUCTION										
North America, Western Europe and Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	650	200	200	200	200	0	0	0	0	0
TOTAL ANNUAL PRODUCTION	620	167	183	152	164	(12)	(11)	(9)	(3)	(12)
ANNUAL PRODUCTION ALLOCATION										
North America	187	76	308	96	80	107	24	49	39	16
Western Europe and Australia	(187)	(109)	(325)	(144)	(116)	(119)	(35)	(58)	(42)	(28)
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	(30)	0	0	0	0	0	0	0	0	0
Article 5(1)	650	200	200	200	200	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	620	167	183	152	164	(12)	(11)	(9)	(3)	(12)
ANNUAL EMISSIONS										
North America	610	595	580	568	552	536	521	505	489	474
Western Europe and Australia	284	271	259	244	234	224	215	256	237	228
Japan	25	25	25	25	25	25	25	25	25	25
CEIT	103	98	94	90	86	82	79	75	72	69
Article 5(1)	866	814	754	700	651	593	535	482	435	392
TOTAL ANNUAL EMISSIONS	1,887	1,803	1,711	1,627	1,547	1,460	1,374	1,343	1,258	1,187
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	135,604	135,571	135,555	135,507	135,470	135,458	135,447	135,439	135,436	135,423
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5(1)	10,843	11,043	11,243	11,443	11,643	11,643	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	147,802	147,969	148,152	148,305	148,468	148,456	148,445	148,437	148,433	148,421

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western Europe and Australia	32,156	32,047	31,722	31,579	31,463	31,344	31,309	31,251	31,209	31,181
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169	8,169
Article 5(1)	38,097	38,297	38,497	38,697	38,897	38,897	38,897	38,897	38,897	38,897
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	147,802	147,969	148,152	148,305	148,468	148,456	148,445	148,437	148,433	148,421
CUMMULATIVE EMISSIONS										
North America	24,527	25,122	25,701	26,270	26,822	27,358	27,879	28,384	28,873	29,347
Western Europe and Australia	22,424	22,695	22,954	23,198	23,431	23,655	23,870	24,126	24,363	24,591
Japan	10,378	10,403	10,428	10,453	10,478	10,503	10,528	10,553	10,578	10,603
CEIT	5,869	5,967	6,060	6,150	6,236	6,318	6,396	6,472	6,544	6,613
Article 5(1)	29,940	30,754	31,508	32,208	32,858	33,451	33,986	34,468	34,903	35,296
TOTAL CUMMULATIVE EMISSIONS	93,138	94,941	96,652	98,279	99,826	101,286	102,660	104,003	105,261	106,448
INVENTORY (BANK)										
North America	17,599	17,080	16,809	16,336	15,864	15,434	14,937	14,482	14,032	13,574
Western Europe and Australia	9,732	9,352	8,769	8,381	8,031	7,689	7,439	7,125	6,846	6,590
Japan	16,876	16,851	16,826	16,801	16,776	16,751	16,726	16,701	16,676	16,652
CEIT	2,300	2,202	2,108	2,019	1,933	1,851	1,772	1,697	1,625	1,556
Article 5(1)	8,157	7,543	6,989	6,489	6,038	5,446	4,911	4,429	3,994	3,601
GLOBAL INVENTORY (BANK)	54,664	53,028	51,500	50,026	48,643	47,170	45,785	44,434	43,172	41,973

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**2015**	**2016**	**2017**	**2018**
ANNUAL PRODUCTION				
North America, Western Europe and Japan	0	0	0	0
CEIT	0	0	0	0
Article 5(1)	0	0	0	0
TOTAL ANNUAL PRODUCTION	(28)	(30)	0	0
ANNUAL PRODUCTION ALLOCATION				
North America	35	35	8	0
Western Europe and Australia	(63)	(65)	(8)	0
Japan	0	0	0	0
CEIT	0	0	0	0
Article 5(1)	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	(28)	(30)	0	0
ANNUAL EMISSIONS				
North America	458	444	430	416
Western Europe and Australia	219	209	201	194
Japan	25	25	25	25
CEIT	66	63	61	58
Article 5(1)	354	319	288	259
TOTAL ANNUAL EMISSIONS	1,122	1,060	1,004	952
CUMMULATIVE PRODUCTION				
North America, Western Europe and Japan	135,395	135,365	135,365	135,365
CEIT	1,355	1,355	1,355	1,355
Article 5(1)	11,643	11,643	11,643	11,643
TOTAL CUMMULATIVE PRODUCTION	148,393	148,362	148,362	148,362

Year	**2015**	**2016**	**2017**	**2018**
North America	42,956	42,991	42,999	42,999
Western Europe and Australia	31,117	31,052	31,044	31,044
Japan	27,254	27,254	27,254	27,254
CEIT	8,169	8,169	8,169	8,169
Article 5(1)	38,897	38,897	38,897	38,897
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148,393	148,363	148,363	148,363
CUMMULATIVE EMISSIONS				
North America	29,805	30,250	30,680	31,095
Western Europe and Australia	24,809	25,018	25,219	25,413
Japan	10,627	10,652	10,677	10,701
CEIT	6,679	6,742	6,803	6,861
Article 5(1)	35,649	35,968	36,256	36,515
TOTAL CUMMULATIVE EMISSIONS	107,570	108,630	109,634	110,586
INVENTORY (BANK)				
North America	13,151	12,741	12,319	11,904
Western Europe and Australia	6,308	6,033	5,824	5,630
Japan	16,627	16,602	16,578	16,553
CEIT	1,490	1,426	1,366	1,308
Article 5(1)	3,248	2,929	2,641	2,382
GLOBAL INVENTORY (BANK)	40,823	39,732	38,728	37,776

