Fire Suppression Technical Options Committee

2022 Assessment Report

UN environment programme | ozone secretariat

Montreal Protocol on Substances that Deplete the Ozone Layer

UNEP

REPORT OF THE FIRE SUPPRESSION TECHNICAL OPTIONS COMMITTEE*

DECEMBER 2022

2022 ASSESSMENT REPORT

*** Formerly known as the Halons Technical Options Committee (HTOC)**

Montreal Protocol
On Substances that Deplete the Ozone Layer

Report of the

UNEP Fire Suppression Technical Options Committee

December 2022

Volume 1

2022 ASSESSMENT REPORT

The text of this report is composed in Times New Roman

Co-ordination:	**Fire Suppression Technical Options Committee**
Composition of the report:	**Fire Suppression Technical Options Committee**
Reproduction:	**UNEP Ozone Secretariat**
Date:	**December 2022**

Under certain conditions, printed copies of this report are available from:

UNITED NATIONS ENVIRONMENT PROGRAMME
Ozone Secretariat, P.O. Box 30552, Nairobi, Kenya

This document is also available in portable document format from the UNEP Ozone Secretariat's website:

Need correct URL

ISBN: 978-9914-733-96-9

Disclaimer

The United Nations Environment Programme (UNEP), the Technology and Economic Assessment Panel (TEAP) Co-chairs and members, the Technical Options Committees Co-chairs and members, the TEAP Task Forces Co-chairs and members, and the companies and organizations that employ them do not endorse the performance, worker safety, or environmental acceptability of any of the technical options discussed. Every industrial operation requires consideration of worker safety and proper disposal of contaminants and waste products. Moreover, as work continues - including additional toxicity evaluation - more information on health, environmental and safety effects of alternatives and replacements will become available for use in selecting among the options discussed in this document.

UNEP, the TEAP Co-chairs and members, the Technical Options Committees Co-chairs and members, and the TEAP Task Forces Co-chairs and members, in furnishing or distributing this information, do not make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or utility; nor do they assume any liability of any kind whatsoever resulting from the use or reliance upon any information, material, or procedure contained herein, including but not limited to any claims regarding health, safety, environmental effect or fate, efficacy, or performance, made by the source of information.

Mention of any company, association, or product in this document is for information purposes only and does not constitute a recommendation of any such company, association, or product, either express or implied by UNEP, the Technology and Economic Assessment Panel Co-chairs or members, the Technical and Economic Options Committee Co-chairs or members, the TEAP Task Forces Co-chairs or members or the companies or organizations that employ them.

Acknowledgements

The UNEP Fire Suppression Technical Options Committee (FSTOC) acknowledges with thanks the outstanding contributions from all individuals and organizations that provided technical support to Committee members.

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

The following persons were instrumental in preparing this report:

Co-chairs

Adam Chattaway	Collins Aerospace	UK
Dr. Sergey Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
Dr. Daniel P. Verdonik	Jensen Hughes, Inc.	US

Members

Mohammed Jane Alam	Jahnabad Trading	Bangladesh
Jamal Alfuzaie	Consultant - retired	Kuwait
Johan Åqvist	FMV (Swedish Defence Materiel Administration)	Sweden
Youri Auroque	European Aviation Safety Agency	France
Dr. Michelle M. Collins	Consultant- EECO International	US
Khaled Effat A. Mohamed	Modern Systems Engineering - MSE	Egypt
Carlos Grandi	Independent Consultant	Brazil
Laura Green	Hilcorp	US
Elvira Nigido	A-Gas Australia	Australia
Emma Palumbo	Safety Hi-tech Europe srl	Italy
Erik Pedersen	Consultant – World Bank	Denmark
Dr. R.P. Singh	Institute of Defence Scientist and Technologist	India
Donald Thomson	MOPIA	Canada
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan

Consulting Experts

Clare Bowens	The Gas Xchange	UK
Sidney de Brito	Embraer	Brazil
Thomas Cortina	Halon Alternatives Research Corporation	US
Joshua Fritsch	US Army Ground Vehicle Systems Center	US
Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan
Nikolai Kopylov	All Russian Research Institute for Fire Protection	Russian Federation
Steve McCormick	U.S. Army Ground Vehicle Systems Center Huntington Ingalls Industries	US
John G. Owens	3M Company	US
John J. O'Sullivan	Bureau Veritas	UK
Mark L. Robin	Chemours	US
Joseph A. Senecal	FireMetrics LLC	US

Peer Reviewers

The Fire Suppression Technical Options Committee also acknowledges with thanks the following peer reviewers who took time from their busy schedules to review the draft of this report and provided constructive comments. At the sole discretion of the Fire Suppression Technical Options Committee, these comments may or may not have been accepted and incorporated into the report. Therefore, listing of the Peer Reviewers should not be taken as an indication that any reviewer endorses the content of the report, which remains solely the opinion of the members of the Committee. The Peer Reviewers for the 2022 Assessment report are listed below.

Dr. Ian Campbell	Parker-Meggitt	US
John Demeter	Wesco	US
Alan Elder	Johnson Controls	UK
Jeff Gibson	American Pacific	US
Dr. Steve Hodges	US Army Ground Vehicle Systems Center Huntington Ingalls Industries	US
Brendan Karchere	ConocoPhilips	US
Michael Kiamanesh	Waysmos	US
Alistair Manning	UK Met Office	UK
George McEachen	Boeing	US

Thibault Pelletier	Airbus	France
Fred Penden	Carrier	US
Bill Polits	A-Gas	US
Al Thornton	Chemours	US
Luke Western	Bristol University Global Monitoring Lab, NOAA	UK

Table of Contents

List of Tables

List of Figures

1 Executive Summary

1.1 Renaming of the Halons Technical Options Committee as the Fire Suppression Technical Options Committee

The Halons Technical Options Committee (HTOC) role has broadened over the years. Its initial focus was solely on halons and their alternatives. Over time, the HTOC also focused on hydrochlorofluorocarbon (HCFC) agents and their alternatives and more recently on hydrofluorocarbons (HFCs) and their alternatives. As a result, the expertise of the HTOC was much wider than just considering alternatives to halons.

Another aspect of this broader role is that of safety aspects beyond general agent toxicity and fire protection systems, both in terms of the high pressures of fire protections system cylinders and the increasing use of flammable refrigerants, as HFCs are phased down in the refrigeration, air-conditioning, and heat pump sector, as outlined in section 2.3.

In the light of this, in November 2022, the parties to the Montreal Protocol adopted Decision XXXIV/11, which *inter alia*, renamed the Halons Technical Options Committee as the Fire Suppression Technical Options Committee (FSTOC). This change was welcomed by the committee.

For this report, all references to the committee's current and past work, actions, and opinions are referred to as the FSTOC. All references to the previous reports are referred to as the HTOC.

1.2 Alternate Refrigerants and their Potential Flammability (Chapter 2)

The FSTOC continues to express concern with expanded use of alternative refrigerants owing to their potential flammability and yet-to-be-determined effects on firefighting systems (e.g., agent effectiveness, by-products generated, etc.). In addition to industry standard tests for measuring flame propagation (e.g., the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34 and the International Organization for Standardization (ISO) Standard 817), new methods are being developed to address these concerns. These issues are of particular concern to the military sector or other applications that may be subject to extreme environments.

1.3 Impact of Existing and Possible Future Regulations on the Fire Protection Sector (Chapter 3)

HFC phasedown regulations in non-Article 5 parties are having a bigger impact on the cost and availability of HFC fire suppressants than initially anticipated by the FSTOC. It is the FSTOC's experience that HFCs contained in fire protection equipment have historically enjoyed a relatively high level of recycling and reuse. As the supply of newly produced HFCs for fire protection decreases in response to phasedown regulations, recycling becomes even more important as an alternative source of supply and is likely to increase in the future.

Commercially used fire suppression agents such as HFCs, fluoroketone (FK)-5-1-12, and 3,3,3-trifluoro-2-bromo-propene (2-BTP) are now classified as perfluoroalkyl and polyfluoroalkyl substances (PFAS) under the Organization for Economic Cooperation and Development (OECD) and European Union (EU) definitions. Five European countries are preparing a proposal for a Registration, Evaluation, Authorization and restriction of CHemicals (REACH) restriction that could prohibit the manufacture, import, sale and use of PFAS and products containing PFAS at some future date. Restricting or prohibiting the sale or use of these agents could have significant impacts on the ability of users to effectively protect a range of hazards from fire and explosion. On December 20, 2022, 3M Corporation announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**. This includes the fire suppressant FK-5-1-12. The FSTOC will continue to monitor this situation.

The misapplication of the Basel Convention continues to provide a significant challenge in relation to accessing facilities capable of reclaiming or destroying Ozone Depleting Substances (ODS) and HFCs from an international movement perspective, especially for countries without reclamation facilities.

In the 2018 Assessment report, the FSTOC was of the opinion that the initial 10% reduction in HFC production would not have a significant impact on the fire protection sector. In contrast, for example, what we have seen in the United States of America (US) is that there has already been significant impact on the cost of HFCs. The FSTOC believes this is for the following reasons:

- HFCs used for fire extinguishing are high-GWP,
- the allocation mechanism in the US is GWP-weighted,
- market factors mean that producers and importers have to decide which HFCs to manufacture or import, based on their GWP and future market needs.

The combined effect of these factors means that the HFC phasedown in the US is having a large effect on the production and consumption of HFC fire extinguishants. The US HFC phasedown began on January 1, 2022, and it has already had a significant impact on the pricing of HFCs for fire protection.

In the EU, the European F-gas Regulation has a much greater level of quota reduction and for the period 2021-2023, the reduction is 55% of the 2015 baseline. A 2020 report by the European Environment Agency (EEA) estimates the total supply of newly-produced HFCs (production and consumption) for fire protection in the EU has decreased by over 90% since the phasedown began in 2015, **EEA (2020)**. It appears that the use of HFCs in the EU has been replaced in part by FK-5-1-12 and inert gases.

In Japan, the use of HFCs for fire protection has been gradually decreasing in response to adoption of the Kigali Amendment and other efforts to prevent global warming. The amount of HFCs newly installed for fire protection in 2021 in Japan is about 30% of the most installed year, 2012.

The FSTOC anticipates additional impacts to the fire protection sector as the Kigali amendment phasedown continues and begins to impact additional regions and parties. This could reduce commercial viability of production of some HFC fire extinguishing agents in the future. This has implications for HFC banking to support enduring uses.

1.4 Alternatives to Halons, HCFCs, and HFCs (Chapter 4)

A new agent, Halocarbon Blend 55 (a 50/50 weight% blend of FK-5-1-12 and hydrochlorofluoro-olefin (HCFO)-1233zd(E)), was added to the US Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) list. It was adopted into National Fire Protection Association (NFPA) 2001, **NFPA (2022)** as "HB-55," and in the International Standard ISO 14520-17, **ISO (2022)** designated as "Halocarbon Blend 55."

As a result of the HFC phasedown, the market share of both inert gas (IG) and FK systems is growing at the expense of HFC systems in total flooding fire extinguishing systems.

For portable extinguishers, no new agents have been developed to commercialization since 2018. There are still two in-kind alternatives to halons, HCFCs, and HFCs, namely FK-5-1-12, and 2-BTP. In some circumstances carbon dioxide (CO_2) can be used.

In the US only, 2-BTP is currently approved for use by the US EPA only in handheld extinguishers, and engine nacelle and APUs on aircraft, **EPA (2016).** In July 2022, the EPA published a Notice of Proposed Rulemaking (NPRM) which would widen allowable non-residential uses, **EPA (2022).** There were no adverse comments to the NPRM related to 2-BTP.

On December 20, 2022, 3M corporation announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**. The FSTOC has been informed that this includes the fire suppressant FK-5-1-12. The FSTOC will continue to monitor this situation.

1.5 Enduring Uses of Halons, HCFCs and HFCs (Chapter 5)

1.5.1 Section 5.1 – Civil Aviation

Civil aviation emissions of halon 1301 are thought to be a significant part of global emissions. Owing to the COVID-19 Pandemic there was a 60% decrease in civil aviation flight hours in 2020. However, emissions of halon 1301 did not go down at all, suggesting most aviation emissions are not occurring during flight operations. The FSTOC continues to liaise with the International Civil Aviation Organization (ICAO) and other aviation stakeholders to better understand the sources of emissions and identify opportunities to reduce them. As part of this, the Halon Recycling Corporation has produced a best practice guidance document on reducing emissions and ensuring quality during servicing of aviation fire extinguishers, **HRC (2022)**.

The FSTOC has identified several issues affecting the availability and quality of recovered halons from all fire protection sectors, but especially from the civil aviation sector. This has been reported in the last two HTOC progress reports and the situation may be getting worse.

As a response to Decision XXX/7, the run-out date for halon 1301 has been re-evaluated, using the latest estimated size of the halon 1301 bank. Depending on the modelling scenario, the run-out dates are estimated to be in the range of 2030 to 2049, compared with 2032 to 2054, as detailed in the 2018 Assessment report.

1.5.2 Section 5.2 – Military Uses

Many commercially available extinguishing agents have been assessed against the range of unique military fire protection requirements. In summary:

- Alternatives to halons have been adopted in military applications where they have been found to be technically and economically feasible.
- For new designs, there are many instances where the original halon or high-Global Warming Potential (GWP) HFC is the only solution that will meet stringent design requirements associated with military applications and will continue to be for the foreseeable future.
- The military sector does not represent a large enough market segment to influence chemical manufacturers to continue production of required HFCs or investigate new alternatives.

- It is not believed that any new chemicals, beyond that noted in section 1.3 above, will be commercially available for the military to evaluate as viable replacements in the foreseeable future.

1.5.3 Section 5.3 – Hydrocarbon Production and Transportation Pipeline

Enduring uses of halon 1301 and halon 2402 systems in the hydrocarbon production and transportation pipeline sector are mainly associated with existing facilities with explosion prevention (inerting) and fire protection (suppression) requirements in inhospitable locations with harsh climatic conditions such as the Alaskan North Slope in the US, the North Sea in Europe, Eastern Europe, and the Russian Federation.

- Alternatives to halons and HFC have been adopted where they have been found to be technically and economically feasible.
- There are instances where the original halon or high-GWP HFCs are the only solutions that will meet hazard management requirements and will continue to be so for the foreseeable future.
- This sector does not represent a large enough market segment to influence chemical manufacturers to continue production of required HFCs or to investigate new alternatives.
- It is not believed that any new chemicals, beyond that noted in section 3 above, will be commercially available for evalution in the foreseeable future.

Therefore, existing facilities will likely remain protected by halon or HFCs resulting in enduring uses of halons, HFC-23 and HFC-227ea throughout the facility lifetime.

1.6 Global Emissions and Banking (Chapter 6)

There are two independent methods to estimate emissions of halon 1301: 1) the FSTOC model which takes account of the total amount of recorded production, allows for production losses, destruction, and emissions from the bank and 2) emissions estimates derived from atmospheric concentration measurements, in this case measured by the Advanced Global Atmospheric Gases Experiment (AGAGE) network. Historically the agreement between these completely independent methods has been remarkably good for halons 1301 and 1211. However, since 2010, the emissions derived from atmospheric measurements have been consistently higher for halons 1301 and 1211 than those estimated by the FSTOC model.

1.6.1 Halon 1301

The FSTOC halon 1301 model emissions compare well with the annual mean emissions derived from mixing ratios (atmospheric concentrations) from the latest data using the methodology of **Vollmer et al. (2016)** (hereafter referred to Vollmer) until about 1998 where the FSTOC model emissions are generally lower than the mean. FSTOC estimates generally fall within +/-1 sigma uncertainty of the mean except for 2011 – 2012, where the FSTOC model estimates are slightly lower than the -1 sigma value.

Differences are seen during the periods of increasing and decreasing emissions from 1999-2000, 2010-2016 and 2018-2021, instead of the decay pattern expected from emissions from a finite global bank. A potential source could have been from fire protection systems from shipbreaking activities, but that is not anticipated in recent years as recovered halon 1301 has a significant market value and it is reported that halon is currently handled carefully during shipbreaking. Another possible source for these emissions could be from halon 1301 production and use as a feedstock for the pesticide Fipronil and several other chemicals, whose emissions would not be accounted for in the FSTOC model but would be included in the Vollmer estimates. However, the amount of halon 1301 that is from feedstock production and use would need to be at the higher end of the Medical and Chemicals (MC)TOC-estimated emissions of 7.5%. The FSTOC is seeking additional information on halon 1301 feedstock production, use, and emissions to better understand if the higher levels of emissions can be attributed primarily to feedstock use versus from the fire protection bank.

Using mean emission estimates from Vollmer provides a global bank estimate range of 26,250 – 27,500 metric tonnes compared to 35,000 metric tonnes for the FSTOC model. This difference is becoming significant as the amount of halon that is available to support enduring fire protection uses becomes smaller over time. The Vollmer data also provide a much higher mean annual emission rate for 2021 of nearly 5.5% of a 26,500 metric tonne bank. This is more than double the approximately 2.25% composite rate from the FSTOC model and much higher than the 2%+/-1% rate developed by **Verdonik and Robin (2004**). The combination of a potential higher emission rate than generated by the FSTOC model and a smaller bank of halon 1301 could also imply that there is going to be a significant reduction in available halon 1301 to support ongoing needs in civil aviation, oil and gas, militaries, etc., which could result in a much earlier run-out date.

1.6.2 Halon 1211

The FSTOC projected regional distribution of the global bank of halon 1211 shows that at the end of 2022, almost 80% of the estimated 20,500 metric tonnes is equally divided between the North America region and the Western Europe and Australia region with about 20% estimated to remain in Article 5 parties. The estimate for Article 5 parties is significantly lower than projected in the 2010 Assessment, which is a reflection of FSTOC concerns with halon 1211 bank management. This trend continues with lower emissions rates expected in the North America region and the Western Europe and Australia region resulting in these regions containing over 90% of the global bank in the next 20 years.

Both the mean and +1 sigma uncertainty emissions from Vollmer are higher than the cumulative production reported to the FSTOC meaning that the bank would be completely exhausted. However, the bank cannot be exhausted as there are still emissions in Northwest Europe being measured and halon 1211 is still widely used on civil aircraft. This suggests that either more halon 1211 has been produced than reported to the FSTOC (and thus more emissions) and/or the emissions are at the lower end of the Vollmer estimates.

1.6.3 Halon 2402

The FSTOC model emission rates as a function of the size of the bank have been updated for this assessment. The current model aligns the emission rates for 2402 with those currently used for halon 1301, with the exception of Japan, which uses the same emission factors as for North America. The FSTOC estimates that the majority of halon 2402 remains in the former Countries with Economies in Transition (CEITs), but also with significant quantities remaining in Europe.

The FSTOC model estimate of emissions is generally higher than the mean estimate of emissions from the updated Vollmer data from about 1980 until 2020 and near or above the +1 sigma uncertainty until 2018. The Vollmer data show increasing emissions from 2016 – 2021, with the FSTOC estimate going below the mean but staying within +/-1 sigma uncertainty. This increase would not be expected from an average emission rate of the bank unless something has changed. It has been reported to the FSTOC that there is a major decommissioning programme underway in Vladivostok, Russia that could account for an increase in emissions. As emissions would be expected to be kept to a minimum, but not totally avoidable, the level of increase in emissions suggests that this effort involves a sizeable amount of decommissioning. It is presumed that this recovered halon 2402 will remain in the global bank to support enduring uses of halon 2402.

Vollmer emissions estimates provide a mean bank range of 15,500–- 19,500 metric tonnes. This is compared with the FSTOC model estimate of a remaining bank of 13,000 metric tonnes. It should be noted that the FSTOC model does not include emissions from the reported use of halon 2402 as a process agent which would place the FSTOC model emissions and bank estimate within the range of uncertainty of the estimates using the Vollmer data.

1.6.4 HFCs

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, to estimate the global emissions from fire protection, it was necessary to create a model that can separate the annual emissions into those three categories of use. The model was initially developed in 2018 in coordination with a Medical and Chemicals (MC)TOC co-chair and a Rigid and Flexible Foams (F)TOC co-chair and has been updated in 2022. The model uses best estimates of annual global production capacity of HFC-227ea beginning in 1993 and carried out until 2021.

The annual emission rate from the fire protection bank was updated to be 3% from 2011 – 2021. Emissions from production were updated ranging from 0.1% to 1.25% per the latest MCTOC estimates.

The HFC-227ea model emissions and the emissions derived from atmospheric measurements are in excellent agreement, with the HTOC model results generally between the +/-1 sigma uncertainly in the atmospheric derived estimates.

The model estimates the global fire protection bank of HFC-227ea to be 178,000 metric tonnes. Based on emission estimates from the US and Northwest Europe, the FSTOC estimates that more HFC-227ea is in Article 5 parties than in non-Article 5 parties.

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.

Unlike HFC-227ea and HFC-125, which are 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. Its use is expected to be small compared to HFC-227ea.

As was the case for HFC-227ea and HFC-125, 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. At this time, there is not sufficient information to estimate HFC-236fa installed quantities or emissions in the fire protection sector.

1.6.5 Global Halon, HCFC, and HFC Banking (Agent Management)

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 concepts and terminologies apply to all fire suppression gases including halons, HCFCs, HFCs, and their alternatives.

FSTOC continues to see issues regarding the loss of historical knowledge due to the length of time over which the Montreal Protocol activities have been implemented. 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 halons, HCFCs, HFCs, and their alternatives use, recycling, and banking. Lack of understanding about long-term needs for halon 1301 has also resulted in halon destruction. FSTOC notes that this lack of experience and historical knowledge is becoming more challenging as it works with various parties and organizations on issues related to acquiring halons to meet their continuing needs. Parties may wish to address awareness programmes to re-establish this loss in institutional memory.

1.7 Emission Reduction Strategies and Banking (Chapter 7)

Avoidable halon and other halogenated gaseous fire extinguishing agent releases account for greater emissions than those needed for fire protection and explosion prevention. Clearly such releases can be minimized.

- Do not use halons in new fire protection applications or new designs of equipment where alternatives exist.
- Take advantage of opportunities to re-evaluate the need for existing halon systems or extinguishers and replace with suitable alternatives where it is technically and economically feasible to do so.
- Do not use HCFCs and high-GWP HFCs in fixed systems unless approved by the facility owner and a full risk analysis has been performed by a fire professional with expertise in their use and specifications, and the agent was deemed the only viable option taking into consideration safety, efficacy, economics, and environmental effects.
- Encourage the application of risk management strategies and good engineering design to take advantage of alternative fire protection schemes.
- Educate and train personnel on system characteristics.
- Manage storage of halon and other halogenated gaseous fire extinguishant reserves and perform routine leak detection.

- Implement national Awareness Campaigns on all environmental concerns (ODS, GWP, Climate Change).
- Develop or adopt Technical Standards and Codes of Conduct.
- Develop databases and implement record keeping on halon, HCFC and HFC installed base quantities, transfers, and emissions.
- Develop halon, HCFC, and HFC fire extinguishing agent management plans including end of useful life considerations.
- Ensure "Responsible Use" of halons and other halogenated gaseous fire extinguishing agents.

1.8 Destruction (Chapter 8)

The FSTOC maintains the position that destruction should only be employed as the final disposition option when halons, HCFCs, HFCs, and their alternatives are too contaminated and cannot be reclaimed to an acceptable purity.

The world's first pilot halon destruction for carbon offset occurred in February 2021 in the US, using internally sourced halon 1301 for the creation of carbon credits which were traded in the voluntary carbon market. The FSTOC is concerned that destroying halon 1301 for carbon credits could contribute to global shortages / regional imbalances of halon 1301 to support long-term enduring uses.

When local access to reclamation or destruction services is not available, the classification of halons as hazardous waste by some the parties results in applying the Basel Convention, The Control of Transboundary Movements of Hazardous Wastes and their Disposal, which continues to obstruct the international movement of halons. In the future this could also affect other fire extinguishing agents.

The FSTOC is not aware of any new information, such as test data, relating to already approved destruction technologies.

1.9 Alternatives to HFCs (Chapter 9)

The fire protection industry has worked on developing alternatives to halons, HCFCs, and now HFCs for over four decades as environmental concerns have evolved. Extensive research was conducted initially to identify alternatives to halons, while simultaneously implementing improvements to maintenance, servicing, and storage of halons, user awareness and training, replacement of halon systems where practical, as well as highly improved risk management. The evolution of alternatives has proceeded along the path of selection of chemicals with the most similar characteristics followed by research and development including testing, certification, toxicity and safety analyses, standards development, and commercialization. In that process, several HFCs were developed through to commercialization (note: both the agent and hardware must successfully pass all testing and certifications). Following the commercialization of HFCs, development of further alternatives continues, and other chemicals were developed including FK-5-1-12, 2-BTP, CF_3I, and some combinations with inert gases, water mist, or solid particulates. This evolution has been fairly linear, as makes sense, in that the most likely candidates would be the most commercially viable due to the extensive cost of research and development.

For fire protection applications, information where alternatives to HFCs are available are provided for applications in the following subsectors of use: civil aviation; military ground vehicles, naval, and aviation applications; oil and gas, general industrial fire protection, and merchant shipping. For an alternative to be acceptable, it must have passed all six Decision XXVI/9 criteria, 1) it is commercially available, 2) technically proven, 3) environmentally sound, 4) economically viable and cost effective, 5) safe to use, and 6) easy to service, according to FSTOC's interpretation of these criteria. FSTOC notes that some alternatives are actually halon alternatives rather than HFC alternatives. Furthermore, in some sectors or applications, HFCs were not used and there are no alternatives to the halons available, e.g., in aircraft cargo compartments. In these cases, it seems appropriate to state that, currently, alternatives to HFCs are not applicable (N/A).

On December 20, 2022, the 3M corporation announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**, including the fire suppressant FK-5-1-12. The FSTOC understands that there are other manufacturers of this agent. Clearly, this is an evolving situation, and the FSTOC expects to understand more fully the potential impacts to HFCs and their alternatives in the future.

1.10 References

3M (2022): 3M Press Release, December 20, 2022. *https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025*

EEA (2020): "Fluorinated greenhouse gases 2020" EEA Report No. 15/2020, https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2020.

EPA (2016): Federal Register December 1, 2016, pages 86778-86895. "Protection of Stratospheric Ozone: New Listings of Substitutes…Final Rule" https://www.govinfo.gov/content/pkg/FR-2016-12-01/html/2016-25167.htm

EPA (2022): Federal Register July 28, 2022. Proposed Rule. "Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program in Refrigeration, Air Conditioning, and Fire Suppression." https://www.federalregister.gov/documents/2022/07/28/2022-14665/protection-of-stratospheric-ozone-listing-of-substitutes-under-the-significant-new-alternatives

HRC (2022): "Halon 1301 Use in Civil Aviation: Guidance for Reducing Emissions and Contamination During Servicing and Maintenance", Halon Recycling Corporation, March 2022. www.halon.org/hrc-av-outreach

2 Introduction

2.1 Renaming of the Halons Technical Options Committee as the Fire Suppression Technical Options Committee

The Halons Technical Options Committee (HTOC) role has broadened over the years. Its initial focus was solely on halons and their alternatives. Over time, the HTOC also focused on hydrochlorofluorocarbon (HCFC) agents and their alternatives and more recently on hydrofluorocarbons (HFCs) and their alternatives. As a result, the expertise of the HTOC was much wider than just considering alternatives to halons.

Another aspect of this broader role is that of safety aspects beyond general agent toxicity and fire systems, both in terms of the high pressures of fire protections system cylinders and the increasing use of flammable refrigerants, as HFCs are phased down in the refrigeration, air-conditioning, and heat pump sector, as outlined in section 2.3.

In the light of this, in November 2022, the parties to the Montreal Protocol adopted Decision XXXIV/11, which *inter alia*, renamed the Halons Technical Options Committee as the Fire Suppression Technical Options Committee (FSTOC). This change was welcomed by the committee.

For this report, all references to the committee's current and past work, actions, and opinions are referred to as the FSTOC. All references to the previous reports are referred to as the HTOC.

2.2 Changes Following the 2018 Assessment Report

The 2018 Assessment report was issued in three volumes: the main Assessment report and two Supplementary reports, one covering Civil Aviation and one covering banking of halons, HCFCs, and HFCs. In addition, the FSTOC updated all five Technical Notes in 2018. This was a significant effort, so the FSTOC has decided to streamline its reports and Technical Notes as follows: the 2022 Assessment report is now a single volume, and the five existing Technical Notes have been rewritten as three and one new one has been created as follows:

Technical Note A: Technical Note #3, Revision 3 - *Explosion Protection: Halon Use and Alternatives* has been incorporated as a chapter into Technical Note #1, Revision 5 - *Fire Protection Alternatives to Halons, HCFCs and HFCs.* This combined Technical Note is now called **Technical Note A.**
https://ozone.unep.org/science/assessment/teap

Technical Note B: Technical Note #2, Revision 3 - *Emission Reduction Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents* has been combined with Technical Note #4, Revision 2 - *Recommended Practices for Recycling Halons and Other Halogenated Gaseous Fire Extinguishing Agents*. This combined Technical Note is now called **Technical Note B**.
https://ozone.unep.org/science/assessment/teap

Technical Note C: Technical Note #5, Revision 2 – *Destruction Technologies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents* has been updated and renamed **Technical Note C**.
https://ozone.unep.org/science/assessment/teap

Technical Note D: Decision XXVII/2, paragraph 4 states:

4. To request the Technology and Economic Assessment Panel to conduct periodic reviews of alternatives, using the criteria set out in paragraph 1 (a) of decision XXVI/9, in 2022 and every five years thereafter, and to provide technological and economic assessments of the latest available and emerging alternatives to hydrofluorocarbons.

To respond to this decision, the FSTOC has summarized the information on alternatives to HFCs in Chapter 9 of this report. It will also be published as FSTOC **Technical Note D**. Placing this information as a stand-alone document confers several advantages: the information is presented in a clear and systematic manner, it should be easy for the parties to find, and finally it should be easy for the FSTOC to update in 5 years' time.
https://ozone.unep.org/science/assessment/teap

2.3 Safety Information

The Globally Harmonized System (GHS) of classification and labelling of chemicals defines "Gases under Pressure" as gases that are contained in a receptacle at a pressure of 200 kPa (gauge) or more at 20°C, or which are liquefied or liquefied and refrigerated. Cylinders containing gases under pressure are safe if treated properly, but if handled incorrectly or damaged, they can be extremely dangerous; the main hazards associated are described below.

2.3.1 Hazard of Pressurized Cylinders

Cylinders holding gas under pressure contain a high amount of stored energy. If a cylinder valve is breached (e.g., breaks off when the cylinder falls and strikes a hard surface, etc.), the stored energy in the cylinder is released as thrust. The cylinder can accelerate to speeds great enough to penetrate concrete walls. The pressure in a cylinder will increase when subjected to increased temperatures. Cylinders are designed with a pressure relief valve, but if this valve fails, then the cylinder can fail. Caution is needed to ensure that systems and apparatus used with these cylinders are not over-pressurized, which could lead to forceful rupture and flying fragments.

The following data sources provide more information on the hazards of pressurized cylinders:

https://ehs.unl.edu/sop/s-gases_under_pressure_haz_risk_min.pdf

https://www.osha.gov/compressed-gas-equipment

https://www.hse.gov.uk/comah/sragtech/techmeascylinder.htm

2.3.2 Toxicological Hazards / Asphyxia

Hazards associated with gases under pressure include oxygen displacement and toxic gas exposures, as well as the physical hazards associated with high pressure systems. When released from the confines of a cylinder, gases under pressure will expand to occupy several hundred or even a thousand times the space. This can displace breathing air and result in an oxygen-deficient atmosphere and a person can be overcome quickly and without warning. If a gas is cryogenic, it can cause brittle fracture of components and freeze skin or mucus membranes upon contact. Special storage, use, and handling precautions are necessary to control these hazards.

In general, personnel should not be exposed unnecessarily to atmospheres into which gaseous fire extinguishing agents have been discharged. Mixtures of air and halon 1301 have low toxicity at fire extinguishing concentrations and there is little risk posed to personnel that might be exposed in the event of an unexpected discharge of agent into an occupied space. The exposure criteria were developed by the United State of America (US) Environmental Protection Agency (EPA) and adopted by the International Organization for Standardization (ISO) in the 1990s and have not changed since then. The highest agent concentration for which no adverse effect is observed is designated the "NOAEL" for "no observed adverse effect level". The lowest agent concentration for which an adverse effect is observed is designated the "LOAEL" for "lowest observed adverse effect level".

In the case of inert gases, the usual concern is the residual oxygen concentration in the protected space after discharge. For vaporizing liquid agents, the primary health concern is cardiac effects arising as a consequence of absorption of the agent into the blood stream. It is evaluated according to a specific dose and exposure time protocol. This means of assessing vaporizing liquid agents has been further enhanced by application of physiologically based pharmacokinetic modeling, or "PBPK", which accounts for exposure times. Some agents have their use concentration limits based on PBPK analysis. The approach is described in more detail in Annex G, **ISO 14520-1 (2016)**.

2.3.3 Acid Gas Decomposition Products

Decomposition of any of the halogenated vaporizing liquid agents in the fire extinguishing process produces acid-gas by-products (mostly hydrofluoric acid (HF) and carbonyl fluoride (COF_2)) that are both toxic and corrosive. It should be noted that the fire itself will generate combustion by-products, which may also be toxic and corrosive. The amount of these decomposition products formed is directly related to the size of the fire, the volume of the space, and the time needed to establish the extinguishing concentration. Large, fast developing fires, such as flammable liquid hazards, produce life safety challenges (toxicity) to those entering a space after extinguishment but before it has been properly ventilated. There is the additional risk of corrosive effects of acid-gas deposition on sensitive contents (e.g., electronics).

2.4 Alternate Refrigerants and their Potential Flammability

2.4.1 Introduction

Flammability is the ability of a substance to burn or ignite, causing fire or combustion. For flammable substances, two important chemical characteristics that contribute to the flammability of a liquid substance are its flash point and vapor pressure. The flash point of a substance is the lowest temperature at which it can vaporize to form an ignitable mixture in air while the vapor pressure indicates the evaporation rate. Higher vapor pressures lead to lower flash points and therefore higher flammability. Standard tests exist to determine the lower and upper concentration limits of a combustible substance that is capable of propagating a flame under specified conditions. These limits therefore define the range of concentrations in which the substance is flammable in air and establish guidelines for safe handling, specifically in assessing ventilation requirements for the handling of gases and vapors.

Applicable standards (e.g., American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34) categorize mildly flammable gases by evaluating their lower and upper explosive limits, heat of combustion, burning velocity, or exhibition of flame propagation, in conformity with EN-1839 and ISO-817. Note that the terms lower and upper explosive limit are considered synonymous with lower and upper flammability limit.

Figure 2.1 summarizes how the refrigerant safety and flammability classifications are assigned by ASHRAE Standard 34.

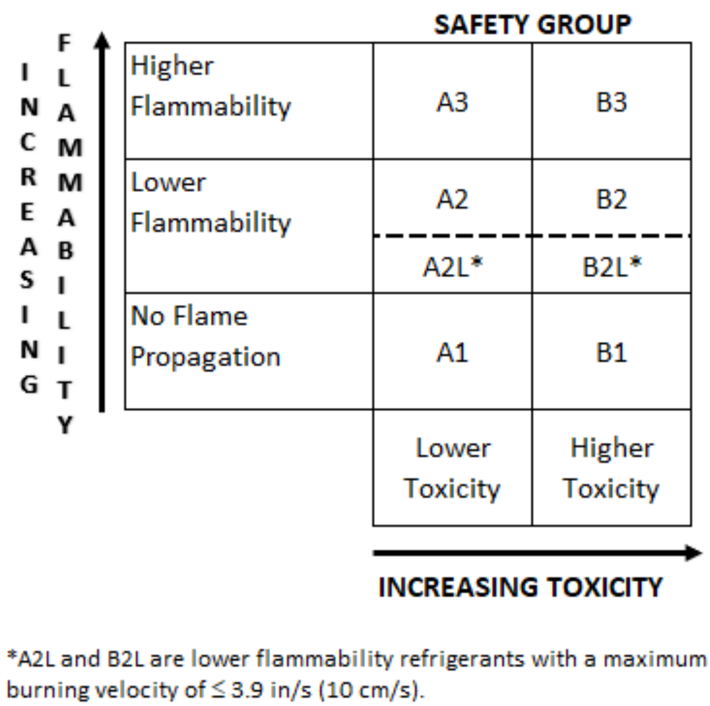


Figure 2.1: Refrigerant Classification According to ASHRAE Standard 34

The FSTOC believes that the A2L classification may not be understood by the wider refrigeration and air conditioning industry and the hazards of A2L refrigerants, which are still flammable after all, may not be fully appreciated.

2.4.2 Refrigerant Toxicity

In ASHRAE 34, there are two classes for toxicity: 1) lower toxicity (Class A) and 2) higher toxicity (Class B). Class A refrigerants are refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 parts per million (ppm) by volume, based on data used to determine threshold limit values (TLV)-time weighted average (TWA) or consistent indices. Class B refrigerants are refrigerants for which there is evidence of toxicity at concentrations below 400 ppm by volume, based on data used to determine TLV-TWA or consistent indices.

2.4.3 Refrigerant Flammability Classifications Using ASTM Standard E 681.

Class 1 (no flame propagation) is for refrigerants (single compound or blends) that do not show flame propagation when tested at 60°C/140°F and 101.3 kPa/14.7 psia.

Class 2 (flammable) is for single compound refrigerants or refrigerant blends that exhibit flame propagation when tested at 60°C/140°F and 101.3 kPa/14.7 psia, have a heat of combustion less than 19,000 kJ/kg (8,174 BTU/lb), and have a lower flammability limit (LFL) greater than 3.5% by volume.

Class 2L (mildly flammable) is for single compound refrigerants or refrigerant blends that exhibit flame propagation when tested at 60°C/140°F and 101.3 kPa/14.7 psia, have a heat of combustion less than 19,000 kJ/kg (8,174 BTU/lb), have a lower flammability limit (LFL) greater than 3.5% by volume, and have a maximum burning velocity of 10 cm/s (3.9 in./s) or lower when tested at 23°C/73.4°F and 101.3 kPa/14.7 psia.

Class 3 (highly flammable) is for single compound refrigerants or refrigerant blends that exhibit flame propagation when tested at 60°C/140°F and 101.3 kPa/14.7 psia, and that either have a heat of combustion of 19,000 kJ/kg (8,174 BTU/lb) or greater or a lower flammability limit (LFL) of 3.5% by volume or lower.

2.4.4 Concerns over Flammability

FSTOC continues to express concern with expanded use of alternative refrigerants owing to their potential flammability and yet to be determined effects on firefighting systems (e.g., agent effectiveness, by-products generated, etc.). Flammable refrigerants need additional care in system design, installation, and servicing. This could be a significant issue in Article 5 parties, where additional training will be required. Parties may wish to consider providing addition funds for training / capacity building in Article 5 parties where flammable refrigerants are being used as part of the HFC phasedown.

2.4.5 New Standards or Tests under Development

In addition to industry standard tests for measuring flame propagation (ASHRAE-34/ISO-817), new methods are being developed to address these concerns. One is the Japanese High-Pressure Gas Safety Act and its related regulations amended specifically to categorize "mildly flammable gases" or Class A2L Refrigerants.

These references contain useful information regarding refrigerant classification and safety considerations: **EPA (2022)**, **ASHRAE (2020)**, **Bacharach (2019),** and **Certifico (2020)**.

2.5 References

ASHRAE (2020): "Factsheet: Update on New Refrigerants Designations and Safety Classifications", https://www.ashrae.org/file%20library/technical%20resources/refrigeration/factsheet_ashrae_english_20200424.pdf

ASTM (2015): ASTM E681-09(2015), "Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)"

Bacharach (2019): "Understanding Refrigerant Safety Classification", https://www.mybacharach.com/understanding-refrigerant-safety-classifications/

Certifico (2020): "ISO 817 Refrigerants – Designation and Safety Classification", https://certifico.com/chemicals/documenti-chemicals/221-documenti-riservati-chemicals/10484-iso-817-refrigerants-designation-and-safety-classification

EPA (2022): "Refrigerant Safety", https://www.epa.gov/snap/refrigerant-safety

3 Impact of Existing and Possible Future Regulations on the Fire Protection Sector

3.1 Kigali Amendment / HFC Phasedown

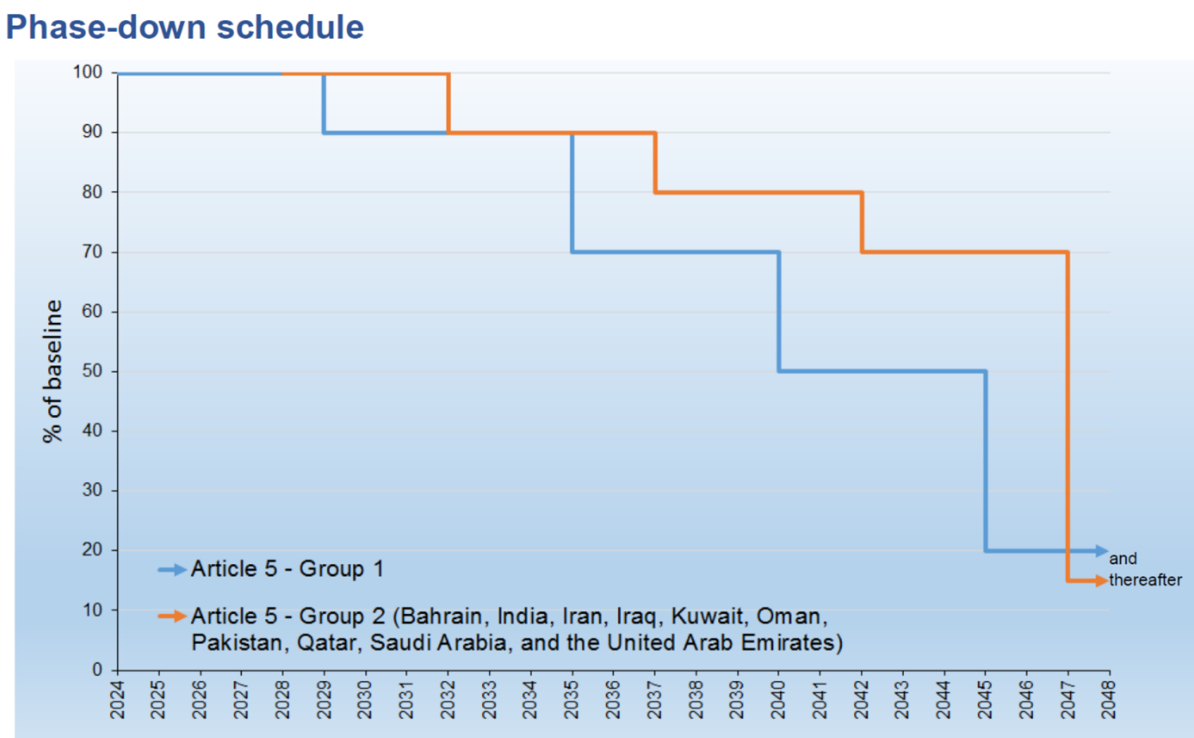
3.1.1 Background

In October 2016, at the 28th Meeting of the parties (MOP) in Kigali, Rwanda, Decision XXVIII/1 contained an amendment to add HFCs to the Montreal Protocol and slowly phase down their production and consumption. The terms “production” and “consumption” in this context have specific meanings, taken from Article 1 of the Montreal Protocol:

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

2. "Consumption" means production plus imports minus exports of controlled substances.

Unlike the controls on ozone-depleting substances (ODSs) that require a complete phaseout of production and consumption of controlled substances, the controls on HFCs are intended to only significantly reduce production and consumption on a global warming potential (GWP) basis, but not eliminate it. Under the Kigali Amendment, the production phasedown began in most non-Article 5 parties with a 10% reduction in 2019 and will end with an 85% reduction in 2036. For most Article 5 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 phasedown schedules for a group of parties in Eastern Europe and a group of parties with high ambient temperatures. The phasedown timeline is presented in Figure 3.1, taken from a UNEP factsheet, **UNEP (2016)**.



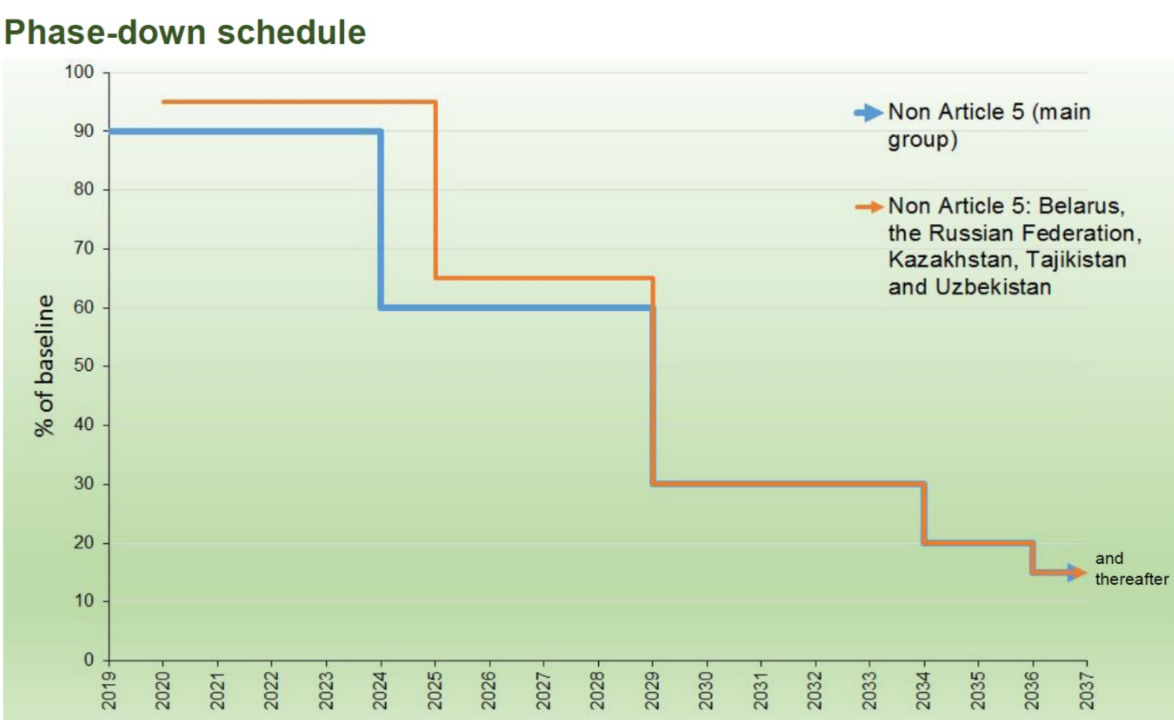


Figure 3.1: HFC Phasedown following the Kigali Amendment to the Montreal Protocol – (a) Article 5 parties and (b) non-Article 5 parties

3.1.2 HFC Phasedown Regulations

Many non-Article 5 parties including those of the European Union (EU), Canada, Japan, Australia, US, and the Russian Federation have implemented regulations to phase down the production of HFCs that follow, or have been adjusted to follow, the Kigali Amendment schedule. Most of these regulations are based on a quota or allowance allocation system that controls the manufacture and import of HFCs. Many of these regulations also include controls on specific HFCs in specific sectors in addition to the production phasedown. For example, the EU regulations include a prohibition on the sale of fire protection equipment containing HFC-23 as of 2016. In addition, a proposal released in April 2022 by the European Commission would prohibit the sale of fire protection equipment containing all HFCs as of January 1, 2024, unless their use is required to meet safety standards. Regulations in Australia, Canada, Japan, and the US do not currently include controls on HFCs used in fire protection.

To meet their obligations under the Kigali Amendment, Article 5 parties have set up systems to monitor the import and export of HFCs. In addition, many Article 5 parties are currently developing phasedown strategies and working on production and import/export quota systems to ensure compliance with the January 1, 2024 production freeze.

3.1.3 Impact on Fire Protection

In the 2018 Assessment report, the FSTOC anticipated that the initial 10% reduction in non-Article 5 parties would not have a significant impact on the availability of HFCs for fire protection. It was reasoned that the use of HFCs in fire protection is extremely small in comparison to other uses, the emissions are low, and sales of HFCs in most non-Article 5 parties were either declining or flat. In contrast, for example, what we have seen in the US is that there has already been significant impact in cost of HFCs. The FSTOC believes this is for the following reasons:

- HFCs used for fire extinguishing are high-GWP,
- the allocation mechanism in the US is GWP-weighted, and
- market commercial factors mean that producers and importers will need to decide which HFCs to manufacture or import, based on their GWP and future market needs

The combined effect of these factors means that the HFC phasedown in the US is having a large effect on the production and consumption of HFC fire extinguishants. The US HFC phase down began on January 1, 2022, and it has already had a significant impact on the pricing of HFCs for fire protection.

For the EU, a 2020 report by the European Environment Agency (EEA) estimates the total supply of newly produced HFCs (production and consumption) for fire protection in the EU has decreased by over 90% since the phasedown began in 2015. It appears that the use of HFCs in the EU has been replaced in part by FK-5-1-12 and inert gases.

In Japan, the use of HFCs for fire protection has been gradually decreasing in response to adoption of the Kigali Amendment and other efforts to prevent global warming. The amount of HFCs newly installed for fire protection in 2021 in Japan is about 30% of the most installed year, 2012.

The FSTOC anticipates additional impacts to the fire protection sector as the Kigali amendment phasedown continues and begins to impact additional regions and parties. This could reduce commercial viability of production of some HFC fire extinguishing agents in the future. This has implications for HFC banking to support enduring uses.

It is the FSTOC's experience that HFCs contained in fire protection equipment have historically enjoyed a relatively high level of recycling and reuse. As the supply of newly produced HFCs for fire protection decreases in response to phase down regulations, recycling becomes even more important as an alternative source of supply and is likely to increase in the future.

3.2 Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

3.2.1 Background

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) refers to a class of chemicals that contain fluorine atoms bonded to carbon atoms. Historically, PFAS was used to describe longer chain compounds that were used in products such as paper, textiles, leather, carpets, and firefighting foam. The regulation of PFAS initially focused on the eight-carbon chemicals perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). More recent PFAS definitions have broadened to include over 4,000 different fluorinated compounds ranging from gases to liquids to solids and including carbon chain lengths as short as a single carbon. As a result, some of these PFAS definitions now encompass HFCs and HFC alternatives such as hydrofluoro-olefins (HFOs) and fluoroketones (FKs).

The Organization for Economic Cooperation and Development (OECD) defines PFAS as follows: "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($–CF_3$) or a perfluorinated methylene group ($–CF_2–$) is a PFAS." The OECD definition of PFAS would encompass the following fire suppression chemicals: FK-5-1-12, HFC-227ea, HFC-125, HFC-236fa, 2-bromotrifluoropropene (BTP), hydrochlorofluorocarbon (HCFC) Blend B, HCFC-123 and Halocarbon Blend 55 (50/50 weight% FK-5-1-12 and hydrochlorofluoro-olefin (HCFO)-1233zd(E)).

Regarding the PFAS definition, OECD states "The term "PFASs" is a broad, general, non-specific term, which does not inform whether a compound is harmful or not, but only communicates that the compounds under this term share the same trait for having a fully fluorinated methyl or methylene carbon moiety." In addition, OECD notes "It also does not conclude that all PFASs have the same properties, uses, exposure and risks."

It should be noted that other countries or organizations may have different definitions of PFAS that may not encompass all of the same fire suppression agents as the OECD definition. It should also be noted that some in the atmospheric science community have reasoned that the definitions for PFAS need to be revised so that they no longer include substances such as HFCs and HFC alternatives that environmentally degrade to produce trifluoroacetic acid (TFA) as the longest perfluorinated carboxylic acid." **Wallington (2021).**

3.2.2 EU REACH

In July 2021, five European countries - Germany, the Netherlands, Norway, Sweden, Denmark - declared their intention to submit to the European Chemicals Agency (ECHA) a proposal for a REACH restriction covering all PFAS chemicals as defined above. The proposed restriction could have the impact of prohibiting the manufacture, import, sale or use of substances that fall under the PFAS definition at some future date. REACH restrictions usually include exemptions (derogations) for uses that have no alternatives. The expected date of submission of the PFAS restriction proposal to ECHA is January 2023. Based on the current schedule, if a PFAS REACH restriction is adopted, it would likely be completed in 2025 and become effective sometime after that.

3.2.3 UK REACH

In November 2021, UK REACH initiated a call for evidence on PFAS in preparation for development of a regulatory management options analysis (RMOA). The UK REACH definition of PFAS is similar to the OECD definitions and would encompass the same fire protection agents.

3.2.4 Impact on Fire Protection

A restriction on PFAS that incorporates HFCs and HFC alternatives could have a substantial impact on future availability and use of these alternatives in the EU unless specific exemptions for fire protection uses were included. Restricting or prohibiting the sale or use of HFCs and HFC alternatives could affect the ability of some users in the EU to effectively protect a range of special hazards from fire and explosion.

For example, if 2-BTP were to be included in PFAS restrictions, it would be devastating to the aviation industry's efforts to replace halons. 2-BTP is the result of a 20-year search for an alternative to halon 1211 in aviation hand-held fire extinguishers. It is currently replacing halon 1211 as a drop-in (same size extinguisher, slight increase in weight) on most new production aircraft, and all existing aircraft in the EU are expected to be retrofitted to 2-BTP by 2026. It took 15 years to develop and gain approval and there are no other in-kind (vaporizing liquids that do not require clean-up) candidate agents for this use that would not be considered PFAS by this definition. Not-in-kind alternatives (i.e., those that would require clean-up) have been tested for this use and failed to pass the minimum performance standards. In addition, vaporizing liquid agents are amongst the current candidates to replace halons in engine and cargo uses. Having them included in a REACH restriction would also derail the aviation industry's efforts to replace halons.

On December 20, 2022, 3M announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**, including the fire suppressant FK-5-1-12. The FSTOC understands that there are other manufacturers of this agent. Clearly, this is an evolving situation, and the FSTOC expects to understand more fully in the future how these proposed regulations will affect both HFCs and their alternatives.

3.3 Halon Regulations

3.3.1 European Union

The EU banned all non-critical uses of halons in 2003. Critical uses are listed in the current Annex VI to Regulation (EC) No. 1005/2009, **EC (2009).** Annex VI was revised in 2010 as per Commission Regulation (EC) No 744/2010 to contain "cut-off dates" for the use of halons in new designs of equipment or facilities and "end dates" when all halon systems or extinguishers in a particular application must be decommissioned (i.e., 'retrofit'), **EC (2010)**. The remaining critical uses are shown in Table 3.1. All of the remaining critical uses have already passed their cut-off dates, so only end dates are shown.

Table 3.1: Phase Out Dates in EC Reg. 1005/2009 Annex VI

Category	Purpose	Type of Extinguisher	Type of Halon	End Date: All Halons Decommissioned
1. On military ground vehicles	1.1 For the protection of engine compartments	Fixed system	1301 1211 2402	2035
	1.2 For the protection of crew compartments	Fixed system	1301 2402	2040
2. On military surface ships	2.1 For the protection of normally occupied machinery spaces	Fixed system	1301 2402	2040
	2.2 For the protection of normally unoccupied engine spaces	Fixed system	1301 1211 2402	2035
	2.3 For the protection of normally unoccupied electrical compartments	Fixed system	1301 1211	2030
	2.4 For the protection of command centres	Fixed system	1301	2030
	2.5 For the protection of fuel pump rooms	Fixed system	1301	2030
	2.6 For the protection of flammable liquid storage compartments	Fixed system	1301 1211 2402	2030
3. On military submarines	3.1 For the protection of machinery spaces	Fixed system	1301	2040
	3.2 For the protection of command centres	Fixed system	1301	2040
	3.3 For the protection of diesel generator spaces	Fixed system	1301	2040

	3.4 For the protection of electrical components	Fixed system	1301	2040
4. On aircraft	4.1 For the protection of normally unoccupied cargo compartments	Fixed system	1301 1211 2402	2040
	4.2 For the protection of cabins and crew compartments	Portable extinguisher	1211 2402	2025
	4.3 For the protection of engine nacelles and auxiliary power units	Fixed system	1301 1211 2402	2040
	4.4 For the inerting of fuel tanks	Fixed system	1301 2402	2040
	4.6 For the protection of dry bays	Fixed system	1301 1211 2402	2040
7. In land-based command and communication facilities essential to national security	7.1 For the protection of normally occupied spaces	Fixed system	1301 2402	2025

The European Commission released a proposal in April 2022 for a revised ODS regulation that would replace Regulation (EC) No. 1005/2009. The proposal includes two changes to the list of critical uses of halons: 1) the cut-off date for the use of halons in cargo compartments on aircraft would be pushed back from 2018 to 2024 to align with the International Civil Aviation Organization (ICAO) requirements and 2) the use of halons in fixed systems in land-based command and communication facilities essential to national security would be removed from the list. In addition, the proposal would prohibit the destruction of halons "unless there is documented evidence that the purity of the recovered or recycled substance does not technically allow its reclamation and subsequent re-use."

3.4 Aviation Halon Regulations

ICAO has established dates for the replacement of halons for all four applications where they are used on board aircraft.

- in lavatory fire extinguishing systems used in aircraft produced on or after December 31, 2011
- in hand-held fire extinguishers used in aircraft produced on or after December 31, 2018; and
- in engine and auxiliary power unit fire extinguishing systems used in aircraft for which application for type certification will be submitted on or after December 31, 2014

- in cargo compartment fire suppression systems used in aircraft for which an application for type certification will be submitted on or after November 28, 2024

It is important to note that these changes to ICAO standards are not requirements. States are expected to try to meet these standards, but they are allowed, and do, file "differences" which explain how they will not meet the standards, in part or whole. This means that they can and will continue to use halons or allow the use of halons past these dates for aircraft in their registry. Operation of such aircraft may, however, not be accepted by another State.

3.4.1 European Union

The following on-board uses of halons in aviation remain on the critical use list under Regulation (EC) No 1005/2009: hand-held, engine nacelle, APU, cargo compartment, and fuel tank inerting. As shown in Table 3.1, these critical uses are subject to end dates when all equipment containing halons must be decommissioned or retrofitted to a different agent. This differs from the approach in the ICAO resolution, which focuses on eliminating the use of halon in new production aircraft and new designs only. Flexibility provisions have, however, been put in place in Regulation (EC) No 1005/2009. For specific cases, derogations from the end dates for existing applications or the cut-off dates for new designs can be granted where it is demonstrated that no technically and economically feasible alternative is available.

Additionally, Regulation (EC) No 2015/640 includes requirements for the use of halon alternative agents in the built-in fire extinguishers of lavatories and in the portable fire extinguishers of large aircraft and large helicopters manufactured after a certain date (forward fit date). The time scale in Regulation (EC) No 2015/640 for halon replacement reflects the dates given in ICAO Annex 6. The forward fit dates set in Regulation (EC) No 2015/640 do not contradict, but complement, the end dates given in Commission Regulation (EC) No 1005/2009. Table 3.2 compares the EU and ICAO halon replacement dates.

Table 3.2: Comparison of EU and ICAO Halon Replacement Requirements

	Requirement	Lavatory	Handheld Extinguisher	Engine / APU	Cargo
New Design Aircraft	EC Cutoff Date	2011	2014	2014	2018[1]
	ICAO	2011	2018	2014	2024
Current Production Aircraft	EC End Date (includes retrofit)	2020	2025	2040	2040
	ICAO	2011	2018	NA	NA

1 - The cut-off date for the use of halons in cargo compartments on aircraft would be pushed back from 2018 to 2024 to align with ICAO requirements

3.5 Transboundary Shipments of ODS and HFCs

A significant challenge in relation to accessing facilities capable of reclaiming or destroying ODS and HFCs from an international movement perspective, especially for countries without reclamation facilities, relates to the Basel Convention, *The Control of Transboundary Movements of Hazardous Wastes and their Disposal,* **UNEP (1989)**. Under the Basel Convention, CFCs and halons are not contained in Annex VIII (list of hazardous wastes) and there are no technical guidelines for the environmentally sound management of wastes consisting of, or containing, ODS within the Basel Convention. As a consequence, the parties to the Montreal Protocol decided in Decision VII/31: Status of recycled CFCs and Halons under the Basel Convention that international transfers of controlled substances of the Montreal Protocol that are recovered but not purified to usable purity specifications prescribed by appropriate international and/or national organizations, including ISO, should only occur if the recipient country has recycling facilities that can process the received controlled substances to these specifications or has destruction facilities incorporating technologies approved for that purpose.

