October 2022

**REPORT OF THE HFC EMISSIONS ESTIMATING PROGRAM (HEEP)
2002 – 2020 DATA COLLECTION**

Introduction

Hydrofluorocarbons (HFCs) have been commercialized as replacements for ozone-depleting substances such as chlorofluorocarbons (CFCs) and halons. The development of these chemicals for use in fire and explosion suppression applications was instrumental in achieving the accelerated halon production phaseout mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer. At the same time, the use of this class of chemicals carries with it some environmental concern and, therefore, the need to minimize emissions.

While HFCs are not ozone-depleting substances, they have been identified by the Intergovernmental Panel on Climate Change as potent greenhouse gases with long atmospheric lifetimes and are part of the basket of six gases included in the United Nations Framework Convention on Climate Change. In 2016 HFCs were added to the Montreal Protocol and scheduled for a phase down of production that began in 2019. In 2020 emissions of HFCs represent about 3% of total greenhouse gas emissions.[1] Emissions of HFCs related to fire protection uses are estimated at about 3% of total HFC emissions from all sources. Nevertheless, because of their significant atmospheric impacts once released, careful management of these gases is an essential component of international climate protection and stratospheric ozone goals.

Fire Protection and Environmental Protection

The U.S. fire protection industry fully supports the goal of minimizing emissions of HFC and PFC fire protection agents, and is committed to continuing to contribute to both ozone layer and climate change protection. The overriding concern of the fire protection industry, however, is the reduction of risk to people and property from the threat of fire through the use of products and systems proven to be effective. With the aim of ensuring that both of these goals are achieved, the fire protection industry has developed a voluntary code of practice that is intended to focus the industry's efforts on minimizing emissions of HFC fire protection agents.

The Voluntary Code of Practice for the Reduction of Emissions of HFC & PFC Fire Protection Agents (VCOP) is a partnership of the U.S. Environmental Protection Agency (EPA), Fire Equipment Manufacturers Association (FEMA), Fire Suppression Systems Association (FSSA), Halon Alternatives Research Corporation (HARC) and National Association of Fire Equipment Distributors (NAFED). Since its was launched in March 2003, this program includes fifteen partner companies, representing fire equipment

1. See https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

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manufacturers and distributors throughout the U.S. that are working to meet the goals of the VCOP through training, education, and reporting on HFC and PFC uses. This innovative partnership serves as an important model for national and international voluntary industry efforts in other sectors, such as mobile air-conditioning and refrigeration, committed to achieving responsible use of HFC alternatives for ozone-depleting substances.

HFC Emissions Estimating Program (HEEP)

Accurate, credible recordkeeping and reporting is central to meeting the goals of the Voluntary Code of Practice (VCOP). Successful implementation of the elements of the VCOP has relied on a verifiable database of HFC emissions from fire extinguishing equipment. The HFC Emissions Estimating Program (HEEP) provides a format to help industry minimize emissions by setting benchmarks, by providing the incentives to make improvements to current standards and practices, by documenting the industry's commitment to safety and responsible use, and by providing data to support these substitutes for halon systems. The essential elements of the HEEP are as follows:

- Collection of HFC and PFC emissions data from reporting parties in industry that are able to make relevant measurements.

- Not all fire equipment companies need to be reporting parties in order for data collection to be substantially complete. Only the following need be reporting parties:

  - Equipment manufacturers or distributors that perform First Fill of original equipment and also recharge equipment.

  - Agent suppliers or equipment manufacturers that sell HFC and PFC agents to distributors that only perform recharge.

- "Emission" for the purposes of the HEEP is defined as the quantity of agent sold for the purpose of "recharge" of fire suppression containers. This approach is deemed reasonable as recharge is only required after agent has been discharged or emitted from equipment.

- Distributors who recharge cylinders but do not fill original equipment – most distributors – do not need to report as their agent use would be reported by their supplier.

- An independent Third Party collects industry reports of emissions by agent type, converts the values to equivalent emissions of carbon dioxide, and reports only aggregate results annually back to industry.

Data Collection Effort

In August 2002 a survey was distributed to companies previously identified as possible reporting parties and to the members of FEMA, FSSA, HARC, and NAFED. The purpose of the survey was to identify all of the companies in the U.S. that were likely to be HEEP reporting parties based on the criteria outlined above. By distributing the survey to the members of the four major fire protection associations, it was felt that substantially all of the appropriate companies would be contacted.

Based on the responses to the survey and additional input from industry experts, a final list of 22 reporting parties was identified. Since that time the number of reporting parties has shrunk to 15 due to mergers/acquisitions, consolidated reporting, and a re-evaluation of the program in 2010 that found some overlap in the data. Although the number of reporting parties has gone down, the overall percentage of the clean agent market they represent should be relatively the same.

In 2015 a change was made to the HEEP program to include reporting of direct recycling by installers, usually distributors of OEM equipment. Based on responses from a survey of installers and some anecdotal information from HARC members, it was determined that a significant amount of HFC fire protection agent is being recycled directly by installers (i.e. removed from decommissioned equipment and then used for recharge of systems and extinguishers). Under its previous structure, the emissions represented by these sales of HFCs for recharge were not captured by the HEEP program. As such it is possible that the HEEP data may have underestimated U.S. emissions of HFCs from fire protection. Four installer-distributors reported direct recycle data in 2021 and HARC is working to increase distributor participation for 2022.

Annually guidance letters and data collection forms are sent to the HEEP reporting parties asking for the quantity of HFC/PFC fire protection agents sold for recharge in the previous year. A list of the agents for which data is requested along with the global warming potentials (GWPs) used to calculate carbon dioxide (CO_2) equivalence for each agent are shown in Table 1.

Table 1. HFCs and PFCs used in fire protection systems and their GWP values.

HFC / PFC Chemical ASHRAE Designation	100-year Global Warming Potential (1995)[2]	100-year Global Warming Potential (2007)[3]
HFC 23	11,700	14,800
PFC 14	6,500	6,500
HFC 125	2,800	3,500
HFC 134a	1,300	1,430
HFC 227ea	2,900	3,220
HFC 236fa	6,300	9,810
PFC 3-1-10	7,000	7,000

Results

Data were submitted by 13-16 reporting parties for the years 2002 to 2014, 17 reporting parties for the years 2015 to 2018 and 16 reporting parties for the years 2019 and 2020. Results from 2002-2008 were adjusted by subtracting overlapping data from six reporting parties. No adjustment in previous results was made for the new reporting parties added in 2015, as data for past years were not available.

[2] IPCC Second Assessment Report (1995).

[3] Intergovernmental Panel on Climate Change (IPCC) fourth assessment report, 2007 (AR4)

In each year emissions data were reported for the agents HFC-23, HFC-125, HFC-236fa, HFC-227ea, and PFC 3-1-10. The total of the reported emissions for each agent was multiplied by its respective GWP to obtain an equivalent of carbon dioxide. The carbon dioxide equivalent emission amounts of the five agents were then added to obtain a total reported emission for each year, expressed in millions of metric tons of carbon dioxide ($MMTCO_2$) and million metric tons of carbon equivalent (MMTCE).

The combined results reported to date are given in the Table 2 and illustrated graphically in Figure 1.

Table 2. Number of reporting parties and total annual emissions of HFC and PFCs in CO_2 equivalent amounts.