Appendix D: Historical Production, Emissions and Bank Values from 1963 – 2018 for Halon 1211

Halon 1211 Summary
(All quantities are metric tonnes)

YEAR	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	50	100	200	300	500	700	900	1,260	1,700	2,200	2,750	3,300
CEIT Production	0	0	0	0	0	0	0	0	0	0	0	0
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0	0	0
Total Production	50	100	200	300	500	700	900	1,260	1,700	2,200	2,750	3,300
ANNUAL PRODUCTION ALLOCATION												
North America	15	30	60	90	150	210	270	378	510	660	825	990
Western Europe and Australia	22	44	88	132	220	308	396	554	748	968	1,210	1,452
Japan	1	1	2	3	5	7	9	13	17	22	28	33
CEIT	3	5	10	15	25	35	45	63	85	110	138	165
Article 5(1)	10	20	40	60	100	140	180	252	340	440	550	660
TOTAL ANNUAL PRODUCTION ALLOCATION	50	100	200	300	500	700	900	1,260	1,700	2,200	2,750	3,300
ANNUAL EMISSIONS												
North America	3	8	17	30	52	80	114	162	224	302	395	500
Western Europe and Australia	6	15	32	55	94	143	200	282	389	520	676	849
Japan	0	0	1	1	2	3	4	6	9	12	15	19
CEIT	0	1	2	4	7	11	16	23	32	43	57	73
Article 5(1)	2	6	13	22	38	58	81	115	158	213	277	350
TOTAL ANNUAL EMISSIONS	11	30	66	113	193	295	416	587	812	1,090	1,420	1,791
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	50	150	350	650	1,150	1,850	2,750	4,010	5,710	7,910	10,660	13,960
CEIT	0	0	0	0	0	0	0	0	0	0	0	0
Article 5(1)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	50	150	350	650	1,150	1,850	2,750	4,010	5,710	7,910	10,660	13,960

YEAR	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	15	45	105	195	345	555	825	1,203	1,713	2,373	3,198	4,188
Western Europe and Australia	22	66	154	286	506	814	1,210	1,764	2,512	3,480	4,690	6,142
Japan	1	2	4	7	12	19	28	40	57	79	107	140
CEIT	3	8	18	33	58	93	138	201	286	396	533	698
Article 5(1)	10	30	70	130	230	370	550	802	1,142	1,582	2,132	2,792
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	50	150	350	650	1,150	1,850	2,750	4,010	5,710	7,910	10,660	13,960
CUMMULATIVE EMISSIONS												
North America	3	11	28	58	110	191	305	466	690	992	1,387	1,888
Western Europe and Australia	6	21	53	109	203	346	546	828	1,217	1,738	2,414	3,263
Japan	0	0	1	2	4	8	12	18	27	38	53	72
CEIT	0	1	4	8	15	26	42	65	97	141	197	270
Article 5(1)	2	8	21	43	80	138	219	333	492	704	982	1,332
TOTAL CUMMULATIVE EMISSIONS	11	41	107	220	413	709	1,124	1,712	2,523	3,613	5,033	6,825
INVENTORY												
North America	12	34	77	137	235	364	520	737	1,023	1,381	1,811	2,300
Western Europe and Australia	16	45	101	177	303	468	664	936	1,295	1,743	2,277	2,880
Japan	0	1	2	4	7	11	16	22	30	41	53	67
CEIT	2	6	14	25	42	66	95	135	188	255	336	428
Article 5	8	22	49	87	150	232	331	469	650	878	1,150	1,460
TOTAL INVENTORY	39	109	243	430	737	1,141	1,626	2,298	3,187	4,297	5,627	7,135

Halon 1211 Summary
(All quantities are metric tonnes)

YEAR	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	3,800	4,356	5,000	5,650	6,280	6,910	6,689	7,485	8,259	10,408
CEIT Production	0	0	0	0	0	0	0	0	0	30
Article 5(1) Production	0	0	0	210	266	336	425	538	680	1,061
Total Production	3,800	4,356	5,000	5,860	6,546	7,246	7,114	8,023	8,939	11,499
ANNUAL PRODUCTION ALLOCATION										
North America	1,140	1,307	1,500	1,695	1,884	2,073	2,007	2,246	2,478	3,122
Western Europe and Australia	1,672	1,917	2,200	2,486	2,763	3,040	2,943	3,293	3,634	4,580
Japan	38	44	50	57	63	69	67	75	83	104
CEIT	190	218	250	283	314	346	334	374	413	550
Article 5(1)	760	871	1,000	1,340	1,522	1,718	1,763	2,035	2,332	3,142
TOTAL ANNUAL PRODUCTION ALLOCATION	3,800	4,356	5,000	5,860	6,546	7,246	7,114	8,023	8,939	11,499
ANNUAL EMISSIONS										
North America	613	736	871	1,017	1,170	1,139	959	1,119	1,272	1,498
Western Europe and Australia	1,031	1,227	1,443	1,673	1,913	1,939	1,608	1,899	2,154	2,554
Japan	23	27	32	37	43	36	41	46	52	61
CEIT	90	108	129	151	175	199	219	242	266	308
Article 5(1)	428	511	604	749	895	1,050	1,179	1,343	1,532	1,853
TOTAL ANNUAL EMISSIONS	2,184	2,609	3,079	3,628	4,195	4,363	4,005	4,648	5,276	6,273
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	17,760	22,116	27,116	32,766	39,046	45,956	52,645	60,130	68,389	78,797
CEIT	0	0	0	0	0	0	0	0	0	30
Article 5(1)	0	0	0	210	476	812	1,237	1,775	2,456	3,516
TOTAL CUMMULATIVE PRODUCTION	17,760	22,116	27,116	32,976	39,522	46,768	53,882	61,905	70,845	82,343

