Halons
Technical Options Committee

2018
Assessment Report

Volume 2

Montreal Protocol
on Substances
that Deplete the
Ozone Layer

UN environment
United Nations
Environment Programme

Ozone Secretariat

MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

REPORT OF THE
HALONS TECHNICAL OPTIONS COMMITTEE

DECEMBER 2018

VOLUME 2

2018 SUPPLEMENTARY REPORT #1

CIVIL AVIATION

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Dedication

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

Thomas A. Bush

Acknowledgements

The UNEP Halons Technical Options Committee (HTOC) 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.

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Preface

The December 2018 HTOC Report consists of three volumes:

Volume 1: 2018 Assessment Report

Volume 2: 2018 Supplementary Report #1 – Civil Aviation

Volume 3: 2018 Supplementary Report # 2 – Global Halon 1211, 1301, and 2402 Banking

Supplemental Report #1, *Civil Aviation*, expands on the abbreviated information contained in the main body of the 2018 Assessment Report of the UNEP Halons Technical Options Committee (HTOC), which briefly introduces the subject of *Civil Aviation* and refers the interested reader to this document. The 2010 HTOC Assessment report was a long and somewhat unwieldy document, with a high proportion of static or unchanged data. The HTOC felt that placing these data in supplementary reports or technical notes would improve the readability of the 2014 Assessment Report. However subsequent feedback indicated the 2014 Assessment report contained too little information. Therefore, the HTOC 2018 Assessment report contains more information, with additional material in this Supplementary Report.

1.0 Introduction

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 extensive. 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 also of passengers and flight crew, who could be exposed to the agent and any decomposition products for periods as long as several hours.
- Weight and space requirements of the agent and associated hardware.

Also significant are short- and long-term damage to aircraft structure or contents resulting from 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 situations have been implemented, the status of halon in the civil aircraft sector must be viewed in three different contexts: existing aircraft, newly produced aircraft of existing models, and new models of aircraft. All of them continue to depend on halon for the majority of their fire protection applications. Given the anticipated 25–40 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 has commenced efforts to stockpile halon.

Decision XV/11 was the first of several Decisions that authorized representatives of the Ozone Secretariat and the Technology and Economic Assessment Panel (TEAP) and its Halons Technical Options Committee (HTOC) to work with the International Civil Aviation Organization (ICAO) on the development of a plan of action that would eventually lead to the elimination of the need for halons on board civil aircraft. The HTOC has worked closely with ICAO bodies to develop Resolutions to require a scheduled halon replacement in certain applications where alternatives were available. At the 29th Meeting of the Parties in Montreal in November 2017 the parties made Decision XXIX/8 which requested the HTOC to

> (a) Continue to liaise with the International Civil Aviation Organization on the development and implementation of alternatives to halons, and their rate of adoption by civil aviation, and to report thereon in its 2018 progress report;
>
> (b) To explore the possibility of forming a joint working group with the International Civil Aviation Organization to develop and thereafter carry out a study to determine the current and projected future quantities of halons installed in civil aviation fire protection systems, the associated uses and releases of halons from those systems and any potential courses of action that civil aviation could take to reduce those uses and releases;

(c) To submit a report on the work of the joint working group, if established under paragraph 1 (b) above, before the Thirtieth Meeting of the Parties and the fortieth session of the Assembly of the International Civil Aviation Organization for consideration and potential further action;

Additionally**,** at the 29th Meeting of the Parties in Quito in November 2018 the parties made Decision XXX/7 which requested the TEAP, through the HTOC to

(a) Continue engaging with the International Maritime Organization 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;

2.0 Estimated Halon Usage and Emissions

2.1 Installed Base of Halon 1301 and 1211

Aircraft fleet and delivery estimates from Airbus and Boeing market reports were used to estimate the current and projected civil aviation fleet worldwide, including mainline aircraft, regional aircraft, business jets, and turboprops.[1] **Error! Reference source not found.** below outlines the current and projected worldwide fleet.

Table 2.1: Fleet Estimates (2018-2036)

Year	2018	2023	2028	2033	2036
Total Mainline Fleet	22,378	27,623	32,869	38,114	41,261
Total Regional Fleet	1,887	2,329	2,771	3,214	3,479
Total Business Jets Fleet	18,900	22,925	26,950	30,975	33,390
Total Turboprops Fleet	9,358	7,906	6,453	5,000	4,128
Total Fleet	**52,523**	**60,783**	**69,043**	**77,303**	**82,258**

Source: ICF (2018)

To estimate the number of installed halon systems per aircraft, activity data for engine nacelles, cargo compartments, APUs, lavatory extinguishing systems, and handheld applications from previous analyses were used, as well as feedback from airframe manufacturers. These "activity data" were used in turn to estimate the installed halon base across the commercial aviation fleet.

The assumptions by halon 1301 application type for in-production aircraft are as follows: the engine nacelle application assumes one halon bottle per engine; the baggage/cargo application varies according to flight distance and estimated cargo space;[2] ; however, it was assumed that half of the business jet fleet has an additional halon 1301 system in the baggage/cargo compartment, the APU application assumes one bottle per aircraft; and the lavatory extinguishing application assumes one bottle per regional aircraft.[3]

Using this bottom-up approach, approximately 2,706 metric tonnes of halon 1301 is estimated to be installed across the civil aviation fleet in 2018 (see Table 2.2). Based on the growth trend observed through 2036, the installed base of halon 1301 was projected out through 2058.

---

[1] Estimates of business jets and turboprops were developed using data provided by Verdonik (2014).

[2] The installed halon in the baggage/cargo section of the aircraft varies depending on the aircraft type and maximum distance to the closest airstrip at any point during the flight. When a fire is detected, there is an initial halon release into the cargo space. The halon continues to be released at a slower rate to maintain halon levels until the plane can safely land at the closest airstrip.

[3] Lavatory fire extinguishing systems no longer use halon 1301 in mainline aircraft (HTOC 2010).