Year	Companies Reporting	$MMTCO_2$	MMTCE	2007 GWP $MMTCO_2$
2002	16	0.484	0.132	
2003	16	0.490	0.134	
2004	15	0.559	0.152	
2005	15	0.618	0.169	
2006	15	0.559	0.152	
2007	15	0.622	0.170	
2008	15	0.573	0.156	
2009	15	0.421	0.115	
2010	14	0.580	0.158	
2011	14	0.527	0.144	
2012	14	0.582	0.159	
2013	15	0.598	0.163	0.751
2014	13	0.547	0.149	0.699
2015	17	0.533	0.145	0.643
2016	17	0.607	0.166	0.732
2017	17	0.645	0.176	0.771
2018	17	0.722	0.197	0.846
2019	16	0.729	0.199	0.860
2020	16	0.599	0.163	0.724
	Statistical Summary			
	Average	0.579	0.158	0.753
	St Dev	0.075	0.020	0.078
	St Dev %	12.9%	12.9%	10.4%

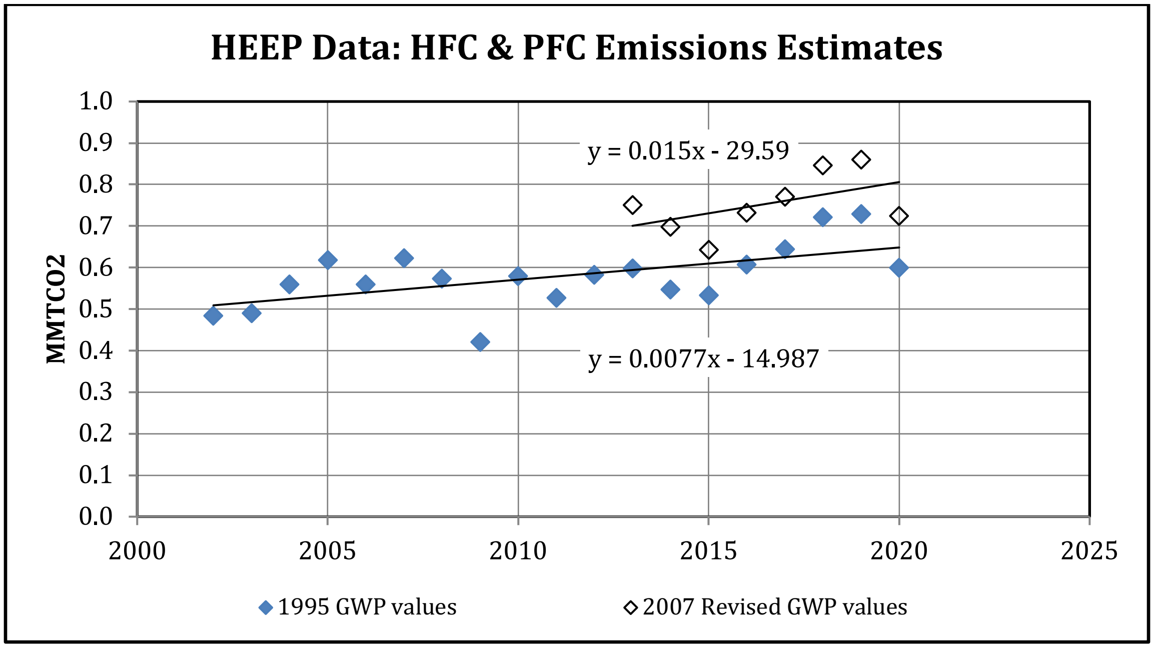

Figure 1. Annual reported CO_2-equivalent emissions of HFC and PFC agents.

Discussion

During the 19-year HEEP sampling period, 2002 to 2020, the year-to-year variations in reported emissions of HFC and PFC fire protection agents do not support a conclusion as to a definite long-term trend, either positive or negative. Thus, the only conclusion that can be thus far reached is that between 2002 and 2020 average annual rate of emissions of HFC and PFC fire protection agents has increased at only about 1.2 % annually.

When the HEEP program began in 2002, the expectation was that emissions of HFCs from fire protection would increase each year as the size of the installed base grew. This expectation is reflected in the EPA vintaging model, which is a source of estimated emissions of greenhouse gases used as substitutes for ozone depleting substances. The EPA model predicts steadily increasing emissions of HFCs between 2002 and 2018 at levels significantly higher than seen in the HEEP data. What HEEP data show are essentially invariant emissions of GHGs over the 2002 through 2020 period of about 0.579 $MMTCO_2$ equivalent.

EPA is currently reviewing their latest vintaging model estimates in conjunction with atmospheric data on emissions of HFC-227ea to account for emissions from other use sectors. Once EPA has completed this review HARC will work with EPA to better understand the differences between the HEEP data and the vintaging model estimates.

The foregoing observations regarding GHG fire systems emissions suggest some combination of the following:

1. The size of the installed base of HFC systems is stable and the normalized discharge frequency of HFC systems is stable;

2. The size of the installed base is increasing and the normalized discharge frequency of HFC systems is decreasing.

Since sales of new OEM HFC-agent fire protection systems continue, it seems likely that despite what is believed to be a growing installed base, the probability of release of high-GWP agents is decreasing owing to improved stewardship by fire protection system owners. At the same time, the ample, and in some cases oversupply, of recycled HFCs seen in the market in recent years likely reflects an increasing number of legacy systems being decommissioned, which would limit growth of the installed base.

Impact of Recycling

When the HEEP program began in 2002 about 13% of the reported HFCs sold for recharge came from recyclers. In recent years that number has increased to an average of about 75% (80% in 2020). This is a very positive trend for the industry as every pound of recycled HFC used for recharge is a pound of new HFC that is not manufactured.

Conclusions

- The HFC Emissions Estimating Program (HEEP), which was devised to develop fire industry emissions data, has been operating successfully for seventeen years.

- In 2015 HEEP began to include heretofore unreported emissions data due to direct HFC agent recycle from decommission of fully charged equipment by installer-distributors reporting. HARC estimates that the HEEP data may be underestimating US emissions of HFCs from fire protection by as much as 10% due to unreported direct HFC recycling by installer-distributors.

- The HEEP data collected annually from 2002 through 2020 show an essentially invariant rate of emissions of high-GWP agents over that period of about 0.579 $MMTCO_2$ equivalent.

- The invariance of fire industry emissions of high-GWP agents, in light of continues sales of new systems, may be credibly attributable, at least in part, to steadily improved stewardship of installed systems by their owners.

- Overall, the VCOP and HEEP programs appear to be serving their intended purposes.

History Of Accomplishments of the Advanced Agent Working Group

May 2004

By: Tom Cortina, Halon Alternatives Research Corporation (HARC) and
Dave Catchpole, BP Exploration Alaska

In mid-1993 an ad hoc working group was formed to determine the feasibility of using trifluoroiodomethane (CF_3I) as a "drop-in" replacement for Halon 1301 based on an assessment of the critical requirements of a drop-in agent: agent stability, toxicity, fire fighting effectiveness, and global environmental impacts. The results of this study revealed that CF_3I, although an effective fire fighting agent, was too toxic for use as a total flooding agent in occupied areas. As a result of this positive international collaboration between government agencies and industry, the Advanced Agent Working Group (AAWG) was formed in late 1994 from the remnants of the CF_3I working group.

The purpose of the AAWG was to continue the search for a drop-in replacement for Halon 1301 in total flooding fire suppression and explosion inerting applications. Funding for the group has been provided by the North Slope Operators, U.S. Army, U.S. Navy, U.S. Air Force, EPA, and NASA. In-kind contributions of testing and agent synthesis have been provided by Kidde International, Kidde-Fenwal Combustion Research, QinetiQ (formerly DERA Hasler), UK MOD, American Pacific Corporation, NMERI, and NIST. Other participants at various times have included 3M, Great Lakes, and DuPont. The group's activities were first managed by NMERI but recently have been managed by HARC.

The AAWG's initial mandate was to do basic research and report on the following:

- Review technologies for fire suppression emphasizing mechanisms.
- Assess the mechanisms to select and group chemical agents that could provide fire suppression equivalent to that of the present halons.
- Assess the potential of the agents using criteria such as fire suppression ability, manufacturability, environmental considerations, and toxicity.
- Develop final conclusions as to the likelihood of a total-flood halon replacement for normally occupied areas requiring minimal hardware changes.

The final report was produced by NMERI and concluded that various phosphorus compounds, metal complexes, silicon compounds and tropodegradable halocarbons were all viable candidates, but that the tropodegradable halocarbons held the most promise.

The next activity of the AAWG was to develop a list of 24 tropodegradable candidate agents for further evaluation and screening. The list was developed by NMERI and included alkenes, alcohols, ethers, amines, carbonyl compounds, and aromatics (see Table 1).