Depending on how the exporting country classifies the extinguishing agents destined for reclamation (i.e., whether they are defined as 'hazardous waste' or not), the Basel Convention can apply, thereby adding another layer of complexity, especially when the reclamation facility is in a country that is not a party to the Basel Convention. The complexities relate to inconsistencies with classification of the material; increased administrative efforts, increased costs associated with shipping, increased time to process Basel paperwork by each port adding time to the journey; difficulties locating a carrier that is prepared to carry the 'hazardous waste.' These are all challenges that arise from a lack of clarity in agent classification. Therefore, parties may wish to consider setting up an awareness campaign directed at the relevant agencies to avoid these issues.

3.6 Carbon Markets

The carbon market is becoming an important instrument in addressing climate change with increased focus by policy makers and government officials around the world creating carbon pricing instruments such as carbon taxes and emission trading schemes. Some of these instruments mandate a compliance-based system for companies that are obligated to reduce their greenhouse gas emissions. Also important is the increase in the voluntary carbon market used by companies to voluntarily purchase carbon offsets as part of reducing their carbon footprint.

3.6.1 HFC Recycling

As an example of carbon offsets or credits, the American Carbon Registry (ACR — a private voluntary US greenhouse gas registry), amended one of its methodologies in April 2022 to produce the 'Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Certified Reclaimed HFC Refrigerants, Propellants, and Fire Suppressants, Version 2.0.' Included in this version of the methodology for the first time is HFC-227ea. The methodology is underpinned by the premise that the use of certified reclaimed HFCs negates the need to manufacture new HFCs that would be a future emission. Companies in the US can submit projects to generate carbon credits. After independent validation and verification confirms that the projects meet the criteria of the methodology, they will generate voluntary credits that can be traded in the market.

3.6.2 Halon Destruction

The world's first pilot halon destruction for carbon credits occurred in February 2021 in the US, using internally sourced halon 1301 (2,687 pounds or 1.22 tonnes) and halon 1211 (884 pounds or 0.40 tonnes) for the creation of carbon credits that were traded in the voluntary carbon market.

The project was performed under the ACR Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removal from the Destruction of Ozone Depleting Substances and High-GWP Foam Version 1.1 **(ACR 2017)**. This methodology allows for the destruction of halon 1211 and halon 1301 from fire equipment or systems and excludes the destruction of halon 1301 originating in stockpiles. The recycled halon for the pilot project was recovered from decommissioned or retired equipment and destroyed using a Technology and Economic Assessment Panel (TEAP) approved destruction technology (i.e., rotary kiln incineration), resulting in the creation of 3,384 tCO_2e (metric tonnes CO_2 equivalent) credits from the project. The credits were then sold to a large reputable US information technology (IT) company.

The creation of carbon credits from the destruction of halons or the re-use of reclaimed HFCs signals that carbon markets are starting to have influence on industry behavior, and in the future we may see an increase in the number of carbon offset projects that could have an impact on fire extinguishing agent supply and demand.

The FSTOC is concerned that large scale destruction of halon 1301 for carbon credits could contribute to global shortages / regional imbalances of halon 1301 for enduring uses.
To ascertain the future impact of these types of programmes, the FSTOC will continue to monitor the international compliance and voluntary carbon markets.

3.7 References

3M (2022): 3M Press Release, December 20, 2022. *https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025*

ACR (2017): Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from the Destruction of Ozone Depleting Substances and High-GWP Foam, Version 1.1, September 2017, https://americancarbonregistry.org/carbon-accounting/standards-methodologies/destruction-of-ozone-depleting-substances-and-high-gwp-foam/acr-destruction-of-ods-and-high-gwp-foam-september-2017-v1-1.pdf

EC (2009): REGULATION (EC) No 1005/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 September 2009 on substances that deplete the ozone layer. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:286:0001:0030:EN:PDF

EC (2010): COMMISSION REGULATION (EU) No 744/2010 of 18 August 2010 amending Regulation (EC) No 1005/2009 of the European Parliament and of the Council on substances that deplete the ozone layer, with regard to the critical uses of halons. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:218:0002:0008:EN:PDF

UNEP (1989): The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal**,** https://www.unep.org/resources/report/basel-convention-control-transboundary-movements-hazardous-wastes

UNEP (2016): The Kigali Amendment to the Montreal Protocol: HFC Phase-down, UNEP OzonAction Factsheet, https://wedocs.unep.org/bitstream/handle/20.500.11822/26589/HFC_Phasedown_EN.pdf?sequence=1&isAllowed=y

Wallington (2021): Wallington *et al*., "The case for a more precise definition of PFAS", Environ. Sci. Processes Impacts 2021 (23) 1834-1838.

4 Fire Protection Alternatives to Halons, HCFCs, and HFCs

4.1 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.

4.1.1 The Success of Halons in Fixed Systems

The wide adoption 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 US Department of Defense at its Pentagon Headquarters in 1959, **Jones (2015)**.

2. The second driver was system cost where, to the surprise of many, it became obvious that halon systems cost less than CO_2 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, equally safe 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 CO_2. With the halt of production of the halons, the use of CO_2 systems increased significantly, especially in the protection of machinery spaces on merchant ships.

The movement of 50-75% of halon application to non-in-kind by those who had chosen halons for their applications in the past 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.

4.2 New Alternatives

Detailed discussion of substitutes for halons, HCFCs, and high GWP HFCs is given in FSTOC Technical Note A, **FSTOC (2022a)**.

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 HCFO-1233zd(E) for consideration as a single-component total flooding alternative fire protection agent for halon 1301, HFC-227ea, HFC-125, or HFC-23 in the major standards bodies in the US and in ISO in 2017, the only progress on potential alternatives is represented by HB-55; refer to section 4.3.4.2. Generally speaking, the FSTOC is of the opinion that although research to identify potential new fire protection agents from existing candidates is continuing, it could take a quite a long time before new alternatives could have a significant impact on the fire protection sector. This is mainly due to the lengthy process of testing, approval/certification, and market acceptance of new fire protection equipment types and agents.

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 from when the recommendation was made). However, there is also no assurance that any new agents will be developed 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/blends 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.

4.3 Initial Substitutes in the Former Halon Sector

4.3.1 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 environmental and safety criteria, namely, they would have to have acceptable ozone-depleting potentials (ODPs), GWPs, and atmospheric lifetimes, 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 US, the EPA, under its Significant New Alternatives Policy (SNAP) program, assumed responsibility for the assessment of certain 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 of substitutes that are deemed acceptable, acceptable with use restrictions, or unacceptable as fire extinguishing agents for use in total flooding and streaming applications. The SNAP lists are available on the EPA website at https://www.epa.gov/snap/substitutes-fire-suppression-and-explosion-protection.

For any agent to be recognized by National Fire Protection Agency (NFPA) 2001 Standard on Clean Agent Fire Extinguishing Systems, **NFPA (2022)**, 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 US 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 fire protection applications of interest. Note, however, inclusion of an agent on the SNAP list does not necessarily mean it is an appropriate choice and additional application-specific evaluation and listings may be required.

4.3.2 Alternatives in General Use

In-kind agents that satisfy the above 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-listed for use in occupied spaces, and that are included in ISO 14520 and NFPA 2001, as follows:

- Inert gas (IG) agents: IG-01, IG-100, IG-55, and IG-541
- Vaporizing liquids: FK-5-1-12, HFC-23, HFC-125, HFC-227ea, HFC-236fa, HB-55

Fewer in-kind agent options have been identified as substitutes for halon 1211, as discussed in section 4.3.8.

4.3.3 Agent Alternatives for Fixed Systems

There are several in-kind alternatives to halons for most applications. These started with HCFCs and perfluorocarbons (PFCs), followed closely by HFCs and IGs, and more recently by an 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 IGs also represent low-GWP and no-GWP alternatives, respectively, 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 lower quantities. HFC-125 is used as the extinguishing agent in some military ground vehicle and 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.

ISO 14520 parts 12, 13, 14, and 15 report properties of four inert gas agents for use as alternatives to halon 1301 in fire extinguishing systems. They are listed below in descending order of minimum extinguishing concentration (MEC) as determined by the cup burner test using heptane as the test fuel. Gas mixture compositions are in volume per cent.

- 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 IG 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 vaporizing liquids, anecdotal information has suggested the split in market share is 55% HFCs and 45% FK-5-1-12 when measured in terms of agent weight sold in systems. However, the market share in terms of systems may be quite different: since the molecular weight of FK is almost double that of HFC-227ea, and their design concentrations are similar, the ratio of installed systems favors HFC-227ea more strongly than the market share by weight.

There are regional differences in the use of vaporizing liquid agents versus inert gas agents. Generally, the Americas more often use vaporizing liquid agents whereas Europe shows a preference for IG systems including all four types. In the Americas, the split is estimated at 80% vaporizing liquid agent systems versus 20% IG systems on a system basis. In Europe, the split is believed to be closer to 50/50 between vaporizing liquid agent systems and IG systems. On a worldwide basis, the market share of the systems sold appears to be evenly split between the vaporizing liquid agent systems and inert gas systems as shown in Figure 4.1.

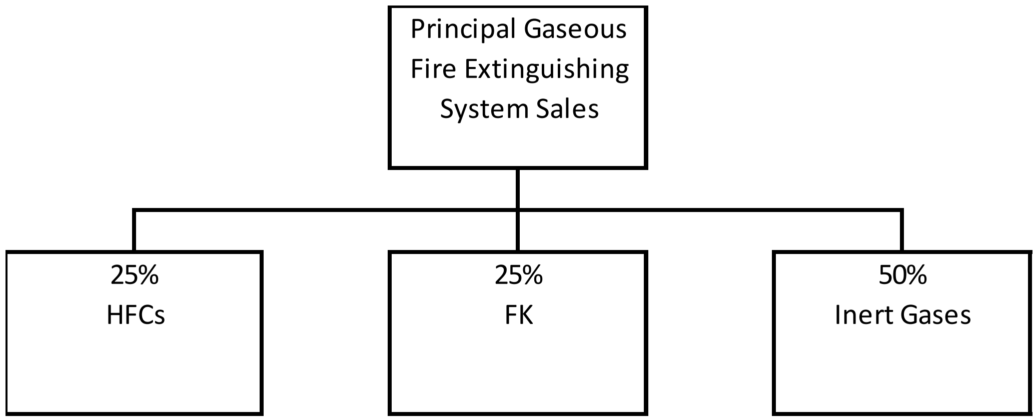


Figure 4.1: Approximate Global Market Share by System Type

4.3.3.1 Vaporizing liquid versus Inert Gas Agents

Vaporizing liquid agents typically are stored in nitrogen-pressurized system cylinders at in-cylinder storage densities from about 500 kg/m^3 to 1400 kg/m^3, depending on their liquid density. Inert gas agents are stored in high-pressure cylinders, typically at 200 or 300 bar, which results in cylinder agent storage densities of about 220 to 400 kg/m^3. Thus, IG systems require more cylinder volume per kilogram of agent than for the vaporizing liquid agents. The early IG systems were limited to a maximum cylinder size of 83 litres pressurized to 150 bar. More recent versions are pressurized to 300 bar, representing a 38% increase in stored agent mass per cylinder. High-pressure cylinders of 140 litres capacity are now available. The increased storage pressure and the increased cylinder capacity has brought the inert gas systems to a cost level that is more competitive with the vaporizing liquid agent systems.

It is a common practice, when discussing agent requirements, to consider the required agent concentration in terms of volume percent. This approach can be misleading because it does not allow direct comparison of the agent weight (mass), cylinder count, and the floor space required. Table 4.1 illustrates how differences in agent properties relate to minimum mass quantities required to protect a typical Class A fire hazard (Class A fires consist of solid combustibles such as wood, coal, paper, plastic, straw, cloth, rubber, or any other solid material). Understanding the agent and cylinder quantities required is central to assessing the system cost and facility floor space requirements for decision making.

Table 4.1: Minimum Agent Design Concentration and Agent Quantity for Surface Class A Fire Applications (at 20°C)

Reference ISO 14520 Subpart	Agent	Minimum design concentration, vol. %	Minimum agent quantity[1], kg/m^3
2	CF_3I [2]	4.6	0.389
5	FK-5-1-12	5.3	0.778
8	HFC-125	11.2	0.640
9	HFC-227ea	7.9	0.625
11	HFC-236fa	8.8	0.632
12	IG-01	41.9	0.902
13	IG-100	40.3	0.601
14	IG-55	40.3	0.728
15	IG-541	39.9	0.721
17	Halocarbon Blend 55	7.8	0.674

[1] Agent quantities were calculated in accordance with ISO 14520-1, sections 7.6.2 for halocarbon agents, and 7.6.3 inert gas agents

[2] CF_3I is approved for non-occupied spaces only

Decomposition of any of the vaporizing liquid agents in the fire extinguishing process produces by-products (including hydrofluoric acid (HF) and carbonyl fluoride (COF_2)) that are both toxic and corrosive. It should be noted that the fire itself will generate combustion by-products that may also be toxic and corrosive. The amount of these decomposition products formed is directly related to the size of the fire, the volume of the space, and the time needed to establish the extinguishing concentration. 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 properly ventilated. There is additional risk of corrosive effects of acid-gas deposition on sensitive contents (e.g., electronics).

Mitigation techniques to limit HF and COF_2 generation have been developed for some systems that use HFC-227ea.

- The U.S 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 of their armoured vehicles. The powder exits the extinguisher before the HFC-227ea, thus knocking down flames before the HFC-227ea arrives to complete the extinguishment. This technique has also been evaluated with FK-5-1-12. However, it was not able to sufficiently mitigate the HF and COF_2 generation. By-products were reduced proportionally, but levels remained above acceptable limits. Additionally, it was found that FK-5-1-12 and sodium bicarbonate are not compatible when mixed directly together, see section 5.2.2.1 for more details.

- The U.S. Navy uses a somewhat similar technique in some larger shipboard spaces where there is significant concern over toxic by-product formation. In these larger systems, a water spray simultaneously discharges with HFC-227ea. The water spray cools the very hot combustion gases in the protected space thereby reducing chemical agent hydrolysis, the process that forms acid gases. However, most Navy shipboard systems use HFC-227ea only (no water spray cooling) and rely on design concentrations that are 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 which allows ventilation shutdown as well as time for any remaining personnel to exit the space before the system discharges.

In addition, HFC-236fa has been used as a halon replacement in the crew compartments of military vehicles at a higher concentration, which also serves to mitigate HF and COF_2 generation.

4.3.3.2 Comparison of HFC, FK, and IG Systems

When considering employing a system with HFCs, or their potential in-kind alternatives (FK-5-1-12 or one of the IGs), end users must consider several factors including system cost, weight and footprint, environmental impact, performance at low application temperatures, and impact of FK agent decomposition products (mainly HF and COF_2). Often, users with numerous systems throughout their facilities will standardize on a particular agent or system type to simplify maintenance. Table 4.2 indicates some of the positive and negative attributes of alternative agents for fire protection systems.

Table 4.2: Historical 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 • Acceptable for use in normally occupied areas	• High GWP_{100} (3220)* • Decomposition in flames produces HF and COF_2 • Potentially impacted by the HFC phasedown under Kigali Amendment to the Protocol

HFC-125	• High volatility at low application temperatures (e.g. aircraft engine nacelles) • Acceptable for use in normally occupied areas	• High GWP_{100} (3500)* • Decomposition produces HF and COF_2 • Potentially impacted by the HFC phasedown under Kigali Amendment to the Protocol
HFC-23	• Very high volatility makes this the only practical choice in some at low-temperature applications. • Acceptable for use in normally occupied areas	• Very high GWP_{100} (14,800)* • Decomposition in flames produces HF and COF_2 • Potentially impacted by the HFC phasedown under Kigali Amendment to the Protocol
FK-5-1-12	• Negligible GWP (<1) • Not affected by HFC phasedown • Acceptable for use in normally occupied areas	• ~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
Inert Gas	• Cost ~ FK-5-1-12 • No decomposition products • No environmental impact • Acceptable for use in normally occupied areas	• Cost greater than for HFC-227ea • High cylinder storage space and weight • IG-541 contains CO_2, which is intended to increase blood oxygenation and cerebral blood flow in low oxygen atmospheres. The design concentration should result in no more than 5% CO_2.

* GWP_{100} values are taken from the 4th IPCC Assessment Report (also known as AR4 values), **IPCC (2007)**.

In regions where the HFC phasedown has begun, the cost of HFC-227ea appears to be rising and therefore the historical economics between alternatives are now changing. It is too early to understand fully the impacts of these changes. The FSTOC will continue to monitor the impacts to the market.

4.3.4 Recent Developments since the 2018 Assessment Report

4.3.4.1 CF_3I

CF_3I was first evaluated in the late 1990's, but following some adverse toxicity results, attention was focused elsewhere. Specifically, its cardiotoxic NOAEL and LOAEL are 0.2 volume% and 0.4 volume%, respectively, which are both well below its MEC. This precludes this agent's use in normally occupied spaces, 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 in terms of space and weight. This is because iodine can undergo the same catalytic radical recombination reactions as bromine, which makes it a very efficient fire extinguishing agent.

The FSTOC is aware that the civil aviation industry is currently refocusing on CF_3I, primarily as an engine nacelle / auxiliary power unit (APU) fire extinguishing agent. It was also investigated for civil aviation cargo compartment applications, but it failed a key test, **Shaw (2019)**. For more information on CF_3I and possible aviation applications refer to section 5.1.5.3 of this report. It is possible that this agent may have expanded use in other applications which are not normally occupied. Recently, under SNAP Rule 25, EPA proposed to allow 2-BTP as total flooding agent for use in normally unoccupied spaces under 500 ft^3, **EPA (2022)**.

4.3.4.2 Halocarbon blend 55 (HB-55)

While HCFO-1233zd(E) was removed from the NFPA 2001 Standard for fire extinguishing agents, HB-55 was added to the US EPA SNAP list as "HCFO-1233zd(E)/C6- perfluoroketone blend." It was adopted into NFPA 2001 (2022) as "HB-55," and in ISO Standard 14520-17 (2022) designated as "Halocarbon Blend 55." Agent Characteristics are listed in Table 4.3 and Table 4.4. All data are taken from ISO 14520, Part 17.

Table 4.3: Fire Extinguishing Data for HB-55

Fuel	Extinguishing concentration (Vol%)	Design Concentration (Vol%)
Class A: Wood	6.0	7.8
Class A: PMMA	5.4*	
Class A: PP	5.4*	
Class A: ABS	5.4*	
Class B (Heptane, cup burner)	5.5	7.8
Class B (Heptane, room test)	6.0	

*The test apparatus for the three polymeric fuel tests was different to the apparatus previously used to determine the extinguishing concentration for other agents.

Table 4.4:Toxicological and Environmental Properties of HB-55

Property	Value
4-hour LC-50	> 11 Vol%
NOAEL	8.7 Vol%
LOAEL	> 8.7 Vol%
100-year GWP	1
ODP	0.000

4.3.5 Paths Forward

Post Kigali, it is likely that the market share of HFCs will continue to decline. It is too early to say how the market share of IG and FK systems will change, as the effect of the proposed PFAS restrictions (see section 3.2 above) is not known at this time. These proposed regulations may change users' perceived importance of the positives and negatives in Table 4.2. The impact of HB-55 remains to be seen. The FSTOC will continue to monitor this rapidly changing situation.

4.3.6 Water Mist

Water mist systems strive to generate and distribute within a protected space very small water mist droplets which serve to extinguish flames by the combined effects of cooling and oxygen dilution by steam generated upon water evaporation. Technologies used to generate fine water mists include:

- Low pressure single fluid atomization
- High pressure single fluid atomization
- Dual-fluid atomization
- Hot water steam generation

Table 4.5 summarizes key attributes of water mist technology.

Table 4.5: Attributes of Water Mist

Agent	Water mist
Applicable Standards	NFPA 750, FM 5560, UL 2167, VdS 3188en, VdS 2498, EN 14972 (series)
Efficacy	For use in occupied spaces. Uses approximately 10 % of the total water quantity discharged by traditional sprinkler system to suppress fires, where tested.
Toxicity	Active antifreeze ingredient Glycol mist poses inhalation toxicity risk.
Safety Characteristics	Risk of burn or frostbite at temperature extremes. Active antifreeze additives can pose risk of explosions, **NFPA (2014), QRFS (2018)**
Environmental Characteristics	No adverse characteristics. Water mist does not contribute to stratospheric ozone depletion or to greenhouse warming of the atmosphere. Water containing additives may, however, have other environmental contamination risks, e.g., foams, antifreeze and other additives

Water mist systems offer some advantages due to their low environmental impact, ability to suppress three-dimensional flammable liquid fires under defined conditions, and reduced water application rates relative to automatic sprinklers in certain applications. More recent innovations include use of nitrogen with water mist to achieve inert gas extinguishing effects and use of dual-fluid (air-water) nozzles to achieve ultrafine droplets and adjustable spray patterns (by varying the air-water ratio). Several systems have been approved by national authorities for use in relatively narrow application areas. To date, these applications include shipboard machinery spaces, combustion turbine enclosures, flammable and combustible liquid storage spaces as well as light and ordinary hazard sprinkler application areas.

The performance of a water mist system is strongly dependent on its ability to generate sufficiently small droplet sizes and distribute adequate quantities of water throughout the compartment. Factors that affect the ability of achieving that goal include velocity, distribution, and spray pattern geometry, as well as the momentum and mixing characteristics of the spray jet and test enclosure effects. Hence, the required application rate varies by manufacturer for the same hazard. Therefore, water mist must be evaluated in the combined context of a suppression system and the risk it protects and not just an extinguishing agent.

Single fluid systems utilize water delivered at 7 - 200 bar pressure and spray nozzles that deliver droplet sizes in the 10 to 100 μm diameter range. Dual systems use air, nitrogen, or another gas to atomize water at a nozzle. Both types have been shown to be promising fire suppression systems. The major difficulties with water mist systems are those associated with design and engineering. These problems arise from the need to distribute and maintain an adequate concentration of mist throughout the space while momentum of hot fire gases, ventilation, gravity, and water deposition loss on surfaces deplete the concentration. Engineering analysis and experimental programmes for specific mist products (with unique droplet distribution and concentration) are employed to minimize the uncertainty.

EPA listed water mist systems composed of potable water and natural sea water as acceptable without restriction. However, water mist systems comprised of mixtures in solution must be submitted to EPA for review on a case-by-case basis.

Water mist does not contribute to stratospheric ozone depletion or to global warming. Water containing additives may, however, have other environmental contamination, safety, and toxicity risks, e.g., foams, antifreeze, and other additives.

Water mist systems can create two issues:

1. If there is a fire, the smoke creates carbon, which in turn will surround the water particles and create a "dirty" water droplet that can then conduct electricity and defeat the whole purpose of a clean fire suppression action.

2. If there is no fire and the system goes off accidentally (also known as cold discharge), the water droplets will not absorb heat/expand, and instead lead to water pooling at the floor, which is where most of the electric cables are fed, creating a potentially dangerous situation.

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. Regarding aircraft applications, in 2017, one water mist-nitrogen system passed all the criteria of the International Aircraft Systems Fire Protection Working Group (IASFPWG) Minimum Performance Standard (MPS) for cargo bays, **Dadia (2017)**.

4.3.7 Aerosol Extinguishing Agents

Another category of technologies being developed and introduced are those related to fine solid particulates and aerosols. These take advantage of the well-established fire suppression capability of solid particulates, with potentially reduced collateral damage associated with traditional dry chemicals. To date, a number of aerosol generating extinguishing compositions and aerosol extinguishing means have been developed in several countries. They are in production and are used to protect a range of hazards.

One principle of these aerosol extinguishants is in generating solid aerosol particles and inert gases in the concentration required and distributing them uniformly in the protected volume. Aerosol and inert gases are formed through a burning reaction of the pyrotechnic charge. An insight into an extinguishing effect of aerosol compositions has shown that extinguishment is achieved by combined action of two factors such as flame cooling due to aerosol particles heating and vaporizing in the flame front as well as a chemical action on the radical level. Solid aerosols must act directly upon the flame. Gases serve as a mechanism for delivering the aerosol towards the seat of a fire. For more information on aerosols refer to FSTOC Technical Note A, **FSTOC (2022a)**.

4.3.8 Agent Alternatives in Portable (Handheld) Extinguishers

There have been several in-kind alternatives to halon 1211 commercialized in a sustainable manner over time beginning with HCFC blends, followed by HFCs and then by FK-5-1-12 and more recently by 2-BTP. PFC based extinguishants proposed before 2000 were not sustainable based on low performance and high GWPs and were withdrawn from the market in that period. Historically, according to The Intergovernmental Panel on Climate Change, **IPCC (2005)**, only a very limited amount of the original halon market had gone to in-kind alternatives. This is based mainly on the much higher cost of the in-kind alternatives compared originally to halon 1211 and now to the not in-kind alternatives. HCFC Blend B has been employed in non- residential applications as well as notable military applications in wheeled type (65-150 lbs each / 29.5 – 68 kg) for airport flightlines since 1999. This remains to be the case. 2-BTP is currently limited to use on civil aircraft, but the US EPA is considering widening the acceptable uses restrictions of 2-BTP in streaming applications (non-residential use except for commercial home office and personal watercraft) and total flooding fire suppression systems applications (in normally unoccupied spaces under 500 ft^3, **EPA (2022).** Nevertheless, this agent will remain a much higher cost agent than the not-in-kind agents.

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, to greatly varying degrees, 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. If 2-BTP is approved for additional uses beyond civil aviation, it is likely that portable extinguishers will be developed that use smaller quantities of agent than the current halon, HCFC, and HFC alternatives.

HFC-227ea has achieved UL Solutions (formerly known as Underwriters Laboratories Inc. (UL)) listings, UL-2129, **UL (2017)**, as a streaming agent in certain equipment types.

In one very specialized portable system application, the US 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 CO_2. Prior to the phaseout 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 (HCFC Blend B, HFC-236fa, and FK-5-1-12) that cost multiple is in the range of 5 to 10x and that difference can be a difficult task to overcome even where the use of a clean agent is justified. 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 demand is being filled primarily by (1) dry chemical extinguishers where a clean agent is not required, or (2) by CO_2 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 more attractive than its non-ODS alternative HFC-236fa from an environmental standpoint owing to HFC-236fa's very high GWP. 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 CO_2 are also HFC-236fa alternatives.

In addition, 2-BTP has been commercialized for use in portable extinguishers on civil aircraft. Its effectiveness is similar to halon 1211, with several manufacturers offering units for sale. Under SNAP Rule 25, the US EPA proposed to allow 2-BTP as streaming agent for non-residential use, except home offices and boats, **EPA (2022)**.

4.3.8.1 Summary

For portable extinguishers, no new agents have been developed recently. Of the current agents, HCFC Blend B is subject to a key raw material phaseout with associated challenges, HFC-236fa is a high-GWP agent subject to a phasedown, leaving 2-BTP and FK-5-1-12. As discussed above, the EPA is proposing to widen the approved uses for 2-BTP.

Testing of FK-5-1-12 in additional applications is ongoing with the aim of expanding its role as both an HCFC and HFC replacement. For example, the US Federal Aviation Administration (FAA) has tested FK-5-1-12 in civil aviation rescue and firefighting (ARFF) 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). In all experimental configurations, FK-5-1-12 required more agent by both weight and volume than HCFC Blend B. However, many standards for ARFF are switching to combinations of a clean agent, dry chemical and aqueous film forming foam (AFFF). The number of ARFF appliances and the amount of fire extinguishing agent is scaled according to the size of aircraft landing at the airport. For more information refer to FAA FAR Part 139, **FAA (2022)**.

4.3.9 References

Dadia (2017): Minimum Performance Standard Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems Testing, https://www.fire.tc.faa.gov/ppt/systems/Nov17Meeting/Dadia-1117-MPSClass-C.pptx

EPA (2022): Federal Register July 28, 2022. "Proposed Rule Protection of Stratospheric Ozone: Listing of Substitutes Under the Significant New Alternatives Policy Program in Refrigeration, Air Conditioning, and Fire Suppression". https://www.federalregister.gov/documents/2022/07/28/2022-14665/protection-of-stratospheric-ozone-listing-of-substitutes-under-the-significant-new-alternatives

FAA(2022): "Part 139 Airport Certification"
https://www.faa.gov/airports/airport_safety/part139_cert/#regulations

FSTOC (2022a): Technical Note A, *Fire Protection Alternatives to Halons, HCFCs, and HFCs.* https://ozone.unep.org/science/assessment/teap

IPCC (2007): IPCC "Climate Change 2007: Impacts, Adaptation and Vulnerability" https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

Jones (2015): Jones, M., "The Pentagon Goes up in Flames", https://boundarystones.weta.org/2015/06/26/pentagon-goes-flames-1959).

NFPA (2014): "Current Requirements for Sprinkler Systems Containing Antifreeze – A Summary", https://www.nfpa.org/-/media/Files/Public-Education/By-topic/Home-fire-sprinklers/Current-requirements-for-sprinkler-systems-containing-antifreeze.ashx

QRFS (2018): "The Use of Antifreeze in Fire Protection Systems", https://blog.qrfs.com/107-the-use-of-antifreeze-in-fire-protection-systems/

Shaw (2019): D J Shaw, "Boeing Cargo MPS Alternate Agent Test Results
https://www.fire.tc.faa.gov/2019Conference/files/Cargo_Halon_Replacement_II/ShawBoeingAlternateAgent/ShawBoeingAlternateAgentPres.pdf

5 Enduring Uses of Halon, HCFCs, and High-GWP HFCs

5.1 Civil Aviation

5.1.1 Introduction

5.1.1.1 Use of Halons on Aircraft

Although the incidence of in-flight fires is low, the consequences in terms of loss of life are potentially devastating, and the use of halon to help guard against such events has been a key aspect of aircraft fire safety. Aviation applications of halon are among the most demanding uses of the agents and require every one of their beneficial characteristics. Particularly important are the following:

- dispersion and suppression effectiveness, which must be maintained even at the low temperatures encountered at high altitude,
- minimal toxic hazard to the health and safety of ground maintenance staff and passengers and flight crew, who could be exposed to the agent and any decomposition products for periods as long as several hours, and
- weight and space requirements of the agent and associated fire protection system.

Also significant are short- and long-term damage to aircraft structure or contents resulting from the following:

- the agent or from its potential decomposition products in a fire,
- avoidance of clean-up problems,
- suitability for use on live electrical equipment,
- effectiveness on the hidden fire, and
- the installed cost of the system and its maintenance over its life.

While alternative methods of fire suppression for ground-based uses have been implemented, the status of halon in the civil aircraft sector must be viewed in three different contexts: 1) existing aircraft, 2) newly produced aircraft of existing models, and 3) new models of aircraft. Although research and development is ongoing, all aircraft continue to depend on halon for the majority of their fire protection applications. Given the anticipated 25 to 30-year lifespan of a newly produced civil aircraft, this dependency could continue beyond the time when recycled halon is readily available. The civil aviation industry must look either to their own stockpiles of halon or to the limited amounts of recycled halon available on the open market to avoid grounding aircraft because of a lack of appropriate fire protection. In the four years since the last Assessment report, it appears that the aviation industry continues efforts to stockpile halon.

5.1.2 Relevant Decisions of the Parties to the Montreal Protocol

There have been numerous decisions by the parties to the Montreal Protocol relating to future availability of halons. The most recent was Decision XXX/7, made at the 30th MOP in Quito, Ecuador in November 2018, which requested "that Technology and Economic Assessment Panel, through its Halons Technical Options Committee:

(a) Continue engaging with the International Maritime Organization (IMO) and the International Civil Aviation Organization, consistent with paragraph 4 of decision XXVI/7 and paragraph 1 of decision XXIX/8, to better assess future amounts of halons available to support civil aviation and to identify relevant alternatives already available or in development;

(b) Identify ways to enhance the recovery of halons from the breaking of ships;

(c) Identify specific needs for halon, other sources of recoverable halon, and opportunities for recycling halon in parties operating under paragraph 1 of Article 5 of the Protocol and parties not so operating; and

(d) Submit a report on halon availability, based on the above-mentioned assessment and identification activities, to the parties in advance of the forty-second meeting of the Open-Ended Working Group of the Parties to the Montreal Protocol;"

Three of the four requests are open ended; only paragraph (d) had a specific deliverable. In the absence of a more recent decision, the FSTOC is continuing to work on the requests (a), (b), and (c).

5.1.3 Estimated Halon Usage and Emissions

5.1.3.1 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 FSTOC expresses concern that these sources 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 FSTOC has previously reported that this might result in civil aviation requesting a party to submit 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. This supply and demand is illustrated in Figure 5.1 (taken from **ICF (2018)**).

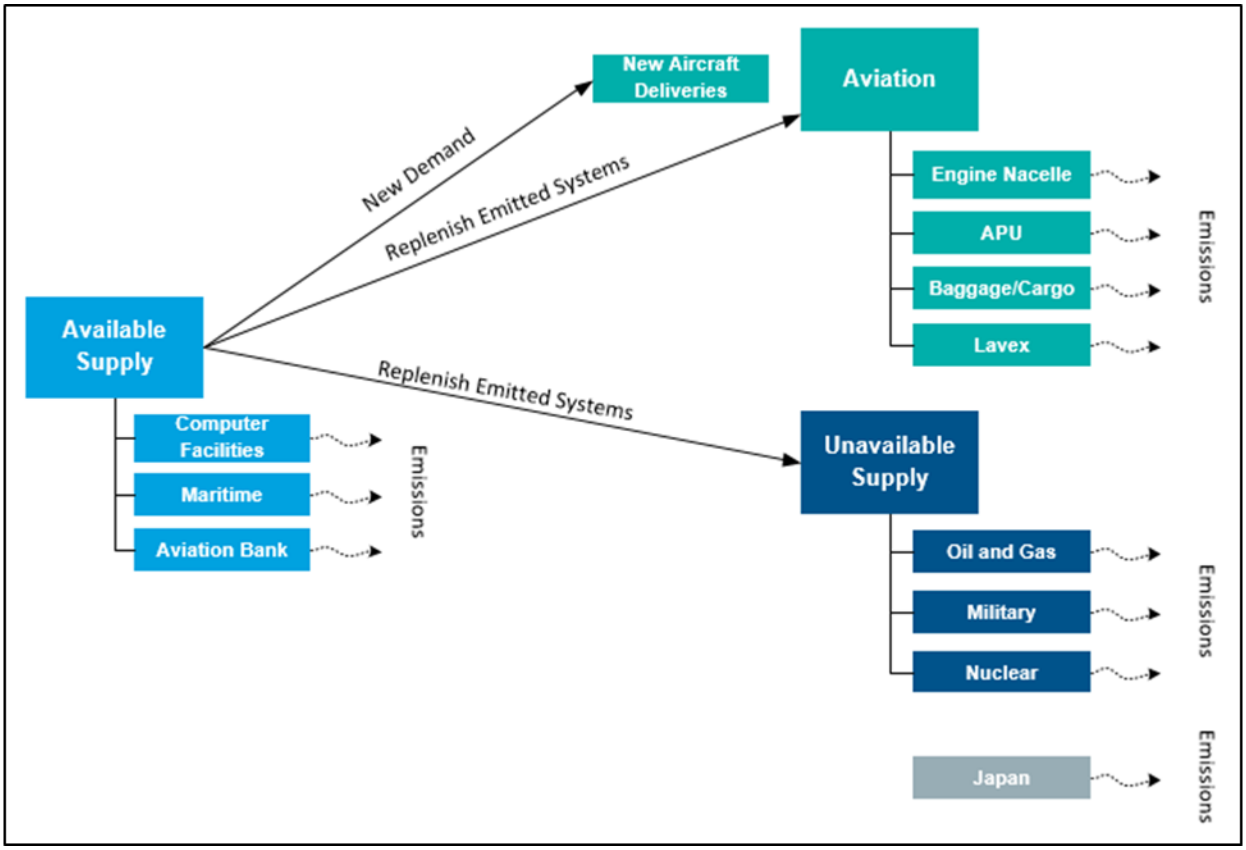


Figure 5.1: Halon 1301 Supply and Demand

From the latest data using the methodology of **Vollmer et al. (2016),** (see Section 6.2.1 for further information) halon 1301 emissions did not change during the COVID-19 pandemic, even though the number of flight hours dropped significantly. Therefore, it is believed that the emissions from the aviation industry occur predominantly during extinguisher service and overhaul operations, which are time-based not flight hours-based. This is shown in Figure 5.2 where the size of the emissions arrow is indicative of the amount of halon 1301 emitted.

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.

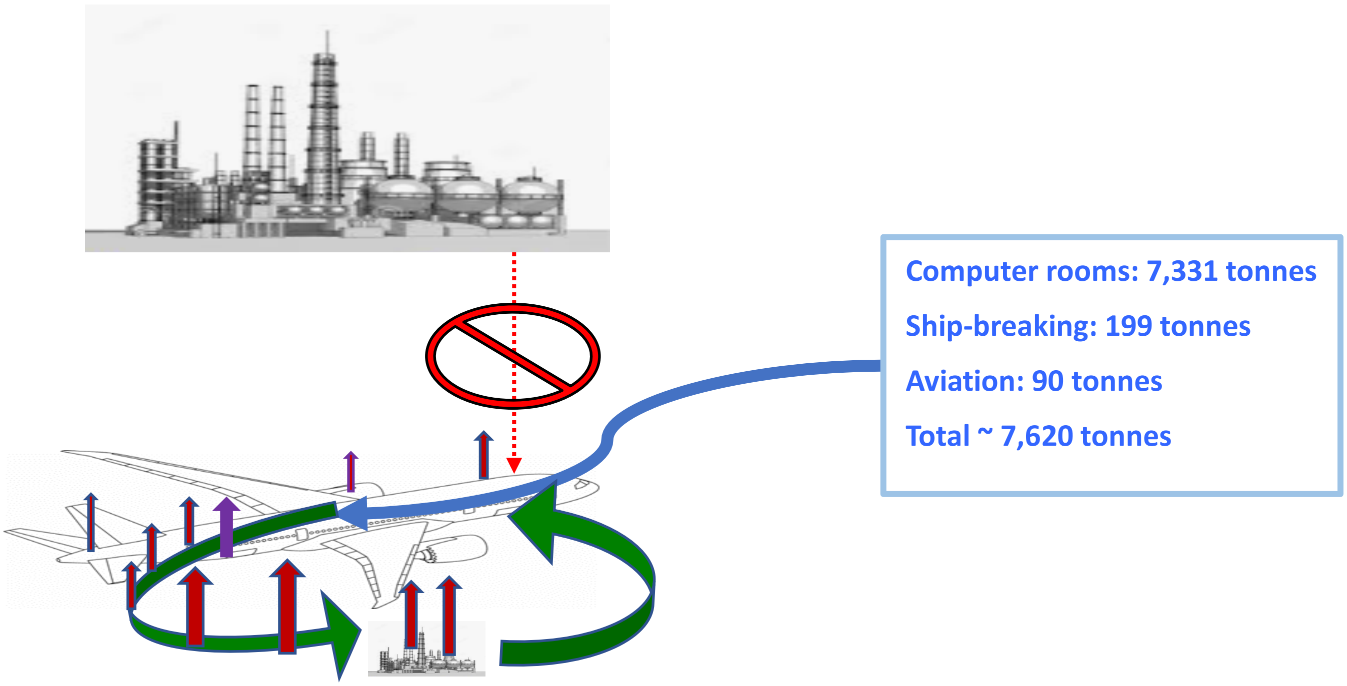


Figure 5.2: Supply and Emissions Sources for the Aviation Industry

5.1.3.2 Estimated Halon 1301 Supplies

The FSTOC previously reported on the potential availability of halon 1301 to support civil aviation using six scenarios initially developed by ICF, **ICF (2015)** and reported to the parties under decision XXVI/7, **ICF (2015)**, **TEAP (2015)**. This was updated to eight scenarios in a response to Decision XXIX/8, **TEAP (2018)** 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. The scenarios account for different potential supply of halon 1301, as estimated by the FSTOC (see 6.2.1 for the latest FSTOC estimates) and 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%) 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 FSTOC is aware of anecdotal information that supports this potentially high emission rate. A draft reevaluation of this analysis was obtained by FSTOC, **ICF (2022)** and is used for this update.

These scenarios did 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 extinguishing systems, while a declining portion of the fleet still contains halon lavatory extinguishing systems (i.e., in aircraft manufactured before 2010).

The eight scenarios model +/- 10% of the total worldwide supply of halon 1301 that could be available to civil aviation as of the end of 2022 at 7,620 metric tonnes (i.e., a low and a high of approximately 6,858 and 8,382 metric tonnes respectively), as shown in Table 5.1.

Table 5.1: Worldwide Halon 1301 Bank as of the End of 2022 (tonnes)

Source	Available to Civil Aviation?	Quantity (tonnes)
Japan	No	16,455
Military installed	No	2,250
Military reserves	No	1,992
Oil and gas facilities	No	1,500
Nuclear installed	No	361
Nuclear reserves	No	131
Aviation Installed	No	4,001
Unavailable Bank (Total)		6,234
Computer facilities	Yes	7,331
Maritime	Yes	199
Aviation bank/stockpile	Yes	90
Available Bank (Total)		7,620
Worldwide Bank Total		**34,310**

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 5.2. The best-case and worst-case scenarios are highlighted in yellow.

Table 5.2: Assumptions and Results for Eight Drawing Down Halon 1301 Scenarios

Scenario	Total Available Supply in 2022 (tonnes)	Annual Emission Rate (Aviation)	Annual Emission Rate (non-Aviation)	Global Overall Emission Rate	Year Available Supply Runs Out	
					2018 Estimate	Latest Estimate
1	6,858	2.3 – 2.8%	0.1 – 3%	1.4%	2048	**2045**
2	6,858	7.6%	0.1 – 3%	1.9%	2038	**2035**
3	6,858	5.0%	1 – 5%	2.3%	2040	**2037**
4	6,858	15.0%	1 – 5%	3.9%	2032	**2030**
5	8,382	2.3 – 2.8%	0.1 – 3%	1.6%	2054	**2049**
6	8,382	7.6%	0.1 – 3%	2.0%	2042	**2037**
7	8,382	5.0%	1 – 5%	2.3%	2045	**2040**
8	8,382	15.0%	1 – 5%	3.8%	2034	**2031**

Based on the results of this draft 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 2030 to 2049, depending on the total worldwide supply in 2022 and annual emission rates. This is two to five years earlier than projected in 2018 and is mainly the result of less halon 1301 projected to be available to civil aviation. For example, more halon 1301 is projected by the FSTOC in 2022 to be in Nuclear Power Plants (NPPs) than was projected in 2015 and 2018 (see 5.4.3 for the FSTOC analysis of installed halon 1301 in NPPs globally).

Three of the modelled scenarios are shown in Figure 5.3, Figure 5.4 and Figure 5.5 below. In all cases the dashed line at year 2022 represents the transition from actual to modelled data.

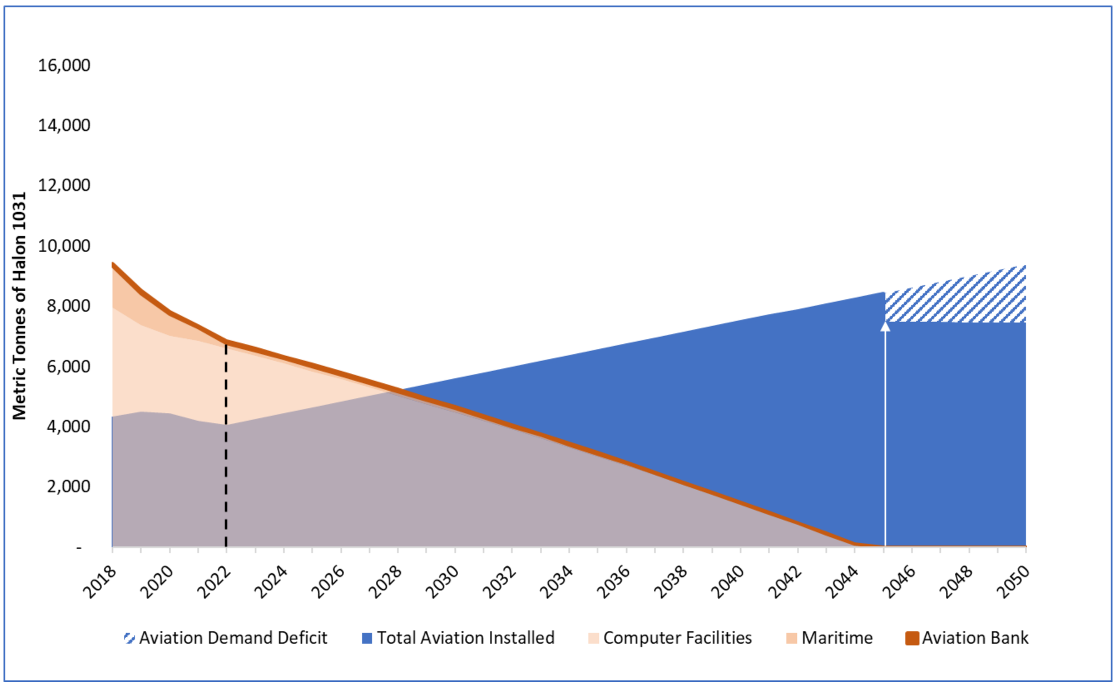


Figure 5.3: Estimated Halon 1301 Run-out Date
(Scenario 1, 1.4% Global Emission Rate)

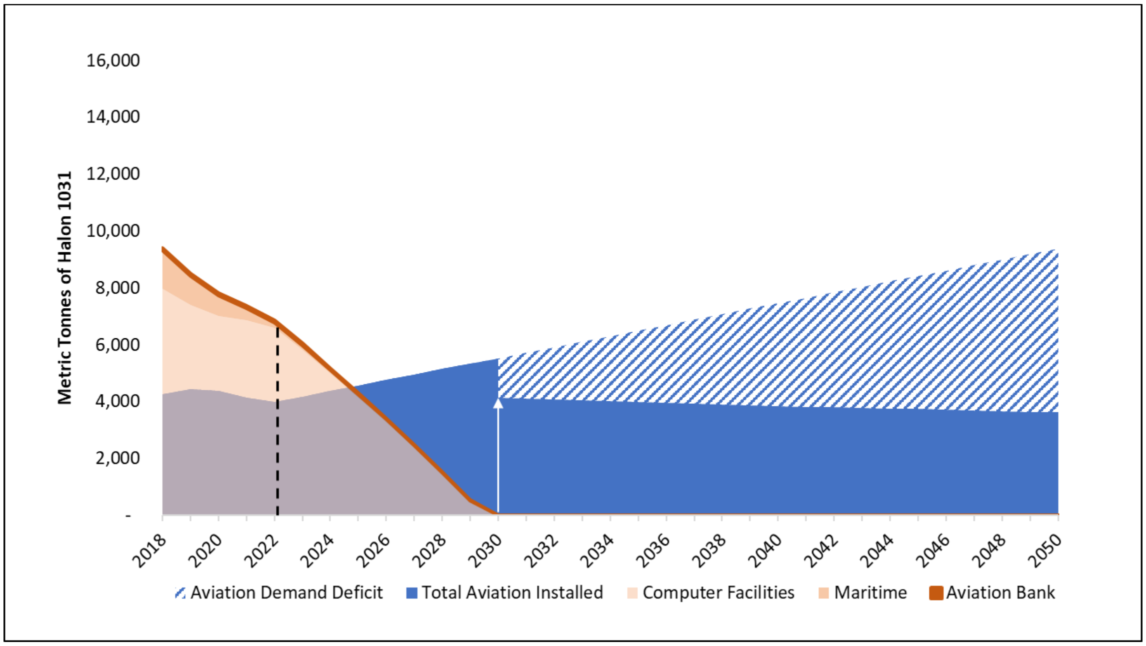


Figure 5.4: Estimated Halon 1301 Run-out Date
(Scenario 4, 4.4% Global Emission Rate)

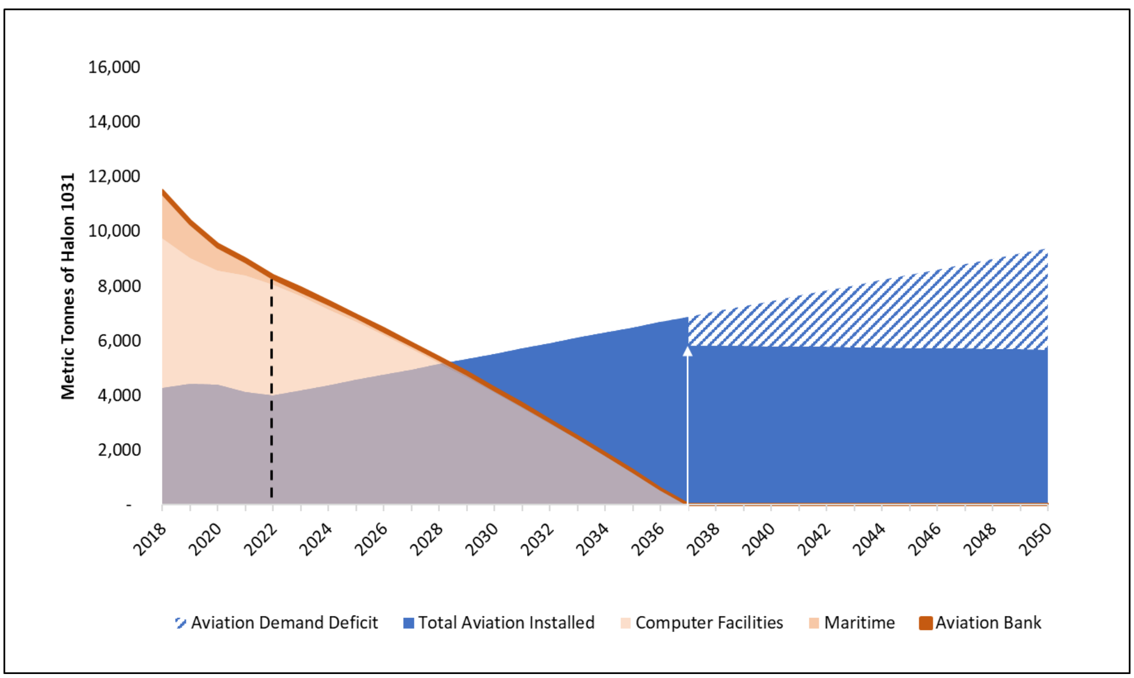


Figure 5.5: Estimated Halon 1301 Run-out Date
(Scenario 6, 2% Global Emission Rate)

As aircraft fire extinguishing agent containers are typically hermetically sealed, the incidence of leakage is likely to be low. It is now believed that the majority of these emissions occur during servicing. A small proportion may be due to the extinguishers being actuated, which may be by accident, or following a fire signal. As stated earlier, the incidence of in-flight fires is low, so it is likely that the majority of aircraft-related emissions are due to false alarms; anecdotal data from industry shows that cargo bay system smoke detector false alarms are the largest driver of civil aviation industry discharges of halon 1301, **Blake (2000)**. The latest generation of “discriminating” smoke detectors use more than one criterion to detect smoke and therefore exhibit much lower false alarm rates.

The attribution of aviation related emissions to service-related activity has been supported by the recent data on halon 1301 emissions during the COVID-19 pandemic. Figure 5.6, taken from the TEAP 2022 Progress report, **TEAP (2022)**, shows the dramatic reduction in commercial flight activity in 2020.

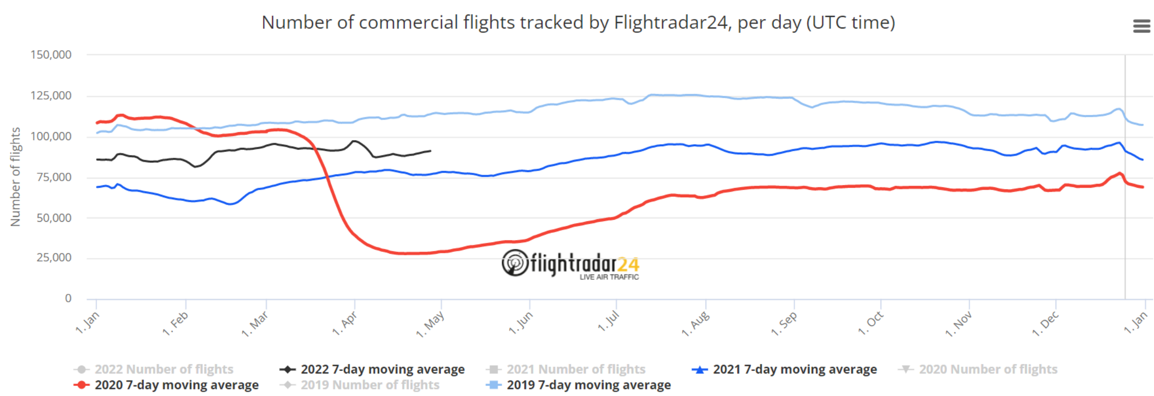


Figure 5.6: Effect of the COVID-19 Pandemic on Global Aviation. Source: Flightradar24

Data from Flightradar24; https://www.flightradar24.com/data/statistics,
Retrieved 28 April 2022

The data for the latest estimates of global emissions based on atmospheric abundances though 2021 do not show any significant decrease in halon 1301 emissions during 2020, see Figure 6.2 in section 6.2.1. Since we know that civil aviation flight hours dropped by 60% during the pandemic, this suggested that global emissions for at least 2020 did not correlate well with civil aviation flight operations. In other words, total global emissions do not seem to be dependent on the number or duration of civil aviation flights. This does not necessarily mean that civil aviation is not the cause of some of or even a significant amount of the emissions but rather that a different part of the aviation lifecycle such as fire extinguisher maintenance could be responsible for much of these emissions.

5.1.3.3 Potential for Smaller Global Halon 1301 Bank

5.1.4 Halon Banks

At present, the halon demands of aviation are being met by recycling agent withdrawn from applications in other industries. As illustrated above, this source of supply will be dramatically reduced, and is likely to be exhausted, long before the aircraft now being built and fitted with halon systems are retired.

Civil aviation original equipment manufacturers (OEMs) and operators who have not already done so are strongly advised to:

- determine their emission rate and, where possible, take actions to reduce it to the lowest level whilst still maintaining safety,
- consider whether the installed stocks of halon they own are sufficient to meet their long-term needs (taking into account the possibility that contaminated halon may have penetrated their own stocks),
- ascertain whether these stocks are being properly managed to ensure they are available for their needs,
- determine whether it is necessary to procure and store additional agent now, while it is relatively easy to do so, to meet long-term demands, and
- continue to implement policies that eliminate or minimize discharge in testing, training, and maintenance.

Further information on halon banks can be found in Chapter 6 of this report.

5.1.5 Status of Halon Replacement Options for Aviation

Halons are used for fire suppression on civil aircraft in:

- lavatory trash receptacles,
- portable (handheld) extinguishers,
- engine nacelles and APUs, and
- cargo compartments.

All new installations of fire extinguishing systems for engines and cargo compartments use halon 1301, and some new installations of handheld extinguishers still use halon 1211. With the exception of lavatory trash receptacles and some handheld extinguishers, there has been no system-wide, large-scale retrofit of halon systems or portable extinguishers with available alternatives in the existing worldwide fleet of aircraft.

Key to the acceptance of one or more of the approved substitutes has been their ability to demonstrate fire extinguishing performance equivalence to halon in specific applications. As such, substitutes for halons in civil aviation fire extinguishing systems are evaluated and approved according to the relevant MPS and testing scenarios developed by the International Aircraft Systems Fire Protection Forum (IASFPF). The status of the development of these MPS for the above applications and the alternatives tested to these MPS are discussed below.

5.1.5.1 Lavatory Trash Receptacle

Halon 1301 has historically been used in lavatory trash receptacle systems, which are designed to extinguish trash receptacle fires in the lavatories of pressurized cabins. Trash receptacles are required to be installed with a lavatory extinguishing system that automatically discharges into the container in the event of a Class A fire (Class A fires consist of ordinary combustibles such as wood, paper, fabric, and most kinds of trash). All lavatory extinguishing systems using halon alternatives must meet the Minimum Performance Standard (MPS), **Marker (1997)**, that includes the ability to extinguish a Class A fire and in the case of discharge while not creating an environment that exceeds the chemical agent's maximum acceptance level for toxicity.

Research and testing have shown that there are suitable alternative suppression systems using the high-GWP agents HFC-227ea or HFC-236fa for this application that are "a drop-in" replacement from a space and weight perspective, meet the toxicological requirements, and cost the same or less than the halon systems being replaced.

Virtually all current production aircraft are fitted with halon replacement agents. Some older legacy platforms have not yet been transitioned to the replacement agent, 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 extinguishing systems with these halon-free alternatives during scheduled maintenance activity.

There are no approved low-GWP alternatives for this application to replace HFC-227ea, HFC-236fa, or halon 1301, and the FSTOC is not aware of any research to develop one. Given that the quantities of fire extinguishing agent in this application are very small (~0.25% of the total quantity installed on aircraft), and emission rates are low, replacing these agents is viewed as low priority by industry at this time.

5.1.5.2 Portable (Handheld) Extinguishers

All handheld extinguishers intended to replace halon 1211 extinguishers must meet the MPS to ensure their performance and safety. These standards require that any handheld extinguisher for aviation use be listed by UL or an equivalent listing organization. To be listed, the extinguisher must be able to disperse in a manner that allows a hidden fire to be suppressed and does not cause any unacceptable visual obscuration, passenger discomfort, or toxic effects where people are present. In addition to the MPS, the US Federal Aviation Administration (FAA) has published an Advisory Circular, **FAA (2011)**, which provides guidance on firefighting effectiveness, selection, location and mounting of extinguishers, and how to obtain certification of a handheld extinguisher for civil aviation use.

The MPS was published in August 2002, **Webster (2002)**. As of 2022, four halon alternatives, HFC-227ea, HFC-236fa, HCFC Blend B, and 2-BTP, have successfully completed all of the required handheld UL™ and MPS tests and are commercially available. Table 4.1 shows that these alternatives have increased space and weight characteristics, environmental concerns of high GWP for the two HFCs, and production phaseout for HCFCs under the Montreal Protocol for the HCFC blend. Qualification and installation certification by airframe manufacturers and regional authorities are needed prior to airline use. Based on these issues, airframe manufacturers chose not to pursue qualification and installation certification for these ODS or high GWP alternatives. However, as reported in the 2018 Assessment report, testing of 2-BTP has been completed. Being "chemically-acting" (i.e., it contains a bromine atom) this agent has a lower space and weight impact compared to other alternatives, as shown in Table 5.3. The agent has received regulatory approval in both the US and the EU.