Table 2.2: Estimated Installed Base of Halon 1301 in Commercial Aircraft Worldwide (metric tonnes)

Application	**2018**	**2028**	**2038**	**2048**	**2058**
Engine Nacelle	970	1,409	1,847	2,286	2,725
APU	84	124	165	205	245
Baggage/Cargo	1,645	2,399	3,154	3,908	4,662
Lavatory Systems	7	7	7	7	7
Total Installed	**2,706**	**3,939**	**5,172**	**6,406**	**7,639**

2.2 Installed Base of Halon 1211

The assumption for the halon 1211 handheld application is two bottles per mainline aircraft and one bottle per regional aircraft. Now that civil aviation has started to install a halon 1211 replacement agent on newly produced aircraft, it is assumed that halon 1211 will only be required to service the existing fleet, and as these aircraft are retired the installed base should begin to decrease. The decrease in the installed base should accelerate once the European retrofit comes into force in 2025 and further still if any airlines or operators undergo any voluntary retrofit activities, which they may choose to do for operational reasons. Thus, at this point in time, it does not appear that there will be a demand deficit for halon 1211.

2.3 Estimated Civil Aviation Emissions

In response to Decision XXIX/8 the HTOC and ICAO formed an informal working group to determine the current and projected future quantities of halon installed in civil aviation fire protection systems, the associated uses and releases of halon from those systems and any potential courses of action to minimize unnecessary halon emissions as requested by Decision XXIX/8. The working group consists of representatives from commercial industry, civil aviation non-governmental organizations, the ICAO secretariat, HTOC and TEAP. The working group prepared a survey that ICAO sent out officially as an ICAO State letter to all civil aviation halon 1301 service providers. The purpose of the survey was to provide a more accurate calculation of the annual amount of halon 1301 emitted civil aviation wide. The timetable agreed by ICAO and HTOC has been set to meet the Decision XXIX/8 deadlines to report back to the 30th Meeting of the Parties and the 40th ICAO General Assembly.

One of the main goals of the survey was to obtain information on the difference between the amount of halon that comes into civil aviation halon 1301 service provider facilities in cylinders for servicing (recovered) and the amount that goes out of the facility in serviced cylinders (filled) as a way of estimating the size and rate of emissions. Unfortunately, many facilities do not keep these exact records and many facilities did not provide complete data, so it was not possible to make this type of determination. For the 10 facilities that did provide some data in this area, the difference between the amount of recovered halon and the amount filled ranged from 4% to 50%, with an average of about 14%. While it is not possible from these limited data to determine the relationship between the 14% data point and the actual emission rate, it does provide additional anecdotal information on top of that contained in the 2014 United States (US) Federal Aviation

Administration (FAA) Halon Aviation Rulemaking Committee report, FAA (2014), that the aviation emissions rate for halon 1301 may be significantly higher than the global industry average of 3-4%.

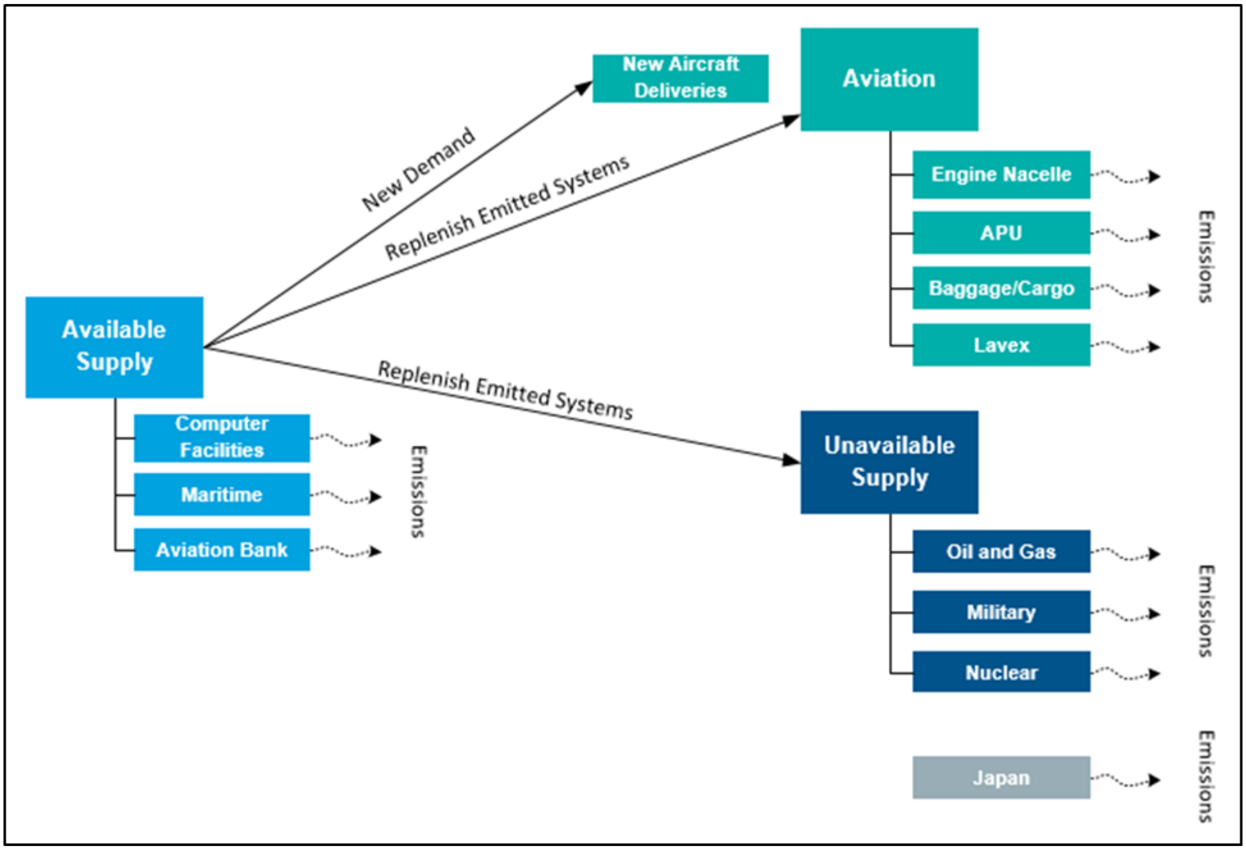
In reviewing the surveys, it was determined that a number of major aviation service companies have not responded and some that did provided data only from the facility that received the survey and not from all of the company's facilities. Seven of the survey respondents that do not service halon 1301 systems themselves provided information on the companies that they contract with to do the service. ICAO is following up with these companies and those that did not respond in an attempt to obtain additional and more complete survey responses. If any significant new information becomes available this supplemental report will be updated, so the reader is advised to check for updates. In addition there might be updated reports on Decision XXIX/8, so the reader is also advised to check the Ozone Secretariat website at https://ozone.unep.org/science/assessment/teap and search for the relevant report