TABLE 1. LIST OF 24 TROPODEGRADABLE CANDIDATE AGENTS

Database ID	Formula	IUPAC name	CAS number
		Alkenes	
872	CH_2=$CHCBrF_2$	3-bromo-3,3-difluoropropene	420-90-6
885	$CBrF_2CH$=$CHCF_3$	*cis*- and *trans*-1-bromo-1,1,4,4,4-pentafluoro-2-butene	
903	$CBrF_2CF_2CH$=CH_2	4-bromo-3,3,4,4-tetrafluorobutene	18599-22-9
902	$CBrF_2C(CF_3)$=CH_2	*cis*- and *trans*-3-bromo-3,3-difluoro-2-(trifluoromethyl)propene	
		Alcohols	
718	$CBrF_2CH_2OH$	2-bromo-2,2-difluoroethanol	420-94-0
1058	$CF_3CBrFCH_2OH$	2-bromo-2,3,3,3-tetrafluoropropanol	94083-41-7
889	$CBrF_2CF_2CH_2OH$	3-bromo-2,2,3,3-tetrafluoropropanol	
970	$CF_3CHOHCH_2Br$	3-bromo-1,1,1-trifluoro-2-propanol	431-34-5
		Ethers	
726	CF_2H-O-CHBrF	bromofluoro(difluoromethoxy)methane	
901	$CBrF_2$-O-CH_3	bromodifluoro(methoxy)methane	
904	$CBrF_2CH_2$-O-CF_3	1-bromo-1,1-difluoro-2-(trifluoromethoxy)ethane	
906	$CBrF_2CF_2$-O-CH_3	1-bromo-1,1,2,2-tetrafluoro-2-methoxyethane	
1052	-$CH_2CF_2CBrFCH_2O$-	2-bromo-2,3,3-trifluoro-1-oxacyclopentane	
		Amines	
735	$N(CBrF_2)(CHF_2)_2$	N,N-bis(difluoromethyl)bromodifluoromethanamine	
743	$N(CBrF_2)(CF_3)(CH_3)$	N-(trifluoromethyl)-N-methyl-bromodifluoromethanamine	
1053	$N(CF_3)_2(CH_2CBrF_2)$	N,N-bis(trifluoromethyl)-1-bromo-1,1-difluoroethanamine	
990	$N(CBrF_2)(CF_3)_2$	N,N-bis(trifluoromethyl)bromodifluoromethanamine	
		Carbonyl Compounds	
1054	$CBrF_2CH_2C(O)H$	3-bromo-3,3-difluoropropanal	
1055	$CH_3C(O)CH_2CBrF_2$	1-bromo-1,1-difluoro-3-butanone	
1056	$CBrF_2CH_2C(O)OCH_3$	methyl 3-bromo-3,3-difluoropropanoate	99953-33-0
1057	$CBrF_2CH_2C(O)OCF_3$	trifluoromethyl 3-bromo-3,3-difluoropropanoate	
		Aromatics	
778	C_6F_5Br	bromopentafluorobenzene	344-04-7
749	$C_6F_5CBrF_2$	(bromodifluoromethyl)pentafluorobenzene	35523-39-8
	$C_6BrF_4CF_3$	bromotetrafluoro(trifluoromethyl)benzene	113601-46-0
808		1-bromo-3,4,5,6-tetrafluoro-2-(trifluoromethyl)benzene	66820-64-2
953		1-bromo-2,4,5,6-tetrafluoro-3-(trifluoromethyl)benzene	5360-80-5
954		1-bromo-2,3,5,6-tetrafluoro-4-(trifluoromethyl)benzene	17823-46-0

Quantitative structure-activity relationship (QSAR) evaluations for potential toxicity were performed on the 24 candidates. Contributing to the QSAR evaluations were the Army, Air Force, EPA, NMERI, and Exxon. Data was also collected on extinguishing capability, physical properties, atmospheric lifetime/ODP, and availability. Although a great deal of work was done on the QSAR assessments and they were somewhat helpful in paring down the initial list of 24 agents, most of the actual decisions on which compounds to pursue were based on physical properties, extinguishing potential, and toxicology testing. Probably the biggest factor in determining which compounds to pursue were physical properties (especially boiling point), availability, and cost of synthesis.

In February of 1997 the AAWG down selected the list of 24 candidates. Based on all available data, the group felt that alkenes had the best potential to produce an agent that would be acceptable from an extinguishing and environmental perspective. Two alkenes were selected for further evaluation along with one alcohol, two carbonyl compounds, and one aromatic. The group considered carbonyl compounds to be the next most likely class to produce an acceptable agent. Ethers and Amines were considered not likely to be acceptable due to atmospheric lifetime and the ability to manufacture. The alcohol and aromatic compounds were subsequently removed from consideration due to concerns over extinguishing capability and high boiling points, respectively.

Selected Candidate Agents (2/97)

Alkenes

ID# 872; 3-bromo-3,3-difluoropropene; $CF_2BrCH{=}CH_2$

ID# 903; 4-bromo-3,3,4,4-tetrafluorobutene; $CF_2BrCF_2CH{=}CH_2$

Carbonyl compounds

ID# 1054; 3-bromo-3,3-difluoropropanal; CF_2BrCH_2CHO

ID# 1056; methyl 3-bromo-3,3-difluoropropionate; $CF_2BrCH_2COOCH_3$

The next step was to attempt to acquire the four down-selected agents, measure physical properties, and do preliminary toxicity, cup burner, and inertion testing. Agents 872 and 903 were obtained from Oakwood Laboratories. It turned out that DuPont had a patent for 903. Agent 903 was subsequently dropped from further consideration because it was flammable (it was later determined that this finding was incorrect and 903 was once again included in the program). Agent 872 was dropped from further consideration after an acute inhalation toxicity test showed four rats died within four hours of exposure to 1% of the agent. Agent 872 was also positive in the Ames test. Agents 1054 and 1056 were to be obtained from Durham Organics in the UK. Work was stopped on agent 1056 based on a determination that its boiling point was too high. Durham Organics was never able to synthesize agent 1054.

Separately to the research being conducted in the USA, QinetiQ (DERA Hasler) began work on development of an alternative to the cup burner test. The cup burner test, developed in the 1970s, involves increasing the volume concentration of the specified agent in the air stream to a heptane/air diffusion flame until extinguishment. The fire performance testing of expensive to produce agents such as the tropodegradable bromocarbons, is hampered by the large quantities of agent required by the cup burner test (50 to 100 g). Thus QinetiQ (DERA Hasler) began research into the flame ionisation detector (FID) test. This latter test, which requires very small quantities of agent, would prove useful for QinetiQ's (DERA Hasler) other work that was to investigate phosphorus-containing compounds (PCCs) on behalf of the UK MoD as their contribution to the total research of the AAWG.

In March of 1998, five new compounds, all alkenes, were proposed for evaluation by the AAWG. This new list included two bromopropenes (707, 873) and 3 bromobutenes (1116, 1280, 1281). The group was never able to find a source to synthesize 1280 or 1281. At this same time, acute toxicity screening was being performed by Lovelace Labs on potential streaming agents for the Air Force, and so some of the agents of interest to AAWG were included in the testing. Based on the results of the Lovelace acute toxicity screening and other data on physical properties and extinguishing ability, AAWG decided to conduct further testing on four of the agents (707, 873, 903, and 1116).

Revised Candidate Agents (3/98)

Alkenes

ID#707; 1-bromo-3,3,3-trifluoropropene; $CF_3CH=CHBr$ ($22,000 per kg)

ID#873; 2-bromo-3,3,3-trifluoropropene; $CF_3CBr=CH_2$ ($955 per kg)

ID#903; 4-bromo-3,3,4,4-tetrafluorobutene; $CF_2BrCF_2CH=CH_2$ ($3,750 per kg)

ID#1116; 2-bromo-3,3,4,4,4-pentafluorobutene; $CF_3CF_2CBr=CH_2$ ($8,500 per kg)

ID#1280; 4-bromo-2,3,3,4,4-pentafluorobutene; $CBrF_2CF_2CF=CH_2$

ID#1281; 1-bromo-3,3,4,4,4-pentafluorobutene; $CF_3CF_2CH=CHBr$

Based on quotes from Synquest Labs, the group decided to initially pursue agents 873, 903, and 1116, as agent 707 was expected to cost in excess of $22,000 per kg to produce. I kg each of agents 873, 903, and 1116 were obtained from Synquest.