Table 5.3: Options for Portable (Handheld) Extinguishers for Aircraft Use

(a) Imperial units

Agent	Agent Weight (Pounds)	Total Weight (Pounds)	Dimensions (H x W x D, inches)	ODP	GWP (100 year)
Halon 1211	2.5	3.93	17 x 4.8 x 3.25	7.91	1890[1]
2-BTP (Option 1)	3.75	5.6	15.75 x 5 x 3.5	0.0028[2] (3D-model)	0.005[2]
2-BTP (Option 2)	3.5	5.0	13.78 x 4.47 x 3.54		
HCFC Blend B	5.5	9.3	15 x 5 x 4.25	0.01[1]	77[1]
HFC-236fa	4.75	9.5	15.9 x 8 x 4.5	0	9820[1]
HFC-227ea	5.75	9.8	16.6 x 6.5 x 4.4	0	3580[1]

(b) S.I. Units

Agent	Agent Weight (kg)	Total Weight (kg)	Dimensions (H x W x D, mm)	ODP	GWP (100 year)
Halon 1211	1.13	1.78	432 x 122 x 83	7.91	1890[1]
2-BTP (Option 1)	1.70	2.54	400 x 127 x 89	0.0028[2] (3D-model)	0.005[2]
2-BTP (Option 2)	1.59	2.27	350 x 114 x 90		
HCFC Blend B	2.50	4.22	381 x 127 x 108	0.01[1]	77[1]
HFC-236fa	2.16	4.31	404 x 203 x 114	0	9820[1]
HFC-227ea	2.61	4.45	422 x 165 x 112	0	3580[1]

Notes:

1. ODP and GWP values from **WMO (2010).** Note that ODP of HCFC Blend B was rounded up from 0.0098

2. ODP value from **Patten and Wuebbles (2010)**. Note that ODP/GWP values can vary depending on the assumed geographical distribution of the release. The latitudes considered include the US and EU.

This transition to 2-BTP for newly produced transport category aircraft is well underway. Several manufacturers have developed and certified handheld extinguishers, which have been selected by major aircraft OEMs. This agent is gradually replacing halon 1211 on a platform-by-platform basis. Retrofit of halon 1211 portable (handheld) extinguishers in civil aviation is required in the EU by the end of 2025. For general aviation, halon 1211 is still the only approved agent for portable extinguishers.

5.1.5.3 Engine and APU Compartment

Halon 1301 is typically used in engine nacelles and APUs to protect against Class B (liquid fuel) fires. The requirements of fire suppression systems for engine nacelles and APUs are particularly demanding, since these compartments contain fuels and other volatile fluids in close proximity to high temperature surfaces. HFC-125 has been used successfully as an alternative to halon for engine fire protection on US military aircraft developed since the early 1990s. In addition, HFC-125 is used on a military derivative of a large commercial aircraft (Boeing 767; military derivative KC-46, Pegasus). HFC-125 has increased space and weight characteristics. It is also included in the Kigali Amendment to the Montreal Protocol for phasedown. Based on these issues, particularly the additional weight, civil airframe manufacturers have chosen not to pursue qualification and installation certification for HFC-125 in engine nacelles and APUs.

The current MPS was published in 2010, **FAA (2010)** but is under revision by the FAA. A deadline for publication of the revised standard has not been defined as yet. Three potential replacement agents, HFC-125, CF_3I, and FK-5-1-12 were tested against the then current version of the MPS and halon 1301 equivalent concentrations were determined, **Ingerson (2007)**. The equivalent concentrations relative to halon 1301 are presented in Table 5.4 along with historical data for CO_2, **FAA (1977)**.

Table 5.4: Equivalent Concentrations for CF_3I, FK-5-1-12, HFC-125, and CO_2 for Aircraft Engine Nacelles

Agent	Equivalent Concentration (Volume%) [1]	Mass (kg/m^3) [2]	Mass Ratio to Halon 1301	Volume Ratio to Halon 1301
Halon 1301	6	0.401	1	1
CF_3I	7.1	0.617	1.54	1.13
FK-5-1-12	6.1	0.904	2.25	2.17
HFC-125	17.6	1.08	2.70	3.50
CO_2	34	0.943	2.35	5.02

[1] Per FAA Advisory Circular AC20-100, **FAA (1997)**, this concentration should be maintained throughout the protected zone for a minimum of 0.5 second.

[2] Halon 1301 calculated from National Fire Protection Agency (NFPA)12A, **NFPA (2018)**, and replacement agents from ISO14520, ISO (2015), using a temperature of 20°C

From Table 5.4, it is clear that CF_3I is closest to a “drop-in” replacement for halon 1301 for engine nacelle and APUs. This is because iodine can undergo the same catalytic radical recombination reactions as bromine, which makes it is a very efficient fire extinguishing agent. Therefore, this agent was evaluated in the late 1990’s, but following some adverse toxicity results, attention was focused elsewhere. However, given the lack of significant progress over the last two decades, the civil aviation industry is refocusing attention on CF_3I as an engine nacelle and APU fire extinguishing agent. It should be noted that CF_3I is the only halon alternative that has low ODP, low GWP, and would not be subject to the proposed EU PFAS REACH restriction, refer to section 3.2.

An engine nacelle system using FK-5-1-12 was developed but it failed a US FAA required live fire test using a cold soaked fire protection agent to simulate low temperature use, **FAA (2011).** Also, an engine nacelle system based on a dry chemical failed a required full-scale test. At this time, the system manufacturer is carrying out further work to improve the performance of the dry chemical system with the intent of returning to the FAA to retest.

5.1.5.4 Industry Activity

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 OEMs Airbus, Boeing, Bombardier, Embraer, and Textron. the Ohio Aerospace Institute is acting as administrator. Other stakeholders (fire extinguishing system suppliers and distributors, chemical companies, airline operators, engine manufacturers, universities, consultants, etc.) were also engaged in this process. The consortium has mapped out a three phase, multi-year approach for alternatives development. Phase I (administrative start-up), with a signed Joint Collaboration Agreement in place, and Phase II (formal creation of Technical and Non-Technical Task Teams), which included the initial FAA engagement, preliminary certification path proposals development, high level Request for Information and the down select finalists have been completed. Two primary solutions candidates were selected to be evaluated on next phase. After Statement of Work and Technical Readiness Level definitions, Phase III has commenced in 2020 for in-depth agent development and evaluation and testing of selected candidates. Phase III is planned to take 2 to 3 years to complete HAAPS activities. Thereafter, airframer members will proceed with independent certification activities to incorporate a solution into their projects, using the information developed under HAAPS, e.g., certification path, means of compliance agreements, and test and qualification data, etc.

The FSTOC notes that the progress of this consortium is slower than was originally forecast by the consortium as reported in both the 2014 and 2018 HTOC Assessment reports.

Except for the customized approval for use of phosphorous tribromide in one model of business jet, the only approved agents for use in civil aviation engine nacelles and APUs remains halon 1301 and HFC-125 on a military derivative of a large commercial aircraft (Boeing 767; military derivative KC-46).

5.1.5.5 Cargo Compartments

In passenger aircraft, the cargo compartments are typically located below the passenger cabin or occupy both the main and lower deck on freighter aircraft. Note, in freighter aircraft only the lower deck is protected with halon; the main deck is considered a Class E cargo compartment where fire suppression is handled differently than other cargo compartments. Fire suppression typically is accomplished by depressurising the Class E cargo compartment and landing as quickly as possible before the fire re-establishes itself. One large freight carrier has reportedly developed a foam system for additional fire protection for the main deck.

In the case of a fire in the lower deck cargo compartment, a rapid discharge of halon 1301 is deployed into the protected space to suppress the fire, which is followed by a discharge that is released slowly to maintain a concentration of halon to prevent re-ignition. The slow discharge is maintained until the plane has landed to protect against any reduction in the concentration of halon caused by ventilation or leakage.

Lower deck cargo compartment fire suppression systems must be able to meet the requirements of four fire tests required in the Cargo Compartment MPS last updated in 2012, **Reinhardt (2012)**. The system must be able to suppress both a Class A deep-seated fire and a Class A fire inside a cargo container. The system must be able to extinguish a Class B fire (flammable liquid such as jet fuel) within 5 minutes, and prevent the explosion of a hydrocarbon mixture, such as might be found in aerosol cans. In addition, the system must have sufficient agent/suppression capability to be able to provide continued safe flight and landing from the time a fire warning occurs, which could be in excess of 350 minutes, depending on the aircraft type and route planned.

A fifth fire threat is being added to the MPS, in part to address the hazard of shipping lithium-ion batteries in aircraft cargo compartments. The FAA has set up the MPS Cargo Compartment Task group to update the MPS, to include a new test element. As well as including lithium-ion batteries the proposed test includes a liquid fuel, ethanol, and cardboard boxes with shredded office paper, so the test is referred to as the "Multiple Fuel Fire Challenge". The timescale for the updated MPS to be issued is not known at this time.

To date, there have been no cases of halon 1301 replacement with an alternative agent in cargo compartments of civil aircraft. All the single-component vaporizing liquid agents that have undergone the exploding aerosol can test, HFC-125, 2-BTP, and FK-5-1-12, 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, **FAA (2004)**. The cargo MPS now requires that pressure increase not occur upon application of a suppressant agent in a quantity less than that needed to suppress a fire or deflagration event. On this basis, all the single halogenated agents tested so far have been found to be unacceptable.

Several approaches are being developed by industry. One fire suppression system manufacturer presented data at the IASFPF in 2016 showing that inert gas alone is capable of passing the Cargo Compartment MPS**, FAA (2016).** Another fire suppression system manufacturer, in conjunction with the FAA, presented data showing a combination of water mist and nitrogen (IG-100) can pass the current MPS, **FAA (2017a**), and the lithium-ion battery fire threat, referred to above, **FAA (2017b**).

Commercial development of both the inert-gas-only and the water mist/nitrogen cargo fire suppression systems continues. The FAA has completed proof-of-concept testing for a blend of 2-BTP and CO_2, **FAA (2018).** MPS testing was successfully conducted in 2019, **FAA (2019)**. Cargo compartment fire extinguishing systems are sized assuming an empty cargo compartment, as that represents the worst case in terms of the discharged agent concentration. In practice, the cargo compartments are usually not empty, so in the event of a fire, the discharged agent concentration is much higher than the design. Whilst this represents an advantage in terms of fire suppression performance it can also have consequences in terms of agent toxicity and/or reduced oxygen concentration. It should be noted that this blend of 2-BTP and CO_2 is toxic at its design concentration. While cargo compartments are classified as unoccupied areas, animals are allowed to be transported in cargo bays and would be put at risk with this blend.

In 2013, the International Coordinating Council of Aerospace Industries Associations (ICCAIA) formed the Cargo Compartment Halon Replacement Working Group (CCHRWG) to begin to recommend to ICAO a viable date for establishing halon deadline on aircraft cargo compartments. This group suggested the end of 2024 as the time by which a cargo compartment fire suppression system containing a replacement agent could be developed and applied for approval in a completely new aircraft type. This is known as applying for a "Type Certificate". This date was accepted by ICAO and adopted as Resolution A39/13 during its 39th assembly in 2016.

Although its primary task has been accomplished, the CCHRWG continues to monitor the progress of halon replacement activity in cargo compartments, with periodic reporting to ICAO's Air Navigation Committee, supporting the ICAO 2024 deadline for new type certification applications submitted on or after 28 November 2024. To avoid confusion with ICAO working groups it has been renamed the Cargo Compartment Halon Replacement Advisory Group (CCHRAG). In 2018, the CCHRAG performed a technical assessment of potential solutions to evaluate the viability to meet that deadline, resulting in a report published for the 40th ICAO General Assembly in 2019, as Information Paper, ref. A40-WP/93, **ICAO (2019)**. This assessment was updated in 2021 and reported as working paper A41-WP/96, **ICAO (2022)** to the 41st ICAO General Assembly held from 27 September - 7 October 2022. The CCHRAG assessed that the ICAO deadline of 2024 is still achievable assuming timely mitigation of risks associated with worldwide regulatory aspects and continued industry efforts to overcome the effects of the COVID-19 pandemic. In addition, A41-WP/96 included the following: "However, the assessment notes regulatory and schedule risks that could lead to delay, in particular upcoming regulatory action on PFAS (per- and polyfluoroalkyl) substances under development in the EU."

5.1.6 Crash Rescue Vehicles

In addition to on-board civil aircraft applications, halon 1211 was used in some Aircraft Rescue and Fire Fighting (ARFF) or Crash Rescue vehicles on airport ramps. After full scale fire testing in 1993-94, the US FAA approved HCFC Blend B as a halon 1211 replacement for this application in the US in 1995. However, because HCFC Blend B is an ODS, national regulations may limit its use for this application in other countries. Since 1995, a significant number of US airports have installed these systems. As such, the TEAP considered 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 with halon 1211 or HCFC Blend B.

Decision XXX/2 allows the use of newly produced HCFCs in fire protection applications existing on 1 January 2020 for the period 2020 - 2029 for non-Article 5 parties. The decision also allows Article 5 parties to use HCFCs in equipment existing on 1 January 2030 through 2039. After these dates, this application will need to rely on recycled / reclaimed agent.

FK-5-1-12 has been tested by the US Air Force in historical 68 kg (150 pound) halon 1211 sized wheeled units and found to require more weight and volume than halon 1211 or HCFC Blend B. Owing to its slightly lower liquid density compared with halon 1211, a slightly larger wheeled unit was needed. A useful reference to wheeled units can be found at **Amerex (2022).** Although the fluoroketone has been shown to be effective in wheeled units and one truck mounted ARFF system, it is not yet approved for use in other ARFF vehicles. Therefore, at this point, there will still be a need to use HCFCs.

5.1.7 Conclusions

Halon alternatives that weigh more and/or take up more space, are unlikely to be implemented by civil aviation airframe manufacturers for the aircraft that are in service. As such, the civil aviation sector is poised to be reliant upon halons for at least the next 30 years, the projected life of aircraft currently being produced. Although the FSTOC previously reported that this situation might result in civil aviation submitting an EUN, the impact could be broader. Since most other enduring users of halon 1301 do not have long-term, dedicated stockpiles, they are competing for the same halon supplies that civil aviation is reliant upon. The timeframe when halon is no longer available to civil aviation could also be the timeframe when halon is no longer available to other who might feel the need to submit an EUN. Depending upon the amount of halon available to support ongoing uses and the rate of emissions from all uses, the timeframe for this to happen is estimated to be between 2039 and 2049. It should be noted that these timescales are not consistent with the EU phaseout dates for ozone depleting substances.

5.1.8 References

Amerex (2022): https://www.amerex-fire.com/products/fire-extinguishers/

Blake (2000): Blake, D., "Aircraft Cargo Compartment Smoke Detector Alarm Incidents on U.S.-Registered Aircraft, 1974-1999", FAA Report No. DOT/FAA/AR-TN00/29.

EPA (2018): The U.S. phaseout of HCFCs: Projected Servicing Demand in The U.S. Air-Conditioning, Refrigeration, and Fire Suppression Sectors for 2020-2030. https://www.epa.gov/sites/production/files/2018-04/documents/draft_report_the_us_phaseout_of_hcfcs_projected_servicing_demands_in_the_u.s._air_conditioning_refrigeration_and_fire_suppression_sector_2020-2030_0.pdf

FAA (1977): AC20-100 – "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments", *http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-100.pdf*

FAA (2004): Reinhardt, J. W.,"Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion" FAA Report No. DOT/FAA/AR-TN04/4

FAA (2010): "Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments", https://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf.

FAA (2011a): AC 20-42D – *Hand Fire Extinguishers for Use in Aircraft.* http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/888491

FAA (2011b): Forced-flow Fire Testing with "cold"-soaked FK-5-1-12, Final Results https://www.fire.tc.faa.gov/pdf/systems/Nov11Meeting/Ingerson-1111-coldGAS.pdf

FAA (2016): Chattaway, A.,"Cargo Compartment Testing at UTAS FPS" https://www.fire.tc.faa.gov/pdf/systems/May16Meeting/Chattaway-0516-Cargo.pdf

FAA (2017a): Dadia, D. & Kirbach, K., "Minimum Performance Standard Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems Testing" https://www.fire.tc.faa.gov/ppt/systems/Nov17Meeting/Dadia-1117-MPSClass-C.pptx

FAA (2017b): Dadia, D. & Kirbach, K., "Minimum Performance Standard Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems Testing – Challenge Fire Test" https://www.fire.tc.faa.gov/ppt/systems/Nov17Meeting/Dadia-1117-MPSChallengeFire.pptx

FAA (2018): Dadia, D**.**, "Proof of Concept Testing – Cargo Halon Replacement" https://www.fire.tc.faa.gov/ppt/systems/Oct18Meeting/Dadia-1018-ProofOfConceptTesting.pptx

FAA (2019): Casey, J, "Full-Scale Evaluation of Novec™ 1230", FAA Report DOT/FAA/TC-19/27.

HTOC (2011): Halons Technical Options Committee United Nations Environment Programme (UNEP) 2010 Assessment Report of the Halons Options Committee. March 2011. ICAO State letter reference AN 3/25.1-10/2

HTOC (2018): 2018 Halons Technical Options Committee Assessment Report https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_assessment_2018.pdf

ICAO (2019): International Civil Aviation Organization, 40th General Assembly, Working Paper A40-WP/93, https://www.icao.int/Meetings/a40/Documents/WP/wp_093_en.pdf

ICAO (2022): International Civil Aviation Organization, 41st General Assembly, Working Paper A41-WP/96, https://www.icao.int/Meetings/a41/Documents/WP/wp_096_en.pdf

ICF (2015) ICF International, "Projections of Halon 1301 Supply and Demand for Aviation Applications, June 2015".

Ingerson (2007): Ingerson, D, "Engine Nacelle Halon Replacement", International Aircraft Systems Fire Protection Working Group Meeting, April 16-17, 2007 https://www.fire.tc.faa.gov/pdf/systems/April07Meeting/ingerson-0407-Engine.pdf

ISO (2015): ISO 14520, "Gaseous fire-extinguishing systems" https://webstore.ansi.org

Marker (1997): Marker, T., "Development of a Minimum Performance Standard for Lavatory Trash Receptacle Automatic Fire Extinguishers", DOT/FAA/AR-96/122, Final Report, February 1997" https://www.fire.tc.faa.gov/pdf/ar96-122.pdf

NFPA (2018): NFPA 12A Standard on Clean Agent Fire Extinguishing Systems, 2018 Edition, 1 Batterymarch Park, Quincy, Massachusetts, 02169**.** https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=12A

O'Sullivan (2005): "National airlines and halon data," Data compiled by a British Airways technical expert, personal communication.

Patten and Wuebbles (2010), University of Illinois at Urbana-Champaign Report "2-Bromo-3,3,3-Trifluoropropylene Ozone Depletion Potentials and Global Warming Potentials" dated December 22, 2010, author Kenneth Patten and Donald Wuebbles.

Reinhardt (2012): Reinhardt, J., "Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems (2012 Update)" DOT/FAA/TC-TN12/11

TEAP (2015): Report of the Technology and Economic Assessment Panel, June 2015, Volume 1 Progress Report, https://ozone.unep.org/sites/default/files/2019-05/TEAP_Task-Force-XXVI-9_Report-June-2015.pdf

TEAP (2018): Report of the Technology And Economic Assessment Panel, September 2018, Volume 2, Decision XXIX/8 On the Future Availability of Halons and Their Alternatives, https://ozone.unep.org/sites/default/files/2019-04/TEAP-Decision-XXIX-8_future-availability-of-halons-and-their-alternatives_September2018_0.pdf

TEAP (2022): TEAP May 2022: Progress Report (Volume 1), https://ozone.unep.org/system/files/documents/TEAP-EETF-report-may-2022.pdf

Webster (2002): Webster, H., "Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft", H Webster, DOT/FAA/AR-01/37, Final Report, August 2002. https://www.fire.tc.faa.gov/pdf/01-37.pdf

WMO (2010), World Meteorological Organization Report No. 52 – "Scientific Assessment of Ozone Depletion: 2010." https://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2010/index.shtml

5.2 Military Applications

5.2.1 Overview

Military fire protection systems are unique in that they must protect personnel and platforms from the consequences of combat damage and also protect against 'peacetime' fires. Fires due to combat events are generally very fast-growing and relatively large. Fire protection systems are required to counter these threats, often while allowing occupants to remain in the affected spaces. A point to consider when choosing extinguishing agent for spaces that are normally occupied (e.g., shipboard command centres, military vehicle crew spaces, etc.) is whether the enclosure must remain operational during combat operations or can be evacuated. If the enclosure must stay occupied during a fire event, then a limited number of agents are available for consideration due to toxicity concerns. However, if evacuation of the enclosure is an option, a wider range of agents is available, similar to commercial applications.

The full range of halon alternatives have been investigated for these ground, sea, and air applications, including CO_2, inert gases, high-GWP HFCs, dry chemicals, and other gaseous chemicals. For some of these specialized applications, high-GWP HFCs have been the only alternatives demonstrated to meet these stringent requirements. Therefore, many militaries have transitioned from halons to high-GWP HFCs. Owing to the wide adoption of these HFCs, and the lack of alternatives, their continued use will be required for the foreseeable future.

Significant research has shown that there are no alternatives to the halons or HFCs that meet all military performance requirements. Owing to the production and consumption phasedowns of high-GWP HFCs (see section 3.1) and potential PFAS restrictions (see section 3.2), the military sector needs be prepared for the diminishing availability of these chemicals. Given that the military sector is not a significant user of these chemicals in terms of global demand, industry sources have informed militaries that they have no plans to invest additional resources to develop alternative chemicals specifically for these unique applications. Therefore, military investigations into alternatives are limited to those chemicals that are used for other commercial applications (e.g., foam blowing, refrigeration, etc.). The likelihood of identifying a new chemical that meets these military requirements is becoming lower due to previous research conducted into all available chemical families. Thus, reliance on reserves from strategically-secure sources is likely to be required.

The parties' defence ministries and military organizations 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. At this point, no militaries are reporting insufficient supplies to support most anticipated future military needs. The FSTOC is aware of shortages of halons only for parties whose national regulations restrict the imports of halons. In fact, the FSTOC knows of at least one military that has determined that it has an excess of halon 1301 and has made this surplus available to other parties for mission-critical applications. While initial estimates for dedicated military halon banks may have been larger than ultimately required, surpluses indicate the positive effect of the halon replacement programmes and ongoing conservation efforts.

Many of today's fielded weapon systems and support equipment will remain in service for the foreseeable future. Barring mandatory decommissioning, their mission-critical halon fire protection systems will need to be supported, to at least 2050 and likely beyond. However, the EU requires phaseout of halons in military uses as shown in Table 5.5 (Commission Regulation EU, 2017/605), **EU (2017)**. Presently, EU cut-off dates are under review and the dates might be brought forward for some applications, and possibly extended for others. Given that the latest end date for halon in these military critical use applications is currently 2040, the replacement processes would have to be initiated in the near future since fleet retrofits can take a decade or more to complete due to funding and logistics constraints.

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 generated during the air purification process. These by-products may include acid gases such as 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 ($COCl_2$, also known as phosgene), depending on the chemical composition of the extinguishing agent used. These toxic gases are of particular concern for the military where fires may be more intense than non-combat fires and egress from the fire zone is not always possible. 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. However, it should be noted that measuring the total average fluorine, chlorine or bromine levels is not an adequate method to determine effects on humans.

Table 5.5: 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)[1]	End date (31 December of stated year)[2]
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**

[1] 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

[2] 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

5.2.2 Military Ground Vehicle Applications

Parties continue 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 replaced halon 1301 in crew and/or engine protection systems with agents based on HFC227-BC, a SNAP listed agent blend of HFC-227ea and sodium bicarbonate-based dry chemical, 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 HFCs (HFC-227ea or HFC-236fa) and replaced halon portable extinguishers with dry chemical in its vehicle crew compartments. CO_2 extinguishers have also replaced halon portable extinguishers on all Swedish and many US military vehicles.

As discussed in Chapter 3, the phasedown of high-GWP HFC production will have a significant impact on the military sector as availability of these chemicals declines. Owing to the relatively small market size of military HFC uses, this will have a disproportionate effect on military applications. As industry works to implement alternatives, these same alternatives may not be suitable for military applications with their unique requirements. If militaries use fire extinguishing agents that are not widely supported by industry owing to their low demand, then supply constraints will be accelerated as chemical manufacturers phase down or stop production. The military sector demand is not large enough to drive industry to continue production of required HFCs. Therefore, it is recommended that militaries ensure that an adequate supply and/or stockpile is available to meet anticipated future needs. Reliance on reclaimed chemicals could be a feasible option for the short-to mid-term. However, for long-term sustainment plans to be successful, availability and quality of the agents need to be considered.

High-GWP HFCs are also used as refrigerants in multiple military applications and will have similar supply constraints as will fire suppressants and require unique safety considerations for applicability in military applications. At least one alternative (HFO-1234yf) being widely adopted commercially has been shown to have significant flammability concerns when subjected to military threats. Therefore, alternative refrigerants which may be suitable for commercial applications should be evaluated for acceptable performance and safe use against military-unique environments and threats.

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 are being made for the same military application.

5.2.2.1 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 HFC-227ea, HFC-236fa, and HFC-125, with and without sodium bicarbonate ($NaHCO_3$) dry chemical, water with zero-GWP 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/$NaHCO_3$ blend and aqueous system were down-selected for further testing. The HFC-236fa based blend also met requirements but was not chosen because of its higher GWP and higher boiling point compared to HFC-227ea. The HFC-227ea/$NaHCO_3$ blend was subsequently SNAP-listed by the US EPA as HFC227-BC and is the only halon alternative 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 designed to simulate the fireball development and blast overpressure 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 US 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 subjected to immediate or delayed incapacitation. Key elements of the criteria are summarized in Table 5.6.

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 to halon 1301 or HFC227-BC was available that had an acceptable space and weight allowance. The Army continues to research low- and zero-GWP potential alternatives but thus far has come to a similar conclusion. Overall, it has been found that low GWP alternatives are more reactive, resulting in shorter atmospheric lifetimes and therefore lower GWPs, and also generate much higher levels of toxic gases compared to the more stable, higher GWP chemicals, **Hodges and Chapman**

(2018). This is of particular concern to the military sector as occupants often must stay in the protected space following fire suppression.

Table 5.6: 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 heat 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 exposure limits per the applicable NFPA standard
Toxic Gases	Acid and Carbonyl Gases, 5 min dose $HF + HBr + 2 \cdot COF_2 < 746$ ppm-min Other gases (e.g., CO_2, CO, NO_X, HCN) are also measured
Oxygen Levels	Not below 16%

5.2.2.2 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 of military vehicles. Several live-fire test programmes were carried out over the years that involved fuel-spray tests developed to simulate the blast overpressure that follows a ballistic penetration of the armour and fuel tank (in conformity with Level 4 of North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4317, **NATO (2018)**). The crew casualty criteria used are similar to those in Table 5.6 , apart from overpressure where the Swedish/German criteria allow a maximum of 5.5 psi (0.38 bar) and the allowed by-product dose is lower and evaluated over ten minutes vs. five as shown in Table 5.7 , **Schepers (1999) and (2000).**

Table 5.7: Swedish Key Elements of 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 heat 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 exposure limits per the applicable NFPA standard
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 (HCFC-123 and argon),
- HFC Blend B (HFC-134a, HFC-125 and carbon dioxide),
- Water mist with additives,
- HFC-227ea mixed with $NaHCO_3$,
- FK-5-1-12, and
- FK-5-1-12 with $NaHCO_3$ (this blend is not stable as the two materials react)

As a result of these 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.

Overall, on main battle tanks, armoured and light armoured vehicles in Sweden, halon 1301 has either been replaced or is scheduled to be replaced when the vehicles go through modification or maintenance. By the end of 2022, the intention was that all halon 1301 systems on these vehicles would be replaced. 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.

5.2.2.3 Brazil

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

- fires were extinguished in less than 250 ms without reflash,
- temperatures were less than the threshold of second-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 by-products were not addressed during the verification process. These toxic gases need to be considered carefully for occupied applications as previously discussed.

5.2.3 Military Aviation Applications

To date, many military aviation applications continue to rely on halons as the only viable options owing to their fire extinguishing capabilities under the wide range of operating conditions that are likely to be experienced by military aircraft.

HFC-125 has been successfully implemented as an alternative to halon 1301 for engine and APU fire protection on U.S. military fighters and helicopters developed since the early 1990s. In addition, HFC-125 is used on a military derivative of a large commercial aircraft recently put in service (KC-46 Pegasus, a military derivative of the Boeing 767), **USAF (2022)**. Military aircraft are designed to have a minimum service life of 30 years, so support for the current systems will be required beyond 2050; it is unlikely these systems will be converted to a lower-GWP agent in the foreseeable future since no replacement has been identified to date.

In the US, there has been success in replacing the standard 150 lb. halon 1211 wheeled extinguishing units employed on military flight lines with similarly sized units containing either HCFC Blend B or FK-5-1-12 at facilities operated by the military inside and outside the US. These units are UL™ listed and have somewhat lower fire extinguishing capability than the halon 1211 units employed for more than 30 years at US military sites.

There are only two standard halon alternative portable extinguishers (5B:C and 2B:C, **UL 711 (2018**) approved for military aircraft. However, there are many different sizes of portable extinguishers installed on military aircraft and helicopters. The process of getting an extinguisher approved for use on aircraft is costly and time consuming. The FSTOC is concerned that there will be difficulties in replacing these other extinguishers as there are currently no standardized test methods, classifications, or certification procedures for these other-sized extinguishers.

5.2.4 Military Naval Applications

For naval vessel applications, the FSTOC is aware of acceptable alternatives to halons for almost all applications in new designs. However, due to technical and economic challenges associated with retrofits, halons 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 CO_2 systems. However, CO_2 systems are prohibited in all spaces on new US naval vessels owing to crew safety considerations based on the toxicity of CO_2 that occurs well below concentrations needed to extinguish fires, see **EPA (2000)** and **NFPA 12 (2022)**. Militaries that use CO_2 systems rely on warnings, established egress procedures, and training for safe usage.

On Norwegian naval vessels, mainly alternatives to both halon and HFCs are used. This includes IG-541 in electrical compartments, and water sprinklers and water mist with and without 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, halon conversion programmes continue for normally unoccupied spaces such as paint lockers and diesel or gas turbine modules. For these applications, both CO_2 and HFCs have been found to be acceptable. Australia and Germany have also converted some machinery space halon systems to HFC-227ea and CO_2, respectively. The Italian Department of the Navy has qualified FK-5-1-12 (thus avoiding the use of high-GWP HFCs) for local explosion suppression onboard its military ships, based on the results of live-fire tests performed using a fuel-spray fire inside a trial room representing ships' machinery spaces. In these tests, a fuel explosion was considered successfully suppressed when the following criteria were met, **Bona and Pallant (2006); Grimaldi and Aceto (2009):**

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

In Sweden, the halon systems on most naval vessels have been retrofitted and the rest will be retrofitted when the upcoming midlife modifications are due within a few years. They have mainly been converted to FK-5-1-12 for occupied and normally unoccupied spaces. Also, some CO_2 systems have been installed but only in normally unoccupied spaces. A small number of inert gas systems have also been installed.

In Denmark, where HFCs are not acceptable because of national legislation, IGs have been installed to protect the engine compartments of some surface ships. When considering IGs for naval vessels, the weight and space occupied by the system is a significant factor. For example, IG systems require over three times the cylinder weight and deck space compared to an equivalent HFC-227ea system. Note that the safety of the inert gas systems also needs to be considered when protecting occupied spaces, see NFPA 2001, **NFPA 2001 (2022)**.

5.2.5 Summary

Many commercially available extinguishing agents have been assessed against the range of unique military fire protection requirements. In summary:

- Alternatives to halons have been adopted in military applications where they have been found to be technically and economically feasible.
- For new designs, there are many instances where the original halon or high-GWP HFC is the only solution that will meet stringent design requirements associated with military applications and will continue to be for the foreseeable future.
- The military sector does not represent a large enough market segment to influence chemical manufacturers to continue production of required HFCs or investigate new alternatives that do not have broader application.
- It is not believed that any new chemicals will be commercially available for the military to evaluate as viable replacements in the foreseeable future.

5.2.6 References

EPA (2000): "Carbon Dioxide as a Fire Suppressant: Examining the Risks" EPA Report No. EPA430-R-00-002, February 2000. www.epa.gov/ozone

EU (2017): Commission Regulation (EU) 2017/605 of 29 March 2017 amending Annex VI to Regulation (EC) No 1005/2009 of the European Parliament and of the Council on substances that deplete the ozone layer, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32017R0605

Bona and Pallant (2006): Bona, P., Dunster, R. G., Pallant, R., "Italian Navy Alternate Halon 1301 Agents Experimental Testing on Automatic Fire Sensing and Suppression Systems," Kidde Research Test Report 4292_en, 2006.

Grimaldi and Aceto (2009): Grimaldi, A. and Aceto, G., Novec 1230 Protection Fluid as a Next Generation Alternative to Halons on the Comandanti Class Ship, NAV 2009 International Conference of Ship and Shipping Research, 2009

Hodges and Chapman (2018): "Evolution of Combustion Byproducts from Gaseous Fire Suppression Agents," Proc. ARL Fire Protection Workshop, October 2018

NFPA 12 (2022): NFPA 12, Standard on Carbon Dioxide Extinguishing Systems, 2022

NFPA 2001 (2022): NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems, 2022

SDMO (2018): Correspondence between Swedish Defence Material Organization (FMV) and Norwegian Defence Materiel Agency (NDMA), Naval Engineering Section, 11 April 2018

USAF (2022): Air Force News Article "KC-46A cleared for worldwide deployments following first combat refuel" published Sept. 20, 2022. https://www.af.mil/News/Article-Display/Article/3163982/kc-46a-cleared-for-worldwide-deployments-following-first-combat-refuel/

5.3 Pipelines / Oil and Gas

5.3.1 Introduction

Risk management and regulations applicable to the hydrocarbon production and transportation industry focus on the potential for liquid hydrocarbon leaks which can lead to spray or pool fires and natural gas leaks which can lead to explosive atmospheres near occupied areas.

The enduring use of halon 1301 and halon 2402 systems in this industry for explosion prevention (inerting) and fire protection (suppression) has been mainly focused on inhospitable locations such as the Alaskan North Slope in the US, the North Sea in Europe, Eastern Europe, and the Russian Federation, where production and transportation facilities have had to be enclosed owing to the harsh climatic conditions.

Halon 1301 was the agent of choice for mitigating this threat in the US and Europe. Because of the effectiveness and availability of halon 1301 in the US at the time, it was also commonly used to protect the enclosures housing various support infrastructure (communication/data rooms, facility control rooms, primary/standby power generation, electrical equipment rooms).

Halon 2402 was the agent of choice for mitigating this threat in Eastern Europe, the Russian Federation and Ukraine. After the break-up of the former Soviet Union, Azerbaijan, Kazakhstan, the Russian Federation, Ukraine, and Uzbekistan were the main users of halon 2402 for fire protection in oil and gas sector. Except for Ukraine, these countries successfully replaced halon 2402 by in-kind and not-in-kind alternatives.

The remaining applications of halon 2402 in the oil and gas sector are floating roof oil tank protection in Japan, gas transportation fire protection in Ukraine, and the petroleum industry in Vietnam.

Table 5.8 provides a summary of halon, HFC, and their alternatives' uses in the oil and gas sector.

Table 5.8: Hydrocarbon Production and Transportation Industry Fire Protection, Agents Use by Application

Application	Agents in Use in Existing Infrastructure (Pre 2021)	Agents Considered for New Developments (Post 2021)
Oil	Halon 1301, Halon 2402, HFC-23, HFC-227ea, fluorinated foams, water or foam deluge, water mist	HFC-23, HFC-227ea, FK-5-1-12, fluorinated foams, water mist
Gas	Halon 1301, Halon 2402, HFC-23, HFC-227ea	HFC-23, HFC-227ea, FK-5-1-12,
Control / Electronics Rooms, Server Rooms, etc.	Halon 1301, HFC-23, HFC-227ea, Water Mist	HFC-227ea, FK-5-1-12, Water Mist

In the 1990s, new oil and gas developments with risk profiles or regulatory drivers for active fire protection systems installed HFC-23 (but not widely owing to its high-GWP), HFC-227ea in hydrocarbon risk areas, and FK-5-1-12 in electronic spaces (control rooms, server rooms, etc.) rather than rely on halons.

When reviewing enduring uses of halons and HFCs, there are two distinct cases to consider: 1) existing facilities and 2) new facilities. It should be noted that the original anticipated operational lifetime of existing oil and gas facilities was in the 20 to 30-year timeframe. Owing to changing technologies in oil and gas extraction, most facilities have already exceeded the original designed lifetime and are anticipated to continue operating for up to another 40 to 50 years. Therefore, existing facilities will likely remain protected by halons or HFCs, resulting in enduring uses of halons, HFC-23, HFC-227ea, (and FK-5-1-12) throughout the facility lifetime. It is not technically or economically feasible to replace existing systems with other common fire protection agents as they are not well suited for use in this industry. These include:

- Dry chemical: time/cost prohibitive to clean up after deployment and byproducts may result in corrosion of equipment risking critical energy infrastructure downtime.
- CO_2: unsuitable for use in areas that may be occupied by personnel, generally limited to power generation enclosures.
- IGs: unsuitable for areas that may be occupied by personnel at concentrations required for hazards present.
- Water deluge: Difficult to clean up after deployment and may result in damage to control equipment risking critical energy infrastructure downtime.
- Water mist: unsuitable for inerting / explosion prevention protection.

New facilities will continue to adopt alternatives based on the specific risks, hazard management and agent functionality in the given ambient environment and protected enclosure. However, it is important to note that for low temperature applications there have been no new low-GWP agents entering the commercial market that are both effective for hydrocarbon fires and safe at inerting concentrations across the wide design temperature spectrum (-46°C to 32°C). Only where sufficient protected enclosure heating can be provided for all emergency scenarios can agents other than halon 1301 and HFC-23 be employed for both hydrocarbon fire and explosion inerting protection. Therefore, this industry will need to continue use of halon and HFCs in new oil and gas developments in low temperature protected enclosures.

The oil and gas production and transportation industry as a whole is reducing reliance on halons and HFCs as a percentage of protected facilities. However, enduring uses related to existing halon and HFC systems will continue into the foreseeable future.

5.3.2 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 as well as the physical layout of the facility. After extensive research, it has been determined that in some cases, the replacement of such systems with currently available alternatives is not technically or economically feasible, and that current research is unlikely to lead to an economically viable solution. Thus, these facilities will likely rely on existing halon supplies and HFC production and supplies for their operating lifetimes, potentially the next 40 to 50 years. However, measures have been taken to reduce use and emissions through the methodologies summarized as follows:

- Reassess the hazards and evaluate whether the potential for an explosion still exists. In some hydrocarbon production and transportation facilities, process pressures have declined or hazard assessments have been conducted to re-evaluate risk. As a result, fixed halon 1301 systems can be decommissioned, the halon recovered, and an alternative fire suppression system installed if necessary to manage risk or comply with regulation.
- Remove and recover halon from non-hydrocarbon support infrastructure that can be adequately protected by other means. Evaluation of the widespread installation of halon during the original design and construction of many existing facilities has identified risks which can be adequately protected by other means. This is particularly true for the non-hydrocarbon containing areas supporting oil and gas facilities (control rooms, etc.).
- Avoid unwanted emissions. In looking at methods to avoid spurious emissions, focus has been on upgrading the fire and the gas detection systems to utilize modern technologies and on better maintenance practices. Newer systems are less prone to common false alarms such as heat signatures, reflections from flare radiation, black body radiation, hot work such as welding, and other problems that affect older technology detectors. Control system logic has also been employed by end users to reduce single device failure which could result in unwanted system discharge.

5.3.3 Offshore Facility Considerations

For offshore platforms and other space-constrained locations, the physical space and weight constraints create a barrier to the replacement of legacy systems. Until an economically viable alternative, with similar weight and space requirements becomes available/accessible (refer to Chapter 9 Alternatives to HFCs), halon and HFC systems that have not already been removed from service or replaced with an acceptable alternative are likely to remain in service for the operating lifetime of the facility.

5.3.4 Article 5 Party Considerations

Article 5 parties in the Asia Pacific region installed halon 1301 systems in refineries, gas pumping stations and offshore oil platforms. Oil pumping stations are gradually switching over to dry chemicals, HFC-227ea, or FK-5-1-12, where possible. IG 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 demand is typically met by local sources of recovered/recycled/reclaimed halon, which are used to refill existing cylinders. However, there is no halon recycling/reclaiming, banking, or quality testing facilities for halon in much of Asia and therefore the quality and effectiveness of the halon supply in this region is a major concern. Newly produced and recycled/reclaimed high-GWP HFCs are available. In land-based halon 1301 systems where an in-kind agent is required, some companies are hesitant to switch over to HFCs owing to concerns over their high GWPs and the risk they would be forced to transition away from the HFC in the near future. It is reported that HFC-23 has not typically been used in this region unlike in cold climates.

5.3.5 New Facilities

For new facilities, many oil and gas industry companies are adopting an inherently safer design approach to mitigate risk within their facilities. The overall objective of the inherently safer design process is to deliver:

- Fewer inherent hazards.
    - Hazards will have been identified, assessed, understood, and documented.
    - Opportunities to minimize risks at the source will have been identified, considered, and implemented, if practical, including reduced inventory that reduces severity of the event.
    - Probability and number of unwanted events will have been reduced by, among other measures, increasing equipment integrity (e.g., explosion-proof equipment), equipment reliability and longevity, and safety integrated systems (e.g., diluting hydrocarbon vapour concentrations through interconnection of ventilation systems with the fire and gas detection and control system).
- Optimal capital investment with view to minimizing risks for lifetime of facility.
- Practical risk management strategy to manage primary risk drivers.

When all such measures have been considered, and an unacceptable level of residual risk remains, other risk reducing measures are considered such as fire suppression and explosion inerting systems. In most cases, robust hydrocarbon gas detection systems are employed to shut-down, isolate, depressurize 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 agent.

It is important to note that even if residual risk does not drive the implementation of fire suppression and explosion inerting fire protection systems, local regulation may still require it.

An unintended consequence of high-rate ventilation in an Arctic climate (-46ºC to 32ºC) is that the protected, enclosed process module may be at or near ambient outside wintertime temperatures during hydrocarbon gas release and subsequent inerting system discharge events. The potential extreme low temperature requires the use of an agent with very high volatility (e.g., an agent with a low boiling point) such as HFC-23 or halon 1301. In some specific instances, total flooding FK-5-1-12 systems have been employed for fire extinguishment and methane explosion inerting protection in Arctic protected enclosures. However, these instances require the mitigation of cold temperature impacts on agent effectiveness by installation of extensive, power intensive heating protocols for all design/emergency scenarios. In other specific instances where only fire extinguishment was required (i.e., no vapour cloud explosion hazard is present or anticipated), fine water mist systems have replaced high GWP HFC systems in new facilities.

5.3.6 Emerging Regulatory Impacts

As indicated above, fluorinated foams have been identified as an effective agent for liquid hydrocarbon fire response in the oil and gas industry. Additionally, the use of FK-5-1-12 has increased in the oil and gas industry. Foams, in particular, have been used both in fixed system as well as in emergency fire response activities. These foams contain PFAS, and as environmental concerns related to the use of PFAS influence regulations, the maintenance, testing, and even for-cause use of fluorinated foams during an emergency situation may be restricted.

The impact of emerging regulations is compounded by proposed regulatory definitions of PFAS containing material which could restrict the use of fire suppression agents including the alternatives to halons and HFCs.

5.4 Telecommunications and Computer Rooms (Electronics)

5.4.1 Introduction

In the early 1990s, the FSTOC estimated that telecommunications and computer rooms accounted for about 65% of the annual use of halon 1301. In its 1993 Assessment, the FSTOC indicated that by then a wide range of suitable non-ODS alternatives including both traditional and new technologies existed for new applications. The FSTOC 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.

The following alternatives are reported as used in the electronics sector for fixed systems (not handheld), with non-HFCs (first 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

- IG systems
- CO_2 systems (very limited)
- HFC-227ea
- HFC-125
- HFC-236fa

5.4.2 Data by Region

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

In Japan, it is reported that IG-100 and high-GWP HFCs have been used as the main alternatives to halon 1301 in telecommunications and computer rooms when reclaimed halon is not used. It should be noted that Japan has one of the world's largest halon banks and through responsible management is able to meet its own halon needs. The Japanese halon bank is, in essence, a closed loop system and not part of the supply/demand of the rest of the world.

The installation rates of fire protection agents (halon 1301, HFC-23, HFC-227ea, IG-100, IG-541, IG-55, FK-5-1-12, and CO_2) in telecommunications and computer rooms as of March 2021 in Japan are shown in Figure 5.7 (the rates in parenthesis are those in the 2018 Assessment report). All the installation rates of alternative agents dropped by at most several percentage points such as HFC-23 and IG-100, 4.6 % and 4.5 %, respectively, even though IG-100 is still the most popular alternative agent, while the rate of halon 1301 considerably increased by 12.5 % since the 2018 Assessment report. This means that halon 1301 is more preferred than its alternatives because of its safety (halon 1301 is the only gaseous agent which is allowed to be used in normally occupied areas in Japan) and total cost effectiveness. Halon 1301 requires the smallest cylinder storage space and there is no need to equip pressure release dampers and ducts in the facility compared to its alternatives. This is especially clear in the case of custom-installation of fire extinguishing systems in existing buildings. This trend in Japan is expected to continue in the future.

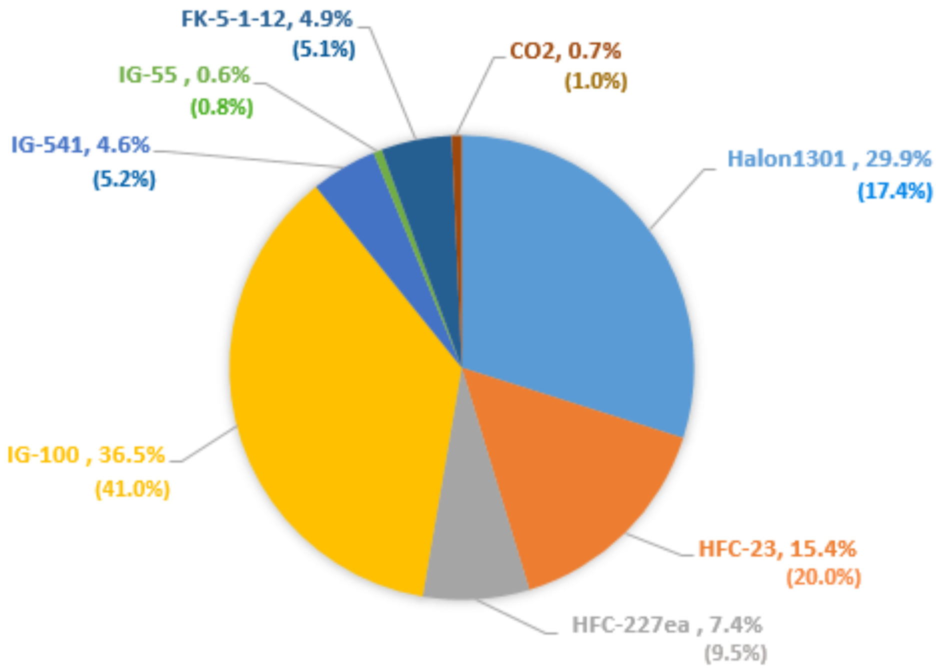


Figure 5.7: Fire Protection Agents in Telecommunications and Computer Rooms in Japan

Data as of March 2021 (Rates in parentheses are data from the 2018 Assessment report)

In Australia, most new data centre fire protection systems use IGs, usually IG-541or IG-55. There are other data centres that have recently either removed gaseous suppression systems completely or have replaced them with pre-action water mist sprinkler systems. In summary, based on all data centres around Australia, approximately 80% use IGs. The other 20% use water mist or pre-action sprinkler systems.

The Egyptian market in 2020 is estimated at 95% vaporizing liquid agent systems (most notably HFC-227ea and increasingly FK-5-1-12) versus 5% IGs systems on a system-by-system basis as shown in Figure 5.8.

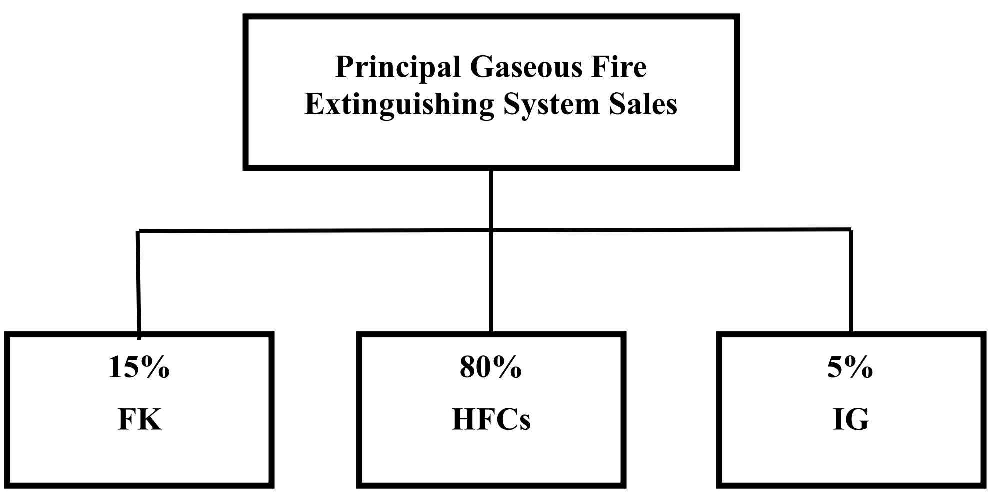


Figure 5.8: Approximate Market Share in Egypt by System Cost in 2020

There are three main sectors in the Egyptian market using vaporizing liquid agent for fire protection as shown in Figure 5.9:

- IT and telecom rooms,
- energy buildings, libraries and archives, and
- oil and gas.

Note: The other sectors such as military, aviation, marine etc., have not been taken into consideration in this report since the data were not available to the public.

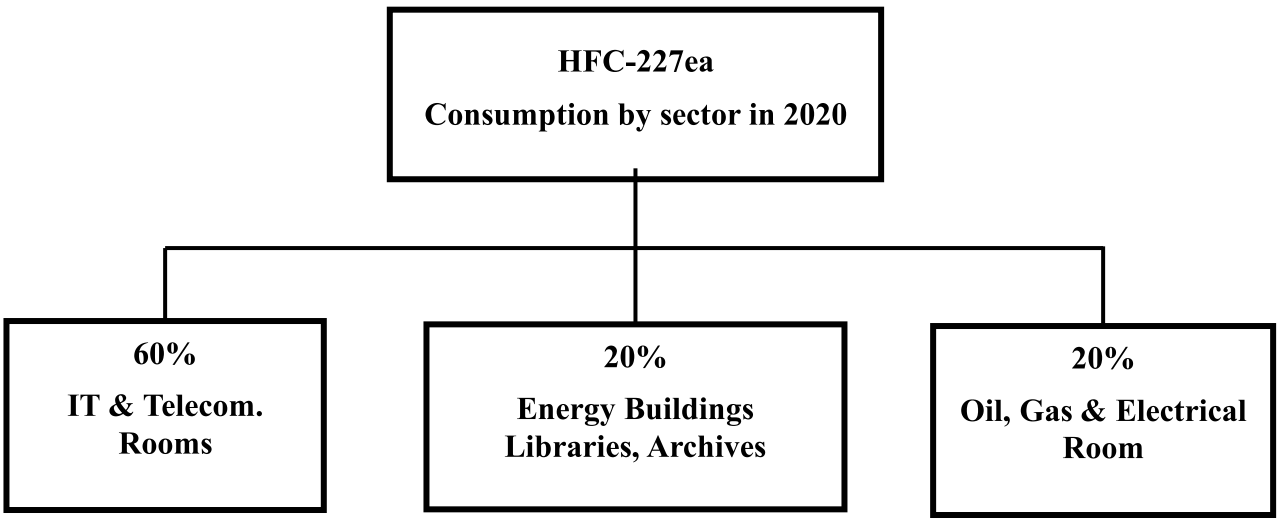


Figure 5.9: **Approximate HFC-227ea Market Share in Egypt by Sector in 2020**

As stated earlier, HFCs have been the substance of choice historically for the Egyptian fire protection industry, and HFC-227ea is used in the vast majority of HFC systems, so this HFC consumption represents a large part of the total annual installations of substances employed in fire protection. Approximately 300 tonnes of HFCs were imported into Egypt in 2020. Table 5.9 illustrates the consumption of different HFCs used for fire suppression from 2016 to 2020 in Egypt which show the increase in consumption to have doubled during this four-year period.

Table 5.9: HFC Consumption by Tonnes in Egypt[1,2]

HFC Type	2016	2017	2018	2019	2020
HFC-227ea	150	200	275	350	300
HFC-236fa	0.15	0	0	0	0
Total	150.15	200	275	350	300

1. This estimate of annual consumption has been derived from a comparison of several sets of data from Egypt's Central Agency for Public Mobilization and Statistics (CAPMAS), suppliers, consultants, and others.
2. Year 2020 shows a decrease of consumption owing to the COVID-19 pandemic

According to the consumption trend for the HFCs during the last five years, the expected consumption through 2025 will be increased, as shown in Table 5.10. Also, the expected consumption by different sectors during the period 2021 – 2025 are shown in Table 5.11.

Table 5.10: **HFC expected consumption by Tonnes in Egypt**

HFC Type	**2021**	**2022**	**2023**	**2024**	**2025**
HFC-23	0	0	0	0	0
HFC-125	0	0	0	0	0
HFC-227ea	330	360	400	450	500
HFC-236fa	0	0	0	0	0
Total	330	360	400	450	500

Note: This expected estimate of annual consumption has been calculated based on the annual growth of each sector.

Table 5.11: HFC Expected Market Volume by Sector in Tonnes[1,2,3]

Sector	**2021**	**2025**	**Growth Rate**
IT and Telecom. rooms	200	360	80%
Oil and Gas	65	40	-40%
Energy Buildings, Libraries, and Archives	65	100	60%
Total	330	500	52%

1. This estimate of annual consumption has been calculated based on the annual growth of each sector.
2. Oil and Gas sector does not specify HFCs anymore for fire suppression, leading to an expected reduction of consumption during the next 5 years.
3. Due to lower initial cost of the HFCs compared to other agents, the rest of the sectors are expected to increase consumption during the coming 5 years.

The Egyptian market has begun to accept the HFC alternatives which is shown clearly in Figure 5.10, reflecting a slight increase in the market share during the last 5 years. It is expected to continue to grow at the expense of the HFC market share. On December 20, 2022, 3M Corporation announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**. The FSTOC has been informed that this will include the fire suppressant FK-5-1-12. The FSTOC understands that there are other manufacturers of this agent. Clearly, this is an evolving situation, and the FSTOC expects to understand more fully the potential impacts to HFCs and their alternatives in the future.

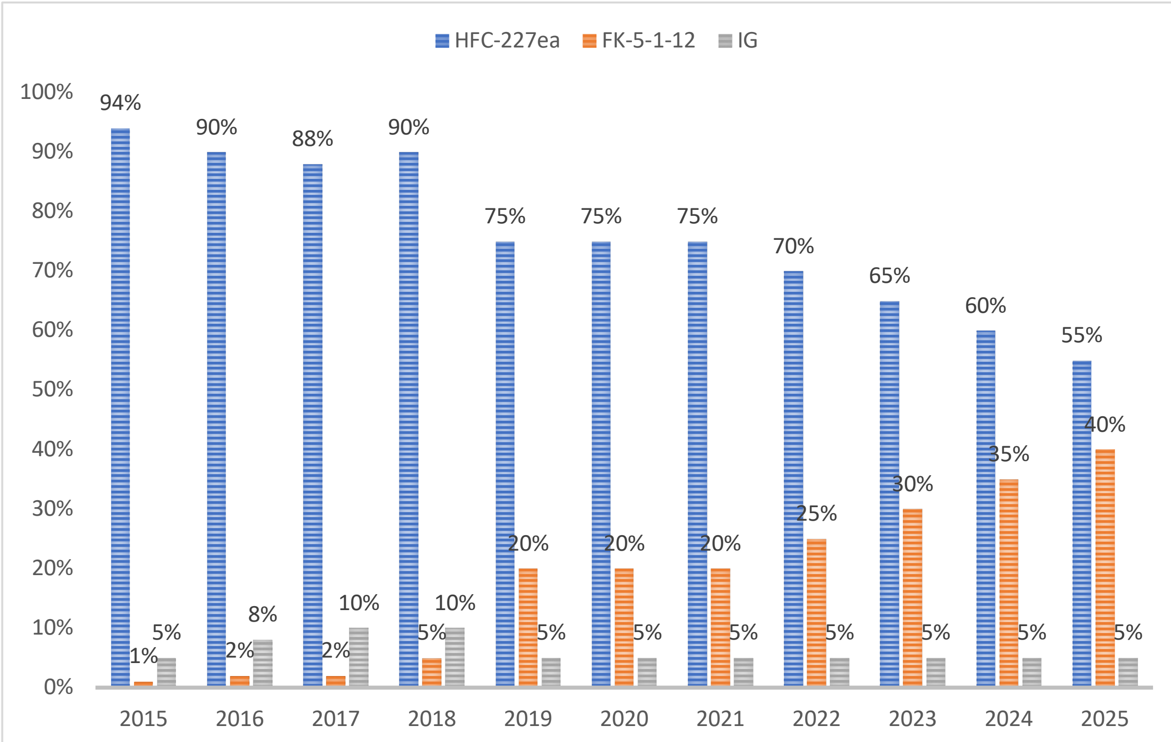


Figure 5.10: Egyptian Market Share: HFCs vs. Alternatives[1,2,3]

1. Years 2016 - 2018: several projects related to Oil and Gas were specifying IG.
2. Year 2019 and 2020: several projects related to the new construction at the New Administrative Capital were specifying FK-5-1-12.
3. The Oil and Gas sector is no longer specifying HFCs for fire suppression, which leads to an expected increase in FK-5-1-12 consumption.

In India, the installed base for fire protection in telecommunication and computer rooms is estimated as: FK-5-1-12 (~60%), HFC-227ea (~30%), and CO_2 (~10%). CO_2 is no longer used for new installations. Cable trays in the subfloors of the computer and airtight server compartments are protected by HFC-236fa, but its usage will be reduced slowly through 2030. Water mist systems are also used for wet benches in clean rooms and for subfloors of computer rooms.

In Sweden, it is estimated that FK-5-1-12 makes up about 40% of the systems, IG systems 35%, HFC systems 20%, and water mist systems about 5%. New systems are split between FK-5-1-12 and IG systems, Few, if any, new HFC systems or water mist systems are being installed. It is therefore likely that the number of HFC systems will drop to 5% within the next five years.

In the Russian Federation, the information on installed capacity in telecom and power sectors is unavailable, however, the FSTOC has been advised that there are no halon systems in these sectors.

5.4.3 Nuclear Power Plants

Nuclear power plants (NPPs) are a subsector of the energy sector that typically employed halon systems and extinguishers. It is a tightly regulated industry with high level safety protocols and systems. The potential risk to life and economy from a poorly managed fire scenario is understandably extreme owing to the exceedingly long-term effects of radiation, the far-reaching environmental impact, the cost of the facility, and loss of direct and indirect revenues.

The automatic fire systems may not be tied directly to the facility design and in which case, some NPP owners have changed out their halon systems where feasible and practical. The industry has expressed concern over future availability of suppression agent and UL™ listed maintenance components. Risk management practices typically involve life cycle planning on all aspects of the NPPs including maintenance of the fire systems. It should be noted that some NPPs are partially or totally decommissioned. The decommissioned NPPs still require staffing, maintenance and fully functional fire suppression systems for the foreseeable future.

Two organizations' websites were utilized to gather data on the number and locations of NPPs world-wide, the World Association of Nuclear Operators (WANO) and the International Atomic Energy Agency (IAEA). It is presumed, in general, that there are larger or more numerous gaseous fire suppression systems in plants that have multiple reactors as opposed to a single reactor plant. In reviewing the online data published by WANO and IAEA, there are approximately 203 NPPs, consisting of 439 reactors, worldwide and 56 in construction, **WANO (2019), IAEA (2022)**. It should be noted, with climate change commitments and energy sourcing challenges, NPP construction is growing rapidly with as many as 50% more reactors coming online in some countries.