2.3.1 Estimates of When Halon 1301 Might Run Out

2.3.1.1 Introduction

At present, the halon demands of civil aviation and most other existing uses of halons (e.g., oil and gas, military, etc.) are being met by recycling agent being withdrawn from applications in other industries and decommissioned aircraft. As reported to parties in the Decision XXVI/7 and the XXIX/8 reports, the HTOC expresses concern that this source of supply will be dramatically reduced or completely exhausted long before the aircraft now being built and fitted (and potentially still designed) with halon systems are retired. Although HTOC has previously reported that this might result in civil aviation submitting an Essential Use Nomination (EUN), the impact could be broader. Since most other existing users do not have long-term, dedicated stockpiles, they are also vying for the same halon supplies that civil aviation does. This supply and demand is illustrated in Figure 2.1 below (taken from ICF 2018).

Figure 2.1: Halon 1301 Supply and Demand



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.

2.3.1.2 Estimated Halon 1301 Supplies

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

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

- Military applications are estimated to have 4,500 metric tonnes in the installed base and reserves.
- Oil and gas facilities are estimated to have 1,500 metric tonnes.
- Nuclear facilities are estimated to have 200 metric tonnes

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

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

To determine the potential availability of halon 1301 to support civil aviation, eight scenarios were developed to estimate halon 1301 resources needed to service the existing aviation fleet, account for aviation growth through 2060, and to also service continuing non-aviation applications (ICF, 2018). Each scenario assumes various annual emission rates from all halon 1301 aviation applications (i.e., 2.3%-2.8%, 5%, 7.6%, or 15%) and varying emission rates for non-aviation sources (i.e., between 0.1% and 5%), which were reevaluated and refined for this update. The highest annual aviation emission rate (i.e., 15%) was estimated using the global average annual halon emission rate of about 4% from Vollmer et al., (2016) and the proportion of halon emissions from the aviation sector. In addition, the HTOC is aware of anecdotal information that supports this potentially high emission rate.

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

The eight scenarios model +/- 10% of the initial total available worldwide supply of halon 1301 as of the end of 2018 at 12,500 metric tonnes (i.e., a low and a high of approximately 11,250 and 13,750 metric tonnes respectively). The general assumptions for all scenarios modeled and the years in which the available halon 1301 is expected to be sufficient to meet demand in each scenario are summarized in Table 4.1. The best-case and worst-case scenarios are highlighted in yellow.

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

Table 2.3: Assumptions and Results for Eight Drawing Down Halon 1301 Scenarios

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

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

As aircraft fire extinguishing agent containers are typically hermetically sealed, the incidence of leakage is likely to be low. Therefore, it follows that the majority of these emissions are likely to 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. Technologies exist from numerous suppliers that can improve this situation and there is an FAA Technical Standard Order (TSO) covering certification of new cargo compartment smoke detection systems.

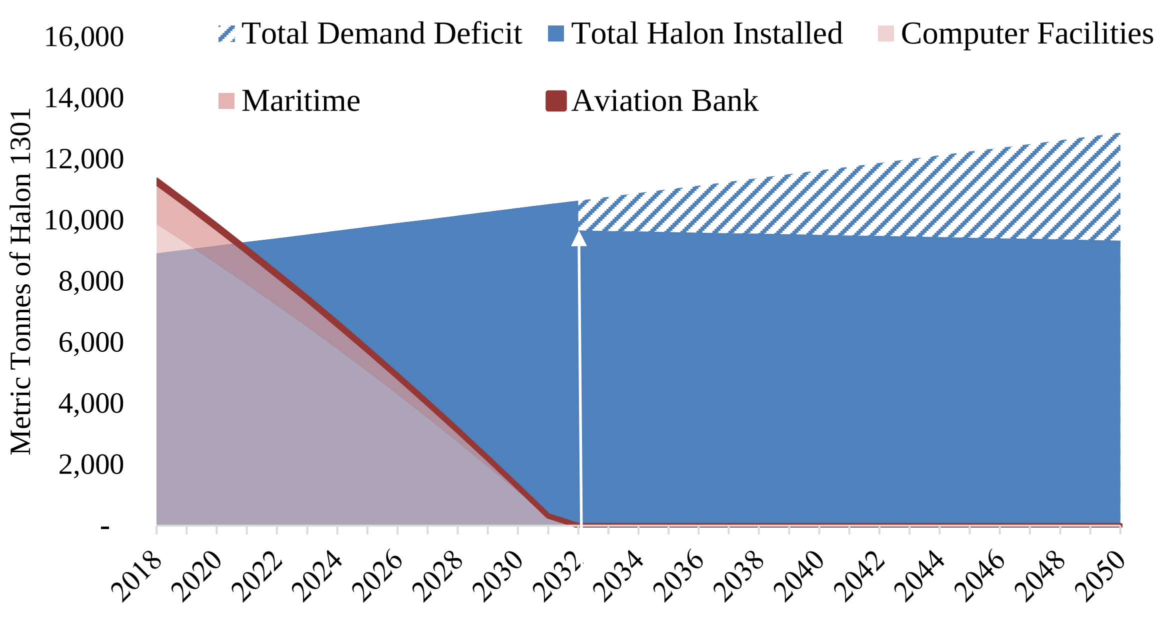


Figure 2.2: Scenario 4: Drawing down Halon 1301 Showing **the Entire Available Supply** (3.9% Overall Emission Rate; 11,250 metric tonnes of Available Supply)