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	5,328	6,635	8,135	9,830	11,714	13,787	15,794	18,039	20,517	23,639
Western Europe and Australia	7,814	9,731	11,931	14,417	17,180	20,221	23,164	26,457	30,091	34,671
Japan	178	221	271	328	390	460	526	601	684	788
CEIT	888	1,106	1,356	1,638	1,952	2,298	2,632	3,007	3,419	3,970
Article 5(1)	3,552	4,423	5,423	6,763	8,285	10,003	11,766	13,801	16,133	19,276
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	17,760	22,116	27,116	32,976	39,522	46,768	53,882	61,905	70,845	82,343
CUMMULATIVE EMISSIONS										
North America	2,501	3,237	4,108	5,125	6,294	7,433	8,392	9,511	10,783	12,281
Western Europe and Australia	4,293	5,520	6,962	8,636	10,548	12,488	14,095	15,994	18,148	20,702
Japan	95	123	155	192	235	271	312	359	411	471
CEIT	360	468	597	748	922	1,122	1,341	1,582	1,849	2,156
Article 5(1)	1,760	2,271	2,875	3,624	4,519	5,568	6,747	8,090	9,621	11,474
TOTAL CUMMULATIVE EMISSIONS	9,009	11,618	14,697	18,325	22,519	26,882	30,888	35,536	40,812	47,084
INVENTORY										
North America	2,827	3,398	4,027	4,705	5,419	6,353	7,401	8,528	9,734	11,358
Western Europe and Australia	3,521	4,211	4,969	5,781	6,632	7,733	9,068	10,463	11,943	13,969
Japan	98	116	135	155	188	214	243	273	317	370
CEIT	638	759	891	1,030	1,176	1,291	1,424	1,571	1,814	2,117
Article 5	2,152	2,548	3,139	3,766	4,435	5,019	5,711	6,512	7,802	9,406
TOTAL INVENTORY	10,498	12,419	14,651	17,003	19,886	22,994	26,369	30,033	35,259	41,681

Halon 1211 Summary
(All quantities are metric tonnes)

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	12,491	13,731	17,058	20,181	16,182	14,852	11,882	7,921	3,960	0
CEIT Production	30	30	35	35	80	700	50	50	0	0
Article 5(1) Production	1,342	1,658	2,049	2,545	3,074	3,717	4,646	7,002	8,713	10,448
Total Production	13,863	15,419	19,142	22,761	19,336	19,269	16,578	14,973	12,673	10,448
ANNUAL PRODUCTION ALLOCATION										
North America	3,747	4,119	5,117	6,054	4,855	4,456	3,565	2,376	1,188	0
Western Europe and Australia	5,496	6,042	7,506	8,880	7,120	6,535	5,228	3,485	1,742	0
Japan	125	137	171	202	162	149	119	79	40	0
CEIT	655	717	888	1,044	889	1,443	644	446	198	0
Article 5(1)	3,840	4,405	5,461	6,581	6,310	6,687	7,022	8,586	9,505	10,448
TOTAL ANNUAL PRODUCTION ALLOCATION	13,863	15,419	19,142	22,761	19,336	19,269	16,578	14,973	12,673	10,448
ANNUAL EMISSIONS										
North America	1,764	2,028	2,401	2,829	2,976	3,109	1,792	1,766	1,463	1,369
Western Europe and Australia	3,018	3,459	4,115	4,857	4,988	4,464	4,290	2,155	1,978	1,906
Japan	71	82	96	113	111	114	67	66	51	47
CEIT	352	404	472	554	624	731	710	668	330	298
Article 5(1)	2,236	2,646	3,192	3,843	4,272	4,718	5,143	5,822	6,517	7,258
TOTAL ANNUAL EMISSIONS	7,441	8,618	10,277	12,196	12,972	13,137	12,004	10,477	10,339	10,877
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	91,288	105,019	122,077	142,258	158,440	173,292	185,174	193,095	197,055	197,055
CEIT	60	90	125	160	240	940	990	1,040	1,040	1,040
Article 5(1)	4,858	6,516	8,566	11,111	14,185	17,901	22,547	29,549	38,262	48,710
TOTAL CUMMULATIVE PRODUCTION	96,206	111,625	130,768	153,529	172,865	192,133	208,711	223,684	236,357	246,805

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	27,386	31,506	36,623	42,677	47,532	51,988	55,552	57,929	59,117	59,117
Western Europe and Australia	40,167	46,208	53,714	62,594	69,714	76,248	81,477	84,962	86,704	86,704
Japan	913	1,050	1,221	1,423	1,584	1,733	1,852	1,931	1,971	1,971
CEIT	4,624	5,341	6,229	7,273	8,162	9,605	10,249	10,695	10,893	10,893
Article 5(1)	23,116	27,520	32,981	39,562	45,873	52,560	59,582	68,168	77,673	88,121
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	96,206	111,625	130,768	153,529	172,865	192,133	208,711	223,684	236,357	246,805
CUMMULATIVE EMISSIONS										
North America	14,045	16,072	18,473	21,302	24,278	27,387	29,180	30,945	32,408	33,777
Western Europe and Australia	23,720	27,179	31,294	36,151	41,139	45,603	49,893	52,048	54,026	55,933
Japan	543	624	721	834	945	1,060	1,127	1,193	1,244	1,290
CEIT	2,508	2,912	3,384	3,938	4,562	5,293	6,003	6,671	7,000	7,299
Article 5(1)	13,710	16,356	19,549	23,392	27,664	32,382	37,526	43,348	49,865	57,123
TOTAL CUMMULATIVE EMISSIONS	54,525	63,143	73,421	85,617	98,588	111,725	123,729	134,206	144,544	155,421
INVENTORY										
North America	13,342	15,433	18,150	21,375	23,254	24,600	26,373	26,983	26,709	25,340
Western Europe and Australia	16,447	19,030	22,420	26,443	28,575	30,645	31,583	32,913	32,678	30,772
Japan	426	500	589	639	673	725	738	727	680	637
CEIT	2,429	2,845	3,335	3,600	4,312	4,245	4,024	3,892	3,594	3,319
Article 5	11,164	13,432	16,170	18,209	20,177	22,056	24,820	27,808	30,998	34,245
TOTAL INVENTORY	48,482	57,347	67,912	74,276	80,408	84,982	89,479	91,813	91,383	91,468