The FSTOC has contacted numerous organizations and associations in the nuclear industry requesting additional information on the fire suppression systems utilized in NPPs. Some information was collected for NPPs in India and in the US. This information is not to be considered party data or information as it has not been provided by, or vetted by, the party. The following analyses are provided based upon the information gathered in 2021-2022.

5.4.3.1 India

In India, halon 1211 and halon 1301 had been used in some occupied areas of the NPPs; however, both agents were phased out in 2012. To manage fire risks, the following are employed in all NPPs in India:

- control rooms and computer rooms: high pressure inert gaseous systems,
- unmanned/unoccupied areas: CO_2 systems,
- occupied areas: HFC 227ea and FK-5-1-12 systems,
- machine rooms, pump rooms, etc.: high pressure water mist systems, and
- basic fire protection for buildings: sprinkler systems

As of November 2020, India has 22 nuclear reactors in operation in eight NPPs. Ten more reactors are under construction.

5.4.3.2 US

Data have been provided by some members of the Nuclear Energy Institute (NEI) on fire suppression in seven NPPs located in the US as shown in Table 5.12, **NEI (2022)**.

Table 5.12: Installed and Reserve Halon 1301 in Seven NPPs in the US.

Site #	1	2	3	4	5	6	7	Average
No. of Reactors	2	2	1	2	2	2	2	N/A
Installed (kg)	1,375	1,741	441	792	1,352	1,838	7,405	2,135
Stored (kg)	1,112	417	907	811	172	263	1,388	724
Total (kg)	2,487	2,158	1,348	1,603	1,524	2,101	8,793	2,859
Total per reactor (kg)	1243.5	1079	1348	801.5	762	1050.5	4396.5	1,526
Emitted Annually (kg)	0	0	0	0	<5	0	0	N/A

None of the seven NPPs reported using HCFCs or HFCs. The quantities of halon vary significantly between the sites. The average installed and reserve halon per reactor is approximately ~1.53 tonnes. There are 100 reactors at 56 NPP sites in the US. Using the information provided by NEI members for seven sites, the installed (and reserve) halon for all sites in the US could be projected to be ~150 metric tonnes (FSTOC estimate and not a party estimate or position). The emission rate provided is not typical for industry, rather it is far below average, and will be investigated further. It is more in line with the low emission rate in Japan where all systems are set on manual.

5.4.3.3 Russia and Former Soviet Union States

Until information is obtained on NPPs in the former Soviet Union States and Russia, the FSTOC presumes that the fire suppression systems utilized in the NPP reactors use halon 2402. Those states include Armenia, Bulgaria, Czech Republic, Hungary, the Russian Federation, Slovakia, Slovenia, and Ukraine. Combined, these states have 89 reactors at 24 sites, **WANO (2019)**.

While the FSTOC continues to reach out to organizations in this sector to gather data on more NPPs, the data from the US can be useful for projecting future suppression agent changes and requirements albeit speculative at this time without input from NPPs in other countries.

5.4.3.4 Estimation of Worldwide Halon 1301 Installed Base in NPPs

To estimate the installed halon 1301 world-wide, the FSTOC used the only data provided to-date (from the seven NEI members who provided information). Assuming, as of April 2022, there are 439 reactors world-wide, and of those there are 89 reactors where halon 2402 is installed and 22 reactors in India where no halon is installed, then the remaining number of reactors potentially using halon 1301 would be 328 reactors.

Using 328 reactors at 1.53 tonnes per reactor as a basis, the installed/reserve halon 1301 could be estimated to be ~500 tonnes. This represents a significant increase over the estimate for NPPs in the 2018 Assessment report of ~200 tonnes. The range of quantities of halon 1301 in the seven NPPs (lowest = 762 kg per reactor, highest = ~4,400 kg per reactor) implies there could be significant uncertainty in the extrapolated value of 500 tonnes. However, this is likely to be within the +/- 10% variation used in the run-out modelling scenarios described in section 0.

The replenishment rate for halon systems in this sector would normally be estimated to be 2-3% from leakage and maintenance activities. Assuming a 2% emission rate, this sector would need a replenishment rate of <10 tonnes per year for the 328 reactors assumed to be using halon 1301 fire suppression systems. Based upon information available at the WANO and IAEA websites, most nuclear reactors have a lifetime of 45-50 years. Bear in mind, the reactors continue minimal operations beyond their energy production years. Therefore, the fire protection system would need to be maintained until the reactor is completely decommissioned. There are no known NPPs that have been completely decommissioned.

None of the seven NEI members reported using HCFCs or HFCs. While it is probable there are NPPs utilizing other gaseous suppression agents, the FSTOC cannot at this time report any uses in this energy subsector other than those reported by India.

5.4.4 Conclusions

The NPP industry utilizes halon 1301 for fire suppression. The NPPs typically operate for 45-50 years with continued halon use and are never decommissioned. The industry is moving to alternative fire suppression methods and agents; however, it is unlikely dependence on halon 1301 will ever be eliminated. The replenishment requirements for halon 1301 are roughly estimated at 10 tonnes per year; this estimate will be revised if the FSTOC can obtain more specific data.

5.4.5 References

IAEA (2020): International Atomic Energy Agency, "PRIS - Power Reactor Information System", 2020, www.iaea.org

NEI (2022): Nuclear Energy Institute, correspondence between NEI and HTOC, April 2022, www.nei.org

WANO (2019): World Association of Nuclear Operators, "Global Membership Map 2020, October 2019, www.wano.info

5.5 Shipbreaking

5.5.1 Introduction

In the mid-1970s, passenger ships and tankers switched from CO_2 to halon 1301 for fire suppression in their main engine rooms as it was more cost effective. When the International Maritime Organization (IMO) banned the use of halons in new constructions in 1992, **IMO (1992)**, CO_2 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 FSTOC to try to estimate the amount of halon 1301 and 1211 that could come onto the market from the breaking of ships. The FSTOC response to Decisions XXVI/7 was also included in its 2018 Assessment report, where it was believed that shipbreaking could be a significant source of halon 1301 to supply the enduring needs described in the previous sections.

However, at that time, the FSTOC had poor visibility as to the quantities of halon 1301 being recovered from shipbreaking. 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 2018 Assessment report, the answers to questions 3 and 5 were estimated as follows. The average charge size of halon 1301 systems on passenger ships and tankers was assumed to vary by the ship's deadweight tonnage (DWT). These charge sizes are listed in Table 5.13 for each size range of passenger ships and tankers.

Table 5.13: Halon 1301 Charge Sizes for Passenger Ships and Tankers (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

The lifetime of ships was estimated to be between 30 and 40 years. This datum, along with the number of and type of ships thought to have halon 1301 fire protection systems fitted allowed Figure 5.11: Total Residual Amount of Halon 1301 Remaining in Service, ICF (2015) to be generated.

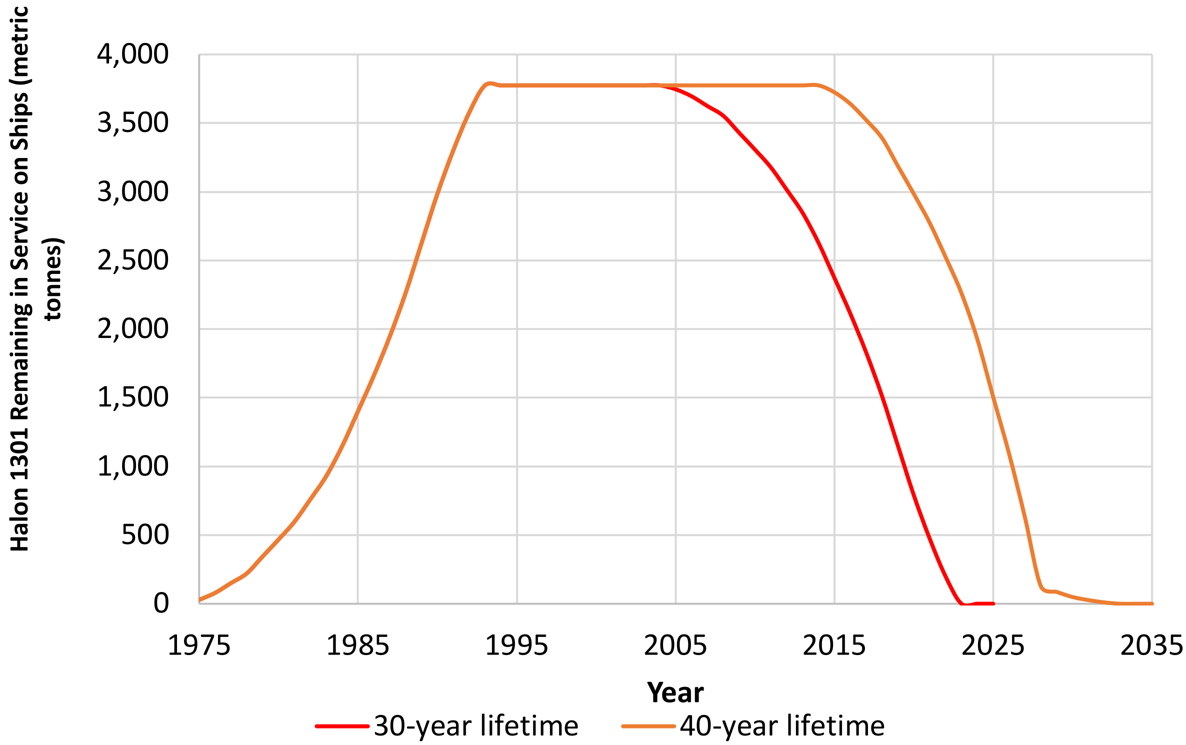


Figure 5.11: Total Residual Amount of Halon 1301 Remaining in Service, ICF (2015)

Estimates were made by ICF that approximately 200 to 300 tonnes of halon 1301 per year could be available, until the supply was exhausted, **ICF (2015)**.

5.5.2 Update from the 2018 report

Recently, the FSTOC recruited a member from the shipbreaking industry and is starting to get data from Bangladesh on the types of ships fitted with halon 1301, the age of the ships being broken, and the quantities of halon being recovered. This has allowed the estimates and assumptions in the 2018 Assessment report to be refined or validated. Data for 2021 are shown in Table 5.14.

Table 5.14: Halon 1301 Recovered from Shipbreaking in 2021 from Bangladesh

Vessel Type	Vessel Name	IMO No.	DWT	Mass 1301 Installed (kg)[1]	Mass Recovered (kg)	Percent Recovered	Age at Breaking (years)
Tanker	Xin Da	8609151	2898	806	672	83%	37
Tanker	Mt Medan	9002207	152680	11200	7420	66%	30
Bulk Carrier	Shanghai	8915407	156750	5740	3920	68%	30
Tanker	Polaris	7922843	11428	1866	1866	100%	40
Tanker	Zhong	8517114	16970	3007	573	19%	33

Tanker	Grand Ocean	8416140	4287	1481	1481	100%	37
Bulk Carrier	Mv Harmony	8915392	156183	8745	5546	63%	30
Refrig. Cargo	Celtic Ice	7727102	2668	1201	1201	100%	42
Tanker	Knight	8515738	19080	1377	1377	100%	34
Tanker	Ji Tai	8606288	4875	1363	765	56%	35
Tanker	Lucky Grow 899	8706648	4999	1012	868	86%	35
Tanker	Pandora	8106824	459	437	437	100%	39
Passenger Ferry	Trin	8902357	5872	3492	3056	88%	31
Tanker	Belogorsk	8700101	3060	1427	1427	100%	33
Tanker	Mt Sunward	8920115	6174	1204	1204	100%	31
Tanker	Ostrov Russkiy	8421262	7199	689	620	90%	36

[1] Mass of halon installed is obtained by multiplying the nominal charge per cylinder by the number of cylinders recovered. There is no information on where the halon was used (main engine room, auxiliary machinery spaces, etc.).

Although this is a relatively small sample size, several observations can be made:

1. The mean age of the ships broken is 34.6 years, which agrees well with the FSTOC estimate of 30-40 years.
2. There is a considerable variation in the amount of halon recovered compared to the mass halon 1301 installed (low end =19%, high end = 100%). The reason for this variation is not known at this time.
3. Of the sixteen ships broken that contained halon 1301, twelve (75%) were tankers, three (19%) were cargo vessels, and one (6%) was a passenger ferry.
4. When considering the amount of halon installed for various sizes of ships, it is possible to compare the actual amounts with the estimates provided by the FSTOC in the 2018 Assessment report. This is shown in Figure 5.12 and Table 5.13. The FSTOC estimates for halon installed is a reasonable fit to the amounts recovered from the 16 ships broken in Bangladesh in 2021, with the exception of the three largest ships.
5. The total amount of halon 1301 recovered from shipyards in Bangladesh in 2021 was 32.4 tonnes, from a possible 45.0 tonnes, or 72.0%.
6. To put the data from Bangladesh into context, it is necessary to extrapolate to the global shipbreaking industry. Data from the NGO offthebeach.org are given in Table 5.15, Figure 5.13, and Figure 5.14 below, **Offthebeach (2022)**.

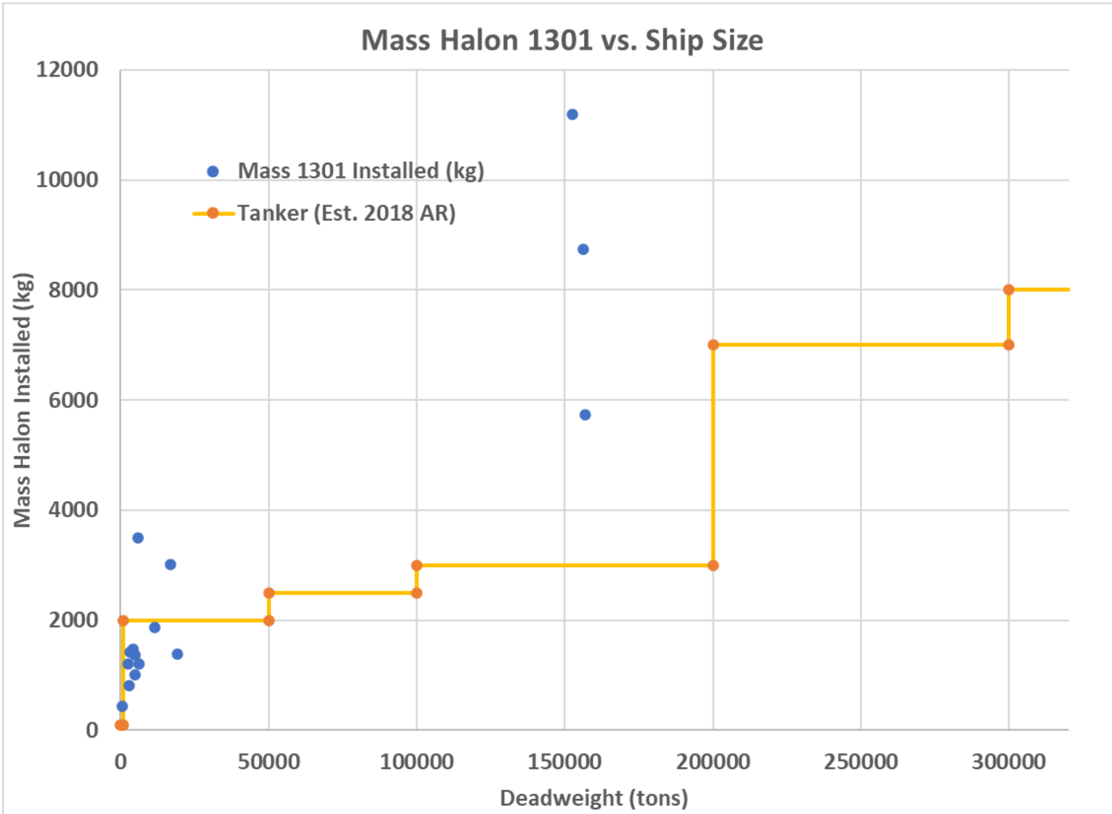


Figure 5.12: Comparison of Amounts of Halon 1301 installed with FSTOC Estimates in 2018 Assessment Report

Table 5.15: Global Shipbreaking Statistics, 2021

	Ships Broken		Gross Tonnage		
Country	**Number**	**Percent**	**Tonnage**	**Percent**	**Average Ship Size (Tonnes)**
Bangladesh	254	33%	8,036,554	50%	31,640
India	210	28%	3,144,135	20%	14,972
Pakistan	119	16%	2,972,585	19%	24,980
Turkey	77	10%	1,368,929	9%	17,778
Rest of World	66	9%	387,278	2%	5,868
EU	37	5%	104,983	1%	2,837
Total	**763**	**100%**	**16,014,464**	**100%**	**20,989**

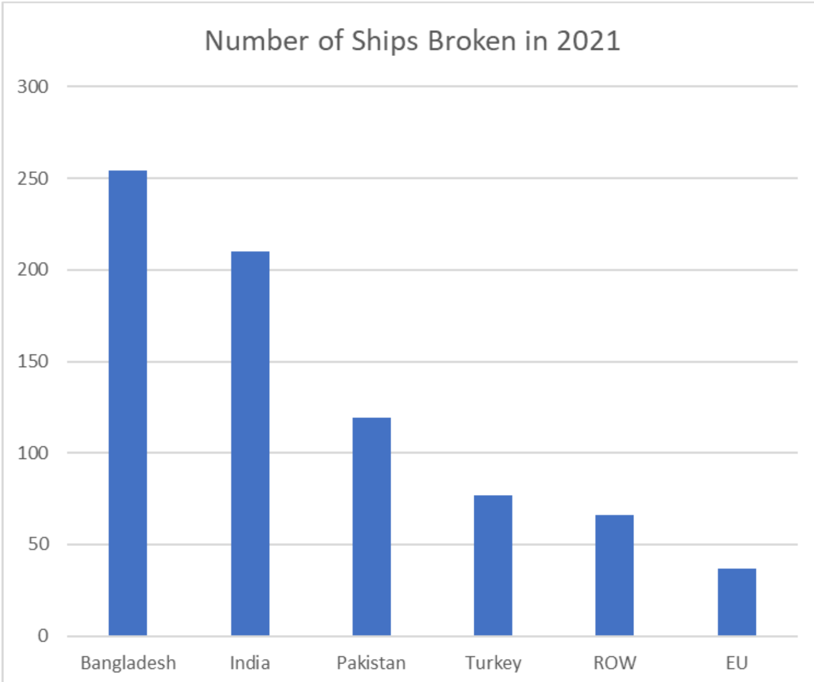


Figure 5.13: Number of Ships Broken in 2021, by Country

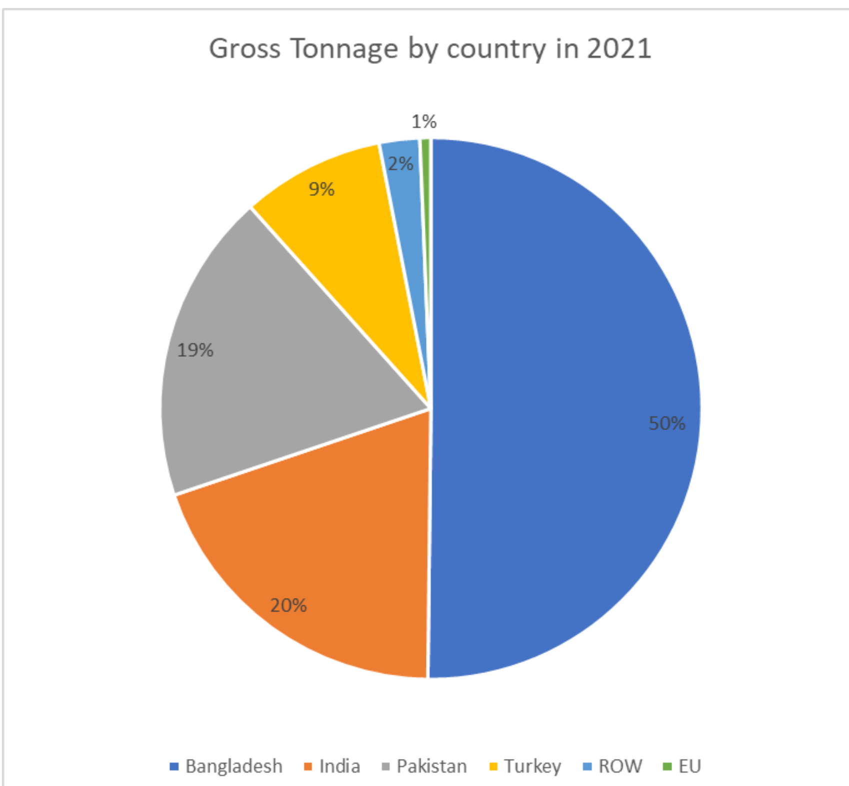


Figure 5.14: Gross Tonnage of Ships Broken in 2021, by Country

From these data, it can be seen that shipyards in Bangladesh specialize in larger ships and possibly those with larger amounts of halon 1301 installed. Recalling that ICF, **ICF (2015)** estimated that approximately 200 to 300 tonnes of halon 1301 could be available per year, the 45 tonnes from Bangladesh seems low. It would be reasonable to assume that since the Bangladesh shipyards account for 50% of the ships broken by tonnage and that they specialize in larger ships, that they would account for at least half of the halon being recovered. One hypothesis is that halon is being removed and entering the recycled agent supply chain prior to ships being broken. The FSTOC is working to understand whether this is the case, or the amounts of halon being recovered are lower for some other reason, for example the supplies of halon are becoming exhausted.

Following the good start made on obtaining data from Bangladesh, the FSTOC plans to try to obtain data from previous years as well collect new data going forward. Additionally, data from other shipbreaking countries will also be collected wherever possible.

5.5.3 References

IMO (1992): 1992 Amendments to the 1974 SOLAS Convention, Resolution MSC.27(61), paragraph 16.
https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.27(61).pdf

ICF (2015): ICF International, Projections of Halon 1301 Supply and Demand for Aviation Applications, May 2015

Offthebeach (2022): https://www.offthebeach.org/

6 Global Estimates of Halons and HFC Fire Extinguishing Agent Quantities

6.1 Introduction

Beginning with the first FSTOC Assessment report in 1989, the FSTOC included estimated historic and projected emissions and global banks of halons 1211 and 1301. This was initially based on the work of former FSTOC 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 (from the European Chemical Industry Council (CEFIC) data or Article 7 reporting) 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 emission 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 (CEIT - former Soviet bloc countries), and 5) all Montreal Protocol "Article 5" parties, which are the remainder of the countries. Different practices that led to emissions were separately identified for each region and are periodically updated by the FSTOC 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 venting it. With the advent of the Montreal Protocol, many emissive practices were 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 included 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 FSTOC developed and reported on a model for halon 2402 similar to the halon 1211 and 1301 models.

For the 2022 Assessment, the FSTOC is again providing the most current estimates of the bank and emissions for halon 1301, halon 1211, and halon 2402. These models reflect all quantities that have been reported as destroyed and account for imports and exports between the five modelled regions where data are available. A significant change was made to add emissions during manufacture using emission factors developed by the Medical and Chemical Technical Options Committee **MCTOC (2022).** To better compare the emissions estimated from the FSTOC model and mean emissions derived from mixing ratios (atmospheric concentrations), the estimated emissions during manufacture are added to the emissions estimated to come from fire protection uses, which are referred to as Total Cumulative Emissions in Table 6.1, Table 6.3, and Table 6.5. No other new information was found to warrant changing any of the emission pattern assumptions for this assessment. In general, this assessment is similar, but not identical, to the 2018 Assessment for all three halons.

The 2022 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 fire suppressants is provided.

6.2 Emissions and Inventories of Halons

6.2.1 Halon 1301

Table 6.1 summarizes the FSTOC's 2022 estimates of total production, annual emissions, cumulative emissions, and resulting inventories (bank) for halon 1301 in five-year increments from 2017 – 2052. Future projected detailed yearly estimates for 2022 – 2051 are provided in Table 6.2. Historic yearly detailed results from 1963 to 2021 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 are the result of either destruction or export out of the model region. These negative values from destruction result in reducing total cumulative production. Export is matched by an import to a different region so there is no net change to total cumulative production. Positive values in the production columns after 1993 for non-Article 5 and after 2009 for Article 5 parties are the result of import of recycled/reclaimed 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 (FEPN) through 2021, **Yagi (2022)**.

Data on emission estimates for Northwest Europe (NWEU) have been updated for the period 1998 – 2020, **BEIS (2022)**. The methodology now uses three additional observation stations in addition to the original two at Mace Head, Ireland and Talconeston, UK: 1) Jungfraujoch, Switzerland, 2) Monte Cimone, Italy and 3) Taunus, Germany. The inclusion of the three additional sites is important as it is challenging to estimate NWEU emissions from measurements limited only to the UK and Ireland. In addition, the Inversion Technique for Emissions Modelling (InTEM) has been updated and improved **Manning et al. (2021)**. Also, the NWEU region estimate has been reduced to remove Denmark. Even so, there remains significant uncertainly in the results as the pollution signals containing halon 1301 are small and intermittent. The latest estimates are all smaller than the estimates obtained in 2018; however, the +/-1 sigma uncertainties have significant overlap. To compare these new emission estimates with the FSTOC model, the FSTOC model emission estimates were scaled for NWEU 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 by 1.62 to scale to the NWEU countries included: Belgium, France, Germany, Ireland, Luxembourg, The Netherlands, and the UK. The resultant annual FSTOC NWEU emissions for 2018 – 2020 are 107 metric tonnes, 103 metric tonnes, and 99 metric tonnes, respectively, as compared to the BEIS updated annual mean emission estimate of 51 (30 – 72) metric tonnes, 42 (23 – 62) metric tonnes and 58 (42 – 74) metric tonnes, respectively. The new estimates are all lower than the FSTOC model by 130 – 350% when considering the total range of +/-1 sigma uncertainty. While they are lower, there are still significant emissions estimated, which implies that a significant amount of halon 1301 is still contained within NWEU. This amount includes halon 1301 in the EU critical uses including civil aviation fleets operating in Europe. While the FSTOC model attempts to account for amounts of halon exported out of Europe (and other regions as well), it is certainly possible that more was exported than accounted for by the FSTOC. The FSTOC will continue to try to find additional information on export of halon 1301 from Europe. It is also possible that the emission rate estimated by FSTOC is too high for NWEU, but no new information has been found by the FSTOC to amend these estimates.

Figure 6.1 graphically presents the projected regional distribution of the global bank of halon 1301. The figure shows that at the end of 2022, the FSTOC projects 48% of the total bank of halon 1301 will be in Japan and 30% in North America rising to 57% for Japan and lowering to 26% for North America over the next 10 years. This is the result of very low emissions in Japan, less than 0.1% on average, and a more typical total average emission rate in the US and is not the result of import/export between the two regions.

As shown in Figure 6.2, the FSTOC model emissions compare well with the mean emissions derived from mixing ratios (atmospheric concentrations) from the latest data using the methodology of **Vollmer et al., (2016)** (hereafter referred to Vollmer) until about 1998 where the FSTOC model emissions are consistently lower than the mean. Taking into account the uncertainties in the updated Vollmer data, the FSTOC estimates generally fall within +/-1 sigma uncertainty of the mean except for 2011 – 2012, where the FSTOC model estimates are slightly lower than the -1 sigma value. However, differences are seen during the periods of increasing and decreasing emissions from 1999-2000, 2010-2016 and 2018-2021, instead of the decay pattern expected from emissions from a finite global bank. The FSTOC is unaware of any singular fire protection use that could account for these emissions. The emissions are at least an order of magnitude higher than the largest single fire protection systems known to exist. While one could theorize that a potential source could have been from fire protection systems from shipbreaking activities (see Section 5.5), that is not anticipated in recent years as recovered halon 1301 has a significant market value and it is reported that halon is currently handled carefully during shipbreaking. Another possible source for these emissions could be from halon 1301 production and use as a feedstock for the pesticide Fipronil and several other chemicals, whose emissions would not be accounted for in the FSTOC model but would be included in the Vollmer estimates. This seems a more plausible explanation than these higher levels of emissions coming from the fire protection bank. However, the amount of halon 1301 feedstock production and use would need to be substantial at the higher end of the MCTOC-estimated emissions of 7.5%. The FSTOC is seeking additional information on halon 1301 feedstock production, use, and emissions to better understand if the higher levels of emissions can be attributed primarily to feedstock use, vs. from the fire protection bank.

For previous assessments, the updated Vollmer data were provided over the entire period from 1963 to the present. For this assessment, these are now only available from 1978 – 2021 using direct atmospheric measurements and no longer include earlier years that relied on the use of firn air (air trapped in glaciers). Therefore, to compare emissions with the FSTOC model and the resulting global bank of halon 1301, three different methods are employed:

1. Use the FSTOC emissions estimates from 1963 – 1977 and add that to the updated Vollmer 1978 – 2021 data,
2. use the FSTOC emissions from 1963 – 2009 and add that to the Vollmer 2010 – 2021 data, and
3. add the previous Vollmer data provided in 2018 for the period 1963 – 1977 to the updated 1978 – 2021 data.

All three of these estimating methods assume that the Vollmer emissions are only from the fire protection bank and from pre-2010 losses from production for fire protection uses and not from feedstock production and use. Each of these methods are discussed further below. It should be noted that the mean values are based on the atmospheric concentration measurements, while the +/-1 sigma ranges are calculated by adding or subtracting the 1 sigma uncertainly. This can result in negative emissions and/or a negative resulting bank. These negative values are then assigned to be "zero" which affects the uncertainly range provided in the text.

1. The Vollmer data from 1978 through 2021 provide cumulative emissions of 115,500 (88,000 - 143,000) metric tonnes. The FSTOC model provides emissions of 5,000 metric tonnes from 1963 to 1977, yielding a total of 120,500 metric tonnes of emissions over the whole period. Based on the global total cumulative fire protection production data of 148,000 metric tonnes from the FSTOC information, the mean values of the Vollmer data through 2021 provide a remaining bank of 27,500 (0 – 55,500) metric tonnes versus the FSTOC model estimate of approximately 113,000 metric tonnes of cumulative emissions and a remaining bank of 35,000 metric tonnes.

2. The Vollmer mean data from 2010 through 2021 provide cumulative emissions of 18,000 (11,000 – 25,000) metric tonnes. The FSTOC model provides emissions of 104,500 metric tonnes from 1963 to 2009, yielding a total of 122,500 metric tonnes over the whole period. Based on the global total cumulative fire protection production data of 148,000 metric tonnes from the FSTOC information, the Vollmer data through 2021 provide a remaining bank of 25,500 (18,500 – 32,500) metric tonnes versus the FSTOC model estimate of approximately 113,000 metric tonnes of cumulative emissions and a remaining bank of 35,000 metric tonnes.

3. The Vollmer mean data from 1978 through 2021 provide cumulative emissions of 115,500 (88,000 - 143,000) metric tonnes and Vollmer data reported in the 2018 FSTOC assessment for 1963 – 1977 provided cumulative emissions of 6,500 metric tonnes, yielding a total of 122,000 metric tonnes of emissions over the whole period. Based on the global total cumulative fire protection production data of 148,000 metric tonnes from the FSTOC information, the mean values of the updated Vollmer data through 2021 provide a remaining bank of 26,500 (0 – 60,500) metric tonnes versus the FSTOC model estimate of approximately 130,000 metric tonnes of cumulative emissions and a remaining bank of 35,000 metric tonnes.

Using the mean values, the three methods provide a range of 26,250 – 27,500 metric tonnes as the remaining global bank of halon 1301 as compared to 35,000 metric tonnes for the FSTOC model. This difference is becoming significant as the amount of halon that is available to support enduring fire protection uses becomes smaller over time. The Vollmer data also provide a much higher mean annual emission rate for 2021 of nearly 5.5% of a 26,500 metric tonne bank (average of the mean of three scenarios above). This is more than double the approximately 2.25% composite rate from the FSTOC model and much higher than the 2%+/-1% rate developed by **Verdonik and Robin (2004**). The combination of a potential higher emission rate than generated by the FSTOC and a smaller bank of halon 1301 also implies that there is going to be significantly less halon 1301 available to support ongoing needs in civil aviation, oil and gas, militaries, etc., which could result in a much earlier "run-out date" as discussed in Section 5.1 Civil Aviation. However, it is important to recall that this is predicated on the assumption that the difference in the Vollmer emissions and the FSTOC model all come from the fire protection bank and not from feedstock production and use, which is likely not a good assumption and results in an overestimate of the emissions from the fire protection bank.

Table 6.1: FSTOC Halon 1301 Model Summary (in metric tonnes)

	2017	2022	2027	2032	2037	2042	2047	2052
CUMULATIVE PRODUCTION								
North America, Western Europe and Japan	135,359	135,246	135,246	135,246	135,246	135,246	135,246	135,246
CEIT	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 CUMULATIVE PRODUCTION	148,356	148,244	148,244	148,244	148,244	148,244	148,244	148,244
ANNUAL EMISSIONS								
North America	430	362	305	256	216	182	153	129
Western Europe and Australia	201	167	141	119	100	85	71	60
Japan	25	24	24	24	24	24	24	23
CEIT	61	49	39	32	25	20	16	13
Article 5	288	172	102	61	36	22	13	8
TOTAL ANNUAL EMISSIONS	1,004	773	611	492	402	332	278	234
CUMULATIVE EMISSIONS								
North America	30,678	32,618	34,251	35,626	36,769	37,744	38,566	39,258
Western Europe and Australia	25,221	26,122	26,876	27,512	28,042	28,495	28,877	29,200
Japan	10,677	10,799	10,921	11,042	11,162	11,281	11,399	11,517
CEIT	6,803	7,069	7,283	7,455	7,591	7,703	7,793	7,865
Article 5	36,256	37,321	37,957	38,336	38,554	38,689	38,769	38,817
Fire Protection Cumulative Emissions	109,634	113,930	117,288	119,971	122,118	123,912	125,405	126,657
TOTAL CUMULATIVE EMISSIONS	112,910	117,206	120,563	123,247	125,427	127,221	128,714	129,966
INVENTORY (BANK)								
North America	12,312	10,351	8,718	7,343	6,200	5,224	4,403	3,711
Western Europe and Australia	5,826	4,833	4,080	3,444	2,914	2,461	2,078	1,755
Japan	16,578	16,455	16,333	16,212	16,092	15,973	15,855	15,738
CEIT	1,365	1,096	882	710	574	462	372	300
Article 5	2,641	1,575	939	560	342	208	127	79
GLOBAL INVENTORY (BANK)	38,722	34,310	30,952	28,269	26,122	24,328	22,835	21,583

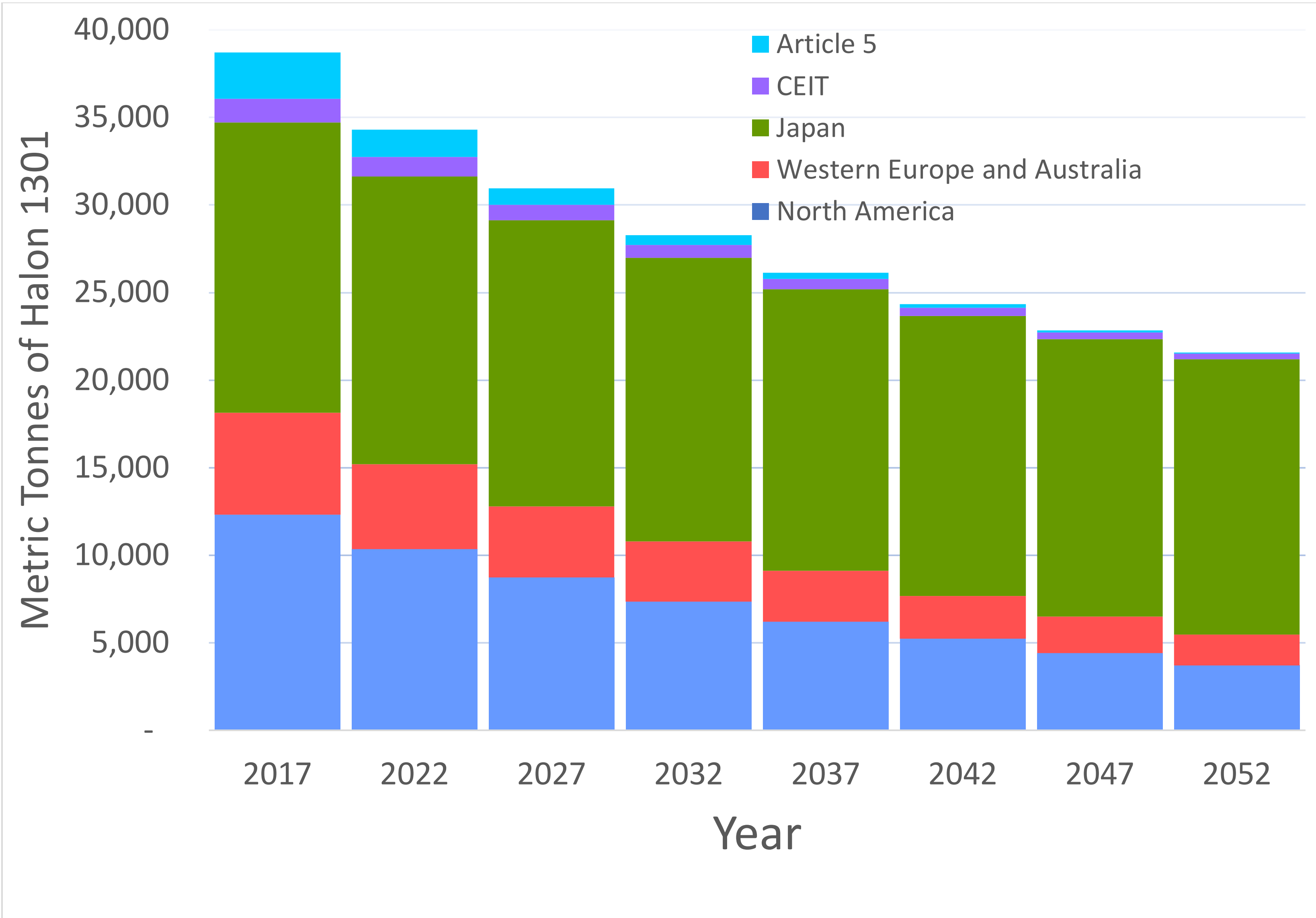


Figure 6.1: Forecast of Regional Distribution of Halon 1301 Bank from the FSTOC Model

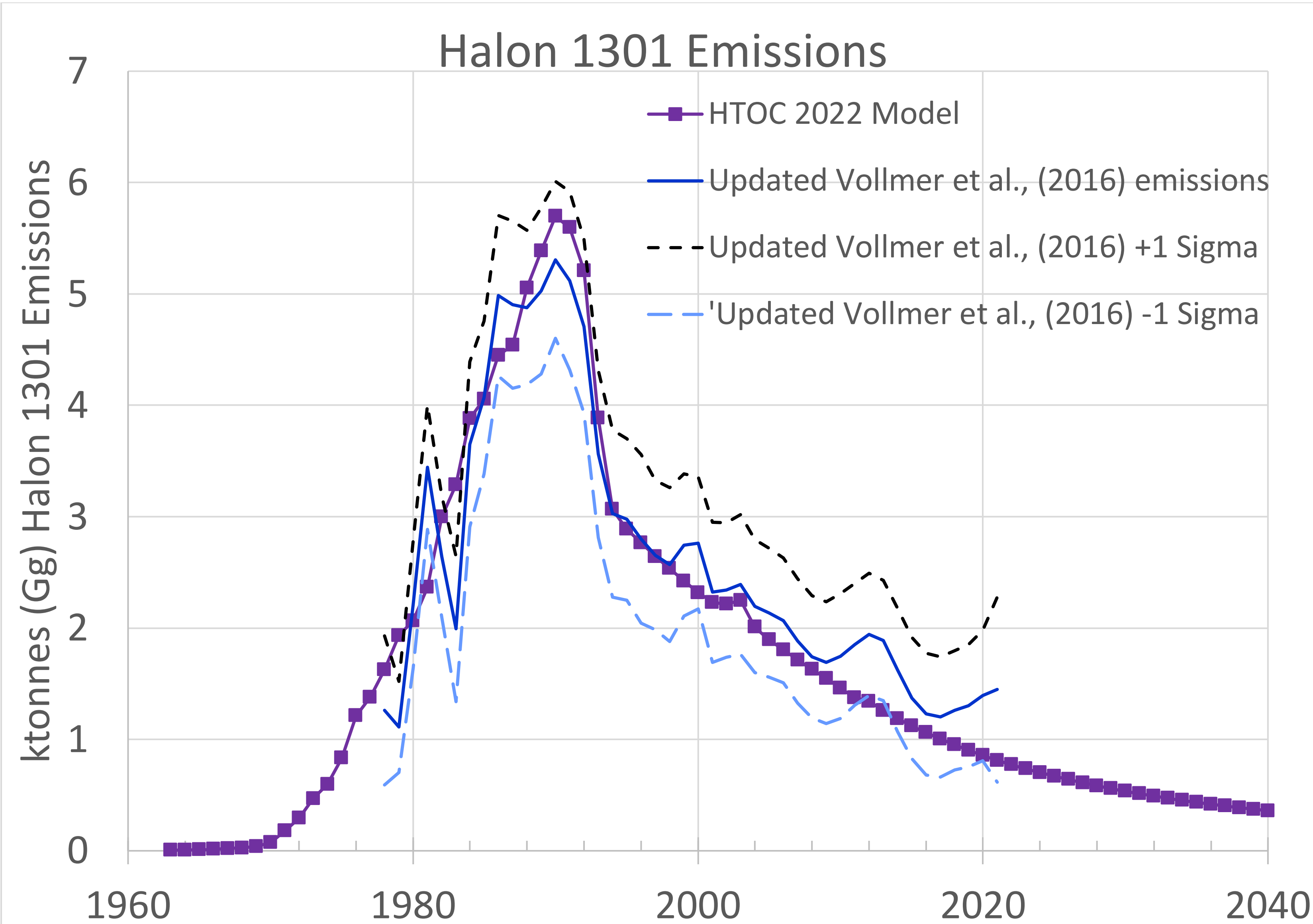


Figure 6.2: Comparison of Global Halon 1301 Emissions from Updated Vollmer et al. (2016) and the FSTOC Model

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes

Halon 1301 Summary										
(All quantities are provided in metric tonnes)										
Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Annual Production										
North America, Western Europe and Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
Annual Emissions										
North America	362	349	338	326	315	305	294	284	275	265
Western Europe and Australia	167	161	156	151	146	141	136	131	127	123
Japan	24	24	24	24	24	24	24	24	24	24
CEIT	49	47	45	43	41	39	37	36	34	33
Article 5	172	155	139	126	113	102	92	83	75	68
Total Annual Emissions - Global Bank	773	736	702	670	639	611	584	559	535	513
Total Annual Emissions with Production Loss	773	736	702	670	639	611	584	559	535	513

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes, continued (2022 – 2031)

Cumulative Production	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
North America, Western Europe and Japan	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246
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 Cumulative Production	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244
Cumulative Production Allocation										
North America	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969
Western Europe and Australia	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165
Article 5	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896
Total Cumulative Production Allocation	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240
Cumulative Emissions										
North America	32,618	32,968	33,305	33,631	33,946	34,251	34,545	34,829	35,104	35,369
Western Europe and Australia	26,122	26,283	26,439	26,589	26,735	26,876	27,012	27,143	27,270	27,393
Japan	10,799	10,824	10,848	10,873	10,897	10,921	10,945	10,970	10,994	11,018
CEIT	7,069	7,116	7,160	7,203	7,244	7,283	7,320	7,356	7,391	7,424
Article 5	37,321	37,476	37,616	37,741	37,855	37,957	38,049	38,133	38,208	38,275
Total Cumulative Emissions - Global Bank	113,930	114,666	115,368	116,037	116,677	117,288	117,872	118,431	118,966	119,479
Total Cum. Emissions w/ Production Loss	117,206	117,942	118,644	119,313	119,953	120,563	121,148	121,707	122,242	122,755
Global Inventory - Bank										
North America	10,351	10,001	9,664	9,337	9,022	8,718	8,424	8,139	7,865	7,599
Western Europe and Australia	4,833	4,672	4,517	4,366	4,220	4,080	3,944	3,812	3,685	3,562
Japan	16,455	16,430	16,406	16,382	16,357	16,333	16,309	16,285	16,260	16,236
CEIT	1,096	1,049	1,005	962	921	882	845	809	774	741
Article 5	1,575	1,420	1,281	1,155	1,042	939	847	764	689	621
Annual Global Inventory - Bank	34,310	33,574	32,872	32,202	31,563	30,952	30,368	29,809	29,274	28,761

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes, continued (2032 – 2041)

Halon 1301 Summary										
(All quantities are provided in metric tonnes)										
Year	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
Annual Production										
North America, Western Europe and Japan	-	-	-	0.0	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	0.0
Article 5	-	-	-	0.0	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	0.0
Annual Production Allocation										
North America	-	-	-	0.0	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	0.0
Japan	-	-	-	0.0	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	0.0
Article 5	-	-	-	0.0	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	0.0
Annual Emissions										
North America	256	248	239	224	216	216	209	202	195	188
Western Europe and Australia	119	115	111	104	100	100	97	94	91	88
Japan	24	24	24	24	24	24	24	24	24	24
CEIT	32	30	29	26	25	25	24	23	22	21
Article 5	61	55	50	40	36	36	33	30	27	24
Total Annual Emissions - Global Bank	492	472	453	418	402	402	387	372	358	345
Total Annual Emissions with Production Loss	492	472	453	435	418	402	387	372	358	345

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes, continued (2032 – 2041)

Cumulative Production	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
North America, Western Europe and Japan	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246	135,246
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5(1)	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643	11,643
Total Cumulative Production	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244	148,244
Cumulative Production Allocation										
North America	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969
Western Europe and Australia	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165
Article 5	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896
Total Cumulative Production Allocation	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240
Cumulative Emissions										
North America	35,626	35,874	36,113	36,337	36,553	36,769	36,978	37,179	37,374	37,562
Western Europe and Australia	27,512	27,626	27,737	27,841	27,941	28,042	28,138	28,232	28,323	28,410
Japan	11,042	11,066	11,090	11,114	11,138	11,162	11,186	11,210	11,234	11,257
CEIT	7,455	7,485	7,514	7,541	7,566	7,591	7,616	7,639	7,661	7,682
Article 5	38,336	38,391	38,441	38,481	38,518	38,554	38,587	38,616	38,643	38,667
Total Cumulative Emissions - Global Bank	119,971	120,443	120,896	121,314	121,716	122,118	122,504	122,876	123,235	123,580
Total Cum. Emissions w/ Production Loss	123,247	123,719	124,172	124,607	125,025	125,427	125,813	126,185	126,544	126,889
Global Inventory - Bank										
North America	7,343	7,095	6,855	6,632	6,416	6,200	5,991	5,789	5,595	5,406
Western Europe and Australia	3,444	3,329	3,218	3,114	3,014	2,914	2,817	2,723	2,633	2,545
Japan	16,212	16,188	16,164	16,140	16,116	16,092	16,068	16,044	16,021	15,997
CEIT	710	680	651	624	599	574	549	526	504	483
Article 5	560	505	456	415	379	342	310	280	253	229
Annual Global Inventory - Bank	28,269	27,797	27,344	26,926	26,524	26,122	25,735	25,363	25,005	24,660

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes, continued (2042 – 2051)

Halon 1301 Summary										
(All quantities are provided in metric tonnes)										
Year	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**
Annual Production										
North America, Western Europe and Japan	0.0	0.0	0.0	0.0	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	0.0	0.0	0.0	0.0
Article 5	0.0	0.0	0.0	0.0	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	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	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	0.0	0.0	0.0	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	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	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	0.0	0.0	0.0	0.0
Total Annual Production Allocation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Annual Emissions										
North America	182	176	170	164	159	153	148	143	138	134
Western Europe and Australia	85	82	79	76	74	71	69	67	65	62
Japan	24	24	24	24	24	24	24	24	23	23
CEIT	20	20	19	18	17	16	16	15	14	14
Article 5	22	20	18	16	14	13	12	11	9	9
Total Annual Emissions - Global Bank	332	320	309	298	288	278	268	259	250	242
Total Annual Emissions with Production Loss	332	320	309	298	288	278	268	259	250	242

Table 6.2: Halon 1301 Year-By-Year Forecast, in Metric Tonnes, continued (2042 – 2051)

Cumulative Production Allocation	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**
North America	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969	42,969
Western Europe and Australia	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955	30,955
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165	8,165
Article 5	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896	38,896
Total Cumulative Production Allocation	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240	148,240
Cummulative Emissions										
North America	37,744	37,920	38,090	38,254	38,413	38,566	38,714	38,857	38,995	39,129
Western Europe and Australia	28,495	28,577	28,656	28,732	28,806	28,877	28,946	29,013	29,078	29,140
Japan	11,281	11,305	11,329	11,352	11,376	11,399	11,423	11,446	11,470	11,493
CEIT	7,703	7,722	7,741	7,759	7,776	7,793	7,808	7,823	7,838	7,852
Article 5	38,689	38,708	38,726	38,742	38,756	38,769	38,781	38,791	38,801	38,810
Total Cumulative Emissions - Global Bank	123,912	124,232	124,541	124,839	125,127	125,405	125,673	125,932	126,182	126,423
Total Cum. Emissions w/ Production Loss	127,221	127,541	127,850	128,148	128,436	128,714	128,982	129,241	129,491	129,732
Global Inventory - Bank										
North America	5,224	5,049	4,879	4,715	4,556	4,403	4,255	4,112	3,973	3,840
Western Europe and Australia	2,461	2,379	2,300	2,223	2,149	2,078	2,009	1,942	1,878	1,815
Japan	15,973	15,949	15,926	15,902	15,878	15,855	15,831	15,808	15,784	15,761
CEIT	462	443	424	406	389	372	357	342	327	313
Article 5	208	188	170	155	140	127	116	105	96	87
Annual Global Inventory - Bank	24,328	24,007	23,698	23,400	23,113	22,835	22,567	22,308	22,058	21,816

6.2.2 Halon 1211

During its 2014 Assessment, the FSTOC was concerned with the status of banking capabilities in some regions of the world and the handling of halon 1211. As a result, the FSTOC 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. FSTOC expresses the same concerns in this assessment but does not have the additional quantitative information needed to justify specific changes in emission factors at this time. The FSTOC plans on taking up this issue over the next few years as it is becoming more evident that halon 1211 emissions are likely higher than the FSTOC model predicts. Additional information on the specific issues leading to this concern are included in the discussion below.

Table 6.3 summarizes the FSTOC 2022 Assessment of estimates of total production, annual emissions, cumulative emissions and resulting bank for halon 1211 in five-year increments from 2017 - 2052. Projected detailed yearly estimates for 2022 – 2051 are provided in Table 6.4. Historic yearly detailed results from 1963 to 2021 are provided in Appendix D. *Note that in some instances the values do not add up exactly due to rounding errors.* Negative production values in the tables 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 6.3 illustrates the FSTOC future projected regional distribution of the global bank of halon 1211 and shows that at the end of 2022, the FSTOC projects almost 80% to be equally divided between the North America region and the Western Europe and Australia region with about 20% estimated to remain in Article 5 parties. No significant amounts are projected to be in the Japan or CEIT regions. The current estimate for the amount of halon 1211 in Article 5 parties is significantly lower than the more than 50% projected in the 2010 Assessment, which again is a reflection of FSTOC concerns with halon 1211 bank management. This trend continues with lower emission rates expected in the North America region and the Western Europe and Australia region resulting in these regions containing over 90% of the global bank in the next 20 years.

As shown in Figure 6.4, there is significantly more uncertainty in the latest halon 1211 data using the methodology of **Vollmer et al. (2016)** (hereafter referred to Vollmer) 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). For example, **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 resulting emissions which would increase the size of the bank. Nevertheless, the current FSTOC emissions are generally lower than the Vollmer estimates (-1 sigma) beginning in 2004, which continues through the rest of the data set. The FSTOC emission estimates for North America are consistent with the 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 annually reported by the Japanese FEPN. Data on emission estimates for NWEU have been updated for the period 1998 – 2020 **BEIS (2022)**. See Section 6.2.1 for further information and changes in this estimation of NWEU emissions. The FSTOC model emission estimates scaled for NWEU are all now significantly higher than the BEIS values, averaging almost twice as high as the mean values and 50% higher than the +1 sigma uncertainty mean annual values. For example, the BEIS mean values for 2017 –

2020 are 172 metric tonnes, 173 metric tonnes, 175 metric tonnes, and 177 metric tonnes respectively, as compared to the FSTOC values of 460 metric tonnes, 440 metric tonnes, 420 metric tonnes, and 400 metric tonnes, respectively. There are three possible reasons for this discrepancy: 1) less halon 1211 is in NWEU than estimated by the FSTOC, 2) the emission rate in NWEU is lower than estimated by the FSTOC, and/or 3) the BEIS 2022 reported emissions are too low due to uncertainties in measurements and modelling. From an FSTOC model perspective, the FSTOC believes, based on the analysis of the Vollmer data below, that it is more likely that the there is less halon 1211 in NWEU than the emission rate being too high. Nonetheless, this still implies that a significant amount of halon 1211 remains in NWEU and likely Europe overall as well. This amount includes halon 1211 in the EU critical uses including civil aviation fleets operating in Europe.

As shown in Figure 6.4, the estimates of emissions from the Vollmer data and the FSTOC model compare fairly well within uncertainty until about 2005 with the exception of 1988-90, where the FSTOC emissions are above the 1 sigma uncertainty. From 2006 - 2012, FSTOC model emissions are below the -1 sigma uncertainty. From 2013 -2021, FSTOC model emissions are very near to the -1 sigma values. The FSTOC has been aware for some time 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 FSTOC model is based on the best handling practices over time, the lack of handling by professional servicers makes the estimation of emission factors for that amount of halon difficult at best. FSTOC believes that it is certainly possible that the emissions are higher than the FSTOC model predicts because of the inability to reliably estimate emissions from "unwanted" halon 1211. In the 2018 Assessment, the FSTOC opined that as halon 1211 is still managed carefully in other parts of the world, the FSTOC model could come back into closer agreement once the non-professionally managed halon 1211 is emitted and emission rates are more predictable. This may already be happening, although at the lowest level of Vollmer emissions, i.e., -1 sigma uncertainty. The Vollmer data suggest more emissions than the FSTOC model and help to suggest, in part, why the FSTOC believes that the discrepancy in NWEU emissions from BEIS versus FSTOC is more likely from less halon 1211 in Europe, and hence more in regions with higher emission rates. As indicated above, FSTOC does not have any quantitative basis to make specific changes to the current assumptions on emission factors or import / export at this time.

As was the case for halon 1301, the current Vollmer data do not cover the entire FSTOC model range which starts in 1963. For this assessment, these are now only available from 1974 – 2021. Therefore, to compare emissions with the FSTOC model and the resulting global bank of halon 1211, two methods are employed:

1. Use the FSTOC emissions estimates from 1963 – 1973 and add that to the updated Vollmer 1974 – 2021 data and
2. add the previous Vollmer data provided in 2018 for the period 1963 – 1973 to the current 1974 – 2021 data.

For both estimating methods, we assume that the Vollmer emissions are only from the fire protection bank and from losses from production (1963 – 2010) for fire protection uses and not from feedstock production and use, if any. It should be noted that the mean values are based on the atmospheric concentration measurements, while the +/-1 sigma ranges are calculated by adding or subtracting the 1 sigma uncertainly. This can result in negative emissions and/or a negative resulting bank. These negative values are then assigned to be "zero". The results from these two estimating methods for both the mean and the +1 sigma emissions estimates give emissions that are more than the cumulative production (i.e., result in a negative global bank which is then set to zero). For the -1 sigma cases, the two methods provide 70,500 and 75,500 metric tonnes in the fire protection bank compared with 20,500 metric tonnes estimated in the FSTOC model. Obviously, the bank cannot be at zero as there are still emissions in NWEU being measured and halon 1211 is still in wide use on civil aircraft. This suggests that either more halon 1211 has been produced than reported to FSTOC (and thus more emissions) and/or the emissions are at the lower end of the Vollmer estimates.