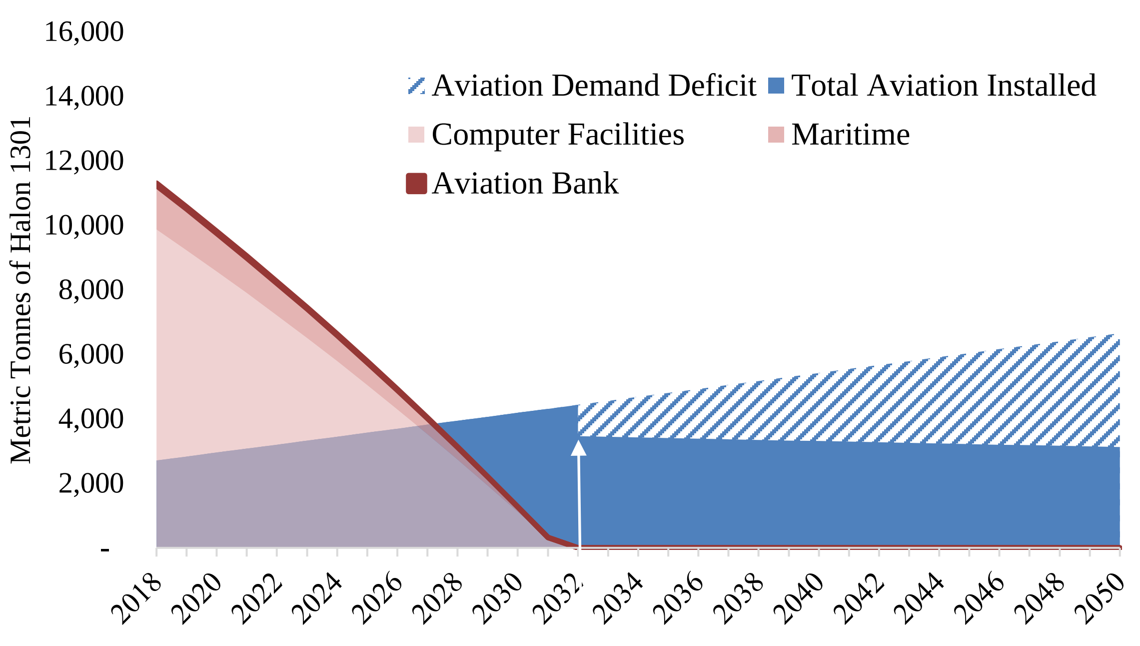


Figure 2.3: Scenario 4: Drawing Down Halon 1301 Showing **the Available Supply and Civil Aviation Bank** (3.9% Overall Emission Rate; 11,250 metric tonnes of Available Supply)

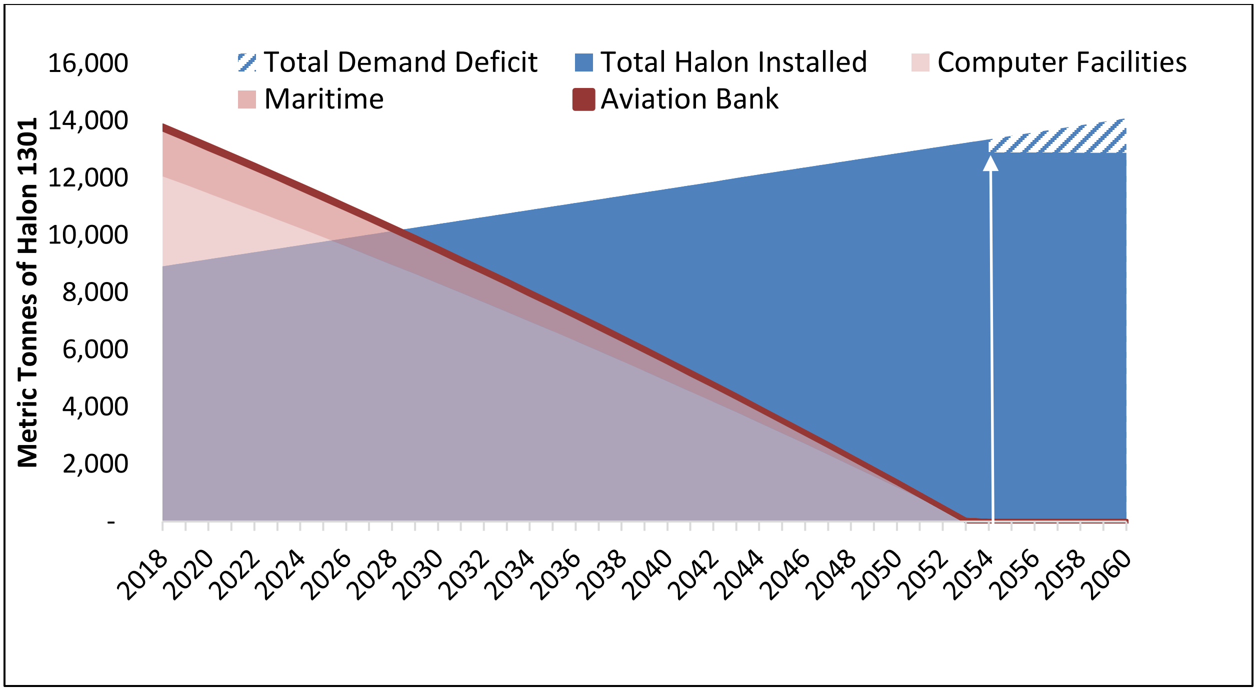


Figure 2.4: Scenario 5: Drawing Down Halon 1301 Showing the **Entire Available Supply** (**1.6%** Overall Emission Rate; **13,750** metric tonnes of Available Supply)