Halon 1211 Summary
(All quantities are metric tonnes)

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	(1)	0	(7)	0	(4)	(1)	(14)	(265)	(184)
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5(1) Production	11,250	14,180	12,124	8,175	6,265	4,278	3,599	2,954	2,384	1,568
Total Production	11,250	14,179	12,124	8,169	6,265	4,274	3,598	2,940	2,119	1,384
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	(1)	0	(7)	0	(4)	(1)	(14)	(265)	(184)
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	11,250	14,180	12,124	8,175	6,265	4,278	3,599	2,954	2,384	1,568
TOTAL ANNUAL PRODUCTION ALLOCATION	11,250	14,179	12,124	8,169	6,265	4,274	3,598	2,940	2,119	1,384
ANNUAL EMISSIONS										
North America	1,299	940	895	860	827	795	764	735	706	679
Western Europe and Australia	1,545	1,461	1,388	1,319	1,253	1,190	1,130	1,073	1,098	883
Japan	44	28	27	26	24	23	22	21	20	20
CEIT	275	254	235	217	200	185	171	158	146	134
Article 5(1)	8,003	8,555	9,186	9,007	8,181	7,581	6,912	6,247	5,594	4,924
TOTAL ANNUAL EMISSIONS	11,166	11,239	11,731	11,429	10,486	9,774	9,000	8,233	7,564	6,639
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	197,055	197,054	197,054	197,048	197,048	197,044	197,043	197,028	196,763	196,579
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5(1)	59,960	74,140	86,264	94,439	100,704	104,982	108,581	111,535	113,919	115,487
TOTAL CUMMULATIVE PRODUCTION	258,055	272,234	284,358	292,526	298,791	303,065	306,663	309,603	311,722	313,106

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	86,704	86,703	86,703	86,697	86,697	86,693	86,692	86,678	86,412	86,228
Japan	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893
Article 5(1)	99,371	113,551	125,675	133,850	140,115	144,393	147,992	150,946	153,330	154,898
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	258,055	272,234	284,358	292,526	298,791	303,065	306,663	309,603	311,722	313,106
CUMMULATIVE EMISSIONS										
North America	35,075	36,015	36,910	37,771	38,598	39,393	40,157	40,892	41,598	42,277
Western Europe and Australia	57,478	58,939	60,327	61,646	62,899	64,088	65,219	66,292	67,389	68,272
Japan	1,334	1,362	1,389	1,415	1,439	1,462	1,485	1,506	1,527	1,546
CEIT	7,574	7,828	8,063	8,280	8,480	8,665	8,836	8,993	9,139	9,273
Article 5(1)	65,126	73,681	82,866	91,874	100,055	107,636	114,548	120,794	126,389	131,313
TOTAL CUMMULATIVE EMISSIONS	166,587	177,826	189,556	200,985	211,470	221,244	230,244	238,478	246,042	252,681
INVENTORY										
North America	24,041	23,101	22,206	21,346	20,519	19,723	18,959	18,225	17,518	16,839
Western Europe and Australia	29,226	27,764	26,376	25,051	23,798	22,604	21,473	20,386	19,023	17,956
Japan	608	582	556	531	508	486	464	444	424	406
CEIT	3,064	2,830	2,613	2,413	2,228	2,057	1,899	1,754	1,619	1,495
Article 5	39,870	42,808	41,976	40,060	36,757	33,444	30,151	26,941	23,585	19,601
TOTAL INVENTORY	94,408	94,801	91,541	87,321	81,821	76,419	71,125	65,680	60,425	54,903

Halon 1211 Summary

(All quantities are metric tonnes)

YEAR	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	(84)	(332)	(307)	(112)	(14)	(12)	(49)	(51)	(11)	(11)
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5(1) Production	165	165	0	0	0	0	0	0	0	0
Total Production	81	(167)	(307)	(112)	(14)	(12)	(49)	(51)	(11)	(11)
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	(84)	(332)	(307)	(112)	(14)	(12)	(49)	(51)	(11)	(11)
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	165	165	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	81	(167)	(307)	(112)	(14)	(12)	(49)	(51)	(11)	(11)
ANNUAL EMISSIONS										
North America	653	627	603	580	557	536	515	495	476	457
Western Europe and Australia	658	628	590	574	549	528	507	486	528	505
Japan	19	18	17	16	16	15	14	14	13	12
CEIT	124	115	106	98	90	83	77	71	66	61
Article 5(1)	4,149	1,658	1,509	1,383	1,268	1,162	1,065	977	1,146	1,024
TOTAL ANNUAL EMISSIONS	5,602	3,046	2,825	2,651	2,479	2,324	2,179	2,043	2,228	2,059
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	196,495	196,163	195,856	195,745	195,731	195,719	195,670	195,618	195,607	195,596
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5(1)	115,652	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	313,187	313,020	312,713	312,601	312,588	312,576	312,526	312,475	312,464	312,453