Table 6.3: FSTOC Halon 1211 Model Summary (in metric tonnes)

	2017	2022	2027	2032	2037	2042	2047	2052
CUMULATIVE PRODUCTION								
North America, Western Europe and Japan	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
Article 5	115,817	115,817	115,817	115,817	115,817	115,817	115,817	115,817
TOTAL CUMULATIVE PRODUCTION	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
ANNUAL EMISSIONS								
North America	406	333	274	224	184	151	124	102
Western Europe and Australia	460	373	309	252	227	173	131	100
Japan	11	9	7	6	4	4	3	2
CEIT	48	32	21	14	10	6	4	3
Article 5	730	415	236	134	76	44	24	14
TOTAL ANNUAL EMISSIONS	1,654	1,162	847	631	502	377	287	221
CUMULATIVE EMISSIONS								
North America	49,043	50,849	52,331	53,548	54,546	55,366	56,038	56,590
Western Europe and Australia	74,907	76,936	78,621	80,013	81,202	82,168	82,903	83,461
Japan	1,734	1,782	1,820	1,850	1,874	1,894	1,909	1,922
CEIT	10,318	10,507	10,634	10,719	10,776	10,814	10,840	10,857
Article 5	149,116	151,750	153,249	154,102	154,587	154,863	155,011	155,100
TOTAL CUMULATIVE EMISSIONS	285,117	291,824	296,655	300,232	302,986	305,106	306,702	307,931
INVENTORY								
North America	10,074	8,268	6,785	5,569	4,570	3,751	3,078	2,526
Western Europe and Australia	10,326	8,296	6,612	5,219	4,030	3,064	2,330	1,771
Japan	236	189	151	120	96	77	61	49
CEIT	574	386	259	174	117	78	53	35
Article 5	6,112	3,477	1,978	1,126	640	364	216	128
TOTAL INVENTORY	27,323	20,616	15,785	12,208	9,454	7,334	5,738	4,510

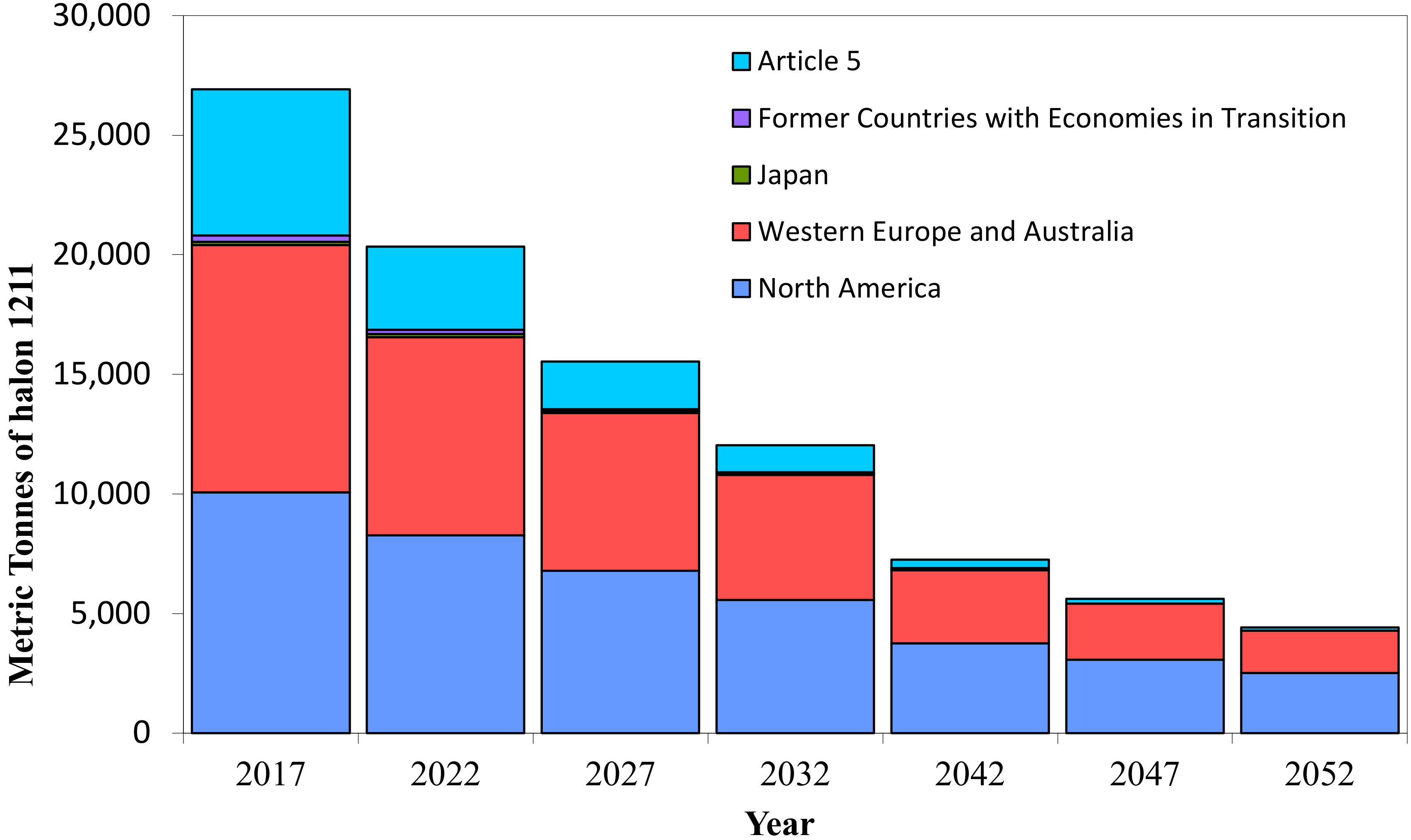


Figure 6.3: Forecast of Regional Distribution of the Halon 1211 Bank from the FSTOC Model

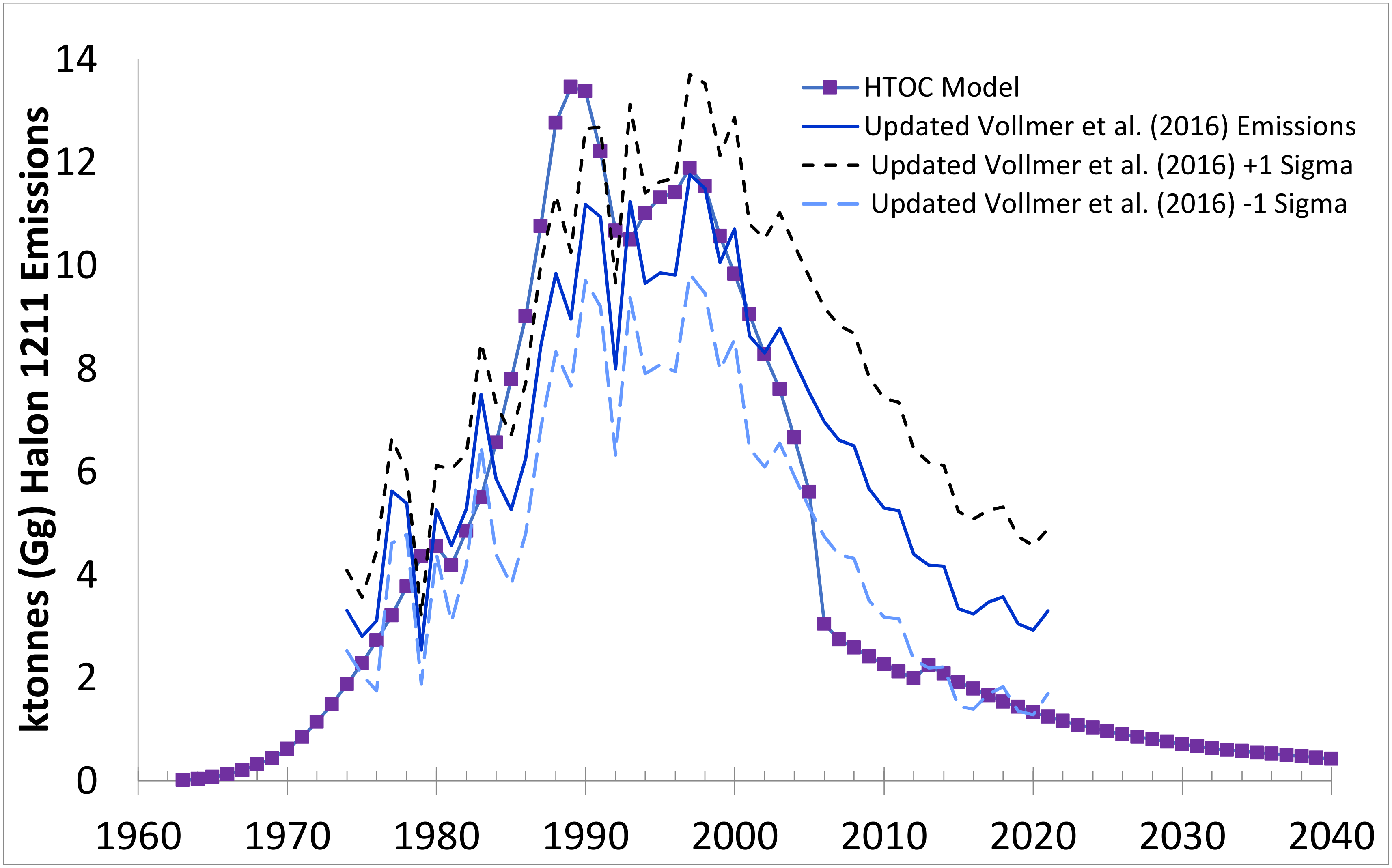


Figure 6.4: Comparison of Halon 1211 Emissions from 1Sigma of Updated Vollmer et al. (2016) and the FSTOC Model

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes

Halon 1211 Summary in metric tonnes										
YEAR	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Annual Production										
North America, Western Europe and Japan Production	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
ANNUAL EMISSIONS										
North America	333	320	308	296	285	274	263	253	243	234
Western Europe and Australia	373	357	358	338	323	309	308	291	277	264
Japan	9	8	8	8	7	7	7	6	6	6
CEIT	32	30	27	25	23	21	20	18	17	16
Article 5	415	371	331	296	264	236	211	189	168	150
Total Annual Emissions - Global Bank	1,162	1,086	1,032	963	902	847	808	757	712	670
Total Annual Emissions with Production Loss	1,162	1,086	1,032	963	902	847	808	757	712	670

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes, continued (2022 – 2031)

Cumulative Production	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
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 Cumulative Production	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Production Allocation										
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 Cumulative Production Allocation	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Emissions										
North America	50,849	51,169	51,477	51,773	52,058	52,331	52,594	52,847	53,090	53,323
Western Europe and Australia	76,936	77,293	77,651	77,989	78,312	78,621	78,929	79,219	79,497	79,761
Japan	1,782	1,790	1,798	1,806	1,813	1,820	1,826	1,833	1,839	1,845
CEIT	10,507	10,537	10,564	10,589	10,612	10,634	10,654	10,672	10,689	10,705
Article 5	151,750	152,121	152,453	152,749	153,013	153,249	153,460	153,649	153,817	153,968
Total Cumulative Emissions - Global Bank	291,824	292,910	293,943	294,906	295,808	296,655	297,463	298,220	298,931	299,601
Total Cum. Emissions w/ Production Loss	297,909	298,995	300,027	300,990	301,893	302,739	303,548	304,305	305,016	305,686
Global Inventory - Bank										
North America	8,268	7,947	7,639	7,343	7,059	6,785	6,522	6,270	6,027	5,793
Western Europe and Australia	8,296	7,939	7,582	7,244	6,921	6,612	6,304	6,013	5,736	5,472
Japan	189	181	173	165	158	151	144	138	132	126
CEIT	386	356	329	304	280	259	239	221	204	188
Article 5	3,477	3,107	2,775	2,479	2,215	1,978	1,767	1,579	1,410	1,260
Annual Global Inventory - Bank	20,616	19,530	18,497	17,535	16,632	15,785	14,977	14,220	13,509	12,839

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes, continued (2032 – 2041)

YEAR	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Annual Production										
North America, Western Europe and Japan Production	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
ANNUAL EMISSIONS										
North America	224	216	207	199	192	184	177	170	164	157
Western Europe and Australia	252	241	250	233	239	227	215	203	193	182
Japan	6	5	5	5	5	4	4	4	4	4
CEIT	14	13	12	11	10	10	9	8	8	7
Article 5	134	120	107	96	86	76	68	61	55	49
Total Annual Emissions - Global Bank	631	595	582	544	531	502	474	447	422	399
Total Annual Emissions with Production Loss	631	595	582	544	531	502	474	447	422	399

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes, continued, 2032 – 2041

Cumulative Production	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
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 Cumulative Production	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Production Allocation										
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 Cumulative Production Allocation	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Emissions										
North America	53,548	53,764	53,971	54,170	54,362	54,546	54,723	54,894	55,057	55,215
Western Europe and Australia	80,013	80,254	80,504	80,736	80,975	81,202	81,417	81,621	81,813	81,996
Japan	1,850	1,855	1,861	1,865	1,870	1,874	1,879	1,883	1,887	1,890
CEIT	10,719	10,732	10,745	10,756	10,766	10,776	10,785	10,793	10,801	10,808
Article 5	154,102	154,222	154,329	154,425	154,511	154,587	154,656	154,717	154,771	154,820
Total Cumulative Emissions - Global Bank	300,232	300,828	301,409	301,953	302,485	302,986	303,460	303,907	304,329	304,728
Total Cum. Emissions w/ Production Loss	306,317	306,912	307,494	308,038	308,569	309,071	309,545	309,992	310,414	310,813
Global Inventory - Bank										
North America	5,569	5,353	5,145	4,946	4,754	4,570	4,393	4,223	4,059	3,902
Western Europe and Australia	5,219	4,979	4,729	4,497	4,257	4,030	3,815	3,612	3,419	3,237
Japan	120	115	110	105	101	96	92	88	84	80
CEIT	174	160	148	137	126	117	108	99	92	85
Article 5	1,126	1,006	898	802	717	640	572	511	457	408
Annual Global Inventory - Bank	12,208	11,613	11,031	10,487	9,956	9,454	8,980	8,533	8,111	7,712

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes, continued (2042 – 2051)

YEAR	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
Annual Production										
North America, Western Europe and Japan Production	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
ANNUAL EMISSIONS										
North America	151	145	140	134	129	124	119	115	110	106
Western Europe and Australia	173	163	155	146	139	131	124	118	111	105
Japan	4	3	3	3	3	3	3	3	2	2
CEIT	6	6	6	5	5	4	4	4	3	3
Article 5(1)	44	34	33	30	27	24	22	19	18	16
Total Annual Emissions - Global Bank	377	353	336	319	302	287	272	258	245	233
Total Annual Emissions with Production Loss	377	353	336	319	302	287	272	258	245	233

Table 6.4: Halon 1211 Year-By-Year Forecast, in Metric Tonnes, continued (2042 – 2051)

Cumulative Production	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**
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 Cumulative Production	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Production Allocation										
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 Cumulative Production Allocation	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440	312,440
Cumulative Emissions										
North America	55,366	55,511	55,651	55,785	55,914	56,038	56,158	56,272	56,382	56,488
Western Europe and Australia	82,168	82,332	82,486	82,633	82,772	82,903	83,027	83,145	83,256	83,361
Japan	1,894	1,897	1,900	1,903	1,906	1,909	1,912	1,915	1,917	1,919
CEIT	10,814	10,820	10,826	10,831	10,836	10,840	10,844	10,848	10,851	10,855
Article 5	154,863	154,898	154,931	154,961	154,987	155,011	155,033	155,052	155,070	155,086
Total Cumulative Emissions - Global Bank	305,106	305,458	305,795	306,113	306,415	306,702	306,974	307,232	307,477	307,710
Total Cum. Emissions w/ Production Loss	311,190	311,543	311,879	312,198	312,500	312,787	313,058	313,317	313,562	313,794
Global Inventory - Bank										
North America	3,751	3,605	3,466	3,331	3,202	3,078	2,959	2,844	2,734	2,628
Western Europe and Australia	3,064	2,901	2,746	2,600	2,461	2,330	2,206	2,088	1,977	1,871
Japan	77	73	70	67	64	61	59	56	54	51
CEIT	78	72	67	62	57	53	49	45	41	38
Article 5	364	330	297	267	240	216	195	175	158	142
Annual Global Inventory - Bank	7,334	6,982	6,646	6,327	6,025	5,738	5,466	5,208	4,963	4,731

6.2.3 Halon 2402

In 2014, the FSTOC estimated cumulative production of halon 2402 based on data from **Kopylov et al. (2003)**, (in Russian) and **Belevtcev and Kunina (1998)**, and by making a series of assumptions about halon 2402 production based on available data. Belevtcev and Kunina**,** provided an estimate of 34,000 metric tonnes total production of halon 2402 from 1965 – 1994. As the quantities of halon 2402 were not reported to the FSTOC as they were by CEFIC for halons 1211 and 1301, there was no information on quantities of halon 2402 produced outside of the former Soviet Union prior to the Montreal Protocol. To develop an estimate, it was assumed that the difference between total Montreal Protocol Article 7 production data for all halons in non-Article 5 parties and the halon 1211 and 1301 quantities used in the FSTOC models represent additional halon 2402 production outside of the former Soviet Union (i.e., in North America, Western Europe and Australia, and Japan) from the years 1986, 1989-1992. The result is that there is 7% more total halon reported in Article 7 data than accounted for by halons 1301 and 1211 alone. The 7% additional halon is assumed to be production of halon 2402 outside of the Soviet Union. To estimate the 1963 – 1985 production of 2402 outside of the Soviet Union, the 7% factor was applied to the halon 1211 and 1301 production quantities per year from 1963 – 1985 and added to the estimate for the Soviet Union. No changes have been made in the production estimates since 2014.

The assumptions for emission rates as a function of the size of the bank have been updated for this assessment. The current model aligns the emission rates for 2402 with those currently used for halon 1301, with the exception of Japan, which uses the same emission factors as for North America. The rationale is that most of the systems left installed are in the total flooding sector, which in most parts of the world was dominated by halon 1301 and the system owners would have the same ability and incentive to minimize unwanted emissions. Halon 1301 is much more volatile than halon 2402, so it is considered conservative to assume the emissions from servicing would be the same.

Table 6.5 provides a summary of the FSTOC 2022 Assessment of estimates of cumulative production, annual emissions, cumulative emissions, and resulting bank for halon 2402 in five-year increments from 2017 – 2052. There is little information available on import / export of halon 2402. Projected detailed yearly estimates for 2022 – 2051 are provided in Table 6.6. Historic yearly detailed results from 1963 to 2021 are provided in Appendix E.

Figure 6.5 provides the regional distribution of the global bank of halon 2402 based on the FSTOC model. The FSTOC estimates that the majority of halon 2402 remains in the former CEIT countries, but also with significant quantities remaining in Europe.

As shown in Figure 6.6, the FSTOC estimate of emissions is generally higher than the mean estimate of emissions from the updated **Vollmer et al., (2016)** data from about 1980 until 2020 and near or above the +1 sigma uncertainty until 2018. The Vollmer data show increasing emissions from 2016 – 2021, with the FSTOC estimate going below the mean but staying within +/-1 sigma uncertainty. This increase would not be expected from an average emission rate of the bank; however, it has been reported to the FSTOC that there is a major decommissioning programme underway in Vladivostok, Russia that could account for an increase in emissions. As emissions would be expected to be kept to a minimum, but not totally avoidable, the level of increase in emissions suggests that this effort involves a sizeable amount of decommissioning. It is presumed that this recovered halon 2402 will remain in the global bank to support enduring uses of halon 2402.

As was the case for the other halons, the Vollmer data do not go back to 1963. In order to compare the FSTOC model estimates with Vollmer, the 1963 – 1977 emissions are estimated in two ways:

1. use the FSTOC emissions estimates from 1963 – 1977 and add that to the updated Vollmer data for 1978 – 2021, and
2. add the previous Vollmer data provided in 2018 for the period 1963 – 1977 to the updated 1978 – 2021 data.

Both estimating methods include emissions from the fire protection bank and losses from production (1963 – 2000). It should be noted that the mean values are based on the atmospheric concentration measurements, while the +/-1 sigma ranges are calculated by adding or subtracting the 1 sigma uncertainty. This can result in negative emissions and a negative resulting bank. These negative values are then assigned to be "zero".

Method 1 results in mean cumulative emissions through 2021 of 39,500 (29,500 – 49,500) metric tonnes and a remaining mean bank of 19,500 (10,000 – 29,500) metric tonnes. Method 2 results in mean cumulative emissions through 2021 of 43,500 (28,000 – 69,000) metric tonnes and a remaining mean bank of 15,500 (0 – 41,500) metric tonnes. This is compared with the FSTOC model estimate of 52,000 metric tonnes of cumulative emissions and a remaining bank of about 13,000 metric tonnes. It should be noted that the FSTOC model does not include emissions from the reported use of halon 2402 as a process agent which would place the FSTOC model emissions and bank estimate within the range of uncertainty of the estimates using the Vollmer data.

Table 6.5: FSTOC Halon 2402 Model Summary, in Metric Tonnes

	2017	2022	2027	2032	2037	2042	2047	2052
CUMULATIVE 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 CUMULATIVE PRODUCTION	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
ANNUAL EMISSIONS								
North America	53	45	38	32	28	23	20	17
Western Europe and Australia	103	86	72	60	50	41	34	29
Japan	11	10	8	7	6	5	5	4
CEIT	313	265	225	191	162	137	116	99
Article 5	54	41	30	23	17	13	9	7
TOTAL ANNUAL EMISSIONS	535	447	374	313	262	220	185	155
CUMULATIVE EMISSIONS								
North America	4,246	4,488	4,693	4,866	5,014	5,138	5,244	5,334
Western Europe and Australia	7,735	8,198	8,583	8,904	9,172	9,394	9,579	9,733
Japan	787	839	883	922	955	984	1,008	1,030
CEIT	26,237	27,656	28,860	29,880	30,744	31,477	32,099	32,625
Article 5	4,926	5,155	5,326	5,454	5,550	5,621	5,675	5,715
Fire Protection Cumulative Emissions	43,930	46,335	48,344	50,026	51,434	52,614	53,605	54,437
TOTAL CUMULATIVE EMISSIONS	44,459	46,864	48,873	50,554	51,963	53,143	54,134	54,811
INVENTORY								
North America	1,587	1,345	1,140	967	820	695	589	499
Western Europe and Australia	2,765	2,302	1,916	1,595	1,328	1,106	921	766
Japan	380	328	284	245	212	183	158	137
CEIT	9,321	7,902	6,698	5,678	4,814	4,081	3,459	2,933
Article 5	908	679	507	379	284	212	159	119
TOTAL INVENTORY	14,961	12,556	10,546	8,865	7,457	6,276	5,286	4,454

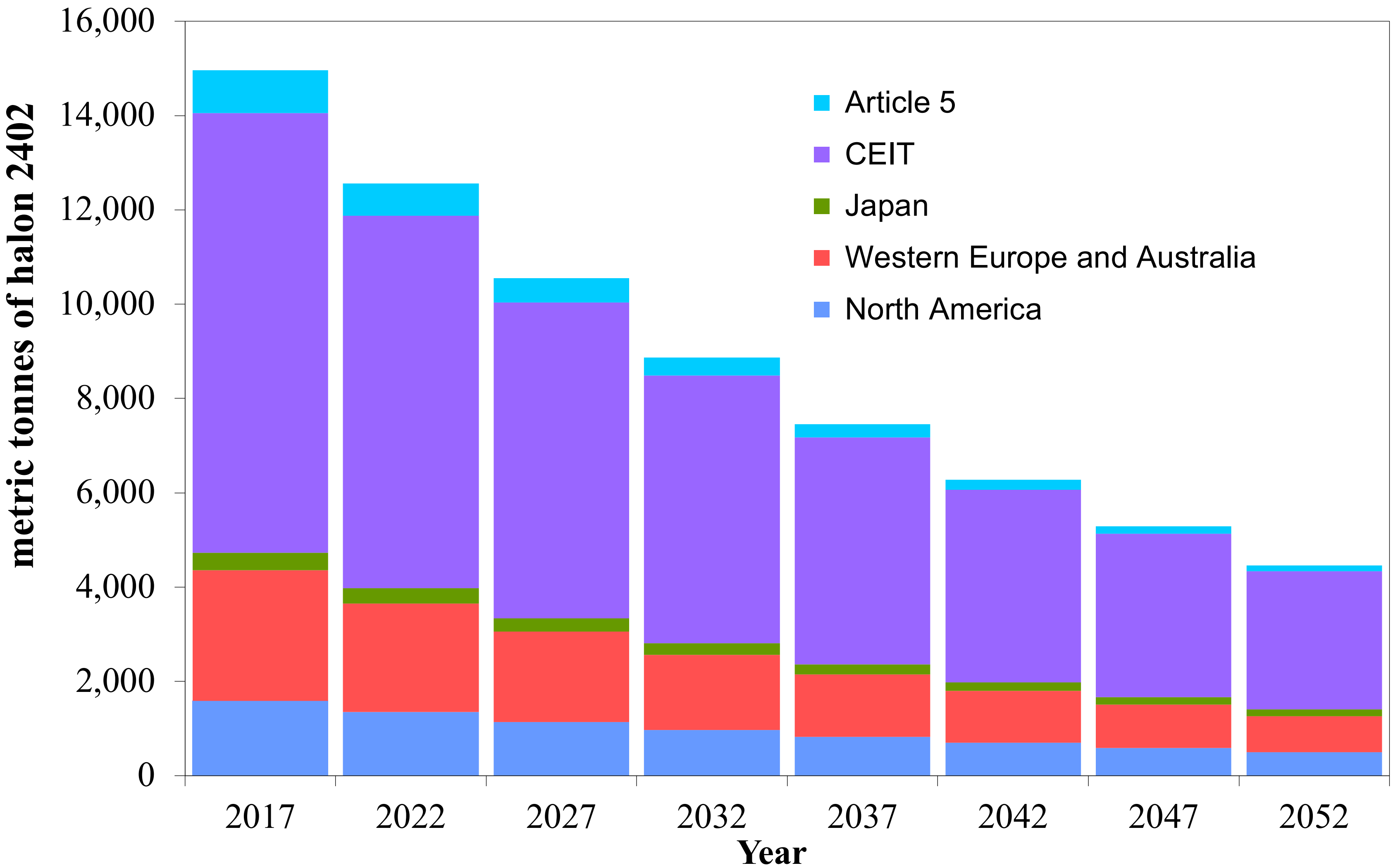


Figure 6.5: Forecast of Regional Distribution of the Halon 2402 Bank from the FSTOC Model

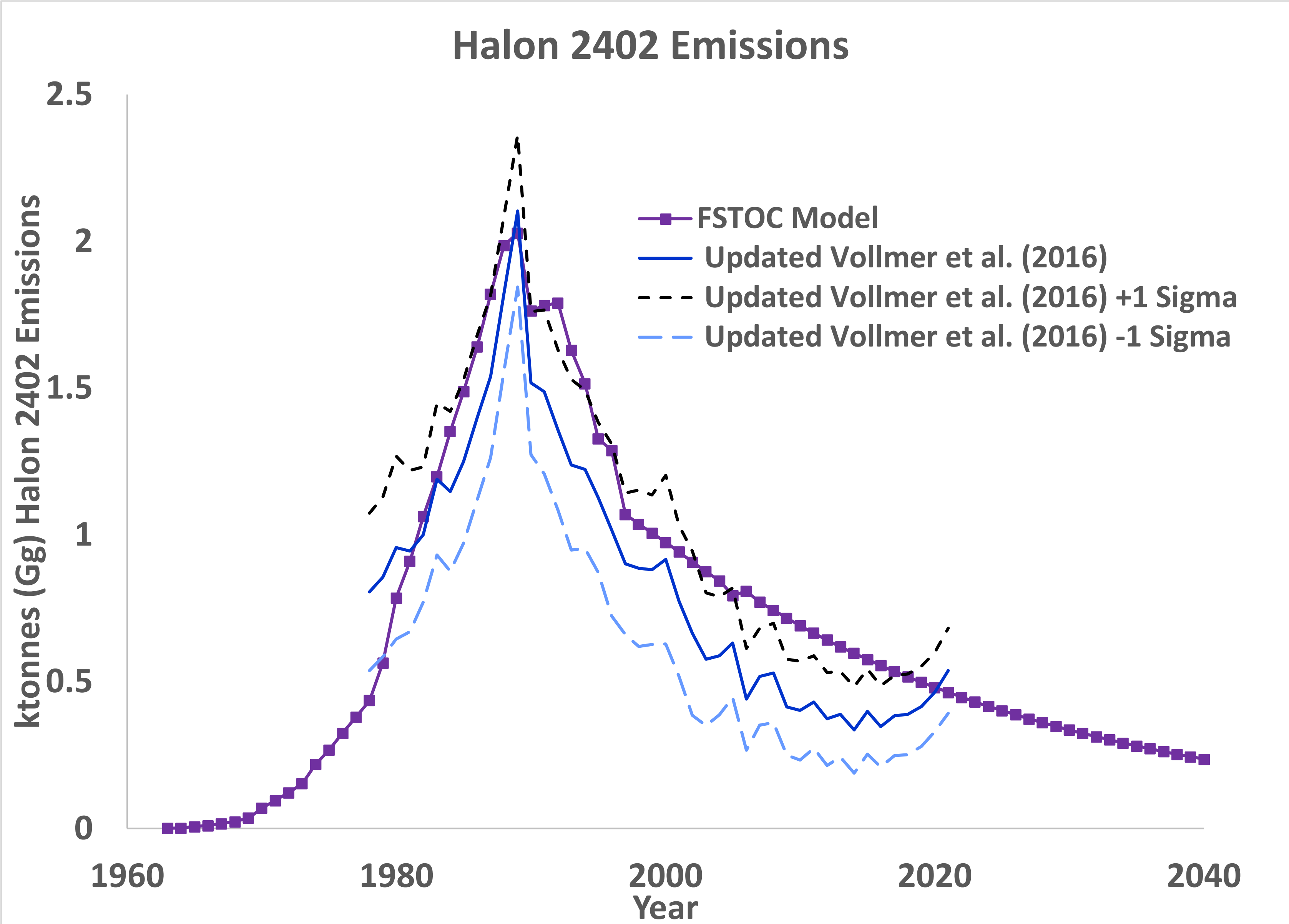


Figure 6.6: Comparison of Halon 2402 Emissions from 1 Sigma of Updated Vollmer et al. (2016) and the FSTOC Model

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes

Halon 2402 Summary										
Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Annual Production										
North America, Western Europe and Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
Annual Emissions										
North America	45	44	42	41	40	38	37	36	35	34
Western Europe and Australia	86	83	80	77	74	72	69	67	64	62
Japan	10	9	9	9	9	8	8	8	8	7
CEIT	265	257	248	240	233	225	218	211	204	197
Article 5(1)	41	38	36	34	32	30	29	27	26	24
Total Annual Emissions - Global Bank	447	431	416	401	387	374	361	348	336	324
Total Annual Emissions with Production	447	431	416	401	387	374	361	348	336	324
Cumulative 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)	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2022-2031)

Cumulative Production Allocation	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
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 Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions										
North America	4,488	4,532	4,574	4,615	4,654	4,693	4,730	4,766	4,800	4,834
Western Europe and Australia	8,198	8,281	8,360	8,438	8,512	8,583	8,652	8,719	8,783	8,845
Japan	839	848	857	866	875	883	891	899	907	914
CEIT	27,656	27,913	28,162	28,402	28,635	28,860	29,077	29,288	29,492	29,689
Article 5	5,155	5,193	5,229	5,263	5,295	5,326	5,354	5,382	5,407	5,431
Total Cumulative Emissions - Global Bank	46,335	46,766	47,182	47,584	47,971	48,344	48,705	49,053	49,389	49,713
Total Cum. Emissions w/ Production Loss										
Global Inventory - Bank										
North America	1,345	1,302	1,259	1,218	1,179	1,140	1,103	1,067	1,033	999
Western Europe and Australia	2,302	2,219	2,139	2,062	1,988	1,916	1,847	1,781	1,717	1,655
Japan	328	319	310	301	292	284	275	268	260	252
CEIT	7,902	7,645	7,396	7,156	6,923	6,698	6,481	6,270	6,066	5,869
Article 5	679	640	604	570	538	507	479	452	426	402
Annual Global Inventory - Bank	12,556	12,125	11,709	11,307	10,920	10,546	10,186	9,838	9,502	9,178

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2022-2031)

Cumulative Production	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
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	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Production Allocation										
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 Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions										
North America	4,866	4,898	4,928	4,958	4,986	5,014	5,040	5,066	5,091	5,115
Western Europe and Australia	8,904	8,962	9,017	9,071	9,122	9,172	9,219	9,265	9,310	9,353
Japan	922	929	935	942	949	955	961	967	973	978
CEIT	29,880	30,064	30,243	30,415	30,583	30,744	30,901	31,052	31,198	31,340
Article 5	5,454	5,475	5,495	5,515	5,533	5,550	5,566	5,581	5,595	5,608
Total Cumulative Emissions - Global Bank	50,026	50,328	50,619	50,900	51,172	51,434	51,687	51,931	52,167	52,395
Total Cum. Emissions w/ Production Loss										
Global Inventory - Bank										
North America	967	935	905	876	847	820	793	767	742	718
Western Europe and Australia	1,595	1,538	1,483	1,429	1,378	1,328	1,280	1,234	1,190	1,147
Japan	245	238	231	225	218	212	206	200	194	189
CEIT	5,678	5,494	5,315	5,143	4,975	4,814	4,657	4,506	4,360	4,218
Article 5	379	358	338	319	301	284	268	252	238	225
Annual Global Inventory - Bank	8,865	8,563	8,272	7,991	7,719	7,457	7,204	6,960	6,724	6,496

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2032-2041)

Halon 2402 Summary										
Year	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
Annual Production										
North America, Western Europe and Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
Annual Emissions										
North America	32	31	30	29	28	28	27	26	25	24
Western Europe and Australia	60	57	55	53	51	50	48	46	44	43
Japan	7	7	7	7	6	6	6	6	6	6
CEIT	191	185	179	173	167	162	156	151	146	142
Article 5	23	21	20	19	18	17	16	15	14	13
Total Annual Emissions - Global Bank	313	302	291	281	272	262	253	244	236	228
Total Annual Emissions with Production Loss	313	302	291	281	272	262	253	244	236	228

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2032-2041)

Cumulative Production	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
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	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Production Allocation										
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 Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions										
North America	4,866	4,898	4,928	4,958	4,986	5,014	5,040	5,066	5,091	5,115
Western Europe and Australia	8,904	8,962	9,017	9,071	9,122	9,172	9,219	9,265	9,310	9,353
Japan	922	929	935	942	949	955	961	967	973	978
CEIT	29,880	30,064	30,243	30,415	30,583	30,744	30,901	31,052	31,198	31,340
Article 5	5,454	5,475	5,495	5,515	5,533	5,550	5,566	5,581	5,595	5,608
Total Cumulative Emissions - Global Bank	50,026	50,328	50,619	50,900	51,172	51,434	51,687	51,931	52,167	52,395
Total Cum. Emissions w/ Production Loss	50,554	50,856	51,148	51,429	51,700	51,963	52,216	52,460	52,696	52,923
Global Inventory - Bank										
North America	967	935	905	876	847	820	793	767	742	718
Western Europe and Australia	1,595	1,538	1,483	1,429	1,378	1,328	1,280	1,234	1,190	1,147
Japan	245	238	231	225	218	212	206	200	194	189
CEIT	5,678	5,494	5,315	5,143	4,975	4,814	4,657	4,506	4,360	4,218
Article 5	379	358	338	319	301	284	268	252	238	225
Annual Global Inventory - Bank	8,865	8,563	8,272	7,991	7,719	7,457	7,204	6,960	6,724	6,496

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2042-2051)

Halon 2402 Summary										
Year	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**
Annual Production										
North America, Western Europe and Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
Annual Emissions										
North America	23	23	22	21	20	20	19	19	18	17
Western Europe and Australia	41	40	38	37	36	34	33	32	31	30
Japan	5	5	5	5	5	5	5	4	4	4
CEIT	137	133	128	124	120	116	112	109	105	102
Article 5	13	12	11	11	10	9	9	8	8	8
Total Annual Emissions - Global Bank	220	212	205	198	191	185	178	172	166	161
Total Annual Emissions with Production	220	212	205	198	191	185	178	172	166	161
Cumulative 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	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

Table 6.6: Halon 2402 Year-By-Year Forecast, in Metric Tonnes, continued (2042-2051)

Cumulative Production Allocation	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**
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 Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions										
North America	5,138	5,161	5,183	5,204	5,224	5,244	5,263	5,282	5,300	5,317
Western Europe and Australia	9,394	9,434	9,472	9,509	9,545	9,579	9,612	9,644	9,675	9,705
Japan	984	989	994	999	1,004	1,008	1,013	1,017	1,022	1,026
CEIT	31,477	31,610	31,738	31,862	31,982	32,099	32,211	32,320	32,425	32,527
Article 5	5,621	5,633	5,644	5,655	5,665	5,675	5,684	5,692	5,700	5,708
Total Cumulative Emissions - Global Bank	52,614	52,827	53,032	53,230	53,421	53,605	53,783	53,956	54,122	54,282
Total Cum. Emissions w/ Production Loss										
Global Inventory - Bank										
North America	695	672	650	629	609	589	570	551	533	516
Western Europe and Australia	1,106	1,066	1,028	991	955	921	887	855	825	795
Japan	183	178	173	168	163	158	154	149	145	141
CEIT	4,081	3,948	3,820	3,696	3,576	3,459	3,347	3,238	3,133	3,031
Article 5	212	200	189	178	168	159	150	141	133	126
Annual Global Inventory - Bank	6,276	6,064	5,859	5,661	5,470	5,286	5,107	4,935	4,769	4,609

6.3 HCFC Estimates

While HCFCs were used for fire suppression in several different blends, all of the HCFCs used in fire suppression are used much more extensively as refrigerants. Therefore, it is not possible to estimate either the global bank or emissions of HCFCs from fire protection uses.

6.4 HFC Estimates

6.4.1 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, to estimate the global emissions from fire protection, it was necessary to create a model that can separate the annual emissions into those three categories of use. HFC-227ea is also 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, resulting in a conservative estimate that overestimates the emissions from fire protection. The model was developed in 2018 in coordination with an MCTOC co-chair and a Rigid and Flexible Foams (F)TOC co-chair and has been updated in 2022. The model uses best estimates of annual global production capacity of HFC-227ea from 1993 until 2021, **Walter-Terrinoni (2018, 2022**) and apportions use to foams, MDIs, and fire protection based on expert opinion. This is a 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 (2022)**. The amount used for production of foam was provided by Walter-Terrinoni who also provided the estimated annual emissions from both the production and use of foams. The amount that went into fire protection was taken to be the remainder of the assumed full 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 FSTOC halons models. The annual emission rates used are as follows.

- MDIs – 100%
- Foams – Production – 25%
- Foams from installed base (bank) – 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 3% by 2011 and remaining at 3% thereafter. While somewhat higher than for the 2018 Assessment, it is based on an assessment of the difference in locations and practices for halon 1301 systems versus HFC-227ea systems. In terms of the global bank, it is estimated that the proportion of HFC-227ea (by mass) is greater than the proportion of halon 1301 installed in Article 5 parties. The estimate of 3% is consistent with estimates of average emissions from total flooding systems of 2+/-1% developed by **Verdonik and Robin (2004)**.

- Production emissions from 0.1% to 1.25% ranging from low to the average of the most likely emissions per MCTOC estimates, **Tope (2021)**.

Updated data were obtained on the global emissions of HFC-227ea through 2020, **SAP Ozone Assessment report, (2022)** and are in excellent agreement with the simplified FSTOC model, as shown in Figure 6.7. The FSTOC simplified model is generally between the +/- 1 sigma uncertainty except for a few short periods 1999, 2001, and 2008 – 2010. For 2008 – 2010, this is the result of the decrease in estimated production of foam during the global financial crisis.

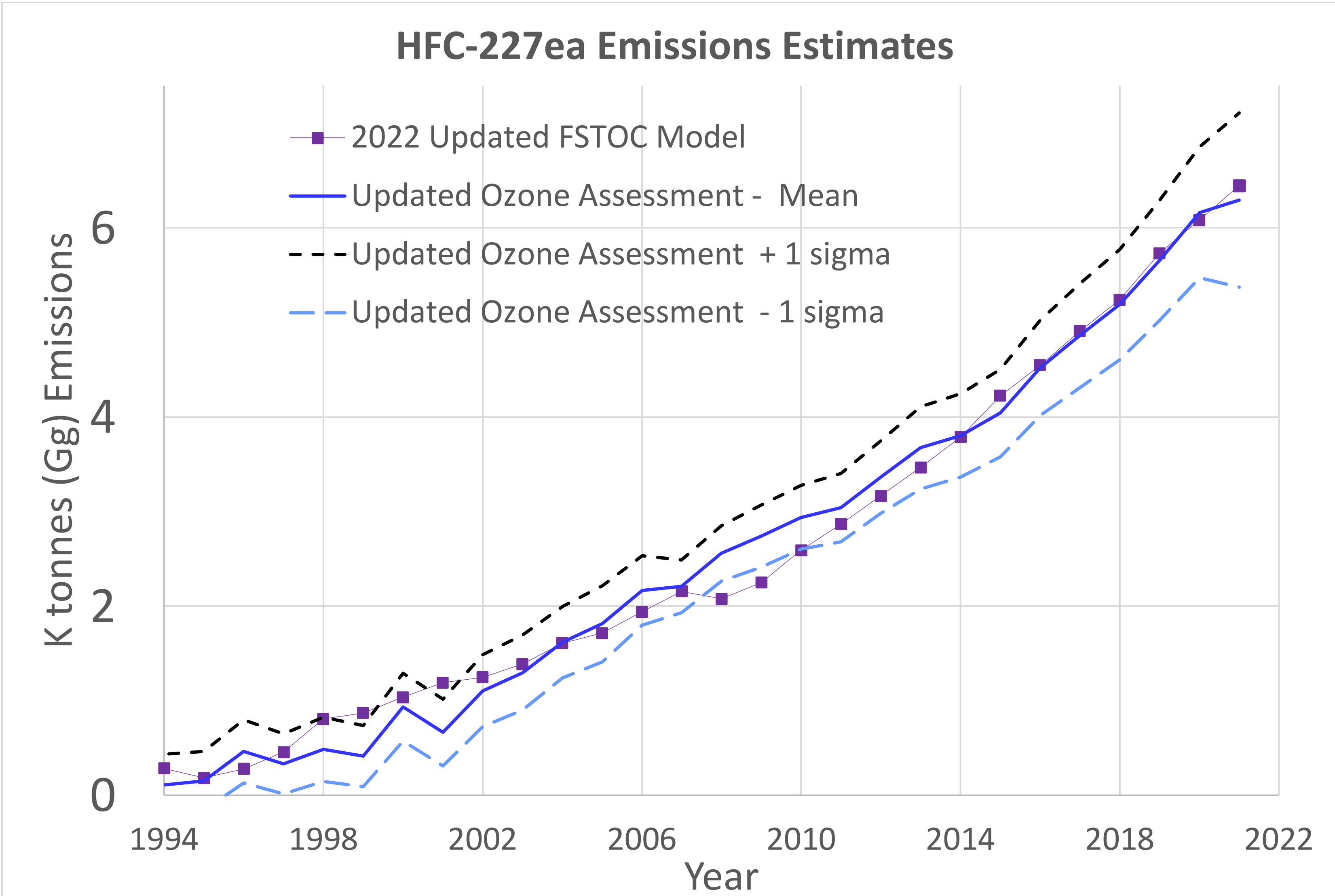


Figure 6.7: Comparison of HFC-227ea Emissions from SAP Ozone Assessment Report (2022) and the FSTOC Model

All of the input data to the model were based directly on the expert opinion of the FSTOC, MCTOC, and FTOC co-chairs. Only small adjustments to the model assumptions for emissions rates or use in the foam sector would be needed to get the FSTOC model and the SAP Ozone Assessment report estimates to agree but doing so would eliminate the independence of the two methods. The very good agreement from the two independent methods is felt as sufficient to use the FSTOC simplified model to estimate the size of the fire protection bank of HFC-227ea and the overall global emissions that comes from fire protection applications. The model provides estimated fire protection emissions of 5,250 metric tonnes and a global HFC-227ea fire protection bank of 168,000 metric tonnes for the end of 2022.

To put that amount into context, the largest that the global halon 1301 bank was projected to be in the FSTOC model was 77,000 metric tonnes in 1991. An initial impression of the FSTOC was that this estimate of the HFC-227ea bank seemed to be too high. However, if one considers that while halon 1301 was commercialized and used as early as 1963, it was not until the mid-1970s that halon 1301 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 marketplace. Using gross domestic product (GDP) growth as a proxy for how much fire protection grew from 1991 – 2022, 4.25-times, **IMF (2022)**, scaling up for the 70% more HFC-227ea required over halon 1301 to protect against the same fire threat, and scaling down for 25% replacement rate of HFC-227ea compared to halon, gives an estimate of 140,000 metric tonnes that would be in the HFC-227ea fire protection bank in 2022, which is in reasonable agreement with the FSTOC model.

Regionally, US 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 US use and emissions of HFC-227ea for foams and MDIs, some assumptions on percentages of use in the US ranging from no use in foams and MDIs to their global average, provide an estimate that the US emissions of HFC-227ea from the fire protection sector are on the order of 10-15% of the global emissions from the fire protection sector. HFC-227ea emissions from NWEU are available for the period 2006 – 2020, **BEIS (2022)**. Scaling the NWEU emissions for all of Europe (see Section 6.2.1) provides estimates of 12% of the global emissions in the early years, dropping to 5% by 2020. All anecdotal information available to the FSTOC would indicate that these ranges are reasonable, which provides further support to the HFC-227ea model estimates in Figure 6.7.

6.4.2 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 by far the largest use of HFC-125 is as a component in several refrigerant blends, 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 FSTOC does not have the necessary information to perform such modelling.

6.4.3 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 4.3.3 Agent Alternatives to Fixed Systems, and 5.3 Pipelines / Oil and Gas. 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. One way to estimate HFC-23 would be to ratio its use against HFC-227ea where both are known. In one case where both are available, its use is higher than expected at around 20% - 25% of HFC-227ea, **Yagi (2022)**. However, this is limited to a region where inert gases dominate this sector and therefore is not illustrative of the global percentage. 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 (2022)**, using the correlation shown in **Verdonik (2004)**. If this region were using HFC-227ea at 6% of the global total, its HFC-227ea bank would be approximately 9,500 metric tonnes in 2020. 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 9,500 metric tonnes of HFC-227ea estimated above 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.

6.4.4 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 also used in European military vehicle applications and there is also one other known small use for fire protection in the US National Association for Stock Car Auto Racing, also known as NASCAR. Additionally, some HFC-236fa is used for asset protection, e.g., computer rooms. At this time, there is not sufficient information to estimate HFC-236fa installed quantities or emissions in the fire protection sector.

6.4.5 References:

BEIS (2022): Department of Business, Energy and Industrial Strategy, UK (BEIS), 2022. Alistair Manning, Simon O'Doherty, Dickon Young, Alison Redington, Daniel Say, Joseph Pitt, Tim Arnold, Chris Rennick, Matt Rigby, Adam Wisher, Angelina Wenger, and Peter Simmonds, "Long-Term Atmospheric Measurement and Interpretation of Radiatively Active Trace Gases, October 2020 – September 2021" Annual Report, February 17, 2002. https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/research/ar18_report.pdf

Belevtcev and Kunina (1998): "The Problems of Phaseout and Regeneration of Halons in Russia," Proceedings of the Halon Options Technical Working Conference, May 12-14, 1998.

Hu et al. (2017): Hu, L. et al., Considerable contribution of the Montreal Protocol to declining greenhouse gas emissions from the United States, Geophys. Res. Lett., 44, doi:10.1002/2017GL074388.

IMF (2022): International Monetary Fund, World Economic Outlook Database, October – 2022, downloaded from https://www.imf.org/external/datamapper/NGDPD@WEO/WEOWORLD

Kopylov et al. (2003): Kopylov N.P., Nikolayev V.M., Zhevlakov A.F., Pivovarov V.V., Tselikov V.N., Russian National Strategy for Halon Management, Chimizdat, StPetersburg-Moscow, 2003.

Manning et al. (2021): Manning, Alistair J., et al. "Evidence of a recent decline in UK emissions of hydrofluorocarbons determined by the InTEM inverse model and atmospheric measurements." Atmospheric Chemistry and Physics 21.16 (2021): 12739-12755.

Millet et al. (2009) "Halocarbon Emissions from the United States and Mexico and Their Global Warming Potential", Environ. Sci. Technol. 2009, **43**, 4, 1055–1060

Newland et al. (2013): Newland, M. J., Reeves, C. E., Oram, D. E., Laube, J. C., Sturges, W. T., Hogan, C., Begley, P., and P. J. Fraser, Atmos. Chem. Phys., 13, 5551–5565, 2013, https://doi.org/10.5194/acp-13-5551-2013

Noakes (2022): Noakes, TJ, Mexichem Fluor, United Kingdom, personal communication with a co-chair of the Medical and Chemicals Technical Options Committee, 2022.

Terrinoni (2018): Walter-Terrinoni, H., co-chair, Foams Technical Options Committee, personal communication, 2018

Tope (2021): Tope, H., co-chair, Medical and Chemicals Technical Options Committee, personal communication, 2021

Verdonik (2004): Verdonik, D.P., Modeling Emissions of HFCs and PFCs in the Fire Protection Sector, Proceedings of the Earth Technology Forum, Washington, DC, 2004

Verdonik and Robin (2004): Verdonik, D.P. and M.L. Robin, 2004: Analysis of Emission Data, Estimates, and Modeling of Fire Protection Agents. Proceedings of the 15th Annual Earth Technologies Forum, April 13-15, 2004, Washington, DC, USA, 11 pp.

Walter-Terrinoni (2022): Walter-Terrinoni, H., co-chair, Foams Technical Options Committee, personal communication, 2022

WMO Ozone Assessment Report (2022): https://ozone.unep.org/science/assessment/sap

Yagi (2022): Yagi, M, Japan Fire and Environment Protection Network, personal communication, 2022

6.5 Global Halon, HCFC, and HFC Banking (Agent Management)

6.5.1 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 concepts and terminologies apply to all fire suppression gases including halons, HCFCs, HFCs, and their alternatives.

Many parties have halon banking programmes that are fully operational (and some HFC/HCFC banking programmes), but more parties have implemented only partial programmes 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 they have the experience to expand those programmes, practices, and processes to include all halogenated gaseous fire extinguishing agents where necessary.

While there may not be any national banking in many countries, there may be several local or commercial enterprises providing a form of banking operations/services. These smaller operations may be addressing targeted users, but they are serving an important purpose in preserving the global bank.

FSTOC continues to see issues regarding the loss of historical knowledge due to the length of time over which the Montreal Protocol activities have been implemented. 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 halons, HCFCs, HFCs, and their alternatives use, recycling, and banking. Lack of understanding about long-term needs for halon 1301 has also resulted in halon destruction. FSTOC notes that this lack of experience and historical knowledge is becoming more challenging as it works with various parties and organizations on issues related to acquiring halons to meet their continuing needs. Parties may wish to address awareness programmes to re-establish this loss in institutional memory.

6.5.2 Pathway to Halons, HCFC, and HFC Management and Banking

Management of halons, HCFCs, and HFCs comprises activities including receipt, testing, recycling/reclamation and repackaging, warehousing, issuing the agents, and disposition.

The pathway to the management of halogenated gaseous fire extinguishing agents can be driven by governments and private companies and can consist of some or all of the following components:

- Initiate and carry out halon/HCFC/HFC surveys, the survey might also estimate future demand for halons for enduring uses
- Awareness campaigns
- Information on alternatives to halons/HCFCs/HFCs
- Establishing phaseout strategies with supporting policies

- Promote and support establishment of recycling programmes and facilities that could also collect and sell halons such as:
    - Government supported recycling facilities
    - Fire equipment companies offering recycling and reclamation services
    - Private companies offering recycling and reclamation services
- Planning for end-of-life, which may include destruction (i.e., where halons are too contaminated)
- Identify equipment using halogenated gaseous fire extinguishing agents and determine what replacements are available for selection at end of life and limiting use of halons, HCFCs, and HFCs to enduring uses only

This approach can also be extended to all halogenated gaseous fire extinguishing agents.

Safety is critical to the management of these halogenated gaseous fire extinguishing agents. These cylinders are often under high pressure; not maintaining system agent cylinders as per the relevant safety standards, including having unsecured agent cylinders, can represent a significant safety hazard. Furthermore, implementing good leak detection practices and physical security will also ensure the protection of scarce, valuable fire extinguishing agents.

6.5.2.1 Banking Strategy

Halon, HCFC, and HFC banking comprises but a portion of an overall Montreal Protocol implementation programme. Other features of a comprehensive programme should occur before banking is established. Examples of these features include:

- Establish governmental policy and program
- Implement awareness campaigns
- Identify appropriate replacements or alternatives
- Develop or adopt standards for the design, installation, and maintenance of fire protection systems (including halons, HCFCs, HFCs, and alternatives to all of the agents)
- Survey installed capacities and establish database of halon, HCFC, and HFC users
- Identify remaining enduring uses and quantity requirements
- Identify and involve stakeholders
- Open discussions with the military, civil aviation, and other remaining users
- Plan for decommissioning of halon, HCFC, and HFC systems

Examples of measures that have been shown to help ensure successful implementation of a banking programme include:

- Emphasize to stakeholders that supplies are limited with reduced or no future production
- Prohibit new halon systems in facilities or new equipment designs
- Prohibit emissions in testing and drills – use only on real fires

- Where possible, replace discharged halon/HCFC/HFC systems with other forms of fire protection
- Require that all halons, HCFCs, and HFCs removed from retired systems be sent to appropriate recycling/reclamation facilities.
- Require purchases of halons via banking operations through regulations or voluntary agreements
- Exchange information and expertise regionally
- Develop import regulations for halons, HCFCs, and HFCs, e.g., a quota system
- Develop and approve codes of conduct/good practice for the management of these halogenated gaseous agents
- Provide information in the form of brochures, newsletter, website, phone, etc.

While a free-market approach is an option, a more formalized strategy has been implemented by many parties. Options for setting up a halogenated gaseous fire extinguishant banking operation include contractor-operated, government-operated, or a combination of these.

A common concept of centralized banking operations is as follows:

- It acts as a centralized warehousing and repair facility
- It becomes a "one stop shop" for all fire extinguishing agent transactions, e.g., turn in, reclamation, storage and reissue
- It receives all halogenated gaseous fire extinguishing agent recovered or removed from service
- It can provide or have access to quality control laboratories that are able to test recycled and reclaimed agent to determine whether the required purity specifications have been met. Halogenated gaseous fire extinguishing agents meeting purity requirements are provided to users to meet fire protection requirements
- It provides simplified recordkeeping and programme management because multiple dispersed physical storage locations and information systems are eliminated

Users of these types of facilities should be apprised of the benefits they derive from their participation in a banking program, such as consistent quality and predictable supplies of halons, HCFCs, and HFCs.

6.5.3 Agent Recycling Considerations

Safety assessments are critical prior to conducting any agent recovery, recycling, or reclamation. Without considering safety, mishandling of the gas cylinders and agent could result in fatalities. Personnel must be fully trained to know and avoid common safety problems when dealing with compressed gas cylinders. Handheld leak detectors should be used at receiving facilities. Each cylinder should be inspected for valve type and integrity to include all safety devices. Personnel should <u>always</u> assume a cylinder is fully pressurized regardless of gauge reading.

Cylinders should always be chained down when being evacuated, moved, or worked on in any way. Personnel need to be trained to know the different types of valves and how they activate, e.g., burst disk/initiator, mechanical/cutter valves, and Schrader valves.

In addition to safety training, personnel and companies undertaking recovery, recycling, and reclamation activities need to be trained to carry out tasks to perform the routine functions, for example:

- Leak test incoming cylinders
- Operate recovery, recycling, and reclamation equipment safely
- Remove/recover all agents to specified level of vacuum
- Repackage into suitable, in-test-date cylinders
- Recycle/reclaim the agent to its specification
- Repackage for storage and issue
- Use certified equipment
- Leak test recovery equipment during operation and gas cylinders after filling
- Test incoming agent to determine the type of product as cylinders may not contain what the label states
- Test reclaimed agent to ensure that it meets purity specifications to avoid contamination
- Provide a certificate of analysis that certifies the agent meets required purity specifications
- Send agent that is not reclaimable becasue it is too contaminated, to an approved facility for destruction.

Reclamation and certification are reviewed in detail for all halons and other gaseous fire extinguishing agents in the FSTOC's Technical Note B, *Emission Reduction and Recycling Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents,* **FSTOC (2022).**

6.5.3.1 Challenges

This section addresses the challenges faced in setting up halon banking and recycling facilities. If lessons are not learned from these activities, the same problems may occur for HCFC and HFC fire extinguishing agents.

Historically the implementation of some of the halon banking and recycling projects in Article 5 parties presented a number of challenges that limited and/or were the main reasons for the failure of these projects. Below are some of these challenges:

- Competition within the fire protection industry in the country resulted in lack of general support from the rest of the fire protection industry; the project was used as a platform for promotion of the company and replacement of halon fire equipment.

- Selection of a company with no prior experience within the fire protection industry
- Selection of a company which only needed the halon for its own use
- The regional centre concept is difficult to implement; the transportation of halon or recycling equipment can be severely problematic
- Not enough business to sustain operation
- Slow or delayed programme implementation resulted in the bulk of halon being removed from the country prior to banking operations coming online
- The bulk of the project funding was exhausted in the purchase of halon recovery and recycling equipment
- The ability of some host countries to operate and maintain halon recovery and recycling equipment centres has been problematic (sustainability of the banks)
- Finding excessive quantities of contaminated halons in some countries. As venting would be unacceptable, shipping to and cleaning up at a reclamation facility would be needed; however, it remains to be determined how to cover such costs
- Selection of inappropriate recycling and recovery equipment and inadequate operators' training
- Data on the installed base and stored inventories of halons is poor or non-existent
- Coordination with military branches is not being done
- Exchange of data and information is not adequate
- National regulations that prevented the free flow of recycled halon (e.g., import / export)
- Lack of regulations or voluntary agreements in support of halon banking and phaseout
- Lack of enforcement of existing regulations
- No focal point for halon programme management including frequent turnover of National Ozone Officers (NOO).
- Little or no awareness campaign
- Insufficient workshops and training and not including all stakeholders
- Lack of a business plan and/or lack of a halon bank management plan
- Where policies are implemented, it is essential they be practical, not prohibitive
- Unanticipated lag in the establishment of halon banking and management programmes globally

Countries that have implemented a form of banking are able to utilize the same structure for the management and phaseout of HCFCs and phasedown of HFCs. Most countries have now implemented some form of legislation, but there might be a need to readdress the policies on transboundary movement of recycled materials.

6.5.3.2 Recycling and Bank Management Challenges

Previous FSTOC reports have identified key elements of successfully managing halon resources and challenges that were encountered. The reader is referred to previous editions of the FSTOC Assessment reports and their adjunct Supplemental reports. If lessons are not learned from the past experiences in halon management, the same problems could occur for HCFC and HFC fire extinguishing agents.

In reviewing the halon recycling component of a number of halon management programmes, there was very often a conflict between the policies introduced and enforced and the objectives the halon recycling activities envisaged. One example was the introduction of policies and regulations banning, or significantly limiting, the use of halons (including recycled halons) while simultaneously establishing a halon recycling programme with the expectation that it be financially self-supporting. This had the added effect of eliminating the market for halon servicing. Another counterproductive policy has been requiring all halon users to turn in decommissioned halon to the bank while requiring them to pay for the testing, transportation, storage, and/or cylinder disposal. In some countries, legislation was passed prohibiting the importation of recycled halons (it appears they believed it was required by the Montreal Protocol) – this will become a long-term problem for those whose supplies are inadequate to service the remaining enduring uses, including civil aviation and military applications.

As the length of time that the fire protection industry has been relying on banked and recycled halons increases, the chance of halons becoming contaminated increases each time the halon is recycled, and as older systems that may not have been charged properly or maintained properly are identified and decommissioned. Additionally, recyclers warn that as the price goes up due to lack of availability, the chances of having this material intentionally adulterated with other substances also increases, thus further limiting the amount of halon globally available and increasing the amount of halon needing destruction.

Halon 1301 availability is diminishing. Large individual sources of halon 1301 are getting more difficult to find. Major recyclers report that the price of halon 1301 has tripled since halon production ceased in 2010.

Halon 2402 is reported to be available in at least one country, and major recyclers report that there is still a demand for this material when it is located.

When local access to reclamation services is not available, the classification of halons as hazardous waste by some parties results in applying the Basel Convention. Classifying halon as a hazardous waste continues to obstruct the international movement of halons. In the future, unwarranted classifications as has happened to halons could similarly affect other used gaseous halocarbon fire extinguishing agents in need of reclamation.

6.5.4 Current Situation in Global Banking

The FSTOC continues to liaise with NOUs, standards-making bodies, and professional associations to gather information regarding banking of fire suppression agents. While there are knowledge gaps, there is still a lot known about the emerging and on-going efforts by many parties, regions, and organizations as outlined in this section. The current situation in global banking as described in the following sections.

6.5.5 HCFC and HFC Banking

Little is known about banking and management surrounding HCFCs and HFCs. This is still an emerging area despite over two decades of production and use in the fire protection sector.

HFCs and some HCFC are still being manufactured. As a result of the ongoing HCFC phaseout and the newly implemented HFC phasedown, supplies of these agents will diminish. This will drive the need for increased use of recycled materials and therefore banking operations. The FSTOC knows of no centralized or governmental HFC/HCFC banking/management operations.

6.5.5.1 Australia

There is no centralized HCFC or HFC banking (from the fire suppression sector applications) in Australia. Replenishment capabilities exist by way of accessing service providers that can offer recycling/reclamation services or moving to alternative agents.

Since 1 January 2018, Australia has seen the gradual reduction in the amount of bulk HFCs permitted to be imported into Australia under the Montreal Protocol HFC phasedown. HFC 227ea is used in Australia as a halon 1301 replacement. Since the introduction of the HFC phasedown there has been an accelerated shift away from HFC-227ea in the Australian gaseous fire protection market.

The decline in demand for HFC-227ea can be attributable to a number of factors. These include the mandated phasedown, import quota restrictions, the price of the product being comparable to environmentally friendly alternatives such as inert gases (IG-55, IG-541, IG-01, IG-100, and FK-5-1-12), and suppliers promoting alternatives to their customers. As 2036 nears, the importation of HFC-227ea is expected to cease, with legacy systems that cannot be transitioned to alternatives being maintained using reclaimed agent.

6.5.5.2 Brazil

In Brazil, there is no HFC or HCFC banking; the country has begun the process of ratifying the Kigali Amendment (submitted to Senate in 2022 for analysis and voting). However, there is an engagement to meet established goals by freezing HFC consumption by 2024, thereafter reducing consumption by 10% by 2029 and 85% by 2045. Effective measures are detailed in the Brazilian Programme for HCFCs Elimination, *Programa Brasileiro de Eliminação dos HCFCs*, which was established in 2011, **PBH (2011), (2016)**.