Agents 873, 903, and 1116 were tested in the NMERI 5/8 Cup Burner and a limited Ames test (Bacterial Reverse Mutation Test in Salmonella typhimurium and Escherichia coli). Results were as follows:

Agent	**873**	**903**	**1116**
Cup Burner (5/8)	2.6%	3.5%	3.8%
Ames	Negative	Negative	Negative

Given the encouraging Ames results and owing to their lower synthesis cost, it was decided to subject agents 873 and 903 to the next level of toxicity testing - chromosomal aberrations in human lymphocytes. Concurrently, Kidde International volunteered to perform full scale cup burner tests on the agents, Kidde-Fenwal Combustion Research volunteered to perform inertion tests in their 8-liter sphere using methane and propane, and QinetiQ (DERA Hasler) volunteered to perform the flame ionisation detector (FID) test. The resulting data accumulation was as follows:

Agent	**873**	**903**	**1116**
Cup Burner (5/8)	2.6%	3.5%	3.8%
Cup Burner (full)	4.7%	5.0%	Not done
FID	4.3%	4.2%	Not done
Inertion (methane)	6.0%	3-4%	Not done
Inertion (propane)	8.5%	6.3%	Not done
Ames	Negative	Negative	Negative
Chromosomal Abs	Negative	Negative	Not done

In addition to the above, NIST provided estimates of the atmospheric lifetimes of these agents, which ranged from 4-8 days and advised that none of them were likely to have significant ODPs. Kidde International also performed a small-scale wood crib test on agent 873, HFC-227ea, and Halon 1301 and measured the resulting decomposition products. Agent 873 produced less decomposition products than HFC-227ea but slightly more than Halon 1301.

Based on the above results, its lower boiling point, and lower cost (agent 903 costs four times more to synthesize than agent 873) the AAWG decided to have a cardiac sensitization study done on agent 873 at Huntingdon Labs in England. The study was initially delayed because of concerns about a NMERI patent on agent 873, but it was eventually performed for BP. The results showed that agent 873 had a lowest observed adverse effect level (LOAEL) for cardiac sensitization of 1%. This disappointing cardiac sensitization study result for agent 873 basically eliminated it from consideration for use in occupied areas. However, it was noted that agent 873 could have potential as a replacement for Halon 1211 in streaming applications due to its superior fire extinguishing properties over current commercial agents.

At this point the AAWG reevaluated the original list of 24 agents (Table 1) in light of what had been learned over the previous six years. It was decided that agents 903 and 707 were still worth pursuing if a way could be found to make them for a reasonable cost. Synquest provided a quote for producing 5-6 kg of 903 at $10,000 and the AAWG began to seriously consider performing a cardiac sensitization test on this agent, although some concern was still being expressed over its high boiling point (BP). American Pacific

Corporation then made an offer to make agent 707 for the AAWG at no charge so that cup burner, inertion, and toxicology testing could be performed. The same basic toxicity screening tests were performed on agent 707 as had been done on agents 873 and 903. Also for agent 707, Kidde International performed cup burner tests and Kidde-Fenwal Combustion Research did inertion tests in the same 8 liter sphere as used previously.

The results for agent 707 were as follows:

Agent	**707**
Cup Burner (5/8)	3.5%
Cup Burner (full)	4.3%
Inertion (methane)	7.2%
Inertion (propane)	7.5%
Ames	Negative
Chromosomal Abs	Negative

Agent 707 was then tested at Huntingdon for cardiac sensitization. Although no cardiac effects were seen, agent 707 was acutely toxic to the dogs at a concentration of 1.5% (head jerking, head, neck and limb rigidity) and the study was terminated. This result basically eliminated agent 707 from consideration for use in occupied spaces.

Some what due to a lack of funds but more due to a lack of ideas of where to go next, the AAGW decided to stop further work on the above agents and to rethink direction. Clearly, apart from the cost of the tests themselves, the cost of synthesizing sufficient quantities of high cost agents is a deterrent to investigative research. In particular, cardiac sensitization studies are very expensive and thus are a limiting factor in the work that can be done. Recently the AAWG was approached for funds to assist in development work for an invitro cardiac sensitization study that would be both inexpensive and utilize very small quantities of the agent to be tested. Both the AAWG, BP, And EPA have contributed to this work, whose results are expected later this year.

TABLE 2 – FINAL RESULTS OF TESTING FOR AGENTS 707, 873, 903, AND 1116

Agent	**707**	**873**	**903**	**1116**
BP (^{0}C)	40	34	65	59
Cup Burner (NMERI 5/8)	3.5	2.6%	3.5%	3.8%
Cupburner (Full scale)	4.3%	4.7%	5.0%	Not done
FID	Not done	4.3%	4.2%	2.5%
Inertion	7.2% methane 7.5% propane	6.0% methane 8.5% propane	3-4% methane 6.3% propane	Not done
Ames	Negative	Negative	Negative	Negative
Chromosome Aberrations	Negative	Negative	Negative	Not done
Cardiac Sensitization	Toxic at 1.5%, no cardiac effects	0.49% NOAEL 1.0% LOAEL	Not done	Not done
Atmospheric Lifetime	40 days (NIST) 2.4-4 days (W)	2.9 days(NIST) 3.87 days (W)	7.3 days(NIST) 1.97 days (W)	3.4 days(NIST) 3.87 days (W)
ODP	0.038 (NIST) 0.0017-.0079 (Wuebbles)	0.0028 (NIST) 0.0037 (Wuebbles)	0.0016 (Wuebbles)	0.0029 (Wuebbles)

International Civil Aviation Organization

WORKING PAPER

ASSEMBLY — 41ST SESSION

TECHNICAL COMMISSION

Agenda Item 31: Aviation Safety and Air Navigation Standardization

AIRCRAFT HALON REPLACEMENT

(Presented by the International Coordinating Council of Aerospace Industries Associations (ICCAIA) and the International Federation of Air Line Pilots Associations (IFALPA))

EXECUTIVE SUMMARY

Industry is actively pursuing alternatives to Halon for commercial airplane cargo fire protection, and meeting the ICAO 2024 deadline seems achievable. However, many candidate agents, as well as already-approved substitutes for halon in other aircraft fire protection applications, are at risk of being subject to the proposed ECHA (European Chemical Agency) PFAS regulation, which on a mid-term perspective will not be limited to Europe. It will be very important to consider aircraft fire suppression as an essential use of PFAS regulations on a global scale, in order to maintain progress in replacing halons.

Action: The Assembly is invited to:

a) Acknowledge the significant impact of international PFAS (Per- and PolyFluoroAlkyl Substances) regulations on the schedule of Aircraft Halon replacement efforts.
b) Request the ICAO Council to urge member states to consider classifying the application of aircraft fire protection as permanent essential use or to grant permanent derogation/exemption to ensure the safe continuation of air transportation using the best available options.
c) Request the ICAO Council to urge harmonization between member States on the classification and restriction of chemicals as essential for the safety of aviation

Strategic Objectives:	This working paper relates to the Safety Strategic Objective.
Financial implications:	None.
References:	A40-WP/93, *Halon replacement – challenges and solutions*

[1] English, Arabic, Chinese, French, Russian and Spanish versions provided by ICCAIA.

1. INTRODUCTION

1.1 The ICAO deadline for replacing Halon 1301 in cargo fire suppression systems is for new airplane models with application for type certificate after 28 November, 2024. The ICCAIA Cargo Compartment Halon Replacement Advisory Group (CCHRAG) has performed an assessment of industry capability to meet that deadline, with an update in 2021 [Appendix 1]. This update finds that there are multiple replacement agents in development and that the deadline is achievable.

1.2 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.

1.3 Current regulatory action in the EU is also planned to be elevated to an international scale as through the introduction of PFAS at Stockholm Convention[2] level, thus the scaling of the effect would be worldwide.

1.4 This paper provides an update on the challenges faced by the aviation industry in identifying suitable alternatives to Halon, and in particular the need for exemptions for chemicals used for fire suppression purposes in aviation.

2. DISCUSSION

2.1 As noted in Appendix 1, Germany, Netherlands, Norway, Sweden, and Denmark are preparing a dossier to support a proposal to amend REACH regulations (Registration, Evaluation, Authorisation and Restriction of Chemicals) to restrict the manufacturing, use, and placement of per- and polyfluoroalkyl substances (PFAS) on the EU market.

2.2 If this proposal is ultimately adopted by the European Commission, it could have a very important bearing on the ability to replace halons in aircraft fire protection.

2.3 Halons are fluorinated fire suppression agents and much of the research effort to replace halons has focused on other fluorinated hydrocarbon agents. This is because fluorinated agents have excellent chemical stability and are able to extinguish or suppress fires at very low concentration, relative to other alternatives.

2.4 Potential replacements for Halons include:

- Iodotrifluoromethane, CF_3I. CF_3I is chemically very close to Halon 1301, CF_3Br, and has been considered a potential replacement for many years.

[2] The Stockholm Convention is a global treaty on UNEP (United Nations Environmental Programme) level to protect human health and the environment from persistent organic pollutants (POPs). It focuses on eliminating or reducing releases of POPs and sets up a system for tackling additional chemicals identified as unacceptably hazardous.