YEAR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	86,144	85,812	85,505	85,394	85,380	85,368	85,319	85,268	85,256	85,246
Japan	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893	10,893
Article 5(1)	155,063	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228	155,228
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	313,187	313,020	312,713	312,601	312,588	312,576	312,526	312,475	312,464	312,453
CUMMULATIVE EMISSIONS										
North America	42,930	43,557	44,160	44,739	45,296	45,832	46,347	46,842	47,317	47,774
Western Europe and Australia	68,930	69,558	70,148	70,722	71,271	71,798	72,305	72,792	73,320	73,824
Japan	1,565	1,583	1,600	1,616	1,632	1,647	1,661	1,674	1,687	1,700
CEIT	9,397	9,512	9,618	9,715	9,806	9,889	9,966	10,037	10,102	10,163
Article 5(1)	135,462	137,120	138,629	140,012	141,280	142,443	143,508	144,485	145,631	146,654
TOTAL CUMMULATIVE EMISSIONS	258,283	261,330	264,154	266,805	269,285	271,608	273,787	275,830	278,057	280,116
INVENTORY										
North America	16,187	15,560	14,957	14,377	13,820	13,285	12,770	12,275	11,799	11,342
Western Europe and Australia	17,214	16,254	15,357	14,672	14,109	13,570	13,013	12,476	11,937	11,421
Japan	388	371	355	339	324	310	296	283	271	259
CEIT	1,381	1,275	1,177	1,087	1,004	927	856	790	730	674
Article 5	18,108	16,599	15,215	13,947	12,785	11,720	10,743	9,597	8,573	7,659
TOTAL INVENTORY	51,690	48,558	45,796	43,303	40,967	38,739	36,646	34,407	32,337	30,422

Halon 1211 Summary
(All quantities are metric tonnes)

YEAR	**2015**	**2016**	**2017**	**2018**
ANNUAL PRODUCTION				
North America, Western Europe and Japan Production	(10)	(3)	0	0
CEIT Production	0	0	0	0
Article 5(1) Production	0	0	0	0
Total Production	(10)	(3)	0	0
ANNUAL PRODUCTION ALLOCATION				
North America	0	0	0	0
Western Europe and Australia	(10)	(3)	0	0
Japan	0	0	0	0
CEIT	0	0	0	0
Article 5(1)	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	(10)	(3)	0	0
ANNUAL EMISSIONS				
North America	440	422	406	390
Western Europe and Australia	483	467	446	427
Japan	12	11	11	10
CEIT	56	52	48	44
Article 5(1)	915	817	730	652
TOTAL ANNUAL EMISSIONS	1,905	1,769	1,640	1,523
CUMMULATIVE PRODUCTION				
North America, Western Europe and Japan	195,586	195,583	195,583	195,583
CEIT	1,040	1,040	1,040	1,040
Article 5(1)	115,817	115,817	115,817	115,817
TOTAL CUMMULATIVE PRODUCTION	312,443	312,440	312,440	312,440

YEAR	2015	2016	2017	2018
CUMMULATIVE PRODUCTION ALLOCATIONS				
North America	59,117	59,117	59,117	59,117
Western Europe and Australia	85,235	85,233	85,233	85,233
Japan	1,971	1,971	1,971	1,971
CEIT	10,893	10,893	10,893	10,893
Article 5(1)	155,228	155,228	155,228	155,228
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	312,443	312,440	312,440	312,440
CUMMULATIVE EMISSIONS				
North America	48,214	48,636	49,043	49,433
Western Europe and Australia	74,307	74,774	75,220	75,647
Japan	1,712	1,723	1,734	1,745
CEIT	10,219	10,271	10,318	10,362
Article 5(1)	147,569	148,386	149,116	149,768
TOTAL CUMMULATIVE EMISSIONS	282,021	283,790	285,430	286,954
INVENTORY				
North America	10,903	10,480	10,074	9,684
Western Europe and Australia	10,928	10,458	10,013	9,586
Japan	247	236	226	216
CEIT	622	574	530	490
Article 5	6,842	6,112	5,460	4,878
TOTAL INVENTORY	28,650	27,010	25,486	24,070

Appendix E: Historical Production, Emissions and Bank Values from 1963 – 2018 for Halon 2402

Halon 2402 Summary
(All quantities are metric tonnes)

YEAR	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	4	8	16	24	39	53	70	102	158	213	283	333
CEIT Production	0	0	30	30	50	50	100	275	275	275	275	550
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0	0	0
Total Production	4	8	46	54	89	103	170	377	433	488	558	883
ANNUAL PRODUCTION ALLOCATION												
North America	1	2	4	6	10	13	18	26	39	53	71	83
Western Europe and Australia	2	4	7	11	17	24	32	46	71	96	127	150
Japan	0	0	1	1	2	3	4	5	8	11	14	17
CEIT	0	0	30	30	50	50	100	275	275	275	275	550
Article 5(1)	1	2	4	6	10	13	18	26	39	53	71	83
TOTAL ANNUAL PRODUCTION ALLOCATION	4	8	46	54	89	103	170	377	433	488	558	883
ANNUAL EMISSIONS												
North America	0	0	1	1	2	3	4	7	10	14	19	25
Western Europe and Australia	0	1	1	2	4	6	8	12	18	25	35	45
Japan	0	0	0	0	0	1	1	1	2	2	3	4
CEIT	0	0	4	6	10	14	23	50	69	86	101	149
Article 5(1)	0	0	0	1	2	3	4	6	9	13	18	25
TOTAL ANNUAL EMISSIONS	0	1	6	10	18	26	40	76	107	140	177	248
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	4	13	29	53	91	144	214	316	474	687	970	1,303
CEIT	0	0	30	60	110	160	260	535	810	1,085	1,360	1,910
Article 5(1)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	4	13	59	113	201	304	474	851	1,284	1,772	2,330	3,213