ODS consumption has decreased over the years, from 11,376 tonnes in 2000, to 1,207 tonnes in 2010 and 453 tonnes in 2020, **GOV.BR (2022),** with a slight increase in 2021 of 491 tonnes.

The baseline of HCFC consumption was frozen in 2013 with an average consumption of 1,327 tonnes between 2009 and 2010. Based on the scheduled reduction, maximum consumption by 2021 should have been 51.6%, **PBH (2022)** of the baseline, which represents 643 tonnes. Indeed, the reported HCFC consumption in 2021 was 491 tonnes **GOV.BR (2022)**, mainly accounted for by HCFC-22 (459 tonnes) and HCFC-141b (31 tonnes).

6.5.5.3 Canada

Canada has no national and no known provincial HFC or HCFC banking. The FSTOC has queried various organizations/companies to ascertain the quantities of installed HFCs and HCFC. The responses are that the information is proprietary.

6.5.5.4 Egypt

HFC banking has not yet begun because the authorities allow full importation of HFCs and there is no incentive to start an HFC bank. Additional disincentives to banking are the low prices of imported, newly produced HFCs compared with recycled HFCs. Starting in 2024, in accordance with the Kigali Amendment, consumption will freeze and start to reduce according to the implementation schedule. So, it is unlikely there will be any HFC banking until after 2024. The authorities are starting to push other sectors such as refrigeration manufacturing to shift away from producing HFC equipment. However, there are no manufacturing facilities for the fire protection sector, so they depend upon 100% importation. Accordingly, there is no incentive for the government to push the manufacturing of alternatives in the fire protection sector. The government convinced consultants to start specifying alternatives such as FK and IGs.

6.5.5.5 India

In India, a regulation was passed in 2014 banning the import of HCFCs and limiting their use in many applications. The 2017 Gazette Notification for the Regulation and Control of ODS requires a 50% reduction of HCFCs and its blends from all applications including firefighting by 2020. Importation of newly produced HCFCs and its blends were no longer permitted.

Currently, there is no known recycling of HCFCs, HFCs, or FK in India. India is still in a transition state and is installing the recommended HFCs and FKs as required. They are in a discovery/planning phase for banking of HFCs and will follow with other fire extinguishing alternatives at a later date.

The use of HCFCs in the civil and government sector has been completely replaced with HFCs, FK-5-1-12, and CO_2 where applicable.

6.5.5.6 Italy

There is no HCFC/HFC banking from fire sector applications; replenishment capabilities exist by way of directly accessing service provider companies who can offer recycling/reclamation services or swapping to alternative agents.

6.5.5.7 Japan

Japan does not use HCFCs in fire protection. In Japan, HFCs and IGs were officially allowed to replace halons beginning in 2006, see

Table 6.7 for installed quantities of halon alternatives and emission rates by Japan fiscal year (FY), which begins April 1st and ends on March 31st.

As these systems have been installed for at most 16 years, most of the systems are still in their useful lifetimes. So, the HFC banking programme in Japan has not yet been established, but if needed, they will do it within a short period of time.

Table 6.7: Amount of Halon Alternatives in Installed Systems (Measured by the Fire and Environment Protection Network)

Halon Alternatives (Unit)		FY 2006	…	FY 2012	…	FY 2020	FY 2021
Halogenated Agents	HFC-227ea (tonnes)	29	…	206	…	470	481
	HFC-23 (tonnes)	10	…	50	…	98	93
	FK-5-1-12 (tonnes)	0	…	23	…	82	84
Inert Gases	IG-541 (m^3)	11,200	…	118.000	…	278,500	301,800
	IG-55 (m^3)	3,600	…	41,400	…	43,800	43,700
	IG-100 (m^3)	139,500	…	1,280,200	…	3,016,300	3,079,800
	CO_2 (tonnes)	409	…	3,208	…	5,464	5,860

The figures in

Table 6.7 are the data registered after starting the registration system in April 2006. As the register of halon alternatives to FEPN is on a voluntary basis, the figures which were not reported to the FEPN after starting the system and the figures installed before April 2000 are not included.

6.5.5.8 Russia

The total installed base of HFCs (HFC-23, HFC-125, and HFC-227ea) in fire protection systems in Russia is estimated to be 4,286 metric tonnes as of 2020. This is more than 2.8 times the size of the FK 5-1-12 installed base (1,498 metric tonnes). Four sectors are the main users of HFCs for fire protection: 1) the military sector, 2) museums and libraries, 3) banking facilities, and 4) the telecommunication sector including data centres. Figure 6.8 reflects the current situation in gaseous fire suppression in Russia.

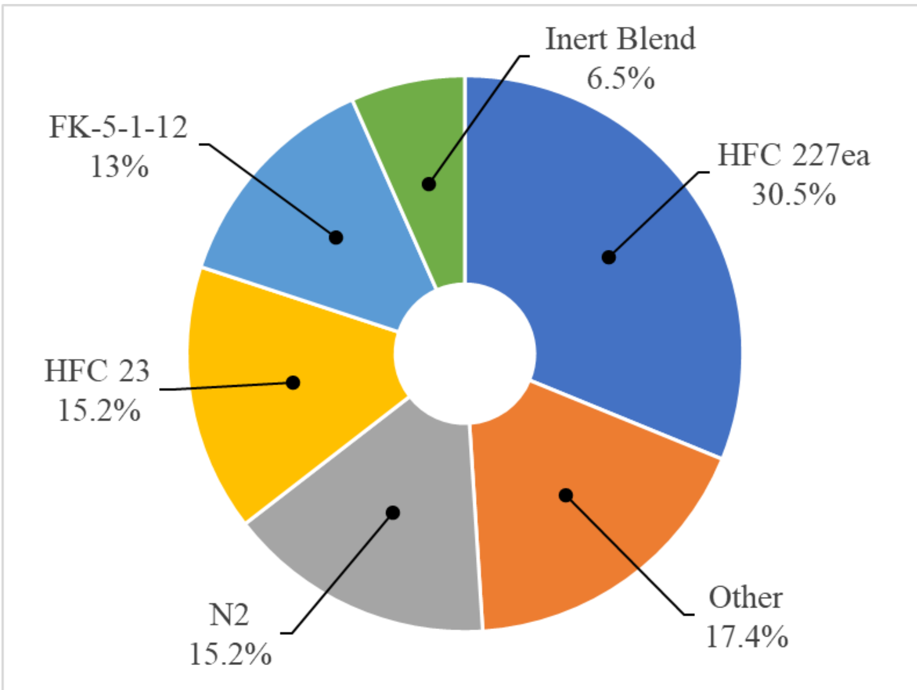


Figure 6.8:Distribution of Installed Fire Suppression Systems in Russia

On average about 30 tonnes of HFCs are recycled per year. Due to economic reasons, Russia stopped the production of HFCs for fire extinguishing at least 5 years ago. The needs are fully met through imports and recycling. In terms of price, the market for fluorinated gaseous fire extinguishing agents, like the market for fire extinguishing substances in general, is growing by an average of 5% per year, with a share of 16% of the market as a whole. Currently, this 16% is allocated as 9% FK 5-1-12 and 7% HFCs (almost 100% HFC-227ea), which means approximately 160 metric tonnes of FK 5-1-12 and 265 metric tonnes of HFC-227ea in physical volumes. In 2014, this ratio was about 110 metric tonnes of FK 5-1-12 against 221 metric tonnes of HFCs. Therefore, the market share of HFCs is slowly decreasing.

6.5.5.9 Southeast Asia and China

It is reported that the main focus in this region is their preparation for ratification and implementation of the Kigali Amendment and the identification of alternatives to HFCs. The National Ozone Units (NOUs) are looking at the overall ceiling/limits in of their respective countries. They then identify which sector/agent has the highest CO_2 equivalents and focus on reductions in that sector to allow for more use in other sectors. The refrigeration sector is rapidly growing and thus the HFC demand is growing in refrigeration and servicing. To provide more use for refrigeration, the NOUs are looking to reduce HFCs in other sectors such as fire protection. The NOUs rely on their fire equipment companies to advise them rather than utilizing the information directly from the FSTOC reports. The militaries are not reporting on their uses/needs. The NOUs are concerned about the 2024 HFC freeze and how to tailor an import system to allow for imports in some sectors and not others.

For HCFCs, parties in this region generally require import licenses. No import licenses have been issued for HCFC-123 for the production of HCFC-based fire extinguishers in 2022 in Indonesia, Malaysia, and Vietnam. Additionally, the ozone regulations in the Philippines and Indonesia include provisions for banning manufacturing and sales of HCFC-based fire extinguishers. The import of HCFC-123 in HCFC Blend B fire extinguishers would be considered importation of an HCFC-containing product and as such is not covered by the ozone regulations in some southeast Asian countries.

China's National Halon Management and Recycling System (NHRMC) was set up by the China Certification Center for Fire Products within the Ministry of Public Security, now known as the Ministry of Emergency Management (MEM), in 2016. Halon recycling activities continue with the guidance and monitoring provided jointly by the MEM and the Ministry of Ecology and Environment (MEE).

The Malaysia Fire Brigade was operating the national halon bank, but it is not anymore. The NOU is looking for alternatives to HFC-227ea.

Indonesia still has a pseudo-national halon recycling center in the Garuda Maintenance Facility Aero Asia (GMF). However, the FSTOC has not received any information as to whether the facility handles HFCs or HCFCs.

6.5.5.10 US

HFC recycling is common and is performed by the primary halons recycling companies. In addition, recovery and reuse of HFCs occurs at the distributor level. The Halon Alternatives Research Corporation (HARC) has developed a recycling code of practice for halogenated clean agents, which is referenced in the National Fire Protection Agency (NFPA) 2001 standard, **NFPA 2001 (2022)**. Data from HARC's HFC Emission Estimating Program (HEEP) show that in recent years about 75% of the HFCs used to service existing fire protection equipment in the US 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 US Defense Logistics Agency (DLA) manages recycling of HFCs for military uses. Up until now, a dedicated supply of HFCs has not been established due to the general availability of these chemicals. With HFC phasedown regulations taking effect in 2022, HFC availability will be monitored to determine if a dedicated supply is required for military uses.

6.5.6 Halon 1301 and 1211 Banking

Those countries that established banking and/or clearinghouse activities have, in general, continued to manage halons and provide servicing. The FSTOC endeavors to provide a review of all parties, however, many parties have little or no known halon uses and thus are not reported on. There are also a number of parties for which the political environment and/or lack of infrastructure make it impossible for the FSTOC to gather information. This section includes updates to activities previously reported in FSTOC Assessment reports and Technical Notes.

Additionally, three countries have provided the following comments:

- The halon bank in South Africa continues to look for economically available halon 1301
- In 2022, a Kuwait oil company notified the FSTOC that they have 700 kg of halon 1301 available for sale (there are no known clearinghouse or recycling facilities in Kuwait)
- The FSTOC was notified that Saudi Arabia no longer conducts any halon recycling

6.5.6.1 Australia

The National Halon Bank, established in 1993, is administered by the Department of Climate Change, Energy, the Environment and Water. The day-to-day management of the Australian National Bank is contracted to a gas management specialist company. The National Halon Bank is a dedicated facility that continues to accept halon 1211 and halon 1301 surrendered for disposition by business and the community. The bank is certified to ISO 14001 Environmental Management Systems **ISO 14001 (2015)**, has recovery and reclamation equipment on hand, and has access to its contractor's ISO 17025 accredited laboratory for testing and certification of halons to recognized international standards.

Recycled or reclaimed halon is stored in bulk pressure vessels and subject to continuous environmental monitoring for the detection of leaks. Contaminated, non-reclaimable halon is destroyed using Montreal Protocol approved destruction technology through a third-party provider.

The bank is the primary supplier of halons to those uses considered "essential" in accordance with the criteria established by the Ozone Protection and Synthetic Greenhouse Gas Management Act of 1989 and associated policies, namely civil aviation and the Australian Defence Force, that continue to rely on halon. Requests for supply are administered by the specialist gas management company and final approval for supply given by the Department of Climate Change, Energy, the Environment, and Water.

The Australian Halon Management Strategy, **Australia (2019**) sets out how Australia will treat the management of Australia's halon stocks in the lead up to their ultimate phaseout. In 2019, the Department reviewed and updated the Australian Halon Management Strategy and policy on the import and export of used ozone depleting substances and synthetic greenhouse gases (e.g., high-GWP HFCs). To further responsibly manage the halon stocks held at the National Halon Bank, the Department commissioned a report in 2020 to better understand Australia's enduring needs and forecast future demand for halons. The 2020 report was titled 'Review of Australia's Non-Defence Requirements,' **Australia (2020).** This report complements the original study performed in 2012 by the same authors. Both reports address civilian halon demand but not Australian Defence requirements.

To better understand what the demand could be for civil aviation in Australia, the 2020 report scrutinized several worst-case scenarios based on various assumptions and impacts. The report provided information regarding the prospects and possible timeframes for transition of remaining civilian halon uses, how long a strategic stockpile of halon would be required, and the quantity of halon likely to be required for the remaining non-defence uses.

The Department continues to take a precautionary view on the disposal of halons. Only halon that is in excess of Australia's needs is available for export. Only recovered halon that is considered too contaminated to be brought back to specification is destroyed. Australia has facilitated the movement of halons between countries.

Currently the National Halon Bank has a central stockpile of 92 metric tonnes of halon 1211 and 164 metric tonnes of halon 1301. It is difficult to accurately substantiate what remains as installed quantities in Australia.

There is a continuing need for halon banking in Australia, with a centralized facility seen by many industry participants as the most efficient way of managing supply and purity. The Department performs periodic reviews of how halon banking is managed in Australia.

6.5.6.2 Brazil

Brazil has engaged in halon banking and recycling by accredited companies selected by the Brazilian Government. Recycling equipment was obtained with resources from the Multilateral Fund for the Implementation of the Montreal Protocol (MLF) in collaboration with the Canadian government. Reclaimed halons are mainly supplied to those uses considered "essential", such as civil aviation.

6.5.6.3 Canada

Canada has no national halon banking and information on provincial banking is not known. Each province in Canada functions independently of the federal government.

6.5.6.4 China

China's NHRMC was set up in 2016; halon recycling activities are ongoing. The halon 1211 stockpile at one former halon producer still exists and is managed by the company. As per the progress reports submitted to the MLF, **UNEP (2019)**, the remaining stock left at the producer's facility is approximately 2,000 metric tonnes of halon 1211. The halon 1301 recycling center continues to operate, and one halon recycling station has been certified.

Three TA (Technical Assistance) activities (surveys) were carried out by China as part of their Montreal Protocol program. The three surveys included the following:

- Civil aviation: A survey were carried out to determine the amount of halons currently used in the civil aviation sector. Annual service demands and expected future demands for halons were estimated.
- Commercial ships: A survey was carried out to find out if halons installed on existing commercial ships could be a possible future source for halon recycling. It was found that halons are not any longer used on commercial ships still in service. Some halons had in the past been recovered from retired ships.
- Provincial halon survey: Surveys were carried out in some key provinces along the east coast to find out how much halons might still be installed in existing halon fire

extinguishing systems and portable fire extinguishers. Only some halon 1211 and 1301 fire extinguishing systems are still installed and might be a source of halons for future recycling.

All three surveys of halons in selected provinces have all been completed.

6.5.6.5 Egypt

Egypt established one halon bank approximately 15 years ago. It operated for about 3 years, then shut down due to lack of halon availability in the market. There is currently no national halon bank.

6.5.6.6 India

In India, several activities related to the implementation of ODS (Regulation and Control) Rules 2000, **India (2000)** and its amendments were carried out inter alia including registration, regulation of export/import, issuance of production quotas, monitoring, and reporting. The statutory reporting for the Montreal Protocol under Article 7 and the Country Programme Progress Report (CPPR) have been prepared and submitted to the Ozone Secretariat and the Secretariat of the MLF. The compiled data submitted under Article 7 and the CPPR for the year 2019 with regards to fire-fighting application are provided in Table 6.8.

Table 6.8: Cumulative Production of Halons in India

ODS	Total production for all uses (tonnes)	Export (tonnes)	Import (tonnes)	Production for feedstock uses (tonnes)
Halon 1211	0.000	0.000	5.000	0.000
Halon 1301	129.045	134.628 (120.000 tonnes feedstock and 14.628 tonnes recycled and recovered)	2.004	129.045

As far as the fire suppression applications in India are concerned, a majority of newer applications have shifted to not-in-kind alternatives such as foam, water mist, aerosols, etc., that require cleanup and also CO_2. There has been significantly increased focus on water mist. For in-kind alternatives that do not require cleanup, the use of HFC-227ea and FK 5-1-12 is preferred in India. For systems already installed with halons, the requirement is met with internal and imported sources.

The activities of halons 1301 and 1211banking in India have not changed over the years. The equipment for halon recovery, recycling, and reclamation is maintained with funds from the government with no or little use by private industry. The use of the banking facility has been reported for public sector organizations with no impact on the civil sector transactions of reclaimed halon. Some public sector agencies of oil and gas, and ship repair and maintenance are also dependent on small traders to fulfil the requirements. As halon activities in the civil sector are not organized, it has an impact on the availability and quality of these two halons.

Owing to the COVID 19 pandemic, the activities related to halon reclamation and recycling in the halon banking facility have slowed down and are operating in a very limited manner.

Recently, FSTOC was notified that during shipbreaking at the Alang Shipbreaking Yard, the Indian Ministry of Environment does not allow the scrapping of halon filled cylinders in India. Hence, it is expected that these cylinders are sold through the grey market. At present, the activities related to shipbreaking at Alang are limited due to COVID or cost-effectiveness (i.e., labour costs, etc., are higher than prior to COVID).

6.5.6.7 Italy

In 2021, the Italian Ministry of Environment updated the list of authorized collection centers for ozone depleting substances. As per the specific law no. 549/1993 and subsequent amendments, the collection centers are authorized to collect ODS and arrange for their recycling / reclaiming / destruction at proper sites. Table 6.9 provides quantitative data on halons by sector in Italy and Table 6.10 provides total quantities of halons in fixed systems and portable extinguishers in Italy. There are no halon approved destruction facilities in Italy; when needed, contaminated halon is shipped to a neighboring country for that disposition.

Table 6.9: Quantities of Halon by Sector in Italy in 2020

CRITICAL USES OF HALONS						
Application			**Quantity (kg)**			
Category of Equipment or Facility		**Halon Type**	**Installed**	**Used**	**Emitted**	**Stored**
1	**On military ground vehicles**	**1301**	23,852	56	0	4,377
		1211	3,304	149	0	1,953
2	**On military surface ships**	**1301**	73,302	0	60	0
3	**On aircraft**	**1301**	12,853	6	4	768
		1211	3,936	37	0	717

Table 6.10: Total quantities of halons in fixed systems and portable extinguishers in Italy

		Halon 1301				**Halon 1211**			
		Installed	**Used**	**Emitted**	**Stored**	**Installed**	**Used**	**Emitted**	**Stored**
Total quantities (kgs) for each type of halon	Fixed systems	**107,970**				**5,810**			
	Portable extinguisher	**2,037**				**1,430**			
	Total, kg	**110,007**	**62**	**64**	**5145**	**7,240**	**186**	**0**	**0**

6.5.6.8 Japan

Japan has a well-established country management system for halons which has been in operation for decades. They also have formal fire service organizations that monitor and manage all aspects of fire protection in the country. Japan retains all halons within the country for their new and remaining internal uses. They do not import halons. The quantities of halons installed in extinguishing systems and emission rates by fiscal year (ending in March) are provided in Table 6.11.

Table 6.11: Amount of Halons in Installed Systems in Japan in Metric Tonnes[1,2,3,4]

Fiscal Year	1994	…	2007	2008	…	2018	2019	2020	2021
Halon 1301	16,637	…	16,876	16,203	…	16,424	16,500	16,547	16,576
Halon 2402	395	…	246	196	…	149	148	146	139
Halon 1211	80	…	48	42	…	38	35	32	31
Total	17,112	…	17,170	16,441	…	16,611	16,683	16,725	16,806
Emission Rate	--	…	0.09%	0.08%	…	0.11%	0.07%	0.04%	0.04%

1. The dates are the Japanese fiscal year, which begins April 1st and ends on March 31st.
2. This table excludes merchant shipping, civil aviation, and military applications. The Japanese government reported halon use in these sectors was 470-560 tonnes of halon 1301, 4 tonnes halon 2402, and 4 tonnes of halon 1211, as of April 2008.
3. The reduction (approximately 730 tonnes) between the amounts of halons in 2007 and 2008 is the result of the second nationwide re-investigation for halons conducted in FY 2007. This decrease was not caused by discharges or emissions.
4. The emission rate is calculated as the amount of halon 1301 refilled to existing systems divided by the total, then multiplied by 100.

6.5.6.9 Malaysia

Management of the centralized Malaysian Halon Bank was previously with the Malaysia Fire Brigade; however, it is now with the Government. The halon recycling equipment at the centralized bank is out of service and in need of repair. The bank does not have a laboratory on site to determine the quality of its halon stockpile. Current regulatory mandates prevent the export of halon for sale or to access offshore reclamation facilities.

6.5.6.10 Sweden

Sweden has two halon banking operations in the country. The military continues to manage a halon bank that primarily supports the ground vehicle fleet. However, since nearly all halon in the fleet has been replaced, the military halon banking operations are expected to be discontinued. Saab does halon banking and recycling to support maintenance servicing of both aircraft manufactured by Saab and the civil aviation market as well as performing all of the servicing and maintenance of the Swedish military fleet. It was reported in the HTOC 2018 Supplemental report #2 that there had been destruction of reusable halons in Sweden. All indications are that the destruction of non-contaminated halons has been discontinued.

6.5.6.11 Thailand

Thailand is not conducting any halon activities through the NOU. There may be some independent fire companies providing servicing and recycling. Thailand's halon clearinghouse was not established for several reasons, firstly being a lack of interest from the fire equipment companies. At least one of the fire equipment companies is known to have established its own recycling facility to serves its own customers. The military, assumed to be one of the main critical halon users, organized its own programme to ensure halons for its own use. Likewise, the

Thai civil aviation companies organized their own halon management programmes.

6.5.6.12 US

In 1993, the Halon Recycling Corporation (HRC) was formed by concerned halon users and the fire protection industry to support the goals of the Montreal Protocol and help manage the phaseout of halons. HRC is a voluntary, non-profit trade association that acts as a facilitating organization for the recycling of halons and is the main liaison for the fire protection industry with the US government on halon-related issues. HRC has been involved in the management of existing halon resources for almost 30 years through its work with the US EPA, UNEP, FSTOC, FAA, ICAO, and others.

HRC developed and recently updated a Code of Practice for Halon Recycling Companies, **HRC (2021)**, that is referenced in the NFPA 12A Standard on Halon 1301 Fire Extinguishing Systems, **NFPA 12A (2018)**. HRC has initiated an outreach programme to promote the continued careful management of existing halons that was presented at meetings of NOUs in 2018 and 2019 and at a Montreal Protocol Open-ended Working Group (OEWG) meeting side event in July 2021. HRC published guidance material for airlines and their service providers that is focused on reducing halon losses during the servicing of aircraft fire protection systems.

The recycling of halons for non-military uses in the US is carried out by a small number of halon recyclers that also supply a significant percentage of the world's halon needs, particularly for aviation. These recyclers search the global community to identify "used" halon, and their halon is acquired from both domestic and international sources. Halon sourced from outside of the US must first be granted import approval, which is obtained by providing the US EPA with documentation that will allow the Agency to independently verify that the halon is truly recovered from an existing fire suppression system. Halon sourced within the US generally comes from local fire equipment distributors that install and service fire suppression systems and extinguishers. When a halon system or extinguisher is ready for decommissioning, these fire equipment distributors normally perform the task. The halon removed is usually sold to one of the domestic halon recyclers.

Halon recyclers are responsible for transporting the decommissioned halon systems to their facilities; sampling and testing the halon for any impurities; consolidating the halon into larger storage cylinders; recycling the halon through equipment designed to remove impurities and return the halon to commercial standards; re-sampling the finished product to determine if it meets the above specifications; and, finally, shipping the recycled halon to the commercial customer. The most important continued uses for halons in the US are in fire extinguishing systems protecting civil aviation, oil and gas production on the North Slope of Alaska, nuclear power plants (NPP), and military ground and air weapon systems. There is an international misconception that most of the recycled halon imported into the US is sold to the US military. In fact, the US military relies on its own reserve, and has not purchased any additional supplies of recycled halon in more than 20 years.

6.5.6.13 Vietnam

Vietnam has no halon bank. There have been no concerns expressed regarding halons. Vietnam airlines have halon cylinders on-board their aircraft, but it is not known who provides the servicing.

6.5.7 Halon 2402 Banking

6.5.7.1 Introduction

Halon 2402 had been produced nearly exclusively in the former Soviet Union, and production was continued by the Russian Federation until the end of 2000. The bank of halon 2402 was very small at the time of production phaseout 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, with the objective being to build a bank of halon 2402 that existing applications could rely on for the remaining useful life of their equipment.

However, as reported in the 2006 HTOC Assessment report, **HTOC (2006),** 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. Over the past four years the number of applications involving halon 2402 has been drastically shrunk globally owing to decommissioning of old fire extinguishing equipment in civil aviation, merchant shipping, and the oil and gas industry. Currently, global demand for halon 2402 to support remaining critical needs is mainly concentrated in the military sector and can be estimated as just several tons per year.

In some Central Asian and Caucasus region countries many of the fire protection systems utilizing halon 2402 have been decommissioned. The FSTOC does not have any information regarding the disposition of those halons (estimated as tens of tonnes). Absence of coordinated information increases the prospects for unintentional and undocumented halon emissions. The lack of coordinated tracking also increases the errors in the FSTOC model.

Equipment associated with halon 2402 systems was almost exclusively manufactured in the former Soviet Union until its dissolution in 1991, and in the Russian Federation and the Ukraine since. In other parties, use of halon 2402 was associated with the use of Russian military equipment and civilian aircraft. However, much of this equipment is no longer used.

The needs of some parties for halon 2402 cannot be estimated due to the unavailability of market information, but it should be assumed that there is a demand for halon 2402 for the servicing of remaining equipment and that halon from outside sources will be required, as banking and recycling facilities do not exist. Currently, there is no apparent shortage of halon 2402 on a global basis, but regional shortages may arise as has been the case in the past.

According to their historical use of halon 2402, parties that used or still use halon 2402 as a fire protection agent can be grouped as follows:

- Russian Federation, Ukraine, and Belarus;
- Afghanistan, Algeria, Cuba, Egypt, Libya, and Syria;
- Caucasus: Armenia, Azerbaijan, and Georgia;
- Central Asia: Kazakhstan, Kyrgyzstan, Tadzhikistan, Turkmenistan, and Uzbekistan;
- Non-EU states of Southeast Europe (i.e., non-EU Balkan States): Serbia, Montenegro, and Republic of North Macedonia;

- EU member states: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Malta, Poland, and Slovakia; and
- South-East and East Asia: China, Mongolia, India, Vietnam, and Japan.

Parties that have initiated operational halon 2402 management programmes are described below:

6.5.7.2 Russian Federation

The Russian Federation remains the largest user of halon 2402. The total amount of halon 2402 installed was estimated at metric 915.5 tonnes in 2021. Like most of the countries that still use halon 2402, decommissioning of old passenger aircraft and changes in fire protection in the oil and gas industry concentrated remaining applications of the halon mainly in the military sector. The market can be estimated as currently well balanced with no surplus available for outside markets. An average of 30 metric tonnes/year of halon 2402 were available for purchase in the period from 2013 to 2021. The pandemic did not affect the halon 2402 market.

6.5.7.3 Ukraine

Ukraine remains the second largest consumer of halon 2402 after the Russian Federation. Over the past decade, it was not economically viable to reduce the use of halon 2402. In particular, there are no signs of transition to alternatives in industrial applications as well as in military and telecommunication sectors. Also, there is no available information on recycling after 2014, and it is reasonable to assume that recycling of the halon was completely stopped because the only facility for halon 2402 collection, recycling, and reclamation established at the Spetsavtomatika Institute at Lugansk is not accessible due to its location on the territory not controlled by the Ukrainian government after 2014. Considering that for the period 2005 to 2014 the total quantity of recovered, reclaimed, and reused halon was close to just 3 metric tonnes of halon 2402, Ukraine may be faced with a lack of recycled halon to support existing critical needs.

Ukrainian national regulations require a 100% reserve of halon to support existing fire suppression units. In 2018, the Ukrainian bank of halon 2402 was estimated to be 300-340 metric tonnes, with approximately 100 metric tonnes contained in fire suppression equipment. Based on this, the total bank of halon 2402 in the Ukraine was sufficient to meet the remaining critical needs with some potential to satisfy the demand of the other countries. However, the recent military action in the Ukraine means that there is no up-to-date information on halon banking.

6.5.7.1 Belarus

Total installed base for halon 2402 is less than 1 metric tonne. The halon is still used in civil aviation. The demand from this sector is covered by reclaimed halon from decommissioned extinguishing systems, but the source is very limited: it was less than 100 kg as of 2017.

6.5.7.2 Afghanistan, Algeria, China, Cuba, Egypt, Libya, Mongolia, and Syria

Information on the installed capacity and demand for halon 2402 in Afghanistan, Algeria, Egypt, China, Cuba, Mongolia, Libya, and Syria is not currently available. Most of the equipment protected by halon 2402 and delivered to these countries has already reached its end-of-life and has been dismantled. However, it is reasonable to assume that in these countries a demand for halon 2402 for the servicing of operating equipment exists in some applications and that halon from outside sources is required, in particular from Russia and Ukraine. Typically, a contract is held between the buyer and seller that ensures spare parts, servicing, and sales. So, halon 2402 needs are likely being met through a contract with the manufacturer or seller.

6.5.7.3 Caucasus: Armenia, Azerbaijan, Georgia

Armenia: After decommissioning of old passenger aircraft produced in the former Soviet Union, the military sector remains the only user possessing significant amounts of halon 2402. The bulk of installed halon has not been identified to provide a clear picture of the installed capacity and demand for halon 2402.

Azerbaijan: Estimates made in 2009 indicated that there were 53 tonnes of halon 2402 in Azerbaijan. After decommissioning of halon fire suppression systems in the oil and gas industry, merchant shipping, and civil aviation sectors and substantial changes in the military sector, there remain only a few military applications which are still using halon 2402. Exact estimations of possible needs for halon are unavailable but it is assumed that the demand is negligible.

There is concern about what is happening to the halon (estimated as tens of tonnes) coming from decommissioned fire protection systems. Absence of coordinated information increases the prospects for unintentional halon emissions.

Georgia: Based on other parties' experiences, it should be assumed that a demand for halon 2402 for the servicing of operating equipment exists mainly in some applications in the military sector and that halon from outside sources will be required.

6.5.7.4 Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan

Generally, these parties have substantial halon 2402 stocks but there is concern about what is happening to the halon (estimated as tens of metric tonnes) coming from decommissioned fire protection systems. Absence of coordinated information increases the prospects for unintentional halon emissions.

Kazakhstan: Halon consumption has been reported as zero from January 2003. Successful replacement of halon 2402 by in-kind and not-in-kind alternatives in the oil and gas industry and decommissioning of old passenger aircraft led to that. Halon 2402 continues to be used in a few military applications.

Kyrgyzstan: As in the case of Kazakhstan, due to successful decommissioning of fire extinguishing systems using halon 2402 in oil and gas industry, mining, hydropower facilities, and the civil aviation sectors, the installed base has shrunk from 80.7 metric tonnes in 2006 to just a few applications in the military sector in 2021.

Uzbekistan: Similar to other parties in the region, halon 2402 is still in use in some military applications, having been replaced by alternatives in all other major applications (civil aviation, gas transport systems, etc.).

6.5.7.5 India

Historically, halon 2402 was typically used in the Indian Navy, Airforce, and military fire and explosion suppression systems including portable and mobile fire extinguishers manufactured and supplied by the former Soviet Union. These systems and extinguishers were the part of the equipment of armoured fighting vehicles, ships, submarines, fighter and transport aircraft, etc. Halon 2402 was never manufactured in India. Servicing and refilling activities had always been supported by former Soviet Union suppliers. Recently, the supply for servicing and refilling from the former Soviet Union has been quickly diminishing, therefore users such as the Air Force have completely switched over to halon 1211 and FK-5-1-12 for engine and portable extinguishers where applicable. In the Navy, halon 2402 based systems and extinguishers have mostly been replaced with HFC-227ea and water mist systems depending upon the suitability. The Army halon 2402 systems were replaced with halons 1301 or 1211. Due to non-availability of halon 2402 in India, there is a drive to find a solution for the replacement of these systems in defence applications. There is no record for the import of halon 2402 in the recent past in India.

There was limited use of halon 2402 in the civil sector, primarily by oil companies for fire and explosion suppression in floating roof tanks. Supplies of halon 2402 came from Europe as well as servicing of equipment. However, the oil companies have replaced these systems with foam flooding systems or other gaseous systems (primarily CF_3I). Based upon a recent survey, it appears that halon 2402 is no longer used in any civil fire protection system.

6.5.7.6 Japan

Total installed halon 2402 has been estimated to be 146 tonnes in Japan as of March 2021. The amount of halon 2402 in ships, aircraft, and the military was estimated to be four metric tonnes as of April 2008. See Table 6.11 for additional information on quantities installed in Japan. Halon 2402 remains a vital material for the fire safety of oil tanks in Japan in floating roof oil tank fire protection in the petrochemical industry. It was also used for explosion suppression, but these systems may have already been replaced. When replaced, some of the halon was collected and some was destroyed. Japan does not currently have any surplus halon 2402 to support other parties' needs. As the timing of decommissioning of halon 2402 fire protection systems is not clear, there are no plans to export halon 2402.

6.5.7.7 Vietnam

Vietnam has not established banking operations for halon 2402. In the past, Vietnam had difficulties sourcing halon 2402 for their petroleum industry and military sector, but there are no signs indicating that the troubles in sourcing are still occurring. The total installed base of halon 2402 is about 3.6 metric tonnes. Remaining applications are concentrated in the military sector and petroleum industry.

6.5.7.8 Countries that have eliminated halon 2402

The following parties have eliminated all uses of halon 2402:

- European Union: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Slovakia
- Non-EU states of Southeast Europe: Serbia, Montenegro, Republic of North Macedonia
- US

6.5.8 Conclusions

Some countries have classified halons as hazardous wastes, which is hampering transboundary movement. The FSTOC continues to see problems with the transboundary movement of halons (which would facilitate movement of halons to where they are needed). In some parties, this is still not possible owing to legislation.

The FSTOC 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 FSTOC 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 that 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 7 of this report and FSTOC Technical Note B, **FSTOC (2022b)**.

As is true for halons, HCFCs and HFCs should be recycled and banking operations are needed. The FSTOC is not aware that HCFC and HFC banking activities have started in new locations. Parties may wish to consider strategies to facilitate this.

The FSTOC continues to see evidence of the loss of institutional knowledge and subsequent consequences such as the inappropriate destruction of halons. Misinformation continues to circulate as individuals new to ODS and HFC fire suppressants bank management come into the field and inadvertently make decisions hampering banking operations., e.g., prohibiting import and export of used fire suppressants, advocating destruction over recycling/reclamation and reuse, etc.

6.5.9 References

Australia (2019): Australian Halon Management Strategy 2019, https://www.dcceew.gov.au/environment/protection/ozone/national-halon-bank/155ustralian-halon-management-strategy-ahms#:~:text=What%20is%20the%20AHMS%3F,halon%20is%20no%20longer%20required.

Australia (2020): Review of Australia's Non – Defence Halon Requirements April 2020, https://www.dcceew.gov.au/sites/default/files/documents/review-australias-non-defence-halon-requirements-2020.pdf

FSTOC (2022b): UNEP Report of the Fire Suppression Technical Options Committee, Technical Note B, Emission Reduction and Recycling Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents, December 2022. https://ozone.unep.org/science/assessment/teap

GOV.BR (2022): Histórico Consumo de SDOs no Brasil. https://www.gov.br/mma/pt-br/assuntos/climaozoniodesertificacao/camada-de-ozonio/historico-consumo-de-sdos-no-brasil_-site.pdf/view

HRC (2021): *Code of Practice for Halon Recycling Companies*, Halon Recycling Corporation, June 2021. www.halon.org/_files/ugd/4e7dd1_1385c061aa9f4d4dae694a8036be92df.pdf

NFPA 2001 (2022): NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems, 2022.

PBH (2011): Programa Brasileiro de Eliminação dos HCFCs (PBH) - Etapa 1. https://www.protocolodemontreal.org.br/site/images/publicacoes/programa_brasileiro_eliminacao_hcfcs/programa-bras-hcfc_ed_2.pdf

PBH (2016): Programa Brasileiro de Eliminação dos HCFCs (PBH) - Etapa 2. https://www.gov.br/mma/pt-br/assuntos/climaozoniodesertificacao/programa-brasileiro-de-eliminao-dos-hcfcs-pbh-etapa-2.pdf

PBH (2022): Programa Brasileiro de Eliminação dos HCFCs - PBH. https://www.gov.br/mma/pt-br/assuntos/climaozoniodesertificacao/camada-de-ozonio/acoes-brasileiras-para-protecao-da-camada-de-ozonio"

UNEP (2019): China Halon Sector Plan Progress Report, **UNEP/OzL.Pro/ExCom/84/22/Add.1** submitted to the 84th meeting of the Executive Committee of the Multilateral Fund, November 2019, http://www.multilateralfund.org/84/pages/English.aspx

7 Emission Reduction and Recycling Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents

7.1 Introduction

This chapter summarizes FSTOC Technical Note B, **FSTOC (2022b)**. The reader is encouraged to refer to Technical Note B where additional details are available.

Discharging gaseous fire extinguishing agents into the protected area is fundamental to the process of flame extinguishment and enclosed space inerting. Historically, significantly less than 5% of all halon emissions were a result of using halons to extinguish fires. These necessary discharges for extinguishing fire represent only a small proportion of the total emissions in the past. Since all users have discontinued system discharge testing and discharge of extinguishers for training purposes, further reductions of emissions can be realized by maintaining or improving maintenance procedures, detection and control devices, and recovery operations.

Users are encouraged to minimize discharges and emissions from fire extinguishing systems for reasons of economics, safety, personnel exposure, and environmental impacts, whether replacing an existing halon, HCFC, or HFC system or contemplating a new installation. Implementing recovery, recycling, and reclamation programmes for fire extinguishing agents extends agent availability for enduring uses not currently able to transition to alternatives. It should be noted that actions geared to recycling and reclamation are contingent on access to appropriate recovery, recycling, and reclamation equipment and trained personnel.

In addition to the direct actions discussed above, indirect actions can be taken to promote and enhance emission reductions, including but not limited to implementing awareness campaigns, workshops, training, policies, and codes of practice.

7.2 Alternative Fire Protection Strategies

Fire Protection should be based upon three **E**s:

> **E**ngineering: Identify the hazards, potential severity, and probability, then apply good engineering principles in a system or facility design to minimize the residual risk to occupants, the facility, the surrounding community, and the environment.
>
> **E**ducation: Educate all organizations involved with the hazard being protected on the function, operation, and maintenance of the fire protection system. Interconnection to other building or safety systems should also be identified and understood.
>
> **E**nforcement: Ensure all applicable standards, codes, and national regulations are applied to the design, installation, operation, and maintenance of the fire protection systems and methods selected for the facility or hazard being protected.

Good engineering practice dictates that, where possible, hazards are designed out of facilities rather than simply providing protection against them. Active fire protection systems for fire suppression or explosion prevention using gaseous agents should not be considered as the only solution. Based on a risk assessment, a combination of prevention, inherently safe design, minimization of personnel exposure, passive protection, equipment duplication, detection, and manual intervention should be considered.

Halons and HCFCs should not be used in new fire protection applications or new designs of equipment where technologically and economically feasible alternatives exist. For HFCs, consideration should be given to minimizing their use consistent with the HFC phasedown. Halon alternatives are available for most applications with very few exceptions, e.g., some civil aviation and military applications. Alternatives for many HCFC and high-GWP HFC uses also exist; however, there are applications where only the original halon, HCFC, or HFC will work, e.g., explosion suppression in cold climates and in crew compartments of armoured vehicles, see Chapters 4 and 5 of this report. In addition, the proposed per- and poly-fluorinated alkyl substances (PFAS) regulation may impact availability of some in-kind alternatives in the future, see Chapters 3 and 9.

7.3 Halogenated Fire Extinguishant Use Minimization

When protection against fire or explosion hazards with halon or other halogenated gaseous fire extinguishant is used, the following methods and/or practices should be considered:

1) Local Application Systems. Local application systems are intended to discharge the extinguishing agent directly on the specific hazard or piece of equipment. This approach is intended to surround the fire location or burning object with a high concentration of agent to extinguish the fire. This approach can often reduce the amount of agent required.

2) Multiple Protection Zones (i.e., Zoned Systems). When a large space or volume can be sub-divided into smaller protected areas, the amount of agent required can be reduced. Where technically feasible, protection of several separate zones by a single bank of agent using total or partial discharge should be considered. This could be considered a bigger version of the local application system where protection of several pieces of equipment or hazards is desired. This approach is also common in water-based fire protection systems (e.g., zoned deluge systems, water mist systems, etc.) where the water supply is limited.

3) Integration of Enclosure Integrity. All possible means to maintain extinguishing concentration of halons, HCFCs, and HFCs from an initial discharge, such as stopping air movement, closing openings, installing system-actuated dampers or shutters, etc., should be explored prior to considering additional agent to overcome leakage out of the protected space.

4) Verification and Evaluation of Original Design Criteria. In addition to regular review of the hazards being protected or changes to the protected space, the original design criteria of the halon, HCFC, and HFC based fire protection systems should be reviewed and verified. For example, for the installation of a halon 1301 system, the design temperature, design concentration, and enclosure integrity have a profound effect on the amount of agent required to protect the space. For example, using the same protected volume, same design concentration, and same integrity but changing the design temperature from 20°C to 4°C increases the required amount of agent by 6%.

7.4 Maintenance Programmes

Inspection, testing, and maintenance of installed fire protection systems are typically required by the applicable standards, codes, and national regulations. End-user sectors (i.e., civil aviation, telecommunications, military, oil and gas, etc.) may have specific requirements in addition to the minimum requirements in the standards. Best practices for inspection, testing, and maintenance programmes include the development and continued validation and update of procedures that outline the steps necessary to complete the work and the responsibilities of the person or group performing the work.

Development and adherence to inspection and maintenance programmes will reduce the likelihood of emissions from leakage and/or inadvertent discharges. This represents money saved in two ways. Firstly, it minimizes the need to purchase new or recycled agent, and secondly it prolongs the useful life of the existing fire protection system.

Maintenance programmes typically require technician qualification and training, complete system documentation, scheduled equipment replacement (i.e., defined operational lifetime for equipment), as well as regular system checks and maintenance.

7.4.1 Personnel Training

Inspection and maintenance programmes need to be carried out in accordance with recognized standards utilizing trained technicians who understand how to perform the maintenance activity safely and without inadvertently discharging the system. Qualifications for technicians performing inspection, testing, and maintenance can be found at different locations such as international, national, state, and local community levels. In addition, end-user sectors may have additional training and qualification programmes for technicians. Training records should be kept ready for demonstrating training and competence to the appropriate level to perform the maintenance and service activity.

It is equally important that the system user be competent in the proper operation of the system and aware of activities that could result in an unwanted discharge. Any individual who could potentially cause a discharge should be educated not only on the operational, safety aspects of the system, and expense of an inadvertent discharge, but also on ozone depletion and climate change issues and policies, and the impact of halogenated gaseous fire extinguishing agent releases, as well as the restrictions on future supplies.

As an example of good practices, in Japan, educational materials and caution labels that request proper recovery of halons and other halogenated fire extinguishing agents are distributed to inspectors and related organizations. The labels are also applied to every agent cylinder.

In Australia, for example, portable fire extinguisher and fixed system maintenance for halogenated agents must be carried out by appropriately licensed personnel who not only have been trained in the maintenance activity but must also be aware of the environmental effects of the emission of these substances into the atmosphere. This is mandated by the Australian Ozone Protection and Synthetic Greenhous Gas Management Regulations 1995. This is similar to the European Union Regulation No. 517/2014, **Australia (1995)**, which requires companies and technicians be registered when inspecting, testing, or performing maintenance on halon, HCFC, and HFC fire protection systems.

In the US, qualification of technicians is typically required on the state and local community level. Technicians are typically required to take a written test, show work history, and perform continuing education to qualify for, and maintain, licensure.

7.4.2 Risk Management and Best Practices

Risk management and best practices for comprehensive inspection, testing, and maintenance programmes include establishing good system documentation and maintenance procedures and practices. System documentation should include, but not be limited to, original system design criteria, construction/installation drawings, operations and maintenance manuals, and records of maintenance and any system modifications. System documentation should also include the quantities of agent provided and their locations. This information will be used to continually track quantities of fire extinguishing agents, in service, storage, and emitted, to determine areas where emissions can be reduced, as well as to identify future recharge needs. Where large quantities of agent(s) are in service, a computer database to track quantities used and component failures is often found to be helpful.

7.4.3 Hazard and Enclosure Review

Regular review of the hazard and the integrity of the enclosure are key to maintaining the fire protection system performance. At the time the system is put into service, the enclosure should be verified for tightness/leakage. During the inspection, testing, and maintenance of the system, a visual check for enclosure modifications or changes to the configuration of the protected space should be performed as well as ensure that the enclosure integrity is intact and that any operable openings such as heating, ventilation, and air conditioning (HVAC) dampers or mechanisms to hold doors open are integrated into the fire protection system and fully close before system discharge. This will allow the amount of agent required to provide fire suppression or explosion prevention to be kept to a minimum.

7.5 Detection and Releasing Systems

Automatic fire extinguishant systems go hand in hand with sensitive detection systems. Poor design and improper maintenance of detection systems will almost always result in unwanted fire extinguishant releases. It is therefore essential that:

- System components should not be mixed.
- Where possible, the fire extinguishant is released only after positive confirmation of the fire.
- Equipment conforms to internationally or nationally accepted specifications.
- Older detection systems are upgraded to take advantage of the latest technology.
- Required maintenance is performed by trained and qualified service personnel.
- System designs consider detection device voting to minimize false discharges due to single device failure/errors.

7.6 Agent Transfer and Storage

Emissions related to agent transfers can be substantially reduced by the use of equipment approved for the handling of that specific agent. Recovery / transfer equipment, vacuum pumps, pressure vessels, storage tanks, pipework, etc., need to be regularly maintained and checked for fitness of purpose and be leakage free. Procedures should be in place to prevent overfilling and over pressurization. Calibrated scales should be used, and agent weights documented during the transfer process to determine recovery efficiencies.

Any operation relating to a high-pressure gas must conform to the appropriate safety standards in line with all relevant local, national, or international regulations. Where available, the equipment used must be certified and regularly calibrated by a recognized standards organization for the agent(s) used. Environmental and operational safety dictate that all filling procedures should be conducted by trained personnel.

Most safety standards require that portable extinguishers be emptied and refilled at regular intervals or disposed of at the end of a specified period/shelf-life. This permits the operation of the appliance to be checked and the cylinder and other components to be inspected for signs/appearance of corrosion and to be subjected to pressure testing. Users are encouraged to follow national standards and manufacturers' specifications for maintenance, inspection, and refilling of portable and system cylinders. Where multiple agents can be recovered, recovery equipment should be operated in a manner that prevents mixing of agents. A Voluntary Code of Practice (VCOP) and more recently a guidance document specific to civil aviation have been written by the Halon Recycling Corporation (HRC) addressing this issue, **HRC (2021, 2022).**

The proliferation of relatively inexpensive, high efficiency recovery systems makes it easier to increase the longevity of agent banks. Good practice dictates that fire extinguishing agents should never be placed or stored in cylinders not intended for the agent's use. For example, the manager of a national halon bank reported finding halon stored in improper cylinders resulting in avoidable leakage. All on-site agent storage tanks should be monitored for leaks.

The following practices for fire extinguishing hardware and agents should be observed:

- Only trained, or where relevant, licensed, personnel should be permitted to handle and store agents.
- Safety Data Sheets should be current, available, and accessible.
- Handle agents with care to prevent accidental discharges.
- Agent cylinders not in service should be made safe to avoid accidental discharge.
- Store agent reserves in suitable storage containers; different types of recovered fire extinguishing agents should be stored in separate containers and not be mixed together.
- Implement a leak detection regime for agent in service and storage.
- Recover surplus agents from systems.
- Transfer and store agents in system cylinders, extinguishers, and storage cylinders designed for the specific agent.
- Appropriately label all agent and recovery cylinders.
- Inspect and test (where appropriate) all cylinders prior to filling with agent.
- Provide good storage conditions (e.g., out of direct sunlight and rain) for both in-service systems/cylinders and backup systems or bulk agent.

- Ensure temperature and pressure limits of storage cylinders and tanks are not exceeded so as not to activate pressure relief devices.

7.7 Minimizing Discharge of Halons and Other Halogenated Gaseous Agents

Discharging halon and other halogenated gaseous agent systems and portable fire extinguishers for testing, training, and other non-fire related procedures is a cause of unnecessary emissions that can easily be avoided. For example, in fixed systems, door-fan testing, **NFPA 2001 (2022)**, has replaced the need for discharge testing. In addition, portable extinguisher training can be accomplished using simulants. Where portable extinguishers are required to be discharged (for example, to accomplish periodic extinguisher performance verification), the agent should be discharged into a recovery tank.

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

Prior to the halt in production of halons, replenishment agent to recharge extinguishers and extinguishing systems had a simple supply chain from manufacturer to servicing company to the end user. With such a short supply chain, the quality assurance needs of all organizations were readily achieved; or, in the rare case of out of specification agent, problems were easily traced back to the source and corrective action taken.

Today, we no longer have newly manufactured halons, and the fire protection industry must rely on recycled or reclaimed halons for the recharge of extinguishers and extinguishing systems. In the case of other halogenated gaseous fire extinguishing agents, while they are still being manufactured, some of the replenishment agent used for the recharge of extinguishers and extinguishing systems is from systems or extinguishers removed from service. The source of replenishment agent has thus shifted from a handful of agent manufacturers around the world to thousands of end users who own extinguishers or extinguishing systems and who may at some point offer the agent for recycling / reclamation. Furthermore, the condition of the agent at its entry (or re-entry) point into the market has shifted from newly manufactured agents with an extremely high level of purity to "used" agent that can have any of several types of impurities. That being the case, the fire protection industry faces the same challenges in ensuring the quality, especially purity, for other halogenated gaseous fire extinguishing agents used for replenishment.

7.8.1 Standard Methods for Treatment of Halons and Other Gaseous Halogenated Fire Extinguishing Agents

In the fire protection industry, there are several terms used to describe the treatment of halons and other halogenated gaseous fire extinguishing agents 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. This activity can happen using suitable recovery equipment operated by trained personnel, either directly from fire protection equipment on-site, or off site where the

decommissioned fire protection equipment is transported to an appropriate off-site facility where the agent is removed.

- Recycle: To clean recovered agent for reuse without meeting all the requirements for reclamation. In general, recycled agent has its pressurizing nitrogen removed and moisture, particulate matter, and non-volatile residue content reduced as required to conform to the relevant standard specifications.
- Reclaim: To reprocess agent to a purity specified in applicable standards. Reclamation is the preferred method to achieve the highest level of purity. Reclamation requires specialized separation/distillation type of equipment to remove other halocarbon impurities. This type of equipment may not be available at servicing companies. Reputable reclamation companies can offer these services (including certified laboratory results for the reclaimed gas) for halons and other halogenated extinguishing agents.

It is common for the expression “recycle” to include both the “reclaim” and “recycle” treatments described above. However, it is essential for everyone in the supply chain to understand the difference and to employ the correct method.

In order to have a credible agent resupply industry, the “used” agents must be properly processed in order to remove impurities and return the agent to a purity level consistent with newly manufactured agent or another appropriate standard. Furthermore, the participants in the agent resupply industry must have the technical ability to test and certify that the agents being offered for replenishment are indeed free of impurities. Without that ability rigorously applied, there can be no credible fire extinguishing agent resupply industry.

7.8.2 Specifications for Agent Treatment, Testing and Certification

Personnel responsible for reclaiming, refilling, and resupplying halons and other halogenated gaseous fire extinguishing agents back into the supply chain should use a laboratory, whether in-house or external, with the technical competence to certify the purity to industry standards that include, but are not limited to, standards from ASTM, ISO, militaries, etc.

The technical competence of the laboratory depends on factors such as having suitable testing facilities, qualified /experienced personnel, the latest specifications/standards, access to the appropriate calibrated and maintained equipment, quality assurance processes/systems that ensure appropriate sampling and testing procedures/methods are used, the traceability of measurements to national standards, and accurate record keeping and reporting processes.

Before and after processing/treatment of the agents, batches should be subjected to the verification of their purity and other quality parameters using the analytical methods prescribed in the relevant and latest standard to determine the condition of the agent prior to treatment as well as the effectiveness of the treatment process in returning the agent back to specification.

7.8.3 Agent Contamination

To ensure the safety of people and to prevent adverse physiological impacts during a fire extinguishing agent exposure event, the toxicity of the agents in normally occupied areas is a critical consideration. Agent contamination can be a significant contributor to toxicity, hence the need for the agents to meet stringent industry specifications.

7.8.4 Firefighting Efficiency

The presence of agents of questionable purity is an insidious problem that does not become apparent until an end user discharges an extinguisher or extinguishing system, often in a serious life safety or potential property loss setting. With an impure agent, the performance can range from poor or no fire extinguishing effectiveness to one where the impure agent may actually intensify the fire in the case where the impurity is a flammable material.

End users do not typically have the means to confirm the purity of replenishment agents they have employed in fire extinguishers or in extinguishing systems. Instead, they must rely on the aftermarket supply chain to collect, process, test, and certify that the agent is of acceptable purity. From the end user's perspective, it is that last step – the certification – that has been the ultimate basis for acceptance of the agent. Given that there has been at least one instance where certification documents were falsified by the agent supplier, relying on a supplier's certification alone can introduce risk with respect to agent purity. It is strongly recommended the end user require a copy of the signed certification of the results for the agent used to fill the fire protection system or extinguishers, and where available, require that the results are certified by a national/international accredited laboratory.

To understand how and/or why agents with impurities can be supplied to end users, one has to look at the circumstances under which the impurities can be introduced. For all practical purposes, the impurities are introduced into the agent in five different manners:

1. The impurities could already be present in the agent when the recycler or servicing company received the agent or the extinguisher containing the agent.
2. The agent could become contaminated during processing by the recycler or servicing company when "good agent" is accidentally batched together with contaminated agent, thus causing the entire batch to become contaminated. This is referred to as 'cross contamination with other halogenated chemicals.'
3. Failure to adequately evacuate the equipment when processing a different agent or refrigerant will introduce impurities by cross contamination with other halogenated chemicals or other contaminants including oil, moisture, particulates, or acids.
4. Agent that has been reclaimed to a standard can be contaminated if it is put into cylinders or long-term storage tanks that have not been properly cleaned, and which contain residual quantities of other agents or contaminants such as water, oil, or particulates.
5. Given the diminishing supply of halons, and the consequent increase in value, one should not discount the possibility of deliberate adulteration to increase profits.

7.8.5 Agent Contamination Mitigation Strategies

In reviewing the supply chain for recycled fire extinguishing agents, the minimum mitigation strategies that can be employed to ensure that the agent meets an industry accepted quality standard include:

- By the Equipment Manufacturer: If the manufacturer supplies more than one fire extinguishing agent, then it should ensure that there are systems and procedures in place to prevent agent contamination in the filling process.

- By the Recycler: Employing robust quality assurance procedures that provide: (1) testing of incoming agent to ensure that it is properly identified and not contaminated before it is combined with other batched agents during the recycling process; (2) processing the batched agent in a manner to remove all contaminants to the specified levels, and (3) ensuring that no new contaminants are introduced into the processed agent up through and including its final storage condition (cylinders, long-term storage tanks, drums, etc.).
- By the Accredited Testing Laboratory: In accordance with good laboratory practice, perform an analysis on samples of the agent and provide written certification that the agent meets the required specification(s). Accredited laboratories are typically independently audited by a recognized third-party certification body.
- By the Servicing Company: Preparing and following good practices when recovering agent or recharging extinguishers and extinguishing systems to ensure that no contaminants are introduced by the agent transfer equipment or by improper cleaning and drying of the extinguisher cylinders or systems.

7.9 Policies, Awareness Campaigns, and Codes of Practice

Non-technical steps can also be taken to reduce halon or other halogenated gaseous fire extinguishant emissions. These steps have been shown to be as important as the technical steps. The FSTOC, various governments, and the fire protection community provide guidance documents on all aspects of halon phaseout that will also be applicable in the HCFC phaseout and the HFC phasedown. The value of these documents should not be underestimated.

7.9.1 Policies, Regulations, and Enforcement

Policies should be in place to meet the party obligations under the Montreal Protocol. Each National Ozone Unit (NOU) has been tasked with implementing policies, programmes, and regulations in support of those obligations under the Montreal Protocol specific to their country. Some parties have elected to utilize a steering group to formulate plans for ODS phaseout, 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 phaseout. It is advisable that a steering group be made up of stakeholders from the following sectors, **UNEP (1999)**:

- public fire services,
- fire equipment trade associations,
- insurance companies,
- halon (and potentially other halogenated gaseous fire extinguishing agents) users,
- environmental advocacy groups, e.g., non-governmental organizations (NGOs),
- environment ministries,
- customs officials, and
- defence ministries.

The steering group can be tasked to put forward a plan for halon or other halogenated gaseous fire extinguishant management by the NOU or other responsible government agency. The NOU can initiate the revision of regulations to eliminate requirements for discharge testing and provide needed assistance to the Authority Having Jurisdiction (AHJ), especially in those cases where such testing is mandated by local regulations that are outdated or otherwise unnecessary. The NOU can also introduce regulations requiring the recovery, recycling, and reclamation of halons or other halogenated gaseous fire extinguishing agents.

Many halon bank managers have cited lack of enforcement of halon control regulations as limiting the success of their operations. This will likely also be the case for HCFC and HFC fire extinguishant banking in the future. Without enforcement and possibly incentives, national halon or other halogenated gaseous fire extinguishant banking functions, especially those operated by industry or commercial entities, are unlikely to be financially viable. Several national halon bank managers have reported to FSTOC members little or no activity in halon recycling, which they attributed directly to lack of policies, regulations, enforcement, and available serviceable recovery and recycling equipment. For more information on banking of halogenated gaseous fire extinguishing agents, refer to the HTOC 2018 Assessment report, Volume 3, Global Halon, HCFC, and HFC Banking, **HTOC (2018)**.

One very successful example of a regulation is the European F-gas Regulation (EU) No 517/2014. The F-gas Regulation is being updated, but the updated Regulation has not been published at the time of writing this report. This multi-tiered regulation contains several aspects:

- Limiting the total amount of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- Banning the use of F-gases in many new types of equipment where less harmful alternatives are widely available, such as refrigerators in homes or supermarkets, air conditioning, and foams and aerosols.
- Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing, and recovery of the gases at the end of the equipment's life.

Although the regulation applies to fluorinated gases, the principles apply equally to all halogenated gaseous fire extinguishing agents, and all three aspects will lead to reduced emissions.

Other examples of regulations include the Australian Ozone Protection and Synthetic Greenhouse Gas Management Act of 1989, **Australia (1989)**, and the Ozone Protection and Synthetic Greenhouse Gas Regulations of 1995, issued by the Australian government,

Since 1 January 2018, it has been illegal to import bulk HFCs into Australia without a controlled substances license and quota under the HFC import quota system. Australia’s HFC import quota system was developed with industry to contribute to the phasedown of high-GWP HFCs by gradually reducing the amount of bulk HFC permitted into Australia. Maintaining the integrity of the import quota system helps Australia to reduce its emissions of HFCs.