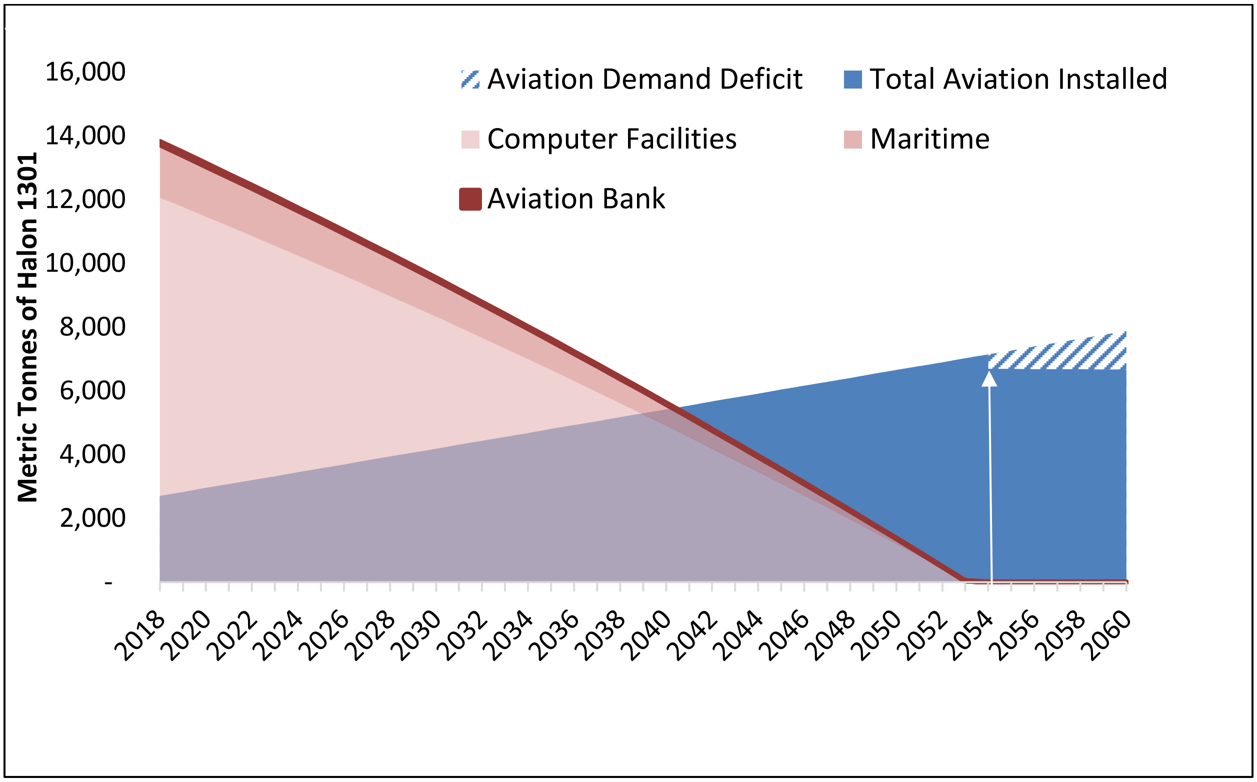


Figure 2.5: Scenario 5: Drawing Down Halon 1301 Showing **the Available Supply and Civil Aviation Bank** (1.6% Overall Emission Rate; 13,750 metric tonnes of Available Supply**)**

2.3.1.3 Potential for Smaller Global Halon 1301 Bank

The above assessment was based on the estimated halon 1301 global bank in the HTOC 2018 model. Atmospheric concentration-based emission estimates in the updated Vollmer paper, Vollmer et al., (2016) mean data through mid-2017 provide cumulative emissions of 118,000 metric tonnes, which is more than was estimated previously in the 2014 HTOC Assessment Report, HTOC (2014). Based on the global total cumulative production data from the HTOC, which is also used by Vollmer et al., the mean values of the updated Vollmer et al. (2016) data through mid-2017 provide a remaining bank of only 30,000 metric tonnes versus the HTOC model estimate of approximately 109,000 metric tonnes of cumulative emissions and a remaining bank of 39,000 metric tonnes. Using the average of the two bank sizes, the difference in remaining banks is nearly 25%. This difference is becoming significant as the global bank (i.e., the amount halon that is available to support fire protection uses) becomes smaller over time. The updated Vollmer et al. (2016) data, provide a much higher mean annual emission rate for 2016/2017 of about 4% of the bank/year than the approximately 2.5% composite rate used by the HTOC. The combination of a potential higher emission rate than assumed by the HTOC and a smaller bank of halon 1301 could also imply that there is going to be significantly less halon 1301 available to support civil aviation and others needs than estimated above. As the supply of halons gets further reduced the likelihood of a significant disruption in supply increases dramatically. If civil aviation does not stop producing new aircraft using halon 1301, they soon will be or are likely already producing and potentially designing new aircraft that cannot be sustained over their economic lifetimes with existing supplies of recycled halon 1301.

3.0 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 levels[4],
- 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 the Halons Technical Options Committee 2018 Assessment Report.

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[4] Recalling that the majority of aircraft related emissions are due to cargo compartment false alarms.

4.0 Status of Halon Replacement Options for Aviation

Halons are used for fire suppression on civil aircraft in:

- Lavatory trash receptacle extinguishing systems;
- Handheld extinguishers;
- Engine nacelle/auxiliary power unit (APU) protection systems; and
- Cargo compartment extinguishing systems.