YEAR	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**

CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	1	3	7	13	23	36	54	79	118	172	242	326
Western Europe and Australia	2	6	13	24	41	65	96	142	213	309	436	586
Japan	0	1	1	3	5	7	11	16	24	34	48	65
CEIT	0	0	30	60	110	160	260	535	810	1,085	1,360	1,910
Article 5(1)	1	3	7	13	23	36	54	79	118	172	242	326
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	4	13	59	113	201	304	474	851	1,284	1,772	2,330	3,213
CUMMULATIVE EMISSIONS												
North America	0	0	1	2	4	8	12	19	28	42	62	87
Western Europe and Australia	0	1	2	4	8	14	22	33	51	76	111	156
Japan	0	0	0	0	1	1	2	3	5	7	11	15
CEIT	0	0	4	10	20	33	56	106	175	261	362	511
Article 5(1)	0	0	1	2	3	6	10	16	24	37	55	79
TOTAL CUMMULATIVE EMISSIONS	0	1	8	18	36	62	102	177	284	424	600	848
INVENTORY												
North America	1	3	6	11	18	28	42	61	90	129	181	239
Western Europe and Australia	2	5	11	19	33	51	75	109	162	233	326	430
Japan	0	1	1	2	4	6	9	13	19	27	38	50
CEIT	0	0	26	50	90	127	204	429	635	824	998	1,399
Article 5(1)	1	3	7	12	20	30	44	63	94	135	188	246
TOTAL INVENTORY	4	11	51	94	165	243	372	674	1,000	1,348	1,729	2,364

Halon 2402 Summary
(All quantities are metric tonnes)

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	407	527	599	677	770	825	867	1,054	1,095	1,337
CEIT Production	550	550	550	550	1,100	2,200	2,200	2,200	2,200	2,200
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0
Total Production	957	1,077	1,149	1,227	1,870	3,025	3,067	3,254	3,295	3,537
ANNUAL PRODUCTION ALLOCATION										
North America	102	132	150	169	192	206	217	263	274	334
Western Europe and Australia	183	237	269	304	346	371	390	474	493	602
Japan	20	26	30	34	38	41	43	53	55	67
CEIT	550	550	550	550	1,100	2,200	2,200	2,200	2,200	2,200
Article 5(1)	102	132	150	169	192	206	217	263	274	334
TOTAL ANNUAL PRODUCTION ALLOCATION	957	1,077	1,149	1,227	1,870	3,025	3,067	3,254	3,295	3,537
ANNUAL EMISSIONS										
North America	32	41	51	62	73	85	91	106	120	139
Western Europe and Australia	58	75	92	111	132	152	164	192	216	250
Japan	6	7	9	11	13	15	17	19	22	25
CEIT	182	212	240	265	356	552	687	811	925	1,029
Article 5(1)	32	41	52	64	78	92	106	120	137	155
TOTAL ANNUAL EMISSIONS	310	377	444	513	652	896	1,064	1,248	1,420	1,599
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	1,710	2,237	2,836	3,512	4,282	5,107	5,974	7,027	8,123	9,460
CEIT	2,460	3,010	3,560	4,110	5,210	7,410	9,610	11,810	14,010	16,210
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	4,170	5,247	6,396	7,622	9,492	12,517	15,584	18,837	22,133	25,670

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	428	559	709	878	1,071	1,277	1,493	1,757	2,031	2,365
Western Europe and Australia	770	1,007	1,276	1,580	1,927	2,298	2,688	3,162	3,655	4,257
Japan	86	112	142	176	214	255	299	351	406	473
CEIT	2,460	3,010	3,560	4,110	5,210	7,410	9,610	11,810	14,010	16,210
Article 5(1)	428	559	709	878	1,071	1,277	1,493	1,757	2,031	2,365
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	4,170	5,247	6,396	7,622	9,492	12,517	15,584	18,837	22,133	25,670
CUMMULATIVE EMISSIONS										
North America	119	160	211	273	346	431	522	628	748	887
Western Europe and Australia	214	288	380	491	623	775	939	1,130	1,346	1,596
Japan	21	28	37	48	61	76	93	112	134	159
CEIT	693	906	1,146	1,411	1,767	2,319	3,006	3,817	4,742	5,771
Article 5(1)	111	152	205	269	347	438	544	664	801	957
TOTAL CUMMULATIVE EMISSIONS	1,158	1,535	1,979	2,492	3,144	4,039	5,103	6,352	7,771	9,370
INVENTORY										
North America	309	399	498	605	725	846	972	1,129	1,283	1,478
Western Europe and Australia	556	718	896	1,090	1,304	1,523	1,749	2,032	2,309	2,661
Japan	64	83	104	127	153	179	206	239	272	314
CEIT	1,767	2,104	2,414	2,699	3,443	5,091	6,604	7,993	9,268	10,439
Article 5(1)	316	407	504	609	724	838	949	1,093	1,229	1,408
TOTAL INVENTORY	3,012	3,712	4,417	5,130	6,348	8,478	10,481	12,486	14,361	16,300

Halon 2402 Summary (All quantities are metric tonnes)