In 2020, an Australian-based fire protection company was fined a record $500,000 for importing bulk HFC for use in fire protection equipment without a license or quota and required to pay for disposal of the remaining gas at a cost of around $100,000. Five metric tonnes of HFC-227ea were imported by the company despite the company being aware that a license and quota were required.

Reducing HFC emissions is an important part of Australia's emissions reduction commitment under the Paris Agreement and is now part of a global commitment under the Montreal Protocol.

7.9.2 Carbon Markets

Carbon markets are becoming an important instrument in addressing climate change. There is increased focus by policy makers and government officials around the world creating carbon pricing instruments such as carbon taxes and emission trading schemes. These instruments can mandate a compliance-based system for companies that are obligated to reduce their greenhouse gas emissions. Equally important, is the scaling of the voluntary carbon market to meet the climate change challenge by providing a means for companies to voluntarily respond by purchasing high integrity, high quality, carbon offsets as part of reducing their carbon footprint.

In the US for example, and in relation to fire protection extinguishing agents such as HFC-227ea, the American Carbon Registry (ACR - a private voluntary greenhouse gas registry), amended one of its methodologies in April 2022 to produce the 'Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Certified Reclaimed HFC Refrigerants, Propellants, and Fire Suppressants, Version 2.0', **ACR (2022)**. This methodology previously did not include HFC-227ea.

The methodology is underpinned by the premise that recovery and reuse of certified HFC-227ea for replenishing fire protection systems when they leak or have been discharged in a fire negates the need to manufacture additional HFCs and thereby reduces emissions. Now that HFC-227ea is accepted as an eligible gas under the methodology, companies in the US may be financially incentivized and rewarded to recover HFC-227ea, develop a reclaim project, and if the project after independent validation and verification is deemed to meet the criteria of the methodology, will generate voluntary offset credits that can be traded in the market.

7.9.3 Awareness Campaigns

Emission reductions can be achieved by implementing a comprehensive awareness campaign. This can include any, or all, of the following: workshops, training, brochures, television or radio commercials, websites, newsletters directly or through fire protection equipment/service providers, fire protection and trade publications, etc.

Involvement of the stakeholders, including government, fire protection system and extinguisher users, code enforcing authorities, military branches, maritime and airline industries, research and testing laboratories, and the fire protection community has been shown to be important.

In parties where there is no comprehensive halon management programme, no national halon bank, or no clearinghouse, it is likely that there are halon installations that are inappropriate for the application and should be replaced with an alternative, **UNEP (1999)**. This may be similarly true for HCFCs and HFCs. Workshops and training are excellent ways to implement an awareness campaign while engaging with the fire protection community.

7.9.4 Standards and Codes of Practice

The fire protection community can:

- Adopt or develop technical standards on the design, installation, testing, and maintenance of extinguishers and fire suppression systems both for halons and other halogenated gaseous fire extinguishing agents.
- Ensure users provide training for the occupants and site manager of spaces that are protected by halon or other halogenated gaseous fire extinguishing agents.
- Develop or adopt a Code of Practice (COP), such as **EPA (2001a)**, **HARC (2002)**, **HARC (2015)**, **HRC (2021)**, **UNEP (1999)** and **UNEP (2001)**:

The following are typical strategies outlined in a Voluntary Code of Practice (VCOP):

1. <u>Regulations and Standards</u>: Follow applicable technical standards for the agent.

2. <u>Emissions</u>: Minimize emissions during storage, handling, and transfer.

3. <u>Equipment</u>: Utilize equipment appropriate for the agent and maintain it regularly according to step 1 and manufacturers' recommendations.

4. <u>Discharge Testing</u>: Eliminate discharge testing of halons and minimize discharge testing for HCFC and high-GWP HFC agents to "essential" tests only.

5. <u>Decommissioning, Servicing, and Disposal</u>: Prohibit venting or release of agent to the atmosphere during decommissioning, servicing, and disposal. Always recover, recycle, reclaim, or destroy the agent using manufacturer instructions for the operation and maintenance of recovery, recycling, and reclamation equipment.

6. <u>Technician Training</u>: Require that technicians who test, maintain, service, repair or dispose of halons and other halogenated gaseous fire extinguishant systems are trained regarding responsible use and handling to minimize unnecessary emissions, see **EPA (2001a), HARC (2022)**. Training can include:

   - Explanation of why training is required (trained technicians prevent emissions).
   - Overview of environmental concerns with halons, HCFCs, and HFCs (ozone depletion, long atmospheric lifetimes, high GWP, etc.).
   - Review of relevant regulations or standards concerning halons, HCFCs, and HFCs.
   - Specific technical instructions relevant to individual facilities (manufacturers' manuals, training materials, references, and resources available to technicians).

7. <u>Communications and Outreach</u>: Ensure dissemination of information designed to minimize emissions and enable phaseout of halons and HCFCs, and phasedown of HFCs.

8. <u>Record Keeping and Reporting</u>: Develop a verifiable data tracking system on stockpiles, installed base, transfers, and emissions. Record keeping should be an integral part of managing halons and other halogenated gaseous fire extinguishing agents from the system user to fire extinguishant banks.

A VCOP/COP is very important where international transfers are concerned to ensure compliance with the provisions of the Basel Convention, **EPA (2001a)**.

There are COPs available in many countries. It may be that another country's COP is applicable and can be translated and adopted. Several parties have successfully used this method to implement their own COP.

7.10 Decommissioning, Transportation, and Destruction

Decommissioning is the process of removing a fire protection system from service. The cylinders containing halons and other halogenated gaseous fire extinguishing agents are under pressure and must be handled with great care. If the pressure is released in an uncontrolled way, not only will it result in unwanted emissions, but more importantly, the cylinder or valve could become a projectile that could cause serious injury or death.

Decommissioning guidelines are available from numerous sources and are applicable to all users, **EPA (2001b)**. Only trained personnel should carry out decommissioning activities. In Australia, for example, decommissioning of fixed gas fire suppression systems that contain halon or other halogenated gases must only be carried out by technicians who specifically hold a decommissioning license.

Transportation of halon and other halogenated gaseous fire extinguishing agents occurs during decommissioning, servicing, and transfers to other users, vendors, banking facilities, or destruction facilities. Halons and other halogenated gaseous fire extinguishing agents are "dangerous goods" as they are pressurized gases and should be transported per national and international guidelines. It is important to develop procedures and ensure that they are properly followed so that the agent is handled and transported safely.

Depending on how the exporting/importing country legally classifies the extinguishing agents destined for reclamation or destruction, (that is, whether they are defined as 'hazardous waste' or not), the Basel Convention could apply, thereby adding layers of complexity when the reclamation or destruction facility is in a country that is not a party to the Basel Convention.

Some of the complexities relate to:

- inconsistencies /differences with classification of the material by domestic legislation of the party of export, import or transit
- increased administrative efforts
- increased shipping costs
- increased time to process Basel paperwork by each port adding time to the journey
- difficulties locating a carrier that is prepared to carry the 'hazardous waste'.

Without a consistent global approach on the definition/classification of ODS, HCFCs and HFCs, access to reclamation and destruction facilities is unnecessarily obstructed and could give rise to emissions as a result.

Destruction of halon and other halogenated gaseous fire extinguishing agents is a final disposition option that should be considered only if the agents are contaminated and cannot be reclaimed to an acceptable purity. There are several processes that have been identified as suitable for halon, HCFC, and HFC destruction and are discussed in FSTOC Technical Note C, **FSTOC (2022c)**, **EPA (2001)** and in chapter 8 of this report.

7.11 Conclusions

Discharges of halon and other halogenated gaseous fire extinguishing agents in the case of fire-events account for a very small fraction of total discharges. Inadvertent discharges or false alarms account for the majority of discharges and the steps outlined above can minimize such avoidable discharges. In reviewing emission reduction strategies, the FSTOC recommends the following:

- Halons should not be used in new fire protection applications or new designs of equipment where alternatives exist.
- HCFCs and high-GWP HFCs should not be used unless a full risk analysis has been performed by a fire professional with expertise in their use and specifications, and the agent was deemed the only viable option taking into consideration safety, efficacy, economics, and environmental effects.
- Verify system design and requirements when changes in hazard have occurred.
- Take advantage of opportunities to reevaluate the need for existing halon systems or extinguishers and replace with suitable alternatives where it is technically and economically feasible to do so.
- Encourage the application of risk management strategies and good engineering design to take advantage of alternative fire protection schemes.
- Implement a regular maintenance programme with improved system documentation.
- Educate and train personnel on system characteristics.
- Encourage end-users of automatic detection/release equipment to take advantage of the latest technology that is designed, listed, and proven in the intended application. Newer systems have been shown to reduce false alarms that trigger system activation.
- Upon decommissioning, recover all fire extinguishing agents.
- Manage storage of halon and other halogenated gaseous fire extinguishant reserves and perform routine leak detection.
- Discontinue fire protection system discharge testing using a test gas and consider amending any existing regulations that mandate such testing. If system discharge must be performed, consider using a simulant.
- Discontinue the discharging to the atmosphere of portable halon, HCFC, and HFC extinguishers and system cylinders during equipment servicing.
- Discontinue the discharge of portable halon, HCFC, and HFC fire extinguishers for training purposes. Live fire training is important but can be adequately done using simulants.
- Implement national awareness campaigns on all environmental concerns (e.g., ozone depletion, climate change).
- Develop or adopt technical standards and codes of conduct.

- Develop databases and implement record keeping on halon, HCFC, and HFC installed base quantities, transfers, and emissions.
- Develop halon, HCFC, and HFC fire extinguishing agent management plans including end of useful life considerations.
- Ensure "Responsible Use" of halons and other halogenated gaseous fire extinguishing agents using the tools from FSTOC Technical Note B, **FSTOC (2022b)**.

7.12 References

ACR (2022) Methodology for The Quantification, Monitoring, Reporting, and Verification of Greenhouse Gas Emissions Reductions and Removals From Certified Reclaimed HFC Refrigerants, Propellants, and Fire Suppressants, Version 2.0, April 2022. https://americancarbonregistry.org/carbon-accounting/standards-methodologies/certified-reclaimed-hfc-refrigerants/acr-certified-reclaimed-hfc_v2-0-final.pdf

Australia (1989): Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, https://www.legislation.gov.au/Series/C2004A03755

Australia (1995): Ozone Protection and Synthetic Greenhouse Gas Management Regulations 1995, https://www.legislation.gov.au/Series/F1996B02085

EPA (2001a): EPA430-B-01-001, *Guidance for the EPA Halon Emissions Reduction Rule* (40 CFR Part 82, Subpart H), United States Environmental Protection Agency, February 2001. www.epa.gov/sites/default/files/2015-07/documents/guidance_for_halon_emissions_reduction_rule_40_cfr_part_82_subpart_h.pdf

EPA (2001b): *Safety Guide for Decommissioning Halon Systems*, Vol. 2 of the U.S. Environmental Protection Agency Outreach Report: Moving Towards a World Without Halon. www.halon.org/safe-decommissioning-of-halons

GIZ (2017): *Guideline for the transboundary movement of ODS waste*, Deutsche Gesselschaft fur Internationale Zusammenarbeit (GIZ) GmbH, 2017. www.giz.de/en/downloads/giz2017-en-no4-guideline-transboundary-movement.pdf

HARC (2002): *Voluntary Code of Practice for the Reduction of Emissions of HFC & PFC Fire Protection Agents*, Halon Alternatives Research Corporation, March 2002. www.harc.org/_files/ugd/4e7dd1_46de828a6955497f8ed980456a7edf17.pdf

HARC (2015): *Code of Practice for Use of Recycled Halogenated Clean Agents*, Halon Alternatives Research Corporation, April 2015. www.harc.org/_files/ugd/4e7dd1_4ab7295ac47e4bdea67020750f544f1b.pdf

HRC (2021): *Code of Practice for Halon Recycling Companies*, Halon Recycling Corporation, June 2021. www.halon.org/_files/ugd/4e7dd1_1385c061aa9f4d4dae694a8036be92df.pdf

HRC (2022): *Halon 1301 Use in Civil Aviation: Guidance for Reducing Emissions and Contamination During Servicing and Maintenance*, Halon Recycling Corporation, March 2022. www.halon.org/hrc-av-outreach

HTOC (2018): *UNEP Report of the Halons Technical Options Committee, Volume 1, 2018 Assessment Report*, December 2018. https://ozone.unep.org/sites/default/files/Assessment_Panel/Assessment_Panels/TEAP/Reports/HTOC/HTOC_assessment_2018.pdf

FSTOC (2022a): UNEP Report of the Fire Suppression Technical Options Committee, Technical Note B, Emission Reduction and Recycling Strategies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents, December 2022, https://ozone.unep.org/science/assessment/teap

FSTOC (2022b): UNEP Report of the Fire Suppression Technical Options Committee, Technical Note C, Destruction Technologies for Halons and Other Halogenated Gaseous Fire Extinguishing Agents, December 2022. https://ozone.unep.org/science/assessment/teap

UNEP (1999): UNEP DTIE, *Eliminating Dependency on Halons: Self-Help Guide for Low Consuming Countries*, 1999, United Nations Publication ISBN: 92-807-1783-9. https://digitallibrary.un.org/record/777850?ln=en

UNEP (2001): *Standards and Codes of Practice to Eliminate Dependency on Halons: Handbook of Good Practices in the Halon Sector*, 2001, United Nations Publication ISBN: 92-807-1988-1. www.unep.org/resources/report/standards-and-codes-practice-eliminate-dependency-halons-handbook-good-practices

8 Destruction

8.1 Introduction

With the worldwide end of halon production for fire protection uses at the end of 2009, the phaseout of HCFCs, and the current state of the phasedown of HFCs, global inventory management and responsible disposal practices have become important considerations in the prevention of emissions during a critical period of global environmental protection.

Halons, HCFCs, and HFCs continue to be of high value due to the ongoing reliance of these extinguishing agents in fire protection systems in certain industries in lieu of the transition to alternatives.

One of the options for avoiding emissions and managing banks of surplus extinguishants is destruction, which involves the permanent transformation or decomposition of all, or a significant portion of the substances being destroyed.

The FSTOC has recommended that destruction should only be the final disposition option when halons are too contaminated and cannot be reclaimed to an acceptable purity. The FSTOC strongly continues to maintain this position and recommends extending it to HCFCs and HFCs as well. Destruction should only be a final resort when the agent cannot be successfully reclaimed to acceptable industry specifications or when the agent is no longer required globally.

8.2 Recent Developments

The FSTOC understands that there has not been any significant halon, HCFC, or HFC fire extinguishing agent destruction projects globally in recent years. Instead, during servicing activities or at end-of-life, the agents are recovered and reclaimed for re-supply into the market for enduring uses.

The world's first pilot halon destruction and carbon offset project occurred in February 2021 in the US using US sourced predominantly halon 1301 (2,687 pounds or 1.219 metric tonnes). The project was performed under the American Carbon Registry (ACR, a private voluntary US greenhouse gas registry), Methodology, **ACR (2017)**. This methodology allows for the destruction of halons 1211 and 1301 from fire equipment or systems and excludes the destruction of halon 1301 originating in stockpiles. The halon for the pilot project was recovered from decommissioned or retired equipment and destroyed using Technology and Economic Assessment Panel (TEAP) approved destruction technology (rotary kiln incineration), resulting in the creation of 3,384 tCO_2e offset credits from the project. The credits were then sold to a large reputable US IT company.

What was not apparent to the FSTOC related to whether the halon 1301 used in the pilot destruction project was not reclaimable (due to contamination), and therefore destruction was the best option, or whether regardless of the halon quality, the project proceeded purely based on wanting to dispose the halon to meet sustainability commitments of the various stakeholders involved and creating carbon offset credits for economic purposes.

A concern of the FSTOC is the unintended consequences of destroying in-specification and out of specification but reclaimable halon to generate offset credits when there continues to be a global need specifically in aviation and other sectors. Even though well-intended, an increase in the number of halon 1301 destruction offset projects (potentially leading to large volumes of halon being destroyed), is likely to put pressure on the global halon 1301 supply chain. In time, this could drive the application of an essential use nomination to recommence manufacture of halon 1301. In the coming years, and as more companies are making their public sustainability and net zero pledges, the FSTOC and the global fire protection industry will need to pay close attention to see how this situation unfolds and the effects it will have on global availability of halon 1301.

8.3 Approved Destruction Technologies

As instructed in Decision XXIX/4 at their 29th Meeting, the parties requested the TEAP to report on, and if needed in a supplementary report to the 40th Open-ended Working Group (OEWG), produce an assessment of the applicability of approved destruction technologies to HFCs and conduct a review of any other technology for possible inclusion in the list of approved destruction technologies for all controlled substances.

The TEAP Task Force on Destruction Technologies (TFDT) published its initial report in early April 2018. Additional information then became available, and a Supplemental report was prepared and submitted to the 40th OEWG. The 40th OEWG formed a contact group, and following those discussions, the TEAP was requested to provide additional information (Addendum to the Supplemental report) for the 30th Meeting of the Parties (MOP), including information on CO_2 emissions associated with energy consumption for a chosen destruction technology (owing to its higher energy intensiveness compared to other destruction technologies). The three TEAP reports arising from Decision XXIX/4 are available on the UNEP Ozone website and provide a comprehensive overview of each of the destruction technologies and their approval status, **TEAP (2018a, 2018b, 2018c)**.

Given the chemical similarity of HFCs, HCFCs, CFCs, and halons, several technologies screened satisfied the criteria for destruction. The technologies approved by the parties for the destruction of halons, HCFC, and HFC fire extinguishing agents are presented in Table 8.1.

Destruction of halons continues to present some unique considerations because of its brominated chemical makeup. Some of the technologies screened by the TFDT satisfied the criteria for the destruction of CFCs and HCFCs, however they had not been tested for halons and were not recommended. The bromine in halons tends to form molecular bromine (Br_2) which is very difficult to remove from the exhaust gases.

As there is nothing particularly different with the HFC fire extinguishants as compared to CFCs, 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. However, there are destruction technologies available to destroy HFC-23 as indicated in Table 8.1.

Decision XXX/6 on destruction technologies for controlled substances requests TEAP to assess destruction technologies for their destruction and removal efficiency, make recommendations to parties for potential approval for inclusion on the list of approved technologies, and to report to the OEWG prior to the 33rd MOP. The TEAP May 2022 Progress report, submitted prior to the 33rd MOP, indicates that the TEAP is not aware of any new information, such as test data, relating to already approved destruction technologies, or new technologies that would allow an assessment.

Technologies for the destruction of controlled substances (ODS and HFCs) are approved by the parties for the purposes of accounting for Article 7 annual production reporting and for the destruction of HFC-23 under Article 2J. The Protocol's definition of 'production' subtracts the amounts destroyed using destruction technologies approved by parties, from the amounts manufactured.

From time to time, factors arise where there might be the use a destruction technology that is not included on the list of approved technologies, or not approved for a particular controlled substance. These factors could include:

- Parties not being interested in reporting destroyed amounts of controlled substances under Article 7,
- need for destruction of controlled substances,
- requirements of national regulations and related standards,
- local and national air quality /emission guidelines,
- capacity and operating conditions,
- capability of the technology to destroy a variety of wastes,
- availability of the technology,
- cost of available technology, and
- viability of the market for destruction.

A destruction technology that is not approved under the Montreal Protocol may still be an acceptable and feasible option for destruction if it meets minimum local regulatory standards and provides ODS/HFC destruction efficiencies acceptable in that jurisdiction.

The subject of halon destruction has been addressed at length in earlier editions of the FSTOC Assessment reports. Following a re-organization of the FSTOC Technical Notes (Technical Note #5), the current version is now Technical Note C, **FSTOC (2022c).**

Over time, the list of destruction technologies approved by parties has been updated and is reproduced as Table 8.1 below.

Table 8.1: List of Technologies Approved and Subject to Review that are Either Not Approved, Not Determined, Based on Annex II, MOP-30

(Reproduced from Annex II to the 30th MOP under decision XXX/6)

Technology	Applicability										
	Concentrated Sources									Dilute Sources	
	Annex A		Annex B			Annex C	Annex E	Annex F			Annex F
	Group 1	Group 2	Group 1	Group 2	Group 3	Group 1	Group 1	Group 1	Group 2		Group 1
	Primary CFCs	Halons	Other CFCs	Carbon Tetrachloride	Methyl Chloroform	HCFCs	Methyl Bromide	HFCs	HFC-23	ODS	HFCs
DRE	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	95%	95%
Cement Kilns	Approved	Not Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
Gaseous/Fume Oxidation	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Liquid Injection Incineration	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Municipal Solid Waste Incineration										Approved	Approved
Porous Thermal Reactor	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
Reactor Cracking	Approved	Not Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Rotary Kiln Incineration	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved	Approved	Approved
Thermal Decay of Methyl Bromide	Not Determined	Not Determined	Not Determined	Not Determined	Not Determined	Not Determined	Approved	Not Determined	Not Determined		
Argon Plasma Arc	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Inductively coupled radio frequency plasma	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		
Microwave Plasma	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		
Nitrogen Plasma Arc	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Portable Plasma Arc	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
Chemical Reaction with H_2 and CO_2	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		

Technology	Applicability										
	Concentrated Sources									Dilute Sources	
	Annex A		Annex B			Annex C	Annex E	Annex F			Annex F
	Group 1	Group 2	Group 1	Group 2	Group 3	Group 1	Group 1	Group 1	Group 2		Group 1
	Primary CFCs	Halons	Other CFCs	Carbon Tetrachloride	Methyl Chloroform	HCFCs	Methyl Bromide	HFCs	HFC-23	ODS	HFCs
Gas Phase Catalytic De-halogenation	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
Superheated steam reactor	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Thermal Reaction with Methane	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		

*Orange shaded cells indicated those destruction technologies subject to review under decision XXX/6, excluding any new technology for which information might become available.

8.4 Transport of ODS, HCFCs, and HFCs for Destruction

TEAP approved ODS, HCFC, and HFC destruction technologies can be found in many facilities around the world. A significant challenge in relation to accessing these facilities from an international movement perspective especially for countries without destruction facilities relates to the Basel Convention. Depending on how the exporting country classifies the extinguishing agents destined for destruction, (whether they are defined as 'hazardous waste' or not), the Basel Convention can apply, thereby adding another layer of complexity when the destruction facility is in a country that is not a party to the Basel Convention, for example the US.

The complexities relate to:

- inconsistencies with classification of the material,
- increased administrative efforts,
- increased shipping costs,
- increased time to process Basel paperwork by each port adding time to the journey, and
- difficulties locating a carrier that is prepared to carry the 'hazardous waste.'

These are some of the challenges being faced by companies trying to be compliant with both their national legislation and the Basel Convention.

8.5 References

ACR (2017): Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from the Destruction of Ozone Depleting Substances and High-GWP Foam, Version 1.1, September 2017, https://americancarbonregistry.org/carbon-accounting/standards-methodologies/destruction-of-ozone-depleting-substances-and-high-gwp-foam/acr-destruction-of-ods-and-high-gwp-foam-september-2017-v1-1.pdf

TEAP (2018a): 2018 TEAP Report, Volume 2: Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances, https://ozone.unep.org/sites/default/files/2019-04/TEAP-DecXXIX4-TF-Report-April2018.pdf

TEAP (2018b): 2018 TEAP Report, Supplement to the April 2018 Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances https://ozone.unep.org/sites/default/files/2019-04/TEAP-DecXXIX4-TF-Supplemental-Report-May2018.pdf

TEAP (2018c): September 2018 TEAP Report: Volume 1 Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances (Addendum to the May 2018 Supplemental Report – Revision), https://ozone.unep.org/sites/default/files/2019-04/TEAP-DecXXIX4-TF-Addendum-to-May2018-Report_September2018.docx

TEAP (2022): Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme (UNEP), Report of the Technology and Economic Assessment Panel May 2022, https://ozone.unep.org/system/files/documents/TEAP-Progress-report-may2022.pdf

9 Alternatives to HFCs

9.1 Introduction

Much of the information requested by Decision XXVIII/2 is contained within other sections of this report and Technical Note A, **FSTOC (2022a)**. However, as is explained below, owing to the evolution of fire protection agents, the information is not easy to extract, and the FSTOC is responding to this decision by providing the information below and updating its technical note. This confers several advantages: the information will be presented in a clear and systematic manner; it should be easy for the parties to find; and it should be easy for the FSTOC to update in five years' time, as required by the decision.

9.1.1 Evolution of Fire Protection Approaches

The fire protection industry was an early and strong supporter of the Montreal Protocol. Extensive research was conducted to identify alternatives, while simultaneously implementing improvements to maintenance, servicing, and storage of halons, user awareness and training, replacement of halon systems where practical, as well as improved risk management. These actions have reduced dependence upon halons. The evolution of halon alternatives has proceeded along the path of selection of chemicals with the most similar characteristics, followed by research and development including testing, certification, toxicity and safety analyses, standards development, and commercialization. During this period, several HCFCs were developed for fire suppression applications.

As many of the early candidates were eliminated due to failure in one or more of the aforementioned steps, more challenging chemicals, many with less favorable characteristics, were added to the research and development process, leading to commercialization of several HFCs (note: both the agent and hardware must successfully pass all testing and certifications). Following the commercialization of HFCs, other chemicals were developed including FK-5-1-12, 3,3,3-trifluoro, 2-bromo-prop(-1)ene (2-BTP), CF_3I, and some combinations with inert gases, water mist, or solid particulates (also referred to as aerosols). This evolution has been continuous, as makes sense, in that the most likely candidates would be the most commercially viable due to the extensive cost of research and development. The fire protection industry has worked on developing alternatives to halons, HCFCs and now HFCs for over three decades as environmental concerns have evolved. Figure 9.1 illustrates how the fire protection market has changed over the lifetime of the Montreal Protocol. Note that the height of the bars in the histogram are normalized. It should not be interpreted that the total market size is the same for each of the years included.

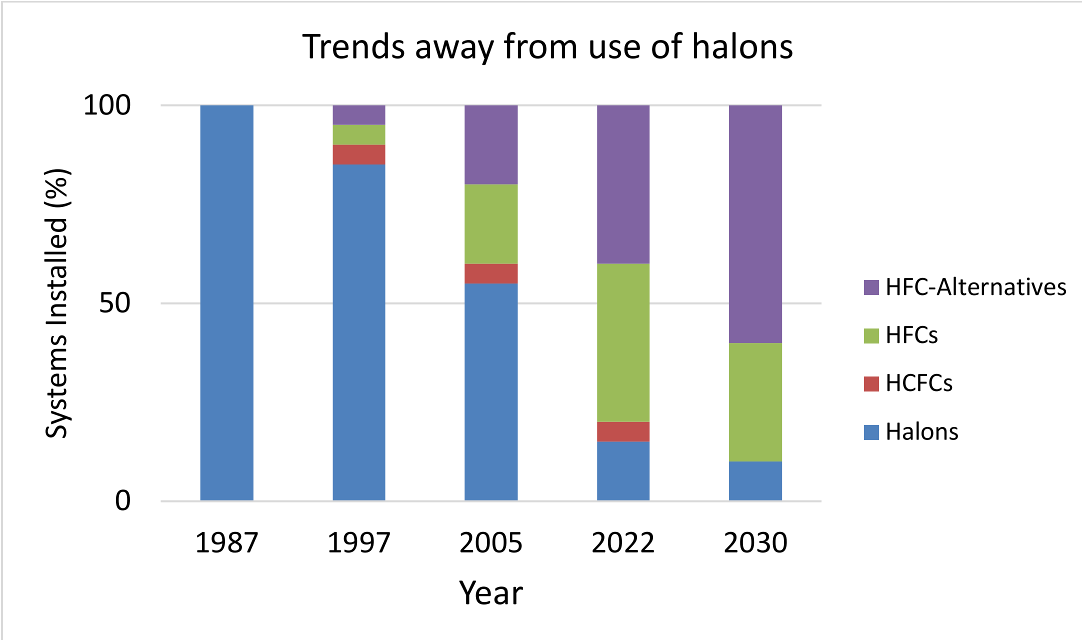


Figure 9.1: Estimated Trend in Fire Protection Systems Installed

9.1.2 FSTOC Interpretation of Criteria Listed in Decision XXVI/9 Paragraph 1(a)

The criteria outlined in decision XXVI/9 paragraph 1(a) can be subject to interpretation depending on the context of their use. From a fire protection perspective, the FSTOC interprets the criteria as:

i. **“Commercially available”**
The fire suppression agent for use in portable or mobile fire extinguishers and fixed fire protection systems which are offered for commercial sale is available on the open market and there is future certainty in the supply, i.e., the agent is not included in any future production phasedown legislation. Commercial availability may also be influenced by national or local governmental requirements affecting the import of one agent over another into the region or country. This does not necessarily mean that the extinguishers, systems, or extinguishing agents are accessible in all parties (for example Article 5 versus non-Article 5). In this context “accessible” follows the concept explained in section 6.1.2 of the TEAP report on alternatives to HFCs, (**TEAP 2018**), but in the context of fire extinguishing agents/systems, as detailed in Appendix B: Definitions.

ii. **“Technically proven”**
The fire protection system design for the fire suppression agent is accepted by regulators and industry because the fire extinguishers and fire protection systems have passed all necessary performance tests for the intended application. The tests, which may include extreme ambient temperatures, full-scale, small-scale, test vessel or test enclosure performance, demonstrate that the alternative agent provides acceptable fire extinguishment/suppression effectiveness and safety. The system design does not require further development and has acceptable space and weight characteristics. The agent is appropriately rated by a notified body or a body accredited by the American National

Standards Institute (ANSI) to assess conformity to recognized standards, for example, UL, or all reviews under the US EPA Toxic Substances Control Act and the Significant New Alternatives Policy (SNAP) program are completed. Other technical considerations for HFC replacements include that the agent has long-term stability in storage, is non-corrosive to metals, and is chemically compatible with materials it will contact. In some cases, the agent must also be "clean," that is, it leaves no residues during use, and/or be electrically non-conductive.

iii. **"Environmentally sound"**
The alternative fire suppression agent has minimal environmental impact (e.g., short atmospheric lifetime) compared to ODS or HFC extinguishing agents. They have zero or very low ozone depleting potential (which could be subject to individual party determination), have very low global warming potential, and are not foreseen to be subject to future production phasedowns. Note that there is potentially another environmental factor to consider; whether or not the candidate agents are included in the definition of PFAS (refer to section 3.2).

iv. **"Economically viable and cost effective"**
The cost to manufacture the alternative fire suppression agent is reasonable and therefore the cost of obtaining the alternative is not prohibitive, the alternative is competitively priced and available on the market, and there is little or no reluctance by owners to adopt the new agent. In the context of fire protection, cost-effectiveness can be a subjective issue and needs to be viewed in the context of the value of the asset being protected, and the cost-effectiveness to replace or modify existing fire suppression systems and components with an alternative agent. For example, in the case of system fire protection, where the asset may be a multi-million dollar building or military platform, cost-effectiveness would be viewed differently compared to a portable fire extinguisher in a domestic situation.

v. **"Safe to use in areas with high urban densities considering flammability and toxicity issues, including, where possible, risk characterization**"
For fire extinguishing agents, the flammability criterion is not relevant in the case of high urban density. In terms of toxicity, fire extinguishing agents are used in two different ways: 1) total flooding and 2) local application (also referred to as streaming). For total flooding agents, especially when used in "normally occupied areas," the toxicology considerations are more stringent than for local applications. For normally occupied areas, the agent must have no observable adverse effects on biological tissue when used at the design concentration. Although for portable extinguishers in enclosed spaces, consideration must also be given to minimum room volume to ensure that the concentration of the agent does not present a hazard to occupants. In addition to intrinsic agent toxicity, the toxicity of any combustion-related by-products (CO_2, acid gases such as HF, COF_2, etc.) must be considered.

vi. **"Easy to service and maintain"**
Recognized and approved standards exist for the servicing and maintenance of portable and mobile fire extinguishers and fixed fire protection systems. Training on service and

maintenance of the system is available and accessible. In the US and Canada, for example, portable fire extinguishers are intended to be selected, installed, inspected, maintained, and tested in accordance with National Fire Protection Association (NFPA) 10, Standard for Portable Fire Extinguishers, **NFPA (2022)**. In general, servicing of fire extinguishing systems and portable extinguishers is a highly technical task. However, the differences between servicing an HFC system and its alternative are relatively small, as is the amount of additional training that would be required.

In carrying out the assessment below, the FSTOC considers that a single "No" for any criterion means that the alternative is not currently acceptable for the application being considered. However, as the alternative agent undergoes further development, it could meet all six criteria in the future.

9.2 Sectors and Applications Where HFCs are Used

Table 9.1 provides a summary of which fire protection sub-sectors do or do not use HFCs that originally used halons.

Table 9.1: Summary of Alternatives for HFCs in Fire Protection

Sector	Application	HFCs being used?
Civil Aviation	Normally unoccupied cargo compartments	No
	Aircraft cabins, cockpits and crew rest compartments	Yes (1)
	Engine nacelles and auxiliary power units	Yes (1)
	Lavatory waste receptacles	Yes
	Fuel tank inerting	No
	Crash rescue vehicles	No
Military Ground Vehicles	Crew compartment	Yes
	Non-occupied compartments	Yes(1)
Military Naval	Normally occupied spaces	Yes
	Normally unoccupied spaces (engine, machinery, electrical etc.)	Yes
Military Aviation	Engine and APU	Yes
	Occupied spaces	Yes (1)
	Dry bays	Yes
	Fuel tank inerting	No
	Cargos compartments	No
Oil & Gas	Computer and control rooms	Yes (1)
	Hydrocarbon production (liquids)	Yes
General Industrial Fire Protection	Normally occupied spaces including data centres and telecommunications facilities	Yes
	Non-occupied spaces	Yes
Merchant shipping	Main engine rooms	No
	Other normally occupied spaces	Yes
	Other normally unoccupied spaces	Yes

Notes:
1. In some specific instances only.

9.3 Where Can Alternatives to HFCs be Used?

9.3.1 Civil Aviation

9.3.1.1 Cargo Compartments

Halon 1301 continues to be used in cargo compartment applications. HFCs have never been used for the protection of cargo compartments in civil aircraft and are unlikely to be so in the future.

HFC-125 (amongst other agents) failed a key element of the US Federal Aviation Administration (FAA) Cargo Compartment Minimum Performance Standard (MPS), **FAA (2004)**. This effectively ruled out HFCs for this application.

9.3.1.2 Aircraft Cabins, Cockpits, and Crew Rest Compartments

These areas on aircraft are protected using portable (handheld) fire extinguishers. Although portable fire extinguishers have been developed using HFCs (e.g., HFC-236fa and HFC-227ea) and some were approved for civil aviation use, it is the FSTOC's understanding that they were only sold commercially for some business jets and in general aviation. HFCs were never adopted in main fleet passenger aircraft. One alternative is available, 2-BTP that is being installed on most newly produced aircraft. It has a "negligible" GWP, **WMO (2018)** and can therefore be considered to be commercially available, technically proven, environmentally-sound, economically viable, safe to use, and easy to service and maintain for this application. It is worth noting, however that 2-BTP does have a larger minimum room volume requirement than the HFC agents for an equivalent fire rating which can restrict its use in smaller aircraft cabins and cockpits.

9.3.1.3 Engine Nacelles and Auxiliary Power Units

Of the agents evaluated for the protection of engine nacelles, only one (HFC-125) has been approved and is in use for some military applications. Potential alternatives to HFC-125 include (a) CF_3I, (b) a finely-ground sodium bicarbonate-based dry chemical (referred to as Powdered Aerosol F in the US EPA SNAP Regulations, **EPA (2022)**, (c) the fluoroketone FK-5-1-12, and (d) possibly CO_2. Table 9.2 shows FSTOC's assessment of these four agents against the six Decision XXVI/9 criteria.

Table 9.2: Summary of Alternatives for HFCs in Engine Nacelle and APU

Decision XXVI/9 Criterion		**Alternatives**			
		CF_3I(1)	**Powdered Aerosol F (1)**	**FK-5-1-12**	**CO_2**
I	Commercially available	Yes	No	Yes	Yes
II	Technically proven	No	No	No (2)	No (3)
III	Environmentally sound	Yes (4)	Yes	Yes	Yes
IV	Economically viable and cost effective	Yes	Yes	Yes	No
V	Safe to use	Yes (5)	Yes	Yes	No (5)
VI	Easy to service	Yes	Yes	Yes	Yes

Notes:

1. Both CF_3I and Powdered Aerosol F are currently being tested against the FAA Minimum Performance Standard (MPS) for aircraft engine nacelles. This will define the certification criteria for these agents and once a certification programme has been completed the agent could be considered to be technically proven.
2. FK-5-1-12 failed a low temperature fire test and is effectively excluded from this application.
3. Although CO_2 has not passed the FAA MPS test, its certification concentration (34%) is

included in FAA Advisory Circular AC20-100, FAA (1977). However, its weight and volume characteristics make it very unattractive in this application and is unlikely to be considered.

4. CF_3I has a "negligible" GWP, **WMO (2018)**.
5. Concern has been expressed by some stakeholders regarding the toxicity of CF_3I. Although engine nacelles are unoccupied, an agent of higher toxicity may present issues during installation, service, and maintenance operations. The same is true of CO_2.

9.3.1.4 Lavatory waste receptacles

Two HFCs, HFC-227ea and HFC-236fa, are used in this application. No alternatives have been evaluated to date. The civil aviation industry is focusing on halon replacement in engine nacelle and cargo compartment applications. Table 9.3 lists some possible alternatives and their assessment against the six Decision XXVI/9 criteria. The alternatives have been divided into two categories: "in-kind" (vaporizing liquids that would operate in a similar fashion to the current HFC agents) and "not-in-kind" (agents with different physical characteristics, Table 9.4).

Table 9.3: Summary of "In-kind" Alternatives for HFCs in Lavatory Waste Receptacles

Decision XXVI/9 Criterion		**"In-kind" Alternatives**		
		2-BTP	**CF_3I**	**FK-5-1-12**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No	No	No
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	Yes	Yes	Yes
V	Safe to use	Yes (1)	Yes (1)	Yes
VI	Easy to service	Yes	Yes	Yes

Notes

1. Calculations suggest that the quantity of agent required may be close to, or exceed, the allowed concentration in small lavatory areas.

Table 9.4: Summary of "Not-in-kind" Alternatives for HFCs in Lavatory Waste Receptables

Decision XXVI/9 Criterion		**"Not-in-kind" Alternatives (1)**		
		CO_2	**Inert Gas**	**Water Mist**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No	No	No
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	NK	NK	NK
V	Safe to use	Yes	Yes	Yes
VI	Easy to service	Yes	Yes	Yes

Notes:

1. These agents are no more than concepts at this stage. Moving to a "not-in-kind" solution would require more research and development and may also give rise to additional technical challenges.
2. NK not known to FSTOC at this time.

9.3.1.5 Fuel Tank Inerting

Flammable hydrocarbon vapour can accumulate in the headspace or ullage of fuel tanks on commercial aircraft. If an ignition source is present, a fuel-air explosion could occur, which can destroy the aircraft. To prevent this from occurring, fuel tank atmospheres are inerted using on-board inert gas generating systems (OBIGGS). These systems are based on an air separation technology, which generates a flow of oxygen-depleted air that inerts the fuel tanks. These are commercially available and have passed all the Decision XXVI/9 criteria. HFCs have never been used in this application and are unlikely to be used in the future.

9.3.1.6 Crash Rescue Vehicles

Historically, this application used halon 1211. Halon alternatives employed include HCFC Blend B, potassium bicarbonate dry chemical and more recently FK-5-1-12. HFCs were not used in this application, so although halon alternatives are available, they are not HFC alternatives in the strictest sense.

9.3.2 Military Ground Vehicles

9.3.2.1 Crew Compartments

Many parties have replaced halon 1301 with HFC227-BC (a blend of HFC-227ea and dry chemical) or HFC-236fa for ground vehicle fire protection in occupied compartments. For these specialized military applications, only these high-GWP HFCs have been technically proven to meet the stringent performance and safety criteria. Research is ongoing to evaluate alternatives, however, no low-GWP alternative has been identified to meet stringent design requirements. Therefore, these high-GWP HFCs will be required for the foreseeable future in occupied compartments. Table 9.5 lists the FSTOC assessment of the in-kind alternatives and Table 9.6 shows not-in-kind alternatives to HFCs in crew compartments of ground vehicles against the Decision XXVI/9 criteria.

Table 9.5: Summary of "In-kind" Alternatives for HFCs in Crew Compartments

Decision XXVI/9 Criterion		**"In-kind" Alternatives**		
		2-BTP	**CF_3I**	**FK-5-1-12**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No	No	No
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	No (1)	No (1)	No (1)
V	Safe to use	No	No	No
VI	Easy to service	Yes	Yes	Yes

Notes:
1. System cost and integration impacts are unknown.

Table 9.6: Summary of "Not-in-kind" Alternatives for HFCs in Crew Compartments

Decision XXVI/9 Criterion		**"Not-in-kind" Alternatives**		
		CO_2	**Inert Gas**	**Water Mist**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No	No	No
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	No (1)	No (1)	No (1)
V	Safe to use	No	No	No
VI	Easy to service	Yes	Yes	Yes

Notes:

1. System cost and integration impacts are unknown.

9.3.2.2 Non-occupied Compartments

In non-occupied compartments of military ground vehicles such as engine compartments, most halon applications have been replaced with HFCs or other chemicals. The HFC alternatives in Table 9.7 and Table 9.8 have been/are being considered for implementation where feasible. However technical challenges in comparison to gaseous HFC agents need to be considered (e.g., additional distribution, nozzles, maintenance including access and cleanup, etc.).

Table 9.7: Summary of "In-kind" Alternatives for HFCs in Non-occupied Compartments

Decision XXVI/9 Criterion		**"In-kind" Alternatives**		
		2-BTP	**CF_3I**	**FK-5-1-12**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No	No	No
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	NK	NK	NK
V	Safe to use	No	No	Yes
VI	Easy to service	Yes	Yes	Yes

Table 9.8: Summary of "Not-in-kind" Alternatives for HFCs in Non-occupied Compartments

Decision XXVI/9 Criterion		"Not-in-kind" Alternatives		
		CO_2	Inert Gas	Dry Chemical
I	Commercially available	Yes	Yes	Yes
II	Technically proven	Yes (1)	Yes	Yes
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	Yes	No (2)	Yes
V	Safe to use	Yes	Yes	Yes
VI	Easy to service	Yes	Yes	Yes (3)

Notes:

1. More research and development would be required and may also give rise to additional technical challenges.
2. Weight and volume characteristics make this a very unattractive option for this application
3. The requirements for post-discharge clean-up may make dry chemical systems unattractive, e.g., if removal of the vehicle powerpack is a time-consuming and costly process.

9.3.3 Military Naval Applications

9.3.3.1 Occupied Spaces

Some parties use alternatives to HFCs, including FK-5-1-12, in some applications on-board naval vessels. However, due to technical and economic challenges associated with retrofits, halons continue to be used in many critical legacy applications. For example, if the enclosure must stay occupied during a fire, then a limited number of agents are available for consideration due to toxicity concerns. It should be noted that agent selection and approval criteria can vary from one party to another. For example, one party might consider gaseous agents to be the only alternative for a specific application, but another would accept other agents such as dry chemicals. Issues such as post-discharge clean-up may affect how cost-effectiveness is viewed.

9.3.3.2 Machinery and Other Unoccupied Spaces

A wide range of agents that include both high-GWP and low/zero-GWP fire suppressants is used for the main machinery and other spaces of new vessels. These include HFC-227ea, fine water spray, hybrid HFC-227ea/water spray, FK-5-1-12, foam, and CO_2 systems. However, CO_2 systems are prohibited in all spaces on new US naval vessels due to crew safety considerations. In some applications, such as electrical compartments or where HFCs are not acceptable because of national legislation, inert gas systems such as IG-541 are used.

Table 9.9 provides the list of alternatives to HFCs in machinery and unoccupied spaces against the Decision XXVI/9 criteria.

Table 9.9: Summary of Alternatives for HFCs in Machinery and Other Unoccupied Spaces

Decision XXVI/9 Criterion		Alternatives				
		Water Spray	FK-5-1-12	AFFF	CO_2	Inert Gas
I	Commercially available	Yes	Yes	Yes	Yes	Yes
II	Technically proven	Yes	Yes	Yes	Yes	Yes
III	Environmentally sound	Yes	Yes	Yes (1)	Yes	Yes
IV	Economically viable and cost effective	Yes	Yes	Yes	Yes	Yes
V	Safe to use	Yes	Yes	Yes	No (2)	Yes
VI	Easy to service	Yes	Yes	Yes	Yes(3)	Yes

Notes:

1. PFAS-containing foams are being eliminated, however PFAS-free foams are commercially available.
2. There are concerns regarding entry to the space after the fire has been extinguished. A toxic concentration may still be present, **Wickham (2003).**
3. An agent of higher toxicity may present issues during installation, service, and maintenance operations.

9.3.4 Military Aviation Applications

9.3.4.1 Engine and APU Spaces

Some parties have successfully implemented HFC-125 as an alternative to halons for engine and APU fire protection. It is unlikely that any HFC alternative will be implemented in the foreseeable future.

9.3.4.2 Occupied Spaces

Military aviation applications are similar to civilian aviation, where these spaces are mainly protected by portable extinguishers. Military portables include halons, HFCs, and CO_2.

9.3.4.3 Dry Bays

Dry bays are the compartments in military aircraft immediately adjacent to fuel tanks or other flammable fluids. They frequently contain fluid lines, control lines, electrical equipment, etc. Ballistic damage to these bays may allow fuel to enter the bay causing fire after contact with electrical components or other ignition sources which could result in loss of the aircraft. Accordingly, key dry bays are protected with fast response fire detection and suppression systems. Some of these systems use HFCs, notably HFC-236fa. Other systems use dry chemical fire extinguishant, which can be considered to be commercially available, technically proven, environmentally-sound, economically viable, safe to use, and easy to service and maintain. However, the impacts of replacing HFCs with dry chemical would have to be evaluated on a case-by-case basis, including the effects of post-discharge clean-up.

9.3.4.4 Fuel Tank Inerting

Halon 1301 and OBIGGS have been used for fuel tank inerting. HFCs have never been used to inert fuel tanks in military aircraft and are unlikely to be so in the future.

9.3.4.5 Cargo Spaces

HFCs have never been used for cargo spaces in military aircraft and are unlikely to be so in the future.

9.3.5 Oil and Gas

9.3.5.1 Computer and Control Rooms

Halons were the agents of choice for mitigating the threat of fires and explosions in enclosed oil and gas production and transportation facilities due to the harsh climatic conditions. Because of the effectiveness and availability of halons 1301 and 2402 at the time of initial development of the facilities, it was also commonly provided in the enclosures housing various support infrastructure (communication/data rooms, facility control rooms, primary/standby power generation, and electrical equipment rooms). HFCs have been used for the protection of support areas such as battery or electrical rooms, or pipeline maintenance buildings. Table 9.10 lists the alternatives to HFCs in computer and control rooms in oil and gas facilities against the Decision XXVI/9 criteria.

Table 9.10: Summary of Alternatives for HFCs in Computer and Control Rooms

Decision XXVI/9 Criterion		Alternatives			
		Inert Gas	Water Mist	FK-5-1-12	CO2
I	Commercially available	Yes	Yes	Yes	Yes
II	Technically proven	Yes	Yes (1)	Yes (1)	Yes
III	Environmentally sound	Yes	Yes	Yes	Yes
IV	Economically viable and cost effective	No	Yes (2)	Yes	No
V	Safe to use	Yes (3)	Yes (2)	Yes (3)	No (4)
VI	Easy to service	Yes	Yes	Yes	Yes

Notes:

1. In cold climates, water mist and FK-5-1-12 may require additional infrastructure (i.e., additional heat loads) to work in conjunction with the facility safety systems to provide adequate protection. Alternatively, water mist systems can employ freeze-protection additives. Also refer to note (2).
2. Electrical safety measures need to be evaluated. Some freeze-protection additives are flammable or introduce safety concerns, e.g., glycol-based additives.
3. Specific to computer rooms co-located in low temperature hydrocarbon production facilities, concern has been expressed by some stakeholders regarding the possibility that protection for some of these hazards may necessitate a design concentration near or above the No Observed Adverse Effect Level (NOAEL) for some alternatives. As these

types of rooms may or may not be normally occupied, this may present issues during installation, service, and maintenance operations which need to be carefully evaluated.

4. Many authorities will not allow CO_2 in normally occupied areas. When allowable, CO_2 systems need to be set to a manual mode when people are present in the space being protected.

9.3.5.2 Hydrocarbon Production

Oil and gas production and transportation facilities face many different hazards, with the most significant being fires and explosions involving flammable liquids or gases. Halons were the agent of choice to mitigate the threat of both fires and explosions in facilities that are enclosed due to harsh climatic conditions. Because of the effectiveness of halon for both inerting the enclosure (i.e., creating a non-explosive environment) and flame extinguishment, and availability of halons at the time of development of the facilities, it was also commonly provided in the enclosures housing oil and gas production areas. In enclosed areas with gas production, the vapour cloud explosion potential eliminates a number of fire suppression mediums from consideration as they are generally effective at either flame extinguishment or inerting the atmosphere, but not both. The decision to use halons as the primary fire protection tool was arrived at after carefully evaluating the agents available at the time. Originally, only halons and CO_2 were assessed to have the ability to both inert hydrocarbon atmospheres and extinguish fires in very low temperature applications. With the introduction of HFCs, HFC-23 was added to this list (under those climatic conditions). However, CO_2 was rejected because it is too slow acting to accomplish inerting or extinguishment in the desired time periods and because it presents a hazard to life at extinguishing concentrations, thus leaving halons and HFC-23. Depending upon the ability to handle the vapour cloud through other means such as high-rate ventilation, some HFC alternatives exist. Table 9.11 lists the alternatives to HFCs for hydrocarbon production against the Decision XXVI/9 criteria.

Table 9.11: Summary of Alternatives for HFCs in Hydrocarbon Production

Decision XXVI/9 Criterion		**Alternatives**		
		Dry Powder	**Water Mist**	**FK-5-1-12**
I	Commercially available	Yes	Yes	Yes
II	Technically proven	No (1)	Yes (1,2)	Yes (1,2)
III	Environmentally sound	Yes	Yes	Yes
IV	Economically viable and cost effective	No	No	Yes
V	Safe to use	Yes	Yes	Yes (3)
VI	Easy to service	Yes	Yes	Yes

Notes:

1. Depending upon the ability to handle the vapour cloud through other means such as high-rate ventilation, this alternative is technically proven.
2. In cold climates, water mist and FK-5-1-12 may require additional infrastructure (i.e., additional heat loads) or modifications away from accepted industry practice to work in

conjunction with the facility safety systems. However, the fire protection scheme may not allow additional heat load systems to operate during specific events or the cost to provide explosion proof heating affects economic viability.

3. Concern has been expressed by some stakeholders regarding the possibility that protection for some of these hazards may necessitate a design concentration near or above the NOAEL for some halocarbon agents. As these types of rooms may or may not be normally occupied this may present issues during installation, service, and maintenance operations which need to be carefully evaluated.

9.3.6 General Industrial Fire Protection

9.3.6.1 Normally Occupied Spaces including Data Centres and Telecommunications Facilities

A number of alternatives to HFCs for the protection of normally occupied spaces are available for the protection of these hazards. Table 9.12 shows the FSTOC assessment against the Decision XXVI/9 criteria.

Table 9.12: Summary of Alternatives for HFCs in Normally Occupied Spaces

Decision XXVI/9 Criterion		**Alternatives**				
		Inert Gas	**Water Mist**	**FK-5-1-12**	**Halocarbon Blend 55**	**CO_2**
I	Commercially available	Yes	Yes	Yes	No (1)	Yes
II	Technically proven	Yes	Yes	Yes	No	Yes
III	Environmentally sound	Yes	Yes	Yes	Yes	Yes
IV	Economically viable and cost effective	Yes	Yes	Yes	NK	No
V	Safe to use	Yes	Yes(2)	Yes	NK	No (3)
VI	Easy to service	Yes (4)	Yes	Yes	NK	Yes

Notes:

1. The blend is not commercially available but the two separate components (FK-5-1-12 and HCFO-1233zd(E)) are available commercially.
2. In cases where there are extremes of temperature water mist systems can employ freeze-protection additives, some of which are flammable or introduce safety concerns, e.g., glycol-based additives.
3. CO_2 systems need to be set to manual mode when people are present in the space being protected.
4. While in some areas these systems can be easy to service, in remote locations with limited transportation, alternative fire protection systems can be very expensive to recharge. Factors such as air transport and ice roads need to be considered. This is especially true in the case of inert gas systems because of the larger amount of extinguishing agent / number of cylinders required.

9.3.6.2 Non-occupied Spaces

A number of alternatives to HFCs for the protection of non-occupied spaces have been available for some time. Table 9.13 shows the FSTOC assessment against the Decision XXVI/9 criteria.

Table 9.13: Summary of Alternatives for HFCs in Non-occupied Spaces

Decision XXVI/9 Criterion		**Alternatives**				
		Inert Gas	**Water Mist**	**FK-5-1-12**	**Halocarbon Blend 55**	**CO_2**
I	Commercially available	Yes	Yes	Yes	No (1)	Yes
II	Technically proven	Yes	Yes	Yes	No	Yes
III	Environmentally sound	Yes	Yes	Yes	Yes	Yes
IV	Economically viable and cost effective	Yes	Yes	Yes	NK	Yes
V	Safe to use	Yes	Yes (2)	Yes	NK	Yes (3)
VI	Easy to service	Yes	Yes	Yes	NK	Yes

Notes:

1. The blend is not commercially available but the two separate components (FK-5-1-12 and HCFO-1233zdE)) are both available commercially
2. In cases where there are extremes of temperature water mist systems can employ freeze-protection additives, some of which are flammable or introduce safety concerns, e.g., glycol-based additives.
3. In the event of a discharge of a CO_2 system, a means to prevent people from entering the space is required until it is safe to do so.

9.3.7 Merchant Shipping

9.3.7.1 Main Engine Rooms and Machinery Spaces

Historically these applications were protected with CO_2. In the mid-1970s passenger ships and tankers switched from CO_2 to halon 1301 for fire suppression in the main engine rooms as it was more cost effective. When the International Maritime Organization (IMO) banned the use of halons in new construction in 1992, **IMO (1992)**, CO_2 once again became the agent-of-choice for these types of ships. It is the FSTOC's understanding that HFCs have been used in this application. Thus, CO_2 is a halon alternative, and could be viewed as an HFC alternative. Additionally, in some smaller vessels FK-5-1-12 has been used.

9.3.7.2 Normally Occupied Spaces

The alternatives to HFCs for the protection of normally occupied spaces in the merchant shipping sector are considered to be comparable to those available for the general industrial fire protection sector. Refer to section 9.3.6.1 above.

9.3.7.3 Non-occupied spaces

The alternatives to HFCs for the protection of non-occupied spaces in the merchant shipping sector are considered to be comparable to those available for the general industrial fire protection sector. Refer to section 9.3.6.2 above.

9.4 Effect of Proposed PFAS Regulations on Alternatives to HFCs in Fire Protection

9.4.1 Background

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) refers to a class of chemicals that contain fluorine atoms bonded to carbon atoms. Historically, PFAS was used to describe longer chain compounds that were used in products such as paper, textiles, leather, carpets, and firefighting foam. The regulation of PFAS initially focused on the eight-carbon chemicals perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). More recent PFAS definitions have broadened to include over 4,000 different fluorinated compounds ranging from gases to liquids to solids and include carbon chain lengths as short as a single carbon. As a result, some of these PFAS definitions now encompass HFCs and HFC alternatives such as hydrochlorofluoro-olefins (HCFOs) and fluoroketones (FKs).

The Organization for Economic Cooperation and Development (OECD) defines PFAS as follows: “PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($–CF_3$) or a perfluorinated methylene group ($–CF_2–$) is a PFAS.” The OECD definition of PFAS would encompass the following fire suppression chemicals: FK-5-1-12, HFC-227ea, HFC-125, HFC-236fa, 3,3,3-trifluoro-2-bromo-propene (2-BTP), hydrochlorofluorocarbon (HCFC) Blend B, HCFC-123 and Halocarbon Blend 55 (50/50 weight% FK-5-1-12 and hydrochlorofluoro-olefin (HCFO)- 1233zd(E)).

Regarding the PFAS definition, OECD states “The term “PFASs” is a broad, general, non-specific term, which does not inform whether a compound is harmful or not, but only communicates that the compounds under this term share the same trait for having a fully fluorinated methyl or methylene carbon moiety.” In addition, OECD notes “It also does not conclude that all PFASs have the same properties, uses, exposure and risks.”

It should be noted that other countries or organizations may have different definitions of PFAS that may not encompass all of the same fire suppression agents as the OECD definition. It should also be noted that some in the atmospheric science community have reasoned that the definitions for PFAS need to be revised so that they no longer include substances such as HFCs and HFC alternatives that environmentally degrade to produce trifluoroacetic acid (TFA) as the longest perfluorinated carboxylic acid.” **Wallington (2021).**

9.4.2 Implications for Alternatives to HFCs in Fire Protection

A restriction on PFAS that incorporates HFCs and HFC alternatives could have a substantial impact on future availability and use of these alternatives in the EU unless specific exemptions for fire protection uses were included. Restricting or prohibiting the sale or use of HFCs and HFC alternatives could affect the ability of some users in the EU to effectively protect a range of special hazards from fire and explosion.

For example, if 2-BTP were to be included in PFAS restrictions, it would be devastating to the aviation industry’s efforts to replace halons. 2-BTP is the result of a 20-year search for an alternative to halon 1211 in aviation hand-held fire extinguishers. It is currently replacing halon 1211 as a drop-in (same size extinguisher, slight increase in weight) on most new production aircraft, and all existing aircraft in the EU are expected to be retrofitted to 2-BTP by 2026. It took 15 years to develop and gain approval and there are no other in-kind (vaporizing liquids that do not require clean-up) candidate agents for this use that would not be considered PFAS by this definition. Not-in-kind alternatives (i.e., those that would require clean-up) have been tested for this use and failed to pass the minimum performance standards. In addition, vaporizing liquid agents are the current candidates to replace halons in engine and cargo uses. Having them included in a REACH restriction would also derail the aviation industry's efforts to replace halons.

On December 20, 2022, 3M announced that it will cease manufacture of all PFAS by the end of 2025, **3M (2022)**, including the fire suppressant FK-5-1-12. The FSTOC understands that there are other manufacturers of this agent. Clearly, this is an evolving situation, and the FSTOC expects to understand more fully in the future how these proposed regulations will affect both HFCs and their alternatives.

9.5 Summary

Table 9.14 summarizes where alternatives to HFCs are available on a sector-by-sector basis. For an alternative to be available, it must have passed all six Decision XXVI/9 criteria, i.e., it is commercially available, technically proven, environmentally sound, economically viable and cost effective, safe to use, and easy to service, according to FSTOC's interpretation of these criteria.

Note: some alternatives listed here are actually halon alternatives rather than HFC alternatives. See footnote. Furthermore, wherein some sectors or applications HFCs were not used and there are no alternatives e.g., in aircraft cargo compartments. In these cases, it seems appropriate to state that alternatives to HFCs are not applicable (N/A).