- 2-bromotrifluoropropene (CF3CBr=CH2), or 2-BTP - already in use as a Halon 1211 replacement in handheld fire extinguishers

- HFC-227ea (CF3CHFCF3) and HFC-236fa (CF3CH2CF3) have both been used as replacements for Halon 1301 in lavatory waste compartment fire protection.

2.5 The member states preparing the proposal have indicated an intent to define PFAS broadly as any molecule with a fully fluorinated methyl group (-CF3) or a fully fluorinated methylene group (-CF2) with some possible exclusions based on presence of chlorine, bromine or iodine atoms[3]. Given the breadth of this proposed definition, and if accepted by the European Commission, a PFAS restriction could extend to halon replacements that are already in use or are in development. All of the above candidates may be included in such a broad definition of PFAS.

2.6 There are four historic applications of halons in commercial airplanes:

- Handheld extinguishers - The most common non-halon handheld fire extinguisher agent that is in use on commercial airplanes is 2-BTP (CF3CBr=CH2).

- Lavatory waste compartment extinguishers - HFC-227ea and HFC-236fa have been used to replace Halon 1211;

- Engine and APU fire extinguishers

- Cargo Compartment fire suppression

In all applications above, the chemicals used as Halon replacement could face potential restriction under new PFAS regulations.

2.7 It should be noted that there is another restriction for PFAS used in firefighting foams that are also widely used in aviation, e.g. for airport firefighting which follows its own regulatory timeline. These two restrictions on a single chemical family is creating a great pressure on availability of performant firefighting products.

2.8 During the development of the proposed restriction, the member states developing the proposal and the European Chemicals Agency (ECHA), which is tasked with providing its expert opinions on the proposal, will invite comments and will consider essential uses. The definition of the term “essential use” is currently under development and its application to specific substances as well as potential time-limited allowances are still underway and require close follow-up and advocacy.

2.9 Transport is deemed essential for society and is vital for fulfilling the free movement of individuals, services and goods. Air transport has to fulfil safety and airworthiness regulations. The fact

[3] PFAS in the scope of this restriction intention have the following structural formula:
X-(-CF2-)n-X’ with n equal to or larger than 1 and X, X’ not being H (thus including X-CF3),
meaning fluorinated substances that contain at least one aliphatic carbon atom that is both, saturated and fully fluorinated, i.e. any chemical with at least one perfluorinated methyl group (-CF3) or at least one perfluorinated methylene group (-CF2-), –), including branched fluoroalkyl groups and substances containing ether linkages, fluoropolymers and side chain fluorinated polymers.

that suitable alternatives to fluorinated hydrocarbon agents for airborne fire suppression are not available should lead to an essential use classification on a global scale which is harmonized between nations.

2.10 Similar regulatory actions are underway in some countries, such as the US and China where some of the major agent manufacturers are located, with other important industrial countries following soon. The Stockholm Convention could speed up these developments.

3. CONCLUSION

3.1 As stated in Appendix 1 to this WP, industry is actively pursuing alternatives to halon for commercial airplane cargo fire protection and meeting the ICAO 2024 deadline seems achievable.

3.2 However, many candidate agents, as well as already-approved substitutes for halon in other aircraft fire protection applications, are at risk of being subject to the proposed ECHA (European Chemical Agency) PFAS regulation which on a mid-term perspective will not be limited to Europe.

3.3 It will be very important to consider aircraft fire suppression as an essential use of PFAS regulations on a global scale, in order to maintain progress in replacing halons.

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APPENDIX

ICCAIA CCHRAG

Cargo Compartment Halon Replacement Advisory Group

2022 Technical Assessment Update

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1. Table of contents

2. Glossary

2.1 Abbreviations

CCHRAG	Cargo Compartment Halon Replacement Advisory Group
CoRAP	Community Rolling Action Plan
ECHA	European Chemical Agency
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
GHG	Green House Gas
GHS	Globally Harmonised System
ICAO	International Civil Aviation Organisation
ISO	International Standards Organization
LOAEL	Lowest Observed Adverse Effect Level
MPS	Minimum Performance Standard
MSDS	Material Safety Data Sheet
NFPA	National Fire Protection Association
NOAEL	No Observed Adverse Effect Level
ODS	Ozone Depleting Substance
OEM	Original Equipment Manufacturer
PED	Portable Electronic Device
PFAS	Per- and polyFluoroAlkyl Substances
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SNAP	Significant New Alternatives Policy
TRL	Technology Readiness Level

2.2 Definition of terms

Participant: Company selected by the CCHRAG to contribute to the assessment. Any company developing a Halon replacement agent can apply to contribute to the assessment

3. Executive Summary and Conclusion

The Cargo Compartment Halon Replacement Advisory Group (CCHRAG) is committed to continuously support the ICAO 2024 deadline for halon replacement in cargo compartment fire suppression for new type certification aircraft applications submitted after 28 November 2024.

In the 2018 – 2019 timeframe, the group had performed a technical assessment of potential technologies in order to determine if a conceptually validated halon-free fire suppression system would be available in time to meet that deadline. The result of the assessment was published for the 40th ICAO General Assembly as Information Paper, ref. A40-WP/93.

For the 41st Assembly, the CCHRAG has performed an update of the technical assessment including reflections on actual regulatory issues and schedule considerations.

As a result of the recent assessment, the CCHRAG concludes that

- there are solutions available in the industry which are beyond TRL4 and have robust plannings for subsequent TRLs in place
- there are risks to be anticipated correlated to world-wide regulatory aspects, especially the upcoming PFAS regulation[4]
- there are remaining development risks to be mitigated, but no showstoppers are identified to date
- weight increase for any Halon replacement system is imminent and will lead to increased fuel burn and correlated CO_2 increase

4. SCOPE / MOTIVATION (Introduction)

The purpose of this report is to update ICAO on the activities of the CCHRAG. As stated in the Information Paper ref. A40-WP/93 issued for the 40th ICAO General Assembly, the CCHRAG is providing the potential consequences and risks with respect to the 2024 deadline in correlation to the actual Technology Readiness Level assessment. This document includes an evaluation of a set of key criteria which have been concluded by the CCHRAG to be the most critical indicators for technology readiness. This document also reflects the industry assessment in terms of development scheduling compared to the timeline which was proposed in 2016. This latter proposal led to the ICAO deadline for halon replacement in cargo compartment fire suppression for new type certification aircraft applications submitted after 28 November 2024.

Throughout the assessment, no proprietary information was submitted and the participant's identities remain anonymous. Moreover, the assessment does not recommend any specific technologies, but provides a review of the current technologies against the identified key criteria and their status against the technology readiness timeline.

5. Participants to the assessment

All organizations (participants) which were involved in the 2019 assessment were invited to update their status on the key criteria described in this report.

One participant has stopped the development of Halon replacement agents. One participant offered an additional Halon replacement technical solution compared to the previous assessment. As in the previous

[4] Most candidate agents, as well as already-approved substitutes for halon in other aircraft fire protection applications, are at risk of being subject to the proposed ECHA (European Chemical Agency) PFAS regulation which on a mid-term perspective will not stay limited to Europe. It will be very important to consider aircraft fire suppression as permanent essential use under PFAS regulations on a global scale, in order to maintain progress in replacing halons.

assessment, one participant submitted information on two solutions. In summary, seven participants delivered information on nine technical solutions. Questionnaires were distributed and follow-up online meetings were held with each of the participants to provide status on the assessment, answer questions, and/or collect additional information.

6. Technologies

The following technologies have been proposed, also in comparison with the 2019 assessment:

Technology	Number of technical solutions - 2019 assessment	Number of technical solutions - 2021 assessment
Chemical Agent	3	5
Inert gas (either bottled, generated by solid propellant or generated by onboard gas generators	4	3
Combined inert gas / water (or foam) mist	2	1

Table 1: Comparison of assessed technologies

For the 2021updated assessment, information on each technology was documented on a simplified spreadsheet listing 10 different criteria related to the categories: firefighting performance, physical properties, environmental, health & safety, production and schedule requirements. The participants indicated if their technology had met the criteria (was "compliant") and/or provided notes with status or more details.

7. Assessment evolvement

For the 2019's assessment, 8 key criteria were selected out of 37 criteria asked in the questionnaire to participants. For the 2021's assessment, 10 criteria were chosen to reduce the complexity of the assessment and to cover all categories.