YEAR	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	1,559	1,736	2,006	2,291	1,913	1,678	1,345	896	448	0
CEIT Production	2,200	2,200	2,300	2,200	2,450	2,450	1,800	1,391	400	400
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0
Total Production	3,759	3,936	4,306	4,491	4,363	4,128	3,145	2,287	848	400
ANNUAL PRODUCTION ALLOCATION										
North America	390	434	502	573	478	419	336	224	112	0
Western Europe and Australia	702	781	903	1,031	861	755	605	403	202	0
Japan	78	87	100	115	96	84	67	45	22	0
CEIT	2,200	2,200	2,300	2,200	2,450	2,450	1,800	1,391	400	400
Article 5(1)	390	434	502	573	478	419	336	224	112	0
TOTAL ANNUAL PRODUCTION ALLOCATION	3,759	3,936	4,306	4,491	4,363	4,128	3,145	2,287	848	400
ANNUAL EMISSIONS										
North America	161	184	211	242	256	186	160	161	157	149
Western Europe and Australia	289	330	380	435	461	276	290	292	286	270
Japan	29	33	38	44	47	29	30	30	30	28
CEIT	1,125	1,214	1,307	1,376	1,396	1,022	1,057	1,070	1,019	985
Article 5(1)	178	204	234	267	302	204	218	224	221	210
TOTAL ANNUAL EMISSIONS	1,782	1,965	2,169	2,365	2,462	1,717	1,754	1,778	1,713	1,642
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	11,019	12,755	14,761	17,053	18,966	20,644	21,988	22,885	23,333	23,333
CEIT	18,410	20,610	22,910	25,110	27,560	30,010	31,810	33,201	33,601	34,001
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	29,429	33,365	37,671	42,163	46,526	50,654	53,798	56,086	56,934	57,334

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	2,755	3,189	3,690	4,263	4,742	5,161	5,497	5,721	5,833	5,833
Western Europe and Australia	4,958	5,740	6,643	7,674	8,535	9,290	9,895	10,298	10,500	10,500
Japan	551	638	738	853	948	1,032	1,099	1,144	1,167	1,167
CEIT	18,410	20,610	22,910	25,110	27,560	30,010	31,810	33,201	33,601	34,001
Article 5(1)	2,755	3,189	3,690	4,263	4,742	5,161	5,497	5,721	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	29,429	33,365	37,671	42,163	46,526	50,654	53,798	56,086	56,934	57,334
CUMMULATIVE EMISSIONS										
North America	1,047	1,231	1,442	1,684	1,940	2,125	2,285	2,446	2,603	2,752
Western Europe and Australia	1,885	2,215	2,595	3,030	3,492	3,768	4,058	4,351	4,636	4,906
Japan	189	222	261	305	351	380	410	441	470	499
CEIT	6,897	8,110	9,417	10,793	12,189	13,211	14,267	15,337	16,356	17,341
Article 5(1)	1,135	1,339	1,573	1,840	2,142	2,346	2,564	2,788	3,009	3,220
TOTAL CUMMULATIVE EMISSIONS	11,152	13,118	15,287	17,652	20,114	21,830	23,585	25,362	27,075	28,717
INVENTORY										
North America	1,707	1,958	2,249	2,580	2,802	3,035	3,212	3,275	3,230	3,081
Western Europe and Australia	3,073	3,524	4,048	4,643	5,043	5,522	5,837	5,948	5,864	5,594
Japan	362	416	477	548	597	652	689	704	696	668
CEIT	11,513	12,500	13,493	14,317	15,371	16,799	17,543	17,864	17,245	16,660
Article 5(1)	1,620	1,850	2,118	2,423	2,600	2,815	2,933	2,933	2,824	2,613
TOTAL INVENTORY	18,276	20,247	22,384	24,511	26,412	28,823	30,214	30,723	29,858	28,617

Halon 2402 Summary (All quantities are metric tonnes)

YEAR	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	400	352	300	255	160	90	0	0	0	0
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0
Total Production	400	352	300	255	160	90	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	400	352	300	255	160	90	0	0	0	0
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	400	352	300	255	160	90	0	0	0	0
ANNUAL EMISSIONS										
North America	183	172	162	153	143	135	127	119	112	106
Western Europe and Australia	232	223	213	204	196	188	180	173	165	159
Japan	26	25	24	23	22	21	20	19	19	18
CEIT	866	841	815	787	758	726	691	656	622	590
Article 5(1)	195	180	167	154	143	132	122	113	105	97
TOTAL ANNUAL EMISSIONS	1,502	1,441	1,381	1,321	1,262	1,202	1,141	1,080	1,023	969
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	34,401	34,753	35,053	35,308	35,468	35,558	35,558	35,558	35,558	35,558
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	57,734	58,086	58,386	58,641	58,801	58,891	58,891	58,891	58,891	58,891

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167
CEIT	34,401	34,753	35,053	35,308	35,468	35,558	35,558	35,558	35,558	35,558
Article 5(1)	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	57,734	58,086	58,386	58,641	58,801	58,891	58,891	58,891	58,891	58,891
CUMMULATIVE EMISSIONS										
North America	2,935	3,108	3,270	3,422	3,566	3,701	3,828	3,947	4,059	4,165
Western Europe and Australia	5,138	5,361	5,574	5,778	5,974	6,162	6,342	6,515	6,680	6,838
Japan	524	549	572	595	617	638	658	678	696	714
CEIT	18,207	19,048	19,863	20,650	21,408	22,134	22,825	23,481	24,103	24,693
Article 5(1)	3,414	3,595	3,761	3,916	4,059	4,191	4,313	4,426	4,531	4,628
TOTAL CUMMULATIVE EMISSIONS	30,219	31,659	33,040	34,362	35,624	36,826	37,966	39,047	40,070	41,039
INVENTORY										
North America	2,898	2,725	2,563	2,411	2,267	2,132	2,006	1,886	1,774	1,668
Western Europe and Australia	5,362	5,139	4,926	4,722	4,526	4,338	4,158	3,985	3,820	3,661
Japan	643	618	594	572	550	529	508	489	470	452
CEIT	16,194	15,705	15,190	14,658	14,060	13,424	12,733	12,077	11,455	10,865
Article 5(1)	2,419	2,239	2,072	1,917	1,775	1,642	1,520	1,407	1,302	1,205
TOTAL INVENTORY	27,515	26,426	25,346	24,279	23,177	22,065	20,924	19,844	18,821	17,852