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 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 equivalent to halon in specific applications. As such, substitutes for halons in civil aviation fire extinguishing systems are evaluated and approved according to the relevant Minimum Performance Standards (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.

4.1 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 (i.e., involving paper materials). All lavatory extinguishing systems using halon alternatives must meet the Minimum Performance Standard, Marker (1997), that includes the ability to extinguish a Class A fire and in the case of discharge, not create an environment that exceeds the chemical agent’s maximum acceptance level for toxicity.

Research and testing has shown that there are suitable alternative suppression systems (using the high Global Warming Potential (GWP) agents HFC-227ea or HFC-236fa) available 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 operations.

There are no approved low-GWP alternatives for this application to replace HFC-227ea, HFC-236fa or halon 1301, and the HTOC is not aware of any research to develop one at this time.

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.

4.2 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 Underwriters Laboratories (UL) or an equivalent listing organisation. To be listed, the extinguisher must be able to disperse in a manner that allows for a hidden fire to be suppressed and does not cause any unacceptable visual obscuration, passenger discomfort, and toxic effects where people are present. In addition to the MPS, the US EPA has published an Advisory Circular, FAA (2011), which provides guidance on fire-fighting 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 2003, three halon alternatives, HFC-227ea, HFC-236fa and HCFC Blend B, 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, and environmental concerns of high GWP for the two HFCs and production phase-out for HCFCs under the Montreal Protocol for the HCFC blend. Qualification and installation certification by airframe manufacturers and regional authorities is needed prior to airline use. Based on these issues, airframe manufacturers have chosen not to pursue qualification and installation certification for these alternatives.

Testing of a “low GWP” and “near-zero ODP” unsaturated HBFO known as 3,3,3-trifluoro-2-bromo-prop-1-ene or 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 4.1. The agent has received regulatory approval in both the US and the EU.

Table 4.1: Options for Handheld Extinguishers for Aircraft Use

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	**3.75**	**5.6**	**15.75 x 5 x 3.5**	**0.0028[2]** **(3D-model)**	**0.005[2]**
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]

1. World Meteorological Organization Report No. 52 – “Scientific Assessment of Ozone Depletion: 2010.” (Note that ODP of HCFC Blend B was rounded up from 0.0098). http://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2010/index.shtml
2. 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. (Note that ODP/GWP values vary depending on the assumed geographical distribution of BTP release. The latitudes considered include the US and EU).

This transition to 2-BTP for newly produced aircraft is ongoing. Two manufacturers have developed approved handheld extinguishers, which have been selected by some of the major aircraft OEMs and this agent is gradually replacing halon 1211 on a platform by platform basis.

4.3 Engine and APU Compartment

4.3.1 Alternative Agent Options

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 nacelle 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 currently being developed for use on a military derivative of a large commercial aircraft (Boeing 767; military derivative KC-46). HFC-125 has increased space and weight characteristics that present installation concerns.

Also, HFCs are considered high global warming chemicals and are now subject to phase-down (not a phase-out, but a limit to future production) under the Kigali Amendment to the Montreal Protocol. Based on these issues, particularly the additional weight, airframe manufacturers have chosen not to pursue qualification and installation certification for HFC-125 in engines/APUs.

A finalized MPS for engine nacelle/APU fire protection will be published in a forthcoming FAA report, but a deadline for formal publication has not been defined as yet. Three potential replacement agents, HFC-125, CF_3I, and FK-5-1-12 were tested against a previous version of the MPS and halon 1301 equivalent concentrations were determined, Ingerson (2007). The equivalent concentrations relative to halon 1301 are presented in Table 4.2 below, along with historical data for CO_2, FAA (1977).

Table 4.2: Equivalent Concentrations for CF3I, FK-5-1-12, HFC-125 and CO2 for Aircraft Engine Nacelles

Agent	**Equivalent Concentration (Volume%)** [a]	**Mass (kg/m^3)**[b]	**Mass Ratio to Halon 1301**	**Volume Ratio to Halon 1301**
Halon 1301	6	0.510	1	1
CF_3I	7.1	0.815	1.60	1.17
Novec 1230	6.1	1.172	2.30	2.21
HFC-125	17.6	1.394	2.73	3.54
CO_2	34	1.186	2.33	4.63

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

[b] Halon 1301 calculated from NFPA12A, NFPA (2018), and replacement agents from ISO14520, ISO (2015), using a temperature of -40°C

From Table 4.2 it is clear that CF_3I is closest to a "drop-in" replacement for halon 1301 for engine / APU applications. 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 testing, attention was focused elsewhere. However, given the lack of significant progress over the last two decades, it is apparent that attention is refocusing on CF_3I as an engine nacelle / APU fire extinguishing agent.

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. Also, an engine nacelle system based on the use of a dry powder failed a required full-scale test. At this time, the system manufacturer is carrying out further work to improve the performance of the dry powder system with the intent of returning to the FAA to re-test.

4.3.2 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, Textron, and the Ohio Aerospace Institute is acting as administrator. Engagement with fire extinguishing suppliers and distributors, chemical companies, airline operators, engine manufacturers, universities, consultants and other stakeholders is planned. The consortium has mapped out a three phase multi-year approach for alternatives development and has recently completed Phase I (administrative start-up), with a signed Joint Collaboration Agreement in place. Phase II (formal creation of Technical and Non-Technical Task Teams) has commenced and has completed the initial FAA Engagement and drafts for a technical requirements document and a Request for Information. Work in-progress includes definition of high level solution(s) strategy, design requirements, performance validation, down selection criteria, regulatory requirements, certification path proposals and formation of the non-technical task team to develop supplier engagement documentation. The consortium projects that Phase II is expected to be complete no later than the end of October 2019 with agent down selection. Phase III will then establish supplier agreements for in-depth agent evaluation and testing. The HTOC notes that the progress of this consortium is slower than was originally forecast by the consortium and reported in the 2014 HTOC Assessment Report. The consortium is of the opinion that the benefits of industry-wide solution(s) will pool resources for testing and development, support more timely agency approvals, and leverage supply chain readiness for more economically viable implementations.