Cat.	#	Full initial assessment criteria coverage	2019 key criteria	2021 key criteria coverage
Fire fighting Performance	1	Cup burner fire extinction/suppression concentration established (ISO, NFPA)	X	X
	2	Other Industry Standards met (UL, ANSI, NFPA, etc.)		
	3	FAA MPS testing concentration determined	X	X
	4	Test method determined to demonstrate compliance with paragraph 25.851(b)(2)	X	*1)
Physical properties	5	Agent & System Weight is less than or equal to Halon system	X	X
	6	Agent & Systems Size is less than or equal to Halon system		
	7	Long & short range applicability		
	8	Clean agent (gaseous) - no clean up required	X	X
	9	Boiling Point		
	10	No damage to aircraft materials after agent discharge	X	*2)
	11	Freezing point is less than normal operating conditions		
	12	Freezing point is less than minimum operating/storage conditions		
	13	Decomposition temperature is greater than fire conditions (or HF formation and thermal decomposition products are under the dangerous toxic level for humans)		
	14	Not thermally conductive		
	15	Not electrically conductive		
	16	No aircraft hydromechanical interfaces required (e.g. bleed air, fuel tank inert gas, etc.)		
	17	Operational impacts have been identified & mitigated		*3)
	18	System (knockdown & metered) available whenever airplane is powered	X	*3)
Production	19	Currently used in other industries and/or applications		X
	20	Supply chain established		
	21	Agent readily available		
	22	Agent modification not needed for aircraft application		
	23	Risks for system adaptation is mitigated or low		X
Health and Safety	24	Not a Montreal Protocol listed ODS		X *4)
	25	Not a Kyoto Protocol listed GHG		
	26	Not GHS-listed Hazardous material		
	27	US EPA SNAP approved		
	28	US EPA TSCA Inventory listed		

Cat.	#	Full initial assessment criteria coverage	2019 key criteria	2021 key criteria coverage
	29	EU REACH Registered, Authorised, and/or Restricted		
	30	Not a PBT, POP, or endocrine disrupter		
	31	Present on other regulatory lists		
	32	US OSHA Regulated		
	33	Not a Carcinogenic, mutagenic, repro-tox substance (CMR)		
	34	Cardiac sensitization: LOAEL, NOAEL is less than or equal to Halon 1301		X
	35	Oral, inhalation, dermal toxicity is less than or equal to Halon 1301		
Schedule	36	Current TRL is greater than 3	X	X *5)
	37	Aviation Authority Certification experience		
	-	TRL6 Roadmap in place (expected TRL6 completion date with +/- 0.5 years accuracy would be appreciated)		X *5)

Table 2: Assessment criteria coverage

Notes to table 2:

*1) This criterion is regarded to be covered by the compliance statement to item #1, Minimum Performance Standard Tests. Therefore, this criterion is not part of the 2021 re-assessment.

*2) This criterion is regarded to be covered by the compliance statement to item #8, Clean agent (gaseous) - no clean up required. Therefore, this criterion is not part of the 2021 re-assessment.

*3) These criteria were initially set up to cover operational phases of the aircraft at which for example not enough bleed air would be available to support on-board gas generating systems. However, an assessment participant could hardly estimate such an impact because only the OEM would know about the characteristics of the individual aircraft product. Therefore, these criteria are not part of the 2021 re-assessment.

*4) During the 2019 assessment it has turned out that the breakdown within the health and safety category is too detailed. In the 2021 assessment, the criterion has been generalized to globally request health and safety issues. The wording has been changed to: “Not present on regulatory lists (e.g. Montreal protocol listed ODS, Kyoto Protocol listed GHG, GHS listed Hazardous material, ECHA/EPA regulatory lists, SNAP/REACH regulated, etc.)”

*5) For the 2021 assessment, the criterion has been changed to: “Current TRL is equal or greater than 4” in order to achieve information about the technical progress. In addition, the following criterion has been added: “TRL6 Roadmap in place (expected TRL6 completion date with +/- 0.5 years accuracy would be appreciated)” This criterion serves as an indicator if the industry is confident that the 2024 date can be reached.

8. FIREFIGHTING PERFORMANCE

8.1 Overview

The technical assessment of the firefighting performance properties of the extinguishing agent was covered by the following items:

- cup burner fire extinction/suppression concentration established (Ref. ISO 14520, Part 1: Annex B and NFPA 2001 Appendix B)

- FAA Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems (Ref. DOT/FAA/TC-TN12/11 - May 2012) (MPS) testing concentration determined

8.2 Cup burner fire extinction/suppression concentration established

The majority of participants (7 out 9 solutions) stated compliance either by conducting cup burner testing or referring to existing standards. Two of the participants have not established a concentration for a full system due to the non-gaseous state of their agent or due to other reasons.

The cup burner concentration should be conducted prior to FAA MPS testing. Depending on the exact nature of the agent, evaluation in a cup burner may not be possible, and some other action might need to be performed prior to FAA MPS.

The CCHRAG concludes that participants' interest has been demonstrated by conducting tests on several solutions.

8.3 FAA MPS testing concentration determined

In the previous assessment the CCHRAG stated that it is essential that more agents successfully complete MPS testing no later than 2020 to reduce the risk of not meeting the 2024 deadline. In 2019, one more agent successfully passed the MPS testing. In total, 2 agents (3 solutions) currently have successfully passed MPS testing including the recently defined multiple fuel fire test which will be implemented in the upcoming update of the MPS. One participant stated that the agent under his development will be subject to full MPS testing in Q3 2022 with successful rehearsal testing in 2021.

The MPS test results for the aforementioned 2 agents are publicly available on the FAA website[5] [6].

The participant who stated successful MPS testing with a combined water mist/inerting system also stated that a pure inerting system would also successfully pass the test.

Since successful MPS testing is necessary to meet FAA and EASA certification requirements, the CCHRAG concludes that the majority of the solutions assessed are still contingent on passing critical testing demonstrations.

It has to be noted that the MPS is currently undergoing a revision and that one test case - the so-called multiple fuel fire test - will be different to the already performed and passed test. This test will have to be repeated for the candidate agents with the risk of failure.

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[5] Minimum Performance Standard Aircraft Cargo Compartment Halon Replacement Fire Suppression System Testing, by Karsten Kirbach and Dhaval Dadia, FAA International Aircraft Systems Fire Protection Forum, May 08-09 2018; below link dated Aug 26 2021
https://www.fire.tc.faa.gov/ppt/systems/May18Meeting/Dadia-0518-MPSTestingClass-CCargoCompartment.pptx

[6] MPS for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems, Dhaval Dadia, Aircraft Fire Safety Conference, October 31, 2019; below link dated Aug 26 2021
https://www.fire.tc.faa.gov/2019Conference/files/Cargo_Halon_Replacement_I/DadiaFAAAlternateAgent/Dadia%20-%201019%20-%20Blend-D.pptx

8.4 Fire Fighting Performance Conclusive Statement

CCHRAG concludes that two solutions successfully passed MPS testing.
MPS is under revision and an altered test is to be re-performed with the risk of failure. Remaining Integration and Certification risks are still to be mitigated.

Note: Even though passing the MPS testing is a key criterion and a pre-requisite to qualify the performance of a fire suppressant, it does not address the challenge of designing and integrating that agent and system into the aircraft prior to certification plan submittal. While demonstration of an agent and its support system's firefighting performance may be achievable, ensuring that performance on an aircraft under extreme conditions may pose significant challenges to the system design and aircraft integration requirements. Continued technology development and refinement is needed to guarantee successful certification.

9. PHYSICAL PROPERTIES OF EXTINGUISHING AGENT

9.1 Overview

Two criteria regarding physical properties of extinguishing agent were evaluated:

- "Agent and system weight is less than or equal to halon system"
- "Clean agent (gaseous) - no clean up required"

9.2 Agent and system weight is less than or equal to halon system

In order to minimize the CO2 emission caused by increased fuel burn due to increased system weight, this criterion has been rated of high importance by the CCHRAG. Also, this criterion is important because it will aid in system integration providing a quicker, less costly transition to clean fire suppression agents for the growing fleet (drop-in replacement).

All participants who have performed more detailed studies of integration and system layout have indicated non-compliance with weight criteria.

The CCHRAG concludes that a weight increase cannot be avoided for any of the halon replacement solutions presented, at least for those which passed the MPS testing.

A couple of participants who are not experienced in delivering aircraft systems stated compliance to this requirement. However, the CCHRAG anticipates a weight increase associated with non-halon cargo fire suppression systems after detailed integration and system layout studies.