Halon 2402 Summary
(All quantities are metric tonnes)

YEAR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
ANNUAL PRODUCTION										
North America, Western Europe and Japan Production	0	0	0	0	0	0	0	0	0	0
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5(1) Production	0	0	0	0	0	0	0	0	0	0
Total Production	0	0	0	0	0	0	0	0	0	0
ANNUAL PRODUCTION ALLOCATION										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	0	0	0	0	0	0	0	0	0	0
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0	0	0	0	0	0	0
ANNUAL EMISSIONS										
North America	99	93	88	83	78	73	69	65	61	57
Western Europe and Australia	187	246	219	205	191	178	166	154	144	134
Japan	17	17	16	15	15	14	14	13	13	12
CEIT	770	686	640	596	556	518	483	450	419	391
Article 5(1)	90	83	77	71	66	61	56	52	48	45
TOTAL ANNUAL EMISSIONS	1,164	1,126	1,040	970	905	844	787	734	685	639
CUMMULATIVE PRODUCTION										
North America, Western Europe and Japan	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5(1)	0	0	0	0	0	0	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

YEAR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CUMMULATIVE PRODUCTION ALLOCATIONS										
North America	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167	1,167
CEIT	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558	35,558
Article 5(1)	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
CUMMULATIVE EMISSIONS										
North America	4,264	4,357	4,445	4,528	4,605	4,679	4,747	4,812	4,873	4,930
Western Europe and Australia	7,026	7,272	7,491	7,696	7,887	8,064	8,230	8,384	8,528	8,662
Japan	732	748	764	780	794	809	822	836	848	860
CEIT	25,463	26,149	26,789	27,385	27,941	28,459	28,942	29,392	29,811	30,202
Article 5(1)	4,718	4,801	4,878	4,949	5,015	5,076	5,132	5,185	5,233	5,278
TOTAL CUMMULATIVE EMISSIONS	42,202	43,328	44,368	45,338	46,243	47,087	47,874	48,608	49,293	49,932
INVENTORY										
North America	1,569	1,476	1,388	1,305	1,228	1,155	1,086	1,021	961	903
Western Europe and Australia	3,474	3,228	3,008	2,804	2,613	2,435	2,270	2,115	1,972	1,838
Japan	435	418	402	387	372	358	344	331	318	306
CEIT	10,095	9,409	8,769	8,173	7,617	7,099	6,616	6,166	5,747	5,356
Article 5(1)	1,115	1,032	955	884	818	757	701	649	600	556
TOTAL INVENTORY	16,688	15,563	14,523	13,553	12,648	11,804	11,017	10,283	9,598	8,959

Halon 2402 Summary
(All quantities are metric tonnes)

YEAR	2015	2016	2017	2018
ANNUAL PRODUCTION				
North America, Western Europe and Japan Production	0	0	0	0
CEIT Production	0	0	0	0
Article 5(1) Production	0	0	0	0
Total Production	0	0	0	0
ANNUAL PRODUCTION ALLOCATION				
North America	0	0	0	0
Western Europe and Australia	0	0	0	0
Japan	0	0	0	0
CEIT	0	0	0	0
Article 5(1)	0	0	0	0
TOTAL ANNUAL PRODUCTION ALLOCATION	0	0	0	0
ANNUAL EMISSIONS				
North America	54	51	48	45
Western Europe and Australia	125	116	109	101
Japan	12	11	11	10
CEIT	364	339	316	295
Article 5(1)	41	38	35	33
TOTAL ANNUAL EMISSIONS	596	556	519	484

CUMMULATIVE PRODUCTION				
North America, Western Europe and Japan	23,333	23,333	23,333	23,333
CEIT	35,558	35,558	35,558	35,558
Article 5(1)	0	0	0	0
TOTAL CUMMULATIVE PRODUCTION	58,891	58,891	58,891	58,891

YEAR	**2015**	**2016**	**2017**	**2018**
CUMMULATIVE PRODUCTION ALLOCATIONS				
North America	5,833	5,833	5,833	5,833
Western Europe and Australia	10,500	10,500	10,500	10,500
Japan	1,167	1,167	1,167	1,167
CEIT	35,558	35,558	35,558	35,558
Article 5(1)	5,833	5,833	5,833	5,833
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	58,891	58,891	58,891	58,891
CUMMULATIVE EMISSIONS				
North America	4,984	5,034	5,082	5,126
Western Europe and Australia	8,787	8,904	9,012	9,113
Japan	872	883	894	905
CEIT	30,566	30,905	31,222	31,517
Article 5(1)	5,319	5,357	5,393	5,426
TOTAL CUMMULATIVE EMISSIONS	50,528	51,084	51,603	52,087
INVENTORY				
North America	850	799	752	707
Western Europe and Australia	1,713	1,596	1,488	1,386
Japan	295	283	272	262
CEIT	4,992	4,653	4,336	4,041
Article 5(1)	514	476	440	408
TOTAL INVENTORY	8,363	7,807	7,288	6,804