Table 9.14: Summary of Alternatives for HFCs in Fire Protection

Sector	Application	HFCs being used?	Alternatives Available?
Civil Aviation	Normally unoccupied cargo compartments	No	N/A
	Aircraft cabins, cockpits and crew rest compartments	Yes (1)	Yes
	Engine nacelles and auxiliary power units	Yes (1)	No
	Lavatory waste receptacles	Yes	No
	Fuel tank inerting	No	Yes (2)
	Crash rescue vehicles	No	Yes (2)
Military Ground Vehicles	Crew compartments	Yes	No
	Non-occupied compartments	Yes	Yes (3)
Military Naval	Normally occupied spaces	Yes	Yes
	Normally unoccupied spaces (engine, machinery, electrical etc.)	Yes	Yes
Military Aviation	Engine and APU	Yes	No
	Occupied Spaces	No	Yes (2)
	Protection of dry bays	Yes	Yes
	Fuel Tank Inerting	No	N/A
	Cargo compartments	No	N/A
Oil & Gas	Computer and control rooms	Yes (1)	Yes (3)
	Hydrocarbon production (liquids)	Yes	Yes (3)
General Industrial Fire Protection	Normally occupied spaces including data centres and telecommunications facilities	Yes	Yes (3)
	Non-occupied spaces	Yes	Yes
Merchant Shipping	Main engine rooms	No	Yes (2)
	Protection of other normally occupied spaces	Yes	Yes
	Protection of other normally unoccupied spaces	Yes	Yes

Notes:

1. In some specific instances only.
2. Alternatives to halons are available, but as HFCs were not used in this application, the alternatives are not HFC alternatives in the strictest sense.
3. May not be useable in all circumstances, or some additional caveats exist.

9.6 References

3M (2022): 3M Press Release, December 20, 2022. *https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025*

EPA (2022): Significant New Alternatives Policy (SNAP), Substitutes in Total Flooding Agents; https://www.epa.gov/snap/substitutes-total-flooding-agents

FAA (1977): AC20-100 – "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments", *http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-100.pdf*

FAA (2004): John W. Reinhardt, "Behavior of Bromotrifluoropropene and Pentafluoroethane When Subjected to a Simulated Aerosol Can Explosion" FAA Report No. DOT/FAA/AR-TN04/4

OECD (2021): Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management, No. 61, OECD Publishing, Paris. https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-per-and-polyfluoroalkyl-substances.pdf

IMO (1992): "1992 Amendments to the 1974 SOLAS Convention". IMO Resolution MSC.27(61), Page 6 Para 16. https ://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.27(61).pdf

NFPA (2022) : NFPA 10 **"**Standard for Portable Fire Extinguishers", https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=10

TEAP (2022): "TEAP September 2022: Decision XXVIII/2 TEAP Working Group Report - Information on Alternatives to HFCs (Volume 5)", https://ozone.unep.org/system/files/documents/TEAP-Decision-XXVIII-2-HFC-%20Alternatives-report-sept2022.pdf

Wallington (2021): Wallington *et al*. *The case for a more precise definition of PFAS*, Environ. Sci. Processes Impacts 2021 (23) 1834-1838.

Wickham (2003): R.T. Wickham, "Review of the Use of Carbon Dioxide Total Flooding Fire Extinguishing Systems", 2003, https://www.epa.gov/sites/default/files/2018-10/documents/review-of-the-use-of-carbon-dioxide-total-flooding-fire-extinguishing-systems.pdf

WMO (2018): World Meteorological Organization, Global Ozone Research and Monitoring Project-Report No. 58: "Scientific Assessment of Ozone Depletion 2018, Appendix A, Table A-1.

Appendix A: List of Acronyms

This is a consolidated list of all acronyms used in this Assessment report and Technotes A - D

2-BTP	3,3,3-2-bromo-trifluoro-prop(-1)-ene ($CF_3C(Br)=CH_2$)
A5	Article 5 Party
ABS	Acrylonitrile butadiene styrene
AFES	Automatic Fire Extinguishing System
AFFF	Aqueous Film Forming Foam
AHJ	Authority Having Jurisdiction
AHRI	Air-Conditioning, Heating & Refrigeration Institute
AIM	American Innovation and Manufacturing Act
APU	Auxiliary Power Unit
ARFF	Aircraft Rescue and Fire Fighting
ASTM	American Society for Testing and Materials
BSI	British Standards Institute
CAPA	CAPA Centre For Aviation
CCHRWG	Cargo Compartment Halon Replacement Working Group
CCTV	Closed Circuit Television
CEIT	Countries with Economies in Transition
CF_3I	Trifluoro(iodo)methane
CFC	Chlorofluorocarbons
CO	Carbon monoxide
CO_2	Carbon Dioxide
COF_2	Carbonyl fluoride
COP	Code of Practice
DE	Destruction Efficiency
DLA	US Defense Logistics Agency
DOD	US Department of Defense
DOT	Department Of Transportation
DRE	Destruction Removal Efficiency
DTIE	Division of Technology, Industry and Economics, part of UN Environment
DWT	Deadweight Tonnage
EASA	European Aviation Safety Agency

EC	European Commission
EEAP	Environmental Effects Assessment Panel
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 ($CF_3CF_2C(O)CF(CF_3)_2$)
FSTOC	Fire Suppression Technical Options Committee
GEF	Global Environment Facility
GHG	Green House Gas
GOST	Gosudarstvennye Standarty State Standard
GWP	Global Warming Potential
HAAPS	Halon Alternatives for Aircraft Propulsion Systems
HARC	Halon Alternatives Research Corporation
HB-55	NFPA 2001 Code for a blend of 50% HCFO-1233zd, 50% FK-5-1-12. Also known as Halocarbon Blend 55 in ISO 14520, part 17.
HBFC	Hydrobromofluorocarbon
HBFO	Hydrobromofluoro-olefin (for example 2-BTP)
HBMP	Halon Bank Management Plan
HBr	Hydrogen bromide
HCFC	Hydrochlorofluorocarbon
HCFC-123	2,2-Dichloro-1,1,1-trifluoroethane (CF_3CHCl_2)
HCFO	Hydrochlorofluoro-olefin
HCFO-1233zdE	Trans-1-Chloro-3,3,3-trifluoropropene ($CF_3CH=CHCl$)
HCl	Hydrogen chloride
HF	Hydrogen fluoride
HFC	Hydrofluorocarbon
HFC Blend B	A blend of 86% HFC-134a (tetrafluoroethane, CF_3CH_2F) 9% HFC-125 (pentafluoroethane, CF_3CHF_2) and 5% carbon dioxide CO_2
HFC-125	Pentafluoroethane (CF_3CHF_2)

HFC-134a	Tetrafluoroethane (CF_3CH_2F)
HFC-227ea	1,1,1,2,3,3,3-Heptafluoropropane (CF_3CHFCF_3)
HFC-23	Trifluoromethane (CHF_3)
HFC-236fa	1,1,1,3,3,3-Hexafluoropropane ($CF_3CH_2CF_3$)
HTOC	Halons Technical Options Committee, renamed FSTOC in 2022
HVAC	Heating, Ventilating, and Air Conditioning
IATA	International Air Transport Association
IC	(Engine/APU Halon Alternatives) Industry Consortium
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industry Associations
ICRFP	Inductively Coupled Radio Frequency Plasma
IG	Inert Gas
IG01	ISO 14520 Code for the inert gas argon
IG100	ISO 15420 Code for the inert gas nitrogen
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
IGG	Inert Gas Generator
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITC	International Toxic Equivalency
kg	kilogram
LC-50	Lethal Concentration 50 (a calculated or interpolated concentration that is expected to kill 50% of the test animals)
LNG	Liquefied Natural Gas
LOAEL	Lowest Observed Adverse Effect Level
LPG	Liquefied Petroleum Gas
MLF	Multilateral Fund
MPS	Minimum Performance Standard
MSDS	Material Safety Data Sheet
NATA	National Association of Testing Authorities (Australia)
NFPA	National Fire Protection Association

NHRMC	China's National Halon Management and Recycling System
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NOO	National Ozone Officer
NOU	National Ozone Unit
NPA	Notice of Proposed Amendment
OBIGGS	On-Board Inert Gas Generating System
ODP	Ozone Depletion Potential
ODP tonnes	Weight of the ODS in metric tonnes multiplied by its ODP
ODS	Ozone Depleting Substance
OEM	Original Equipment Manufacturer
OOS	Out of Specification
PCDD	Polychlorinated Dibenzodioxin
PCDF	Polychlorinated Dibenzofuran
PFC	Perfluorocarbon
PGA	Pyrotechnically Generated Aerosol
PIC	Pacific Island Countries
PMMA	Poly(methyl methacrylate)
PMN	Pre-manufacturing Notice
PNG	Papua New Guinea
PP	Polypropylene
SAP	Science Assessment Panel
SDS	Safety Data Sheet
SNAP	Significant New Alternatives Policy
SOLAS	Safety of Life at Sea
tCO_2e	Metric Tonnes CO_2 Equivalent
TEAP	Technology and Economic Assessment Panel
TFDT	Task Force on Destruction Technologies
tonne	Metric Tonne
TSCA	Toxic Substances Control Act

TSP	Total Suspended Particles
UK	United Kingdom
UL™	UL Solutions (formerly known as Underwriters Laboratories Inc.)
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US	United States of America
USSR	Soviet Union
VCOP	Voluntary Code of Practice
VSD	Video Smoke Detection

Appendix B: Definitions

Accessibility vs Availability:

This topic has been discussed extensively within the Technology and Economic Assessment Panel (TEAP) in the context of technologies related to the HFC phasedown and its interrelationship with energy efficiency in the refrigeration and air conditioning sectors.

"**Availability**" is the ability of the industry to manufacture products with new technologies. It is controlled by the manufacturers and is related to technology. The factors affecting availability of products that are manufactured locally can be summarized as:

- The ability of the industry in a country to absorb new technologies;
- Technical capabilities needed to implement the technology;
- Scalability of operations; and
- Technology barriers such as Intellectual Property Rights (IPR) and patents.

"**Accessibility**" on the other hand is focused on the consumer and varies with location within a region, country, or even with district within a country. Some of the factors which affect accessibility include:

- Supply chain; Importers/Suppliers for complete systems or parts, including the fire suppression agent;
- Presence of local manufacturing and/or assembly;
- Service sector capacity and quality;
- Affordability;
- Acceptability and preferences; and
- Presence or absence of laboratories and certification/verification bodies.

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 phaseout 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/systems and storage cylinders within any organization, country, or region.

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

Clearinghouse: A virtual banking method whereby agent transfer is facilitated between users, e.g., an office that facilitates contact between owners and buyers.

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 party 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. Decisions are numbered as follows: XXX/7, where the Roman numerals indicate the meeting number and the Arabic numerals indicate the sequential decision of that meeting

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 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 4th 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.

Fire Suppression Technical Options Committee (FSTOC): An international body of experts established by the parties to the Montreal Protocol on Substances That Deplete the Ozone Layer 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). In November 2022 Decision XXXIV/11 renamed the Halons Technical Options Committee as the Fire Suppression Technical Options Committee (FSTOC).

General Assembly: The Assembly is a United Nations 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 have 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 vaporization.

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 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). In November 2022 Decision XXXIV/11 renamed the Halons Technical Options Committee as the Fire Suppression Technical Options Committee (FSTOC).

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: 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 phaseout 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.

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

Phaseout: 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 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 reduce moisture and particulate matter.

Reuse: To remove an agent cylinder or extinguisher from one application and re-install in another application.

Technology and Economic Assessment Panel: In 1990, the Technology and Economic Assessment Panel (TEAP) was established as the technology and economics advisory body to the Montreal Protocol parties. The TEAP provides, at the request of Parties, technical information related to the alternative technologies that have been investigated and employed to make it possible to virtually eliminate use of Ozone Depleting Substances (such as CFCs and halons), that harm the ozone layer.

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.

Vienna Convention for Protection of the Ozone Layer: A framework convention that lays out principles agreed upon by many parties. The Vienna Convention took effect in 1988 and was the first convention to reach universal ratification (signed by all UN countries) in 2009. The parties to the Vienna Convention meet once every three years (at a time adjacent to the Meeting of the Parties to the Montreal Protocol) to make decisions on important issues including on Research and Systematic observations as well as financial and administrative matters. The Vienna Convention does not, however, require countries to take control actions to protect the ozone layer. This is achieved through the Montreal Protocol.

Voluntary Code of Practice: A VCOP outlines the responsible handling procedures for companies/organizations that recover/recycle/reclaim/store used halocarbon fire suppression agents. VCOPs can be developed "in house" or adopted from reputable sources. VCOPs provide assurance that persons engaged in the business of halocarbon agent recovery, recycling, reclamation and storage operate in a manner that promotes safe and environmentally responsible practices.

Water Mist: A firefighting agent that uses relatively small water droplets 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 – 2021 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	-	-	-	-	-	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-	-	-	-	-	-
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 - Global Bank	4	7	9	14	19	24	37	67	165	272	436	561
Total Annual Emissions with Production Lo	4	7	10	15	20	26	40	72	178	293	469	597
Cumulative Production												
North America, Western Europe and Japan	10	30	60	100	150	210	310	510	1,060	1,899	3,191	4,652
CEIT	-	-	-	-	-	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	10	30	60	100	150	210	310	510	1,060	1,899	3,191	4,652

Cummulative Production Allocation	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
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 - Global Banl	4	11	20	33	52	76	113	180	345	617	1,054	1,614
Total Cum. Emissions w/ Production Loss	4	11	21	36	56	81	121	193	372	664	1,133	1,730
Global 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
Annual 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	-	-	-	-	-	-	-	-	-	30
Article 5(1)	-	-	-	-	-	-	-	-	-	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 - Global Bank	782	1,133	1,289	1,527	1,814	1,944	2,223	2,807	3,102	3,661
Total Annual Emissions with Production Lo	833	1,212	1,378	1,627	1,932	2,066	2,366	2,996	3,287	3,880
Cumulative 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	-	-	-	-	-	-	-	-	-	30
Article 5(1)	-	-	-	-	-	-	-	-	-	70
Total Cumulative Production	6,671	9,843	13,393	17,408	22,126	27,003	32,697	40,262	47,648	56,440

Cummulative Production Allocation	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
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 - Global Banl	2,396	3,530	4,819	6,346	8,160	10,103	12,327	15,133	18,236	21,896
Total Cum. Emissions w/ Production Loss	2,563	3,776	5,154	6,781	8,713	10,779	13,144	16,140	19,427	23,307
Global 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
Annual 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	-
CEIT	30	30	35	30	30	1,100	50	50	-	-
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	-
Western Europe and Australia	2,445	2,769	2,901	3,138	2,788	2,279	1,832	1,221	611	-
Japan	1,956	2,215	2,321	2,510	2,230	1,823	1,465	977	488	-
CEIT	519	584	615	658	588	1,556	416	294	122	-
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 - Global Bank	3,807	4,168	4,244	4,734	5,101	5,564	5,497	5,140	3,844	3,056
Total Annual Emissions with Production Lo	4,055	4,449	4,539	5,054	5,386	5,696	5,596	5,208	3,884	3,065
Cumulative 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 Cumulative Production	66,345	77,579	89,411	102,206	113,615	124,190	132,137	137,582	140,763	141,463

Cummulative Production Allocation	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
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 - Global Banl	25,704	29,872	34,115	38,849	43,950	49,514	55,011	60,151	63,995	67,051
Total Cum. Emissions w/ Production Loss	27,362	31,811	36,351	41,404	46,790	52,486	58,083	63,291	67,174	70,239
Global 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
Annual 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	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
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	-	-	-	-	-	-	-
CEIT	-	-	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 - Global Bank	2,878	2,757	2,634	2,527	2,417	2,312	2,222	2,207	2,243	2,003
Total Annual Emissions with Production Lo	2,887	2,767	2,643	2,534	2,423	2,318	2,229	2,215	2,248	2,008
Cumulative 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 Cumulative Production	142,213	143,013	143,758	144,289	144,735	145,160	145,728	146,359	146,767	147,182

Cummulative Production Allocation	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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 - Global Banl	69,928	72,685	75,319	77,846	80,263	82,575	84,798	87,005	89,248	91,251
Total Cum. Emissions w/ Production Loss	73,126	75,893	78,536	81,070	83,493	85,810	88,040	90,254	92,502	94,511
Global 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
Annual 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	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5(1)	650	200	200	200	200	-	-	-	-	-
Total Annual Production	620	167	183	152	164	(12)	(11)	(8)	(3)	(12)
Annual Production Allocation										
North America	187	76	308	96	80	105	23	44	39	15
Western Europe and Australia	(187)	(109)	(325)	(144)	(116)	(118)	(35)	(53)	(42)	(28)
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	(30)	-	-	-	-	-	-	-	(0)	-
Article 5(1)	650	200	200	200	200	-	-	(0)	(0)	(0)
Total Annual Production Allocation	620	167	183	152	164	(12)	(11)	(8)	(3)	(12)
Annual Emissions										
North America	610	595	580	568	552	536	521	505	489	473
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 - Global Bank	1,887	1,803	1,711	1,627	1,547	1,460	1,374	1,343	1,258	1,187
Total Annual Emissions with Production Lo	1,895	1,805	1,713	1,628	1,549	1,460	1,374	1,343	1,258	1,187
Cumulative 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	135,424
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 Cumulative Production	147,802	147,969	148,152	148,305	148,468	148,456	148,445	148,436	148,434	148,422

Cummulative Production Allocation	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
North America	42,126	42,202	42,510	42,606	42,686	42,791	42,815	42,859	42,898	42,913
Western Europe and Australia	32,156	32,047	31,722	31,579	31,463	31,345	31,311	31,258	31,216	31,189
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	8,168	8,168
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	148,436	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	29,346
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	35,295
Total Cummulative Emissions - Global Banl	93,138	94,941	96,652	98,279	99,826	101,286	102,660	104,003	105,261	106,448
Total Cum. Emissions w/ Production Loss	96,406	98,211	99,924	101,553	103,102	104,562	105,936	107,279	108,537	109,724
Global Inventory - Bank										
North America	17,599	17,080	16,809	16,336	15,864	15,433	14,935	14,475	14,025	13,567
Western Europe and Australia	9,732	9,352	8,769	8,381	8,031	7,690	7,441	7,132	6,853	6,597
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	1,624	1,555
Article 5(1)	8,157	7,543	6,989	6,489	6,038	5,446	4,911	4,428	3,994	3,601
Annual Global Inventory - Bank	54,664	53,028	51,500	50,026	48,643	47,170	45,785	44,433	43,172	41,973

Halon 1301 Summary							
(All quantities are provided in metric tonnes)							
Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Annual Production							
North America, Western Europe and Japan	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-
Article 5(1)	-	-	-	-	-	-	-
Total Annual Production	(28)	(30)	(7)	(2)	(27)	(65)	(22)
Annual Production Allocation							
North America	35	35	8	(1)	(16)	(5)	-
Western Europe and Australia	(63)	(65)	(14)	(1)	(11)	(57)	(22)
Japan	-	-	-	-	-	-	-
CEIT	-	-	-	(0)	-	(2)	(0)
Article 5(1)	-	-	(0)	-	-	(0)	-
Total Annual Production Allocation	(28)	(30)	(7)	(2)	(27)	(65)	(22)
Annual Emissions							
North America	458	444	430	416	401	387	374
Western Europe and Australia	219	209	201	194	188	180	173
Japan	25	25	25	25	25	25	25
CEIT	66	63	61	58	56	53	51
Article 5(1)	354	319	288	259	234	211	190
Total Annual Emissions - Global Bank	1,122	1,060	1,004	952	903	856	812
Total Annual Emissions with Production Lo:	1,122	1,060	1,004	952	903	856	812
Cumulative Production							
North America, Western Europe and Japan	135,396	135,365	135,359	135,357	135,330	135,268	135,246
CEIT	1,355	1,355	1,355	1,355	1,355	1,355	1,355
Article 5(1)	11,643	11,643	11,643	11,643	11,643	11,643	11,643
Total Cumulative Production	148,393	148,363	148,356	148,355	148,328	148,266	148,244

Cummulative Production Allocation	2015	2016	2017	2018	2019	2020	2021
North America	42,948	42,982	42,990	42,990	42,973	42,969	42,969
Western Europe and Australia	31,126	31,061	31,047	31,046	31,035	30,977	30,955
Japan	27,254	27,254	27,254	27,254	27,254	27,254	27,254
CEIT	8,168	8,168	8,168	8,168	8,168	8,165	8,165
Article 5(1)	38,897	38,897	38,897	38,897	38,897	38,896	38,896
Total Cummulative Production Allocation	148,393	148,362	148,356	148,354	148,327	148,262	148,240
Cummulative Emissions							
North America	29,805	30,248	30,678	31,094	31,495	31,882	32,257
Western Europe and Australia	24,810	25,020	25,221	25,415	25,602	25,782	25,955
Japan	10,627	10,652	10,677	10,701	10,726	10,750	10,775
CEIT	6,679	6,742	6,803	6,861	6,916	6,970	7,020
Article 5(1)	35,649	35,968	36,256	36,515	36,749	36,960	37,150
Total Cummulative Emissions - Global Banl	107,570	108,630	109,634	110,586	111,489	112,345	113,157
Total Cum. Emissions w/ Production Loss	110,846	111,906	112,910	113,862	114,764	115,621	116,433
Global Inventory - Bank							
North America	13,143	12,734	12,312	11,896	11,478	11,086	10,712
Western Europe and Australia	6,316	6,041	5,826	5,631	5,433	5,195	5,000
Japan	16,627	16,602	16,578	16,553	16,528	16,504	16,479
CEIT	1,489	1,426	1,365	1,307	1,251	1,196	1,145
Article 5(1)	3,248	2,929	2,641	2,382	2,148	1,937	1,747
Annual Global Inventory - Bank	40,823	39,732	38,722	37,768	36,838	35,918	35,083

Appendix D: Historical Production, Emissions and Bank Values from 1963 – 2021 for Halon 1211

Halon 1211 Summary in 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 Production	0	0	0	0	0	0	0	0	0	0	0	0
Total Annual 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	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	2	6	13	22	38	58	81	115	158	213	277	350
Total Annual Emissions - Global Bank	11	30	66	113	193	295	416	587	812	1,090	1,420	1,791
Total Annual Emissions with Production Loss	13	32	71	121	206	313	438	619	854	1,145	1,489	1,874
Cumulative 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	0	0	0	0	0	0	0	0	0	0	0	0
Total Cumulative Production	50	150	350	650	1,150	1,850	2,750	4,010	5,710	7,910	10,660	13,960

Cumulative Production Allocation	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
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	10	30	70	130	230	370	550	802	1,142	1,582	2,132	2,792
Total Cumulative Production Allocation	50	150	350	650	1,150	1,850	2,750	4,010	5,710	7,910	10,660	13,960
Cumulative 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	2	8	21	43	80	138	219	333	492	704	982	1,332
Total Cumulative Emissions - Global Bank	11	41	107	220	413	709	1,124	1,712	2,523	3,613	5,033	6,825
Total Cum. Emissions w/ Production Loss	13	45	115	236	442	755	1,193	1,812	2,666	3,811	5,300	7,174
Global Inventory - Bank												
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
Annual Global Inventory - Bank	39	109	243	430	737	1,141	1,626	2,298	3,187	4,297	5,627	7,135

Halon 1211 Summary in metric tonnes										
YEAR	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
Annual Production										
North America, Western Europe and Japan Production	2,750	3,300	3,800	4,356	5,000	5,650	6,280	6,910	6,689	7,485
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	210	266	336	425	538
Total Annual Production	2,750	3,300	3,800	4,356	5,000	5,860	6,546	7,246	7,114	8,023
Annual Production Allocation										
North America	825	990	1,140	1,307	1,500	1,695	1,884	2,073	2,007	2,246
Western Europe and Australia	1,210	1,452	1,672	1,917	2,200	2,486	2,763	3,040	2,943	3,293
Japan	28	33	38	44	50	57	63	69	67	75
CEIT	138	165	190	218	250	283	314	346	334	374
Article 5	550	660	760	871	1,000	1,340	1,522	1,718	1,763	2,035
Total Annual Production Allocation	2,750	3,300	3,800	4,356	5,000	5,860	6,546	7,246	7,114	8,023
ANNUAL EMISSIONS										
North America	395	500	613	736	871	1,017	1,170	1,139	959	1,119
Western Europe and Australia	676	849	1,031	1,227	1,443	1,673	1,913	1,939	1,608	1,899
Japan	15	19	23	27	32	37	43	36	41	46
CEIT	57	73	90	108	129	151	175	199	219	242
Article 5	277	350	428	511	604	749	895	1,050	1,179	1,343
Total Annual Emissions - Global Bank	1,420	1,791	2,184	2,609	3,079	3,628	4,195	4,363	4,005	4,648
Total Annual Emissions with Production Loss	1,489	1,874	2,279	2,718	3,204	3,774	4,358	4,544	4,183	4,849
Cumulative Production										
North America, Western Europe and Japan	10,660	13,960	17,760	22,116	27,116	32,766	39,046	45,956	52,645	60,130
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	210	476	812	1,237	1,775
Total Cumulative Production	10,660	13,960	17,760	22,116	27,116	32,976	39,522	46,768	53,882	61,905

Cumulative Production Allocation	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
North America	3,198	4,188	5,328	6,635	8,135	9,830	11,714	13,787	15,794	18,039
Western Europe and Australia	4,690	6,142	7,814	9,731	11,931	14,417	17,180	20,221	23,164	26,457
Japan	107	140	178	221	271	328	390	460	526	601
CEIT	533	698	888	1,106	1,356	1,638	1,952	2,298	2,632	3,007
Article 5	2,132	2,792	3,552	4,423	5,423	6,763	8,285	10,003	11,766	13,801
Total Cumulative Production Allocation	10,660	13,960	17,760	22,116	27,116	32,976	39,522	46,768	53,882	61,905
Cumulative Emissions										
North America	1,387	1,888	2,501	3,237	4,108	5,125	6,294	7,433	8,392	9,511
Western Europe and Australia	2,414	3,263	4,293	5,520	6,962	8,636	10,548	12,488	14,095	15,994
Japan	53	72	95	123	155	192	235	271	312	359
CEIT	197	270	360	468	597	748	922	1,122	1,341	1,582
Article 5	982	1,332	1,760	2,271	2,875	3,624	4,519	5,568	6,747	8,090
Total Cumulative Emissions - Global Bank	5,033	6,825	9,009	11,618	14,697	18,325	22,519	26,882	30,888	35,536
Total Cum. Emissions w/ Production Loss	5,300	7,174	9,453	12,171	15,375	19,149	23,507	28,052	32,235	37,083
Global Inventory - Bank										
North America	1,811	2,300	2,827	3,398	4,027	4,705	5,419	6,353	7,401	8,528
Western Europe and Australia	2,277	2,880	3,521	4,211	4,969	5,781	6,632	7,733	9,068	10,463
Japan	53	67	82	98	116	135	155	188	214	243
CEIT	336	428	528	638	759	891	1,030	1,176	1,291	1,424
Article 5	1,150	1,460	1,792	2,152	2,548	3,139	3,766	4,435	5,019	5,711
Annual Global Inventory - Bank	5,627	7,135	8,751	10,498	12,419	14,651	17,003	19,886	22,994	26,369

Halon 1211 Summary in metric tonnes										
YEAR	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Annual Production										
North America, Western Europe and Japan Production	8,259	10,408	12,491	13,731	17,058	20,181	16,182	14,852	11,882	7,921
CEIT Production	0	30	30	30	35	35	80	700	50	50
Article 5 Production	680	1,061	1,342	1,658	2,049	2,545	3,074	3,717	4,646	7,002
Total Annual Production	8,939	11,499	13,863	15,419	19,142	22,761	19,336	19,269	16,578	14,973
Annual Production Allocation										
North America	2,478	3,122	3,747	4,119	5,117	6,054	4,855	4,456	3,565	2,376
Western Europe and Australia	3,634	4,580	5,496	6,042	7,506	8,880	7,120	6,535	5,228	3,485
Japan	83	104	125	137	171	202	162	149	119	79
CEIT	413	550	655	717	888	1,044	889	1,443	644	446
Article 5	2,332	3,142	3,840	4,405	5,461	6,581	6,310	6,687	7,022	8,586
Total Annual Production Allocation	8,939	11,499	13,863	15,419	19,142	22,761	19,336	19,269	16,578	14,973
ANNUAL EMISSIONS										
North America	1,272	1,498	1,764	2,028	2,401	2,829	2,976	3,109	1,792	1,766
Western Europe and Australia	2,154	2,554	3,018	3,459	4,115	4,857	4,988	4,464	4,290	2,155
Japan	52	61	71	82	96	113	111	114	67	66
CEIT	266	308	352	404	472	554	624	731	710	668
Article 5	1,532	1,853	2,236	2,646	3,192	3,843	4,272	4,718	5,143	5,822
Total Annual Emissions - Global Bank	5,276	6,273	7,441	8,618	10,277	12,196	12,972	13,137	12,004	10,477
Total Annual Emissions with Production Loss	5,499	6,560	7,787	9,004	10,756	12,765	13,455	13,378	12,211	10,664
Cumulative Production										
North America, Western Europe and Japan	68,389	78,797	91,288	105,019	122,077	142,258	158,440	173,292	185,174	193,095
CEIT	0	30	60	90	125	160	240	940	990	1,040
Article 5	2,456	3,516	4,858	6,516	8,566	11,111	14,185	17,901	22,547	29,549
Total Cumulative Production	70,845	82,343	96,206	111,625	130,768	153,529	172,865	192,133	208,711	223,684

Cumulative Production Allocation	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
North America	20,517	23,639	27,386	31,506	36,623	42,677	47,532	51,988	55,552	57,929
Western Europe and Australia	30,091	34,671	40,167	46,208	53,714	62,594	69,714	76,248	81,477	84,962
Japan	684	788	913	1,050	1,221	1,423	1,584	1,733	1,852	1,931
CEIT	3,419	3,970	4,624	5,341	6,229	7,273	8,162	9,605	10,249	10,695
Article 5	16,133	19,276	23,116	27,520	32,981	39,562	45,873	52,560	59,582	68,168
Total Cumulative Production Allocation	70,845	82,343	96,206	111,625	130,768	153,529	172,865	192,133	208,711	223,684
Cumulative Emissions										
North America	10,783	12,281	14,045	16,072	18,473	21,302	24,278	27,387	29,180	30,945
Western Europe and Australia	18,148	20,702	23,720	27,179	31,294	36,151	41,139	45,603	49,893	52,048
Japan	411	471	543	624	721	834	945	1,060	1,127	1,193
CEIT	1,849	2,156	2,508	2,912	3,384	3,938	4,562	5,293	6,003	6,671
Article 5	9,621	11,474	13,710	16,356	19,549	23,392	27,664	32,382	37,526	43,348
Total Cumulative Emissions - Global Bank	40,812	47,084	54,525	63,143	73,421	85,617	98,588	111,725	123,729	134,206
Total Cum. Emissions w/ Production Loss	42,583	49,143	56,930	65,934	76,690	89,455	102,910	116,288	128,499	139,162
Global Inventory - Bank										
North America	9,734	11,358	13,342	15,433	18,150	21,375	23,254	24,600	26,373	26,983
Western Europe and Australia	11,943	13,969	16,447	19,030	22,420	26,443	28,575	30,645	31,583	32,913
Japan	273	317	370	426	500	589	639	673	725	738
CEIT	1,571	1,814	2,117	2,429	2,845	3,335	3,600	4,312	4,245	4,024
Article 5	6,512	7,802	9,406	11,164	13,432	16,170	18,209	20,177	22,056	24,820
Annual Global Inventory - Bank	30,033	35,259	41,681	48,482	57,347	67,912	74,276	80,408	84,982	89,479

Halon 1211 **Summary in metric tonnes**

YEAR	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Annual Production										
North America, Western Europe and Japan Production	3,960	0	0	(1)	0	(7)	0	(4)	(1)	(14)
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	8,713	10,448	11,250	14,180	12,124	8,175	6,265	4,278	3,599	2,954
Total Annual Production	12,673	10,448	11,250	14,179	12,124	8,169	6,265	4,274	3,598	2,940
Annual Production Allocation										
North America	1,188	0	0	0	0	0	0	0	0	0
Western Europe and Australia	1,742	0	0	(1)	0	(7)	0	(4)	(1)	(14)
Japan	40	0	0	0	0	0	0	0	0	0
CEIT	198	0	0	0	0	0	0	0	0	0
Article 5	9,505	10,448	11,250	14,180	12,124	8,175	6,265	4,278	3,599	2,954
Total Annual Production Allocation	12,673	10,448	11,250	14,179	12,124	8,169	6,265	4,274	3,598	2,940
ANNUAL EMISSIONS										
North America	1,463	1,369	1,299	940	895	860	827	795	764	735
Western Europe and Australia	1,978	1,906	1,545	1,461	1,388	1,319	1,253	1,190	1,130	1,073
Japan	51	47	44	28	27	26	24	23	22	21
CEIT	330	298	275	254	235	217	200	185	171	158
Article 5	6,517	7,258	8,003	8,555	9,186	9,007	8,181	7,581	6,912	6,247
Total Annual Emissions - Global Bank	10,339	10,877	11,166	11,239	11,731	11,429	10,486	9,774	9,000	8,233
Total Annual Emissions with Production Loss	10,497	11,008	11,306	11,416	11,882	11,531	10,564	9,828	9,045	8,270
Cumulative Production										
North America, Western Europe and Japan	197,055	197,055	197,055	197,054	197,054	197,048	197,048	197,044	197,043	197,028
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	38,262	48,710	59,960	74,140	86,264	94,439	100,704	104,982	108,581	111,535
Total Cumulative Production	236,357	246,805	258,055	272,234	284,358	292,526	298,791	303,065	306,663	309,603

Cumulative Production Allocation	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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	86,704	86,704	86,703	86,703	86,697	86,697	86,693	86,692	86,678
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	77,673	88,121	99,371	113,551	125,675	133,850	140,115	144,393	147,992	150,946
Total Cumulative Production Allocation	236,357	246,805	258,055	272,234	284,358	292,526	298,791	303,065	306,663	309,603
Cumulative Emissions										
North America	32,408	33,777	35,075	36,015	36,910	37,771	38,598	39,393	40,157	40,892
Western Europe and Australia	54,026	55,933	57,478	58,939	60,327	61,646	62,899	64,088	65,219	66,292
Japan	1,244	1,290	1,334	1,362	1,389	1,415	1,439	1,462	1,485	1,506
CEIT	7,000	7,299	7,574	7,828	8,063	8,280	8,480	8,665	8,836	8,993
Article 5	49,865	57,123	65,126	73,681	82,866	91,874	100,055	107,636	114,548	120,794
Total Cumulative Emissions - Global Bank	144,544	155,421	166,587	177,826	189,556	200,985	211,470	221,244	230,244	238,478
Total Cum. Emissions w/ Production Loss	149,659	160,667	171,974	183,390	195,272	206,802	217,366	227,194	236,239	244,509
Global Inventory - Bank										
North America	26,709	25,340	24,041	23,101	22,206	21,346	20,519	19,723	18,959	18,225
Western Europe and Australia	32,678	30,772	29,226	27,764	26,376	25,051	23,798	22,604	21,473	20,386
Japan	727	680	637	608	582	556	531	508	486	464
CEIT	3,892	3,594	3,319	3,064	2,830	2,613	2,413	2,228	2,057	1,899
Article 5	27,808	30,998	34,245	39,870	42,808	41,976	40,060	36,757	33,444	30,151
Annual Global Inventory - Bank	91,813	91,383	91,468	94,408	94,801	91,541	87,321	81,821	76,419	71,125

Halon 1211 Summary in metric tonnes										
YEAR	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Annual Production										
North America, Western Europe and Japan Production	(265)	(184)	(84)	(332)	(307)	(112)	(14)	(12)	(49)	(51)
CEIT Production	0	0	0	0	0	0	0	0	0	0
Article 5 Production	2,384	1,568	165	165	0	0	0	0	0	0
Total Annual Production	2,119	1,384	81	(167)	(307)	(112)	(14)	(12)	(49)	(51)
Annual Production Allocation										
North America	0	0	0	0	0	0	0	0	0	0
Western Europe and Australia	(265)	(184)	(84)	(332)	(307)	(112)	(14)	(12)	(49)	(51)
Japan	0	0	0	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0	0	0	0
Article 5	2,384	1,568	165	165	0	0	0	0	0	0
Total Annual Production Allocation	2,119	1,384	81	(167)	(307)	(112)	(14)	(12)	(49)	(51)
ANNUAL EMISSIONS										
North America	706	679	653	627	603	580	557	536	515	495
Western Europe and Australia	1,098	883	658	628	513	501	482	466	450	434
Japan	20	20	19	18	17	16	16	15	14	14
CEIT	146	134	124	115	106	98	90	83	77	71
Article 5	5,594	4,924	4,149	1,658	1,509	1,383	1,268	1,162	1,065	977
Total Annual Emissions - Global Bank	7,564	6,639	5,602	3,046	2,748	2,578	2,413	2,262	2,121	1,990
Total Annual Emissions with Production Loss	7,594	6,659	5,604	3,048	2,748	2,578	2,413	2,262	2,121	1,990
Cumulative Production										
North America, Western Europe and Japan	196,763	196,579	196,495	196,163	195,856	195,745	195,731	195,719	195,670	195,618
CEIT	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
Article 5	113,919	115,487	115,652	115,817	115,817	115,817	115,817	115,817	115,817	115,817
Total Cumulative Production	311,722	313,106	313,187	313,020	312,713	312,601	312,588	312,576	312,526	312,475

Cumulative Production Allocation	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
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	86,412	86,228	86,144	85,812	85,505	85,394	85,380	85,368	85,319	85,268
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	153,330	154,898	155,063	155,228	155,228	155,228	155,228	155,228	155,228	155,228
Total Cumulative Production Allocation	311,722	313,106	313,187	313,020	312,713	312,601	312,588	312,576	312,526	312,475
Cumulative Emissions										
North America	41,598	42,277	42,930	43,557	44,160	44,739	45,296	45,832	46,347	46,842
Western Europe and Australia	67,389	68,272	68,930	69,558	70,071	70,572	71,054	71,519	71,969	72,403
Japan	1,527	1,546	1,565	1,583	1,600	1,616	1,632	1,647	1,661	1,674
CEIT	9,139	9,273	9,397	9,512	9,618	9,715	9,806	9,889	9,966	10,037
Article 5	126,389	131,313	135,462	137,120	138,629	140,012	141,280	142,443	143,508	144,485
Total Cumulative Emissions - Global Bank	246,042	252,681	258,283	261,330	264,077	266,655	269,068	271,329	273,451	275,441
Total Cum. Emissions w/ Production Loss	252,103	258,762	264,366	267,414	270,162	272,740	275,153	277,414	279,535	281,525
Global Inventory - Bank										
North America	17,518	16,839	16,187	15,560	14,957	14,377	13,820	13,285	12,770	12,275
Western Europe and Australia	19,023	17,956	17,214	16,254	15,434	14,822	14,326	13,849	13,350	12,865
Japan	444	424	406	388	371	355	339	324	310	296
CEIT	1,754	1,619	1,495	1,381	1,275	1,177	1,087	1,004	927	856
Article 5	26,941	23,585	19,601	18,108	16,599	15,215	13,947	12,785	11,720	10,743
Annual Global Inventory - Bank	65,680	60,425	54,903	51,690	48,635	45,946	43,520	41,246	39,076	37,035

Halon 1211 Summary in metric tonnes							
YEAR	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Annual Production							
North America, Western Europe and Japan Production	(11)	(11)	(10)	(3)	0	0	0
CEIT Production	0	0	0	0	0	0	0
Article 5 Production	0	0	0	0	0	0	0
Total Annual Production	(11)	(11)	(10)	(3)	0	0	0
Annual Production Allocation							
North America	0	0	0	0	0	0	0
Western Europe and Australia	(11)	(11)	(10)	(3)	0	0	0
Japan	0	0	0	0	0	0	0
CEIT	0	0	0	0	0	0	0
Article 5	0	0	0	0	0	0	0
Total Annual Production Allocation	(11)	(11)	(10)	(3)	0	0	0
ANNUAL EMISSIONS							
North America	476	457	440	422	406	390	375
Western Europe and Australia	544	521	498	481	460	440	421
Japan	13	12	12	11	11	10	10
CEIT	66	61	56	52	48	44	41
Article 5	1,146	1,024	915	817	730	652	582
Total Annual Emissions - Global Bank	2,244	2,074	1,920	1,784	1,654	1,537	1,430
Total Annual Emissions with Production Loss	2,244	2,074	1,920	1,784	1,654	1,537	1,430
Cumulative Production							
North America, Western Europe and Japan	195,607	195,596	195,586	195,583	195,583	195,583	195,583
CEIT	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
Total Cumulative Production	312,464	312,453	312,443	312,440	312,440	312,440	312,440

Cumulative Production Allocation	2015	2016	2017	2018	2019	2020	2021
North America	59,117	59,117	59,117	59,117	59,117	59,117	59,117
Western Europe and Australia	85,256	85,246	85,235	85,233	85,233	85,233	85,233
Japan	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
Article 5	155,228	155,228	155,228	155,228	155,228	155,228	155,228
Total Cumulative Production Allocation	312,464	312,453	312,443	312,440	312,440	312,440	312,440
Cumulative Emissions							
North America	47,317	47,774	48,214	48,636	49,043	49,433	49,808
Western Europe and Australia	72,947	73,468	73,966	74,447	74,907	75,347	75,768
Japan	1,687	1,700	1,712	1,723	1,734	1,745	1,754
CEIT	10,102	10,163	10,219	10,271	10,318	10,362	10,403
Article 5	145,631	146,654	147,569	148,386	149,116	149,768	150,350
Total Cumulative Emissions - Global Bank	277,685	279,759	281,679	283,463	285,117	286,654	288,084
Total Cum. Emissions w/ Production Loss	283,769	285,844	287,764	289,548	291,202	292,739	294,168
Global Inventory - Bank							
North America	11,799	11,342	10,903	10,480	10,074	9,684	9,308
Western Europe and Australia	12,309	11,778	11,270	10,786	10,326	9,886	9,464
Japan	283	271	259	247	236	226	216
CEIT	790	730	674	622	574	530	490
Article 5	9,597	8,573	7,659	6,842	6,112	5,460	4,878
Annual Global Inventory - Bank	34,779	32,694	30,764	28,977	27,323	25,786	24,357

Appendix E: Historical Production, Emissions and Bank Values from 1963 – 2021 for Halon 2402

Halon 2402 Summary in metric tonnes												
Year	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
Annual Production												
North America, Western Europe and Japan	4	8	16	24	39	53	70	102	158	213	283	333
CEIT	-	-	30	30	50	50	100	275	275	275	275	550
Article 5	-	-	-	-	-	-	-	-	-	-	-	-
Total Annual 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	-	-	30	30	50	50	100	275	275	275	275	550
Article 5	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	6	9	12	17	22
Western Europe and Australia	0	1	1	2	3	5	7	11	16	22	31	40
Japan	0	0	0	0	0	0	1	1	2	2	3	4
CEIT	-	-	4	5	9	12	20	46	60	73	85	130
Article 5	-	0	0	1	1	2	2	3	5	7	10	14
Total Annual Emissions - Global Bank	0	1	6	9	16	22	34	67	91	117	146	210
Total Annual Emissions with Production Loss	0	1	6	10	17	23	36	70	95	122	153	218
Cumulative Production												
North America, Western Europe and Japan	4	13	29	53	91	144	214	316	474	687	970	1,303
CEIT	-	-	30	60	110	160	260	535	810	1,085	1,360	1,910
Article 5(1)	-	-	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	4	13	59	113	201	304	474	851	1,284	1,772	2,330	3,213

Cumulative Production Allocation	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
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	-	-	30	60	110	160	260	535	810	1,085	1,360	1,910
Article 5	1	3	7	13	23	36	54	79	118	172	242	326
Total Cumulative Production Allocation	4	13	59	113	201	304	474	851	1,284	1,772	2,330	3,213
Cumulative Emissions												
North America	0	0	1	2	4	7	11	17	26	38	55	77
Western Europe and Australia	0	1	2	4	7	12	20	30	46	68	99	139
Japan	0	0	0	0	1	1	2	3	4	7	9	13
CEIT	-	-	4	9	18	30	50	96	156	228	313	443
Article 5	-	0	0	1	2	3	6	9	14	21	31	45
Total Cumulative Emissions - Global Bank	0	1	7	16	32	54	88	155	246	363	509	718
Total Cum. Emissions w/ Production Loss	0	2	8	18	34	57	93	163	258	380	533	751
Global Inventory - Bank												
North America	1	3	6	11	19	29	43	62	93	134	187	248
Western Europe and Australia	2	5	11	20	34	52	77	112	167	241	337	447
Japan	0	1	1	2	4	6	9	13	19	28	39	52
CEIT	-	-	26	51	92	130	210	439	654	857	1,047	1,467
Article 5	1	3	7	12	21	33	48	70	105	150	211	280
Annual Global Inventory - Bank	4	11	51	96	169	251	386	697	1,038	1,409	1,821	2,495

Halon 2402 Summary in metric tonnes										
Year	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**
Annual Production										
North America, Western Europe and Japan	283	333	407	527	599	677	770	825	867	1,054
CEIT	275	550	550	550	550	550	1,100	2,200	2,200	2,200
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	558	883	957	1,077	1,149	1,227	1,870	3,025	3,067	3,254
Annual Production Allocation										
North America	71	83	102	132	150	169	192	206	217	263
Western Europe and Australia	127	150	183	237	269	304	346	371	390	474
Japan	14	17	20	26	30	34	38	41	43	53
CEIT	275	550	550	550	550	550	1,100	2,200	2,200	2,200
Article 5	71	83	102	132	150	169	192	206	217	263
Total Annual Production Allocation	558	883	957	1,077	1,149	1,227	1,870	3,025	3,067	3,254
Annual Emissions										
North America	17	22	28	37	45	54	64	74	79	93
Western Europe and Australia	31	40	51	66	81	97	116	134	142	167
Japan	3	4	5	6	8	9	11	13	14	16
CEIT	85	130	155	178	200	221	308	490	592	687
Article 5	10	14	18	24	30	38	46	54	63	73
Total Annual Emissions - Global Bank	146	210	257	311	364	419	545	765	889	1,036
Total Annual Emissions with Production Loss	153	218	267	324	379	436	564	785	910	1,062
Cumulative Production										
North America, Western Europe and Japan	970	1,303	1,710	2,237	2,836	3,512	4,282	5,107	5,974	7,027
CEIT	1,360	1,910	2,460	3,010	3,560	4,110	5,210	7,410	9,610	11,810
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	2,330	3,213	4,170	5,247	6,396	7,622	9,492	12,517	15,584	18,837

Cumulative Production Allocation	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
North America	242	326	428	559	709	878	1,071	1,277	1,493	1,757
Western Europe and Australia	436	586	770	1,007	1,276	1,580	1,927	2,298	2,688	3,162
Japan	48	65	86	112	142	176	214	255	299	351
CEIT	1,360	1,910	2,460	3,010	3,560	4,110	5,210	7,410	9,610	11,810
Article 5	242	326	428	559	709	878	1,071	1,277	1,493	1,757
Total Cumulative Production Allocation	2,330	3,213	4,170	5,247	6,396	7,622	9,492	12,517	15,584	18,837
Cumulative Emissions										
North America	55	77	106	143	188	242	306	380	459	551
Western Europe and Australia	99	139	190	257	338	435	551	684	826	993
Japan	9	13	18	24	32	41	52	65	78	95
CEIT	313	443	597	776	976	1,197	1,505	1,995	2,587	3,274
Article 5	31	45	64	88	118	156	201	256	319	392
Total Cumulative Emissions - Global Bank	509	718	976	1,287	1,651	2,070	2,615	3,380	4,268	5,304
Total Cum. Emissions w/ Production Loss	533	751	1,018	1,343	1,722	2,158	2,722	3,507	4,418	5,480
Global Inventory - Bank										
North America	187	248	322	417	521	636	765	897	1,035	1,205
Western Europe and Australia	337	447	579	750	938	1,146	1,376	1,614	1,862	2,170
Japan	39	52	67	87	110	134	162	191	220	257
CEIT	1,047	1,467	1,863	2,234	2,584	2,913	3,705	5,415	7,023	8,536
Article 5	211	280	364	472	591	722	869	1,021	1,175	1,365
Annual Global Inventory - Bank	1,821	2,495	3,195	3,960	4,745	5,552	6,877	9,137	11,315	13,533

Halon 2402 Summary in metric tonnes										
Year	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Annual Production										
North America, Western Europe and Japan	1,095	1,337	1,559	1,736	2,006	2,291	1,913	1,678	1,345	896
CEIT	2,200	2,200	2,200	2,200	2,300	2,200	2,450	2,450	1,800	1,391
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	3,295	3,537	3,759	3,936	4,306	4,491	4,363	4,128	3,145	2,287
Annual Production Allocation										
North America	274	334	390	434	502	573	478	419	336	224
Western Europe and Australia	493	602	702	781	903	1,031	861	755	605	403
Japan	55	67	78	87	100	115	96	84	67	45
CEIT	2,200	2,200	2,200	2,200	2,300	2,200	2,450	2,450	1,800	1,391
Article 5	274	334	390	434	502	573	478	419	336	224
Total Annual Production Allocation	3,295	3,537	3,759	3,936	4,306	4,491	4,363	4,128	3,145	2,287
Annual Emissions										
North America	104	121	133	153	176	202	212	186	158	159
Western Europe and Australia	187	218	240	275	317	364	381	275	287	288
Japan	18	21	23	26	30	35	36	28	29	30
CEIT	777	862	942	1,017	1,099	1,158	1,163	1,050	1,076	1,085
Article 5	84	96	111	128	147	169	189	204	214	218
Total Annual Emissions - Global Bank	1,171	1,319	1,449	1,598	1,769	1,929	1,981	1,742	1,764	1,779
Total Annual Emissions with Production Loss	1,198	1,352	1,488	1,642	1,820	1,986	2,029	1,763	1,781	1,790
Cumulative Production										
North America, Western Europe and Japan	8,123	9,460	11,019	12,755	14,761	17,053	18,966	20,644	21,988	22,885
CEIT	14,010	16,210	18,410	20,610	22,910	25,110	27,560	30,010	31,810	33,201
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	22,133	25,670	29,429	33,365	37,671	42,163	46,526	50,654	53,798	56,086

Cumulative Production Allocation	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
North America	2,031	2,365	2,755	3,189	3,690	4,263	4,742	5,161	5,497	5,721
Western Europe and Australia	3,655	4,257	4,958	5,740	6,643	7,674	8,535	9,290	9,895	10,298
Japan	406	473	551	638	738	853	948	1,032	1,099	1,144
CEIT	14,010	16,210	18,410	20,610	22,910	25,110	27,560	30,010	31,810	33,201
Article 5	2,031	2,365	2,755	3,189	3,690	4,263	4,742	5,161	5,497	5,721
Total Cumulative Production Allocation	22,133	25,670	29,429	33,365	37,671	42,163	46,526	50,654	53,798	56,086
Cumulative Emissions										
North America	655	777	910	1,063	1,239	1,441	1,653	1,839	1,997	2,155
Western Europe and Australia	1,180	1,398	1,638	1,913	2,230	2,594	2,975	3,250	3,537	3,824
Japan	113	134	157	183	213	248	284	312	342	371
CEIT	4,051	4,914	5,855	6,872	7,971	9,129	10,292	11,342	12,418	13,503
Article 5	476	572	683	811	958	1,126	1,316	1,520	1,734	1,952
Total Cumulative Emissions - Global Bank	6,475	7,794	9,243	10,841	12,611	14,539	16,520	18,263	20,027	21,806
Total Cum. Emissions w/ Production Loss	6,678	8,031	9,518	11,160	12,980	14,966	16,994	18,758	20,539	22,329
Global Inventory - Bank										
North America	1,375	1,588	1,845	2,126	2,452	2,822	3,089	3,322	3,500	3,566
Western Europe and Australia	2,475	2,859	3,320	3,827	4,413	5,079	5,559	6,040	6,358	6,474
Japan	293	339	394	455	525	605	664	720	758	773
CEIT	9,959	11,296	12,555	13,738	14,939	15,981	17,268	18,668	19,392	19,698
Article 5	1,555	1,793	2,072	2,378	2,733	3,137	3,426	3,641	3,763	3,769
Annual Global Inventory - Bank	15,657	17,876	20,186	22,524	25,061	27,623	30,006	32,391	33,771	34,280

Halon 2402 Summary in metric tonnes										
Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Annual Production										
North America, Western Europe and Japan	448	-	-	-	-	-	-	-	-	-
CEIT	400	400	400	352	300	255	160	90	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	848	400	400	352	300	255	160	90	-	-
Annual Production Allocation										
North America	112	-	-	-	-	-	-	-	-	-
Western Europe and Australia	202	-	-	-	-	-	-	-	-	-
Japan	22	-	-	-	-	-	-	-	-	-
CEIT	400	400	400	352	300	255	160	90	-	-
Article 5	112	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	848	400	400	352	300	255	160	90	-	-
Annual Emissions										
North America	155	130	110	107	103	100	97	93	90	88
Western Europe and Australia	281	237	200	194	187	181	175	170	164	159
Japan	29	24	21	21	20	20	19	18	18	17
CEIT	944	918	800	782	586	572	561	547	531	514
Article 5	216	207	195	184	174	164	155	146	138	130
Total Annual Emissions - Global Bank	1,623	1,516	1,327	1,287	1,070	1,037	1,007	975	942	908
Total Annual Emissions with Production Loss	1,629	1,516	1,327	1,287	1,070	1,037	1,007	975	942	908
Cumulative 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	33,601	34,001	34,401	34,753	35,053	35,308	35,468	35,558	35,558	35,558
Article 5(1)	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	56,934	57,334	57,734	58,086	58,386	58,641	58,801	58,891	58,891	58,891

Cumulative Production Allocation	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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	33,601	34,001	34,401	34,753	35,053	35,308	35,468	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 Cumulative Production Allocation	56,934	57,334	57,734	58,086	58,386	58,641	58,801	58,891	58,891	58,891
Cumulative Emissions										
North America	2,310	2,440	2,551	2,657	2,760	2,860	2,957	3,050	3,141	3,228
Western Europe and Australia	4,105	4,342	4,542	4,735	4,923	5,104	5,279	5,449	5,613	5,772
Japan	400	424	445	466	486	506	525	543	561	579
CEIT	14,447	15,365	16,165	16,947	17,533	18,105	18,665	19,212	19,744	20,258
Article 5	2,168	2,375	2,570	2,755	2,929	3,093	3,248	3,394	3,531	3,661
Total Cumulative Emissions - Global Bank	23,430	24,946	26,273	27,560	28,631	29,668	30,674	31,649	32,590	33,498
Total Cum. Emissions w/ Production Loss	23,958	25,474	26,802	28,089	29,160	30,196	31,203	32,177	33,119	34,027
Global Inventory - Bank										
North America	3,523	3,393	3,283	3,176	3,073	2,973	2,876	2,783	2,692	2,605
Western Europe and Australia	6,395	6,158	5,958	5,764	5,577	5,396	5,220	5,051	4,887	4,728
Japan	766	743	721	701	680	661	642	623	605	588
CEIT	19,154	18,636	18,236	17,806	17,520	17,203	16,803	16,346	15,814	15,300
Article 5	3,665	3,458	3,263	3,079	2,905	2,741	2,586	2,440	2,302	2,172
Annual Global Inventory - Bank	33,504	32,388	31,461	30,525	29,755	28,973	28,127	27,242	26,301	25,393

Halon 2402 Summary in metric tonnes										
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Annual Production										
North America, Western Europe and Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-	-	-	-
Annual Production Allocation										
North America	-	-	-	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-	-	-	-
Annual Emissions										
North America	85	82	79	77	74	72	69	67	65	63
Western Europe and Australia	154	149	124	163	149	144	138	133	129	124
Japan	17	16	16	15	15	15	14	14	13	13
CEIT	497	481	465	450	436	422	408	395	382	369
Article 5	123	116	109	103	97	92	87	82	77	73
Total Annual Emissions - Global Bank	875	844	794	808	771	743	716	691	666	642
Total Annual Emissions with Production Loss	875	844	794	808	771	743	716	691	666	642
Cumulative 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)	-	-	-	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891

Cumulative Production Allocation	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
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 Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions										
North America	3,313	3,395	3,474	3,551	3,625	3,697	3,766	3,833	3,898	3,961
Western Europe and Australia	5,926	6,074	6,198	6,361	6,510	6,654	6,792	6,925	7,054	7,178
Japan	595	612	628	643	658	673	687	701	714	727
CEIT	20,755	21,236	21,701	22,152	22,587	23,009	23,417	23,811	24,193	24,563
Article 5	3,784	3,900	4,009	4,112	4,209	4,301	4,388	4,469	4,546	4,619
Total Cumulative Emissions - Global Bank	34,373	35,217	36,011	36,819	37,590	38,334	39,050	39,741	40,407	41,049
Total Cum. Emissions w/ Production Loss	34,902	35,746	36,540	37,348	38,119	38,862	39,579	40,269	40,935	41,577
Global Inventory - Bank										
North America	2,520	2,438	2,359	2,282	2,208	2,136	2,067	2,000	1,935	1,872
Western Europe and Australia	4,574	4,425	4,302	4,139	3,990	3,846	3,708	3,574	3,446	3,322
Japan	571	555	539	523	508	494	479	466	452	439
CEIT	14,803	14,322	13,857	13,406	12,971	12,549	12,141	11,747	11,365	10,995
Article 5	2,049	1,933	1,824	1,721	1,624	1,532	1,445	1,364	1,287	1,214
Annual Global Inventory - Bank	24,518	23,674	22,880	22,072	21,301	20,557	19,841	19,150	18,484	17,842

Halon 2402 Summary in metric tonnes							
Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Annual Production							
North America, Western Europe and Japan	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-
Total Annual Production	-	-	-	-	-	-	-
Annual Production Allocation							
North America	-	-	-	-	-	-	-
Western Europe and Australia	-	-	-	-	-	-	-
Japan	-	-	-	-	-	-	-
CEIT	-	-	-	-	-	-	-
Article 5	-	-	-	-	-	-	-
Total Annual Production Allocation	-	-	-	-	-	-	-
Annual Emissions							
North America	61	59	57	55	53	52	50
Western Europe and Australia	120	115	111	107	103	100	96
Japan	13	12	12	12	11	11	11
CEIT	357	346	335	324	313	303	293
Article 5	69	65	61	58	54	51	48
Total Annual Emissions - Global Bank	619	597	576	555	535	516	498
Total Annual Emissions with Production Loss	619	597	576	555	535	516	498
Cumulative Production							
North America, Western Europe and Japan	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
Article 5(1)	-	-	-	-	-	-	-
Total Cumulative Production	58,891	58,891	58,891	58,891	58,891	58,891	58,891

Cumulative Production Allocation	2015	2016	2017	2018	2019	2020	2021
North America	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
Japan	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
Article 5	5,833	5,833	5,833	5,833	5,833	5,833	5,833
Total Cumulative Production Allocation	58,891	58,891	58,891	58,891	58,891	58,891	58,891
Cumulative Emissions							
North America	4,022	4,081	4,138	4,193	4,246	4,298	4,348
Western Europe and Australia	7,298	7,413	7,524	7,631	7,735	7,834	7,930
Japan	740	752	764	776	787	798	809
CEIT	24,920	25,266	25,600	25,924	26,237	26,540	26,833
Article 5	4,688	4,753	4,814	4,871	4,926	4,977	5,025
Total Cumulative Emissions - Global Bank	41,668	42,264	42,840	43,395	43,930	44,447	44,944
Total Cum. Emissions w/ Production Loss	42,196	42,793	43,369	43,924	44,459	44,975	45,473
Global Inventory - Bank							
North America	1,811	1,752	1,695	1,640	1,587	1,535	1,485
Western Europe and Australia	3,202	3,087	2,976	2,868	2,765	2,666	2,570
Japan	427	414	402	391	380	369	358
CEIT	10,638	10,292	9,958	9,634	9,321	9,018	8,725
Article 5	1,145	1,081	1,020	962	908	856	808
Annual Global Inventory - Bank	17,223	16,626	16,051	15,496	14,961	14,444	13,946

UN environment programme | ozone secretariat