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

4.4 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 as a Class E cargo compartment in which fire suppression is realized differently. Fire control typically is effected by depressurising the main deck cargo compartment, reaching the landing site 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 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.

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 a Class A deep-seated fire for at least 30 minutes and a Class A fire inside a cargo container for at least 30 minutes. 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.

To date, there have been no cases of halon 1301 replacement with an alternative agent in cargo compartments of civil aircraft. All halogenated agents that have undergone the exploding-aerosol-can test have been shown to cause an undesired increase in the test compartment pressure if discharged at a concentration below which the agent will suppress a fire or deflagration event.

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 halogenated agents tested so far have been found to be unacceptable.

Currently there are several approaches 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 a challenge test focused on lithium ion batteries, FAA (2017b). Commercial development of both the inert-gas-only and the water mist/nitrogen cargo fire suppression systems continues. Recently, the FAA has completed proof-of-concept testing for a halogenated agent, FAA (2018). MPS testing was planned to be conducted in December 2018.

The International Coordinating Council of Aerospace Industries Associations (ICCAIA) formed the Cargo Compartment Halon Replacement Working Group (CCHRWG) to begin to coordinate a single industry effort to find an alternative to halon 1301 in cargo bays. This group has suggested the end of 2024 as the time by which a cargo compartment fire suppression system containing a replacement agent could be developed and a type Certificate applied for. This date was accepted by ICAO and adopted as Resolution A39/13 during its 39th assembly in 2016. For further information see section 5 below. However, there are other factors / unknowns to consider including the lack of a comprehensive list of agents / systems, the need to obtain regulatory approval for any new agents, and possibly the need to develop new measurement methodologies for any novel agent or system. Furthermore, depending on the nature of the agent / system chosen, the FAA MPS may need to be rewritten, which would impose further delays.

Although this task has now been completed the Group still continues to monitor the progress of halon replacement activity in cargo compartments. To avoid confusion with ICAO working groups it has been renamed the Cargo Compartment Halon Replacement Advisory Group (CCHRAG).

4.5 Crash Rescue Vehicles

In addition to on-board civil aircraft applications, halon 1211 is used in some Aircraft Rescue and Fire Fighting (ARFF) or Crash Rescue vehicles on airport ramps. The FAA approved HCFC Blend B as a halon replacement for this application in the US. 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 such systems. As such, the Technology and Economic Assessment Panel (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 through the supply of halon 1211 or HCFC Blend B.

Regarding HCFC Blend B, TEAP initially estimated the annual requirement of HCFC-123 (the principal constituent) to be 900 tonnes (almost 20 ODP tonnes). This analysis was re-assessed following Decision XXIX/9 - Hydrochlorofluorocarbons and Decision XXVII/5. A recent report by the USEPA[5] has modelled the projected servicing demand for HCFCs in air-conditioning, refrigeration, and fire suppression sectors in the US for the period 2020-2030. The overall annual demand for HCFC-123 in the US is estimated to be 820 tonnes in 2020, falling to 580 tonnes in 2030 of which fire protection is estimated to be 260 tonnes per annum throughout this period. Therefore, this implies that the overall demand for HCFC-123 for fire protection globally estimated in previous report was too high. Based on these new data, the TEAP estimates that the global demand for HCFC-123 in fire protection is likely to be half of the original estimate, i.e. a total of 450 tonnes annually. In November, 2018, the parties to the Montreal Protocol agreed to adjust the Protocol and adopted a corresponding Decision XXX/2 to allow the use of newly produced HCFCs for the servicing of niche applications such as fire suppression and fire protection equipment existing on 1 January 2020 for the period 2020-2029 for non-A5 parties and also on existing equipment in 1 January 2030 for the period 2030-2039 for A5 parties.

The fluoroketone FK-5-1-12 has been tested by the United States Airforce and has proved to be effective in 65 kg (150 pound) wheeled units, exhibiting similar performance to halon 1211. Due to the slightly lower liquid density of FK-5-1-12 compared with halon 1211, a slightly larger wheeled unit was needed.

Although the fluoroketone has been shown to be effective in this application, it is not yet approved for all ARFF applications. Work is continuing in this area and the agent was recently evaluated by the US FAA. The results of this evaluation have not been published at the time of writing this report. Therefore, at this point in time, there will still be a need to use HCFCs in the period 2020-2030 and specifically up to 450 tonnes of HFC-123 (10 ODP-tonnes) annually for fire protection. It is possible that this estimate can be revised downward in the future, once the uptake of the fluoroketone in the various ARFF applications is known.

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[5] Draft Report: 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

5.0 Legislation

5.1 ICAO Activities

In addition to the informal working group activity to better estimate the quantity of halon 1301 installed and the associated emissions, the following ICAO activities have taken place:

At the 39th General Assembly meeting ICAO adopted the recommendation from the Cargo Compartment Halon Replacement Working Group and set a date by which halon replacement was mandated for cargo compartments. The key paragraph is reproduced here:

[The Assembly]
Directs the Council to mandate the replacement of halon in cargo compartment fire suppression systems used in aircraft for which application for type certification will be submitted after a specified date in the 2024 timeframe;

This means that ICAO now have established dates for all four applications where halons may no longer produced used on board aircraft

- in lavatory fire extinguishing systems used in aircraft produced after December 31, 2011;
- in hand-held fire extinguishers used in aircraft produced after December 31, 2018; and
- in engine and auxiliary power unit fire extinguishing systems used in aircraft for which application for type certification will be submitted after December 31, 2014.
- in cargo compartment fire suppression systems used in aircraft for which application for type certification will be submitted after a specified date in the 2024 timeframe;

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.