As an outlook, one participant stated that a replacement agent which will undergo MPS testing in 2022, might come close to Halon 1301 system weight. No detailed information was provided at this point in time.

The following schematic depicts the increased system complexity and weight of the already published system architecture proposals.

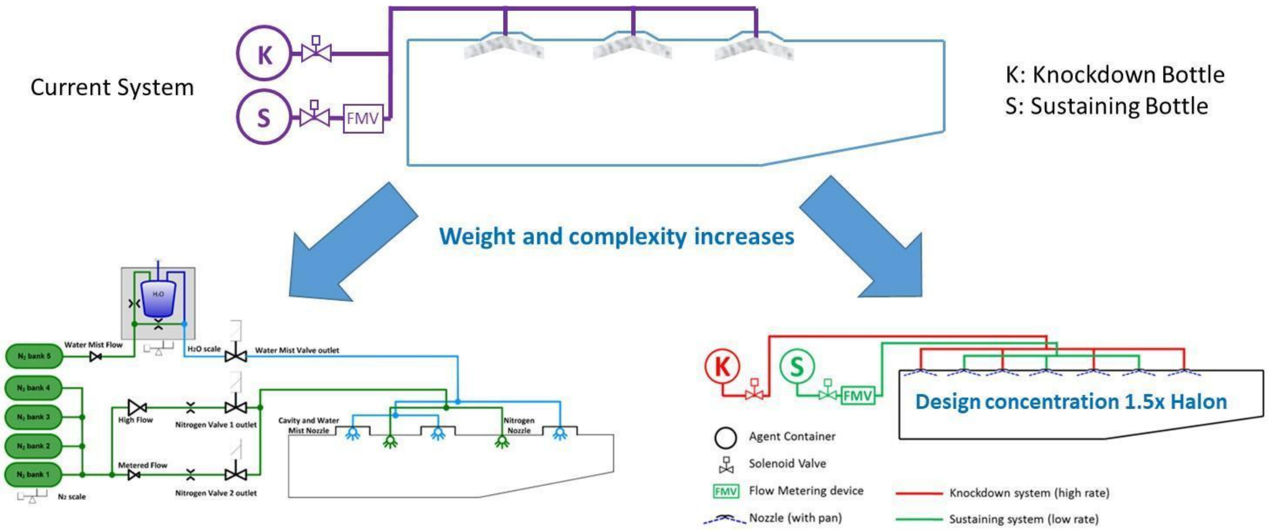

Figure 1: Halon Replacement System Architectures

9.3 Clean agent (gaseous) - no clean up required

It is important that the aircraft stays clean after a fire extinguishing discharge to minimize damage to the aircraft and cargo contained in the compartment. This is especially relevant in case of a spurious discharge when no actual fire occurred. Participants report that all gaseous agents are compliant.

One Participant that proposed a non-gaseous agent identified a non-compliance and the need for further investigation.

Based on survey results, CCHRAG concludes that the majority of the proposed agents are gaseous, and the need for additional maintenance efforts within the compartment after an inadvertent agent discharge can be kept to a minimum.

However, the participants have not provided details of the maintenance procedure at this stage of the assessment. Although gaseous, a substance might be chemically interacting with the cargo compartment materials or the transported goods. Material compatibility analyses are ongoing and not finalized.

9.4 Physical Properties Conclusive Statement

CCHRAG concludes that weight increase is imminent.
Material compatibility risks to be mitigated

10. PRODUCTION / Industrialisation

10.1 Overview

The CCHRAG assessed the production properties with the following two items:

- “currently used in other industries and/or applications”
- “risks for aircraft system adaptation/integration are mitigated or low”

10.2 Currently used in other industries and/or applications

All participants indicated that their solutions are currently used in other industries, except for one participant who has developed the aerospace application specifically. One solution is also used in the cabin for PED fire suppression by some commercial aircraft operators.

10.3 Risks for aircraft system adaptation/integration are mitigated or low

Six participants for total seven solutions, including two solutions which passed the FAA MPS test, indicated low risks. However, for the solutions which have not passed the FAA MPS test yet, the risk should be defined again. In addition, among those seven solutions, one is more suitable to smaller aircraft than larger aircraft for longer flight time.

One participant who owns two solutions cannot assess the risk without the involvement of direct suppliers to aircraft OEMs because they are the chemical manufacturer.

10.4 Production / Industrialization Conclusive Statement

CCHRAG concludes that all solutions are at pre-industrial / prototype status. Integration risks are to be mitigated.

11. Regulations / ENVIRONMENTAL, HEALTH & SAFETY

11.1 Overview:

Two criteria regarding Regulations and Environmental, Health & Safety were evaluated:

- "Less toxic than Halon 1301"
- "Not Present on regulatory lists & Cardiac sensitization"

11.2 Less toxic than Halon 1301

For the 2 solutions that have already passed MPS testing it was reported that

- 1 solution has been evaluated in the European CoRAP. Regarding hazard, the available information shows that the substance causes adverse effects on reproduction, potentially leading to impairment of sexual function, fertility and on development.[7] However, the need for follow-up regulatory action has been identified. This solution is also more toxic than Halon in terms of LOAEL and NOAEL.
- The second solution is considered non-toxic; however, the solution is technically complex and heavy compared to Halon 1301

For the remaining 7 solutions not MPS tested yet it was reported that

- 5 solutions have less or equal cardiac sensitization or toxicity levels compared to Halon 1301,
- 1 solution requires confirmation of impact and
- 1 solution is reported to have greater impact than Halon 1301.

[7] Substance Evaluation Conclusion document EC No 627-872-0

5 solutions are reported as being either already EPA SNAP approved or that the substance used is considered approved based on usage in other industries, which is an evolution from the 4 candidates reported in 2019.

It is foreseen that the definition of safe handling procedures and the specification of material characteristics in Material Safety Data Sheets (MSDS) will need to be developed for any Halon 1301 alternative.

11.3 Not Present on regulatory lists

Germany, Netherlands, Norway, Sweden, and Denmark have issued a questionnaire[8] as the next step for preparing a REACH Annex XV Restriction Dossier on per- and polyfluoroalkyl substances (PFAS) to restrict the manufacturing, use, and placement of PFAS on the EU market. One of the solutions which has passed MPS testing and is to date the most promising alternative falls into this substance category.

Risk of PFAS Chemical Restriction

If the amendment of REACH Annex XV to restrict the manufacturing, use, and placement of per- and polyfluoroalkyl substances (PFAS) on the EU market is ultimately adopted by the European Commission, it could have a very important bearing on the ability to replace halons in aircraft fire protection. Because the restriction proposal is only now in development, and the outcome is not certain, it is difficult to anticipate the impact on the industry's international Halon replacement efforts.

What fire suppression chemicals will be counted as PFAS?

The member states preparing the proposal have indicated an intent to define PFAS broadly as any molecule with a fully fluorinated methyl group (-CF_3) or a fully fluorinated methylene group (-CF_2) with some possible exclusions based on presence of chlorine, bromine or iodine atoms[9]. Given the breadth of this proposed definition, and if accepted by the European Commission, a PFAS restriction could extend to halon replacements that are already in use or are in development. One chemical that has been studied as a halon replacement agent is iodotrifluoromethane, CF_3I. CF_3I is chemically very close to Halon 1301, CF_3Br, and has been considered a potential replacement for many years. Depending on the final definition, CF_3I may face potential restriction as a PFAS. Another chemical that is already in use as a Halon 1211 replacement in handheld fire extinguishers is 2-bromotrifluoropropene ($CF_3CBr{=}CH_2$), or 2-BTP. 2-BTP contains a CF_3 group attached to another carbon atom, so it could also be considered a PFAS if a broad definition of PFAS is included in any final PFAS restriction. Lastly, HFC-227ea (CF_3CHFCF_3) and HFC-236fa ($CF_3CH_2CF_3$) have both been used as replacements for Halon 1301 in lavatory waste compartment fire protection. Both of these agents are likely to be included in a broad definition of PFAS.
It should be noted that there is another restriction for PFAS used in firefighting foams that are also widely used in Aviation, e.g. for airport firefighting which follows its own regulatory timeline. These two restrictions on a single chemical family is creating a great pressure on availability of performant firefighting products.

Will fire protection be considered an essential use?