5.2 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. All current on-board uses of halons in aviation are included on the critical use list under the EC regulation. Annex VI was revised in 2010 as per Commission Regulation (EU) No 744/2010 of 18 August 2010) which contains “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’; see Table 5.1 below). Engine nacelle and cargo compartment applications in new type designs are subject to Regulation (EU) No 744/2010 in the EU. This differs from the approach that was supported by HTOC for the ICAO resolution, which focuses on eliminating the use of halon in new production aircraft and new designs only. Important safeguards have however been put in place in Regulation (EC) No 1005/2009 to avoid adverse impacts on safety and excessive costs: there are provisions for case by case derogations and for periodic reviews of the annex in order to account for the technological progress and the technical feasibility in terms of retrofit.

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

Table 5.2 compares the EU with the ICAO phase-out dates.

Table 5.1: Aviation Halon Phase Out Dates in EC Reg. 744/2010 Annex VI

Purpose	Type of Extinguisher	Type of Halon	Cut-off Date: Application for New Type Certification	End Date: All Halons Decommissioned
Normally unoccupied cargo compartments	Fixed system	1301 1211 2402	2018	2040
Cabin and crew compartments	Portable extinguisher	1211 2402	2014	2025
Engine nacelles and APU	Fixed system	1301 1211 2402	2014	2040
Inerting of fuel tanks	Fixed system	1301 2402	2011	2040
Lavatory waste receptacles	Fixed system	1301 1211 2402	2011	2020
Protection of dry bays	Fixed system	1301 1211 2402	2011	2040

Table 5.2: Comparison of EU and ICAO halon Phase-out Requirements

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

5.3 United States

Within the US, the Clean Air Act Amendments (CAAA) of 1990 provided the Environmental Protection Agency (EPA) with the authority to regulate the production and consumption of halons consistent with the Montreal Protocol. The CAAA of 1990 did not give the EPA the authority to regulate uses of halons. The import/export of previously used halons is allowed under a licensing system overseen by the EPA. Although the US FAA has included provisions for the use of alternative fire-extinguishing and suppression agents as part of the airworthiness standards for the issue of type certificates (i.e., 14 Code of Federal Regulation (CFR) Part 25 - AIRWORTHINESS STANDARDS), currently there does not exist a time schedule for halon replacement by the FAA.

6.0 New Generation Aircraft

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

7.0 Conclusion

Halon alternatives that are not drop-in replacements, i.e., that weigh more and/or take up more space, are unlikely to be implemented by civil aviation airframe manufacturers. As such the Civil Aviation sector is likely to be reliant upon halons for the next 30 years and beyond. Although the HTOC has previously reported that this situation might result in civil aviation submitting an Essential Use Nomination (EUN), the impact could be broader. Since most other enduring users of halon 1301 do not have long-term, dedicated stockpiles, they are also vying for the same halon supplies that civil aviation is reliant on. The timeframe when halon is no longer available to civil aviation could also be the timeframe when halon is no longer available to other users that do not have dedicated, long-term stockpiles, who might then also feel the need to submit one or several EUNs. Depending upon the amount of halon that available to support ongoing uses and the rate of emissions from all uses, the timeframe for this to happen is estimated to be between 2032 and 2054.

8.0 References

FAA (1977): AC 20-100 - *General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments* *http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-100.pdf*

FAA (2011): 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 (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

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

Ingerson (2007): Engine Nacelle Halon Replacement, International Aircraft Systems Fire Protection Working Group, 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".

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 British Airways technical expert.

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

Webster (2002): “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.

Appendix A: List of Acronyms and Abbreviations

2-BTP	2-bromo-3,3,3-trifluoro-prop-1-ene ($CF_3C(Br)=CH_2$)
APU	Auxiliary Power Unit
ARFF	Aircraft Rescue and Fire Fighting
CAPA	CAPA Centre For Aviation
CCHRWG	Cargo Compartment Halon Replacement Working Group
CO2	Carbon Dioxide
DOT	Department Of Transportation
EASA	European Aviation Safety Agency
EC	European Commission
EU	European Union
FAA	Federal Aviation Authority
GWP	Global Warming Potential
HBFC	Hydrobromofluorocarbon
HBFO	Hydrobromofluoro-olefin (for example 2-BTP)
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HTOC	Halons Technical Options Committee
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IC	Engine/APU Halon Alternatives Industry Consortium
ICCAIA	International Coordination Council of Aerospace Industries Associations
MPS	Minimum Performance Standards
NPA	Notice of Proposed Amendment
ODP	Ozone Depletion Potential
OEM	Original Equipment Manufacturer
PMN	Pre-manufacturing Notice
SNAP	Significant New Alternatives Policy
TEAP	Technology and Economic Assessment Panel
TSCA	Toxic Substances Control Act
UNEP	United Nations Environment Programme
US	United States

Appendix B: Definitions

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

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

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 other halocarbon fire extinguishing agents (see TEAP).

Hydrobromofluorocarbons (HBFCs): A family of chemicals related to halons that contain hydrogen, bromine, fluorine, and carbon atoms. HBFCs are partly halogenated and have much lower ODP than halons.

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.

Kigali Amendment: An amendment to the Montreal Protocol, taken at the twenty-eighth Meeting of the Parties in Kigali in October 2016. This amendment phases down HFC production step-wise by various amounts for A5 and non-A5 countries. The first step is a phase-down of 10% in non-A5 countries.

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.

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 and CFC-12 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, which 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 or bromine.

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

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

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

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

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

Technical Standard Order (TSO): A TSO is a minimum performance standard, defined by the FAA, used to evaluate an article. An article can be a material, part, component, process, or appliance.

Technology and Economic Assessment Panel (TEAP): An international body of experts established in 1990 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 reduce, and where possible, eliminate use of ODS. The TEAP is one of three Assessment Panels; the other two being the Environmental Effects Assessment Panel (EEAP) and the Science Assessment Panel (SAP).