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8 https://www.reach-clp-biozid-helpdesk.de/SharedDocs/Downloads/DE/REACH/Verfahren/Beschr%C3%A4nkung/Consultation-PFAS.pdf?__blob=publicationFile&v=3 link dated August 26 2021

9 PFAS in the scope of this restriction intention have the following structural formula: X-(-CF2-)n-X' with n equal to or larger than 1 and X, X' not being H (thus including X-CF3), meaning fluorinated substances that contain at least one aliphatic carbon atom that is both, saturated and fully fluorinated, i.e. any chemical with at least one perfluorinated methyl group (-CF3) or at least one perfluorinated methylene group (-CF2-), –), including branched fluoroalkyl groups and substances containing ether linkages, fluoropolymers and side chain fluorinated polymers.

During the development of the proposed restriction, the member states developing the proposal and the European Chemicals Agency (ECHA), which is tasked with providing its expert opinions on the proposal, will invite comments and will consider essential uses. The definition of the term "essential use" is currently under development and its application to specific substances as well as potential time-limited allowances are still underway and require close follow-up and advocacy. Transport is deemed essential for society and is vital for fulfilling the free movement of individuals, services and goods. Air transport has to fulfil safety and airworthiness regulations. The fact that suitable alternatives to fluorinated hydrocarbon agents for airborne fire suppression are not available should lead to an essential use classification on a global scale which is harmonized between the nations. Similar regulatory actions are underway in some countries where some of the major agent manufacturers are located such as the USA where currently a PFAS action plan is rolled out. China has started rolling out its New Pollutant Action. Other important industrial countries will follow soon. The Stockholm Convention could speed up these developments.

How could REACH restriction of PFAS affect aircraft halon replacement?

Halons are fluorinated fire suppression agents and much of the research effort to replace halons has focused on other fluorinated hydrocarbon agents. This is because fluorinated agents have excellent chemical stability and are able to extinguish or suppress fires at very low concentration, relative to other alternatives. There are four historic applications of halons in commercial airplanes:

- Handheld extinguishers - The most common non-halon handheld fire extinguisher agent that is in use on commercial airplanes is 2-BTP ($CF_3CBr{=}CH_2$). This chemical could face potential restriction if a broad definition of PFAS is adopted.
- Lavatory waste compartment extinguishers - As already noted above, HFC-227ea and HFC-236fa have been used to replace Halon 1211 and both chemicals could face potential restriction if a broad definition of PFAS is adopted.
- Engine and APU fire extinguishers – Most of the agents being considered to replace Halon 1301 in engine and APU fire extinguishing could face potential restriction if a broad definition of PFAS is adopted.
- Cargo Compartment fire suppression - Most of the agents being considered to replace Halon 1301 in cargo fire suppression could face potential restriction if a broad definition of PFAS is adopted.

When will we know more about the risk to the 2024 deadline?

ECHA will perform a 6-month public consultation to be initiated at the beginning of 2023. When ECHA responds to these comments in 2023, it will be clearer how the prospects for replacing halon in aircraft cargo compartments are affected.

11.4 Regulations / Environmental, Health and Safety Conclusive Statement

CCHRAG concludes that health & safety risks for some high potential replacement agents are more severe than for Halon.

The risk of potential replacement agents being regulated has to be actively counteracted.

12. SCHEDULE

12.1 Overview:

Two criteria regarding Schedule were evaluated:

- "Current TRL is equal or greater than 4"
- "TRL 6 Roadmap in place"

Progress of development solutions is monitored in accordance with the Technical Readiness Level (TRL) method and rated from TRL 1 to TRL 9, where TRL 4 corresponds to a technology validated in the laboratory and TRL 6 corresponds to a technology demonstrated in a relevant environment:

Figure 2: TRL Definition

A generic timeline was drafted in 2016 during initial activities of CCHRAG to support the proposal of deadline for halon replacement in aircraft cargo compartments. This timeline also includes concrete criteria for TRL achievement in the context of the CCHRAG assessment.

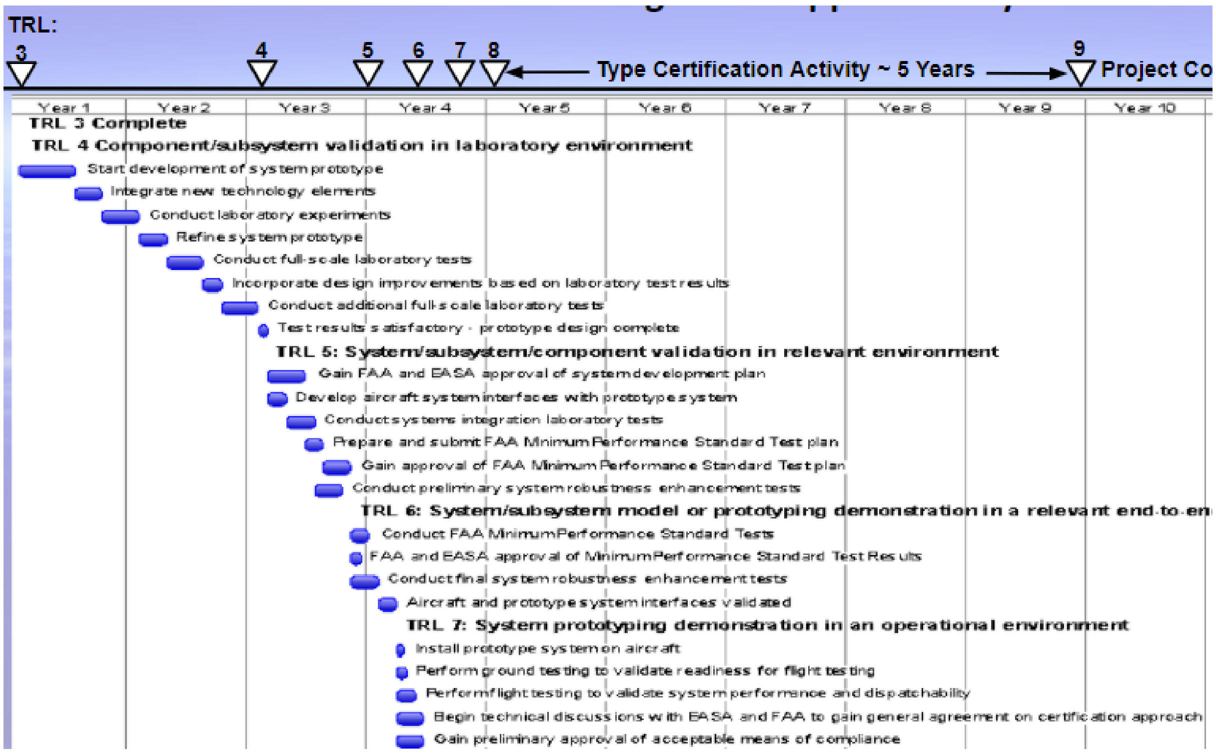


Figure 3: Initial Halon replacement schedule proposed by CCHRAG in 2016 (39th Assy)

This timeline indicates a halon-free system would be available for a new application for type certification by the 2024 timeframe, assuming TRL4 would be achieved in 2021. However, the proposed timeline might have been too optimistic in a sense that the achievement of 4 subsequent TRLs (5-8) within appr. one year seems more than challenging.

In previous CCHRAG documentation, it is stated that “If a candidate system has not been demonstrated to be application ready (actively being worked in TRL 7) by the 41st Session of the ICAO Assembly, the reasons for not adhering to the timeline will be identified and ICCAIA will indicate the consequences on the 2024 deadline”.

The pandemics has slowed down the development, but the industry is still actively working on Halon replacements.

12.2 TRL assessment

Participants have presented their self-assessment to indicate the solution TRL status. However, some of the participants might be more familiar with the TRL process than others, especially if they have experience in collaboration with aircraft OEMs. Within the nine presented candidate solutions, two solutions have already passed the FAA’s Minimum Performance Standard (MPS) tests and become main promising candidates. One additional solution is planned to be MPS tested in the second half of 2022.

The two solutions that already passed the FAA’s MPS tests stated to be at least compliant with TRL 4, which is in line with the CCHRAG view. Additional four out of the remaining seven solutions, were stated by the participants to have reached TRL 4 but would need further substantiation.

Within the nine presented candidate solutions, the two solutions that already passed the FAA's MPS tests stated to have a TRL6 roadmap in place, although no date for achievement had been disclosed. Additional three solutions, out of remaining seven solutions not yet tested to MPS, were also stated to have a TRL 6 roadmap in place.

Although TRL7 will not be fully achieved at the time of the 41st ICAO General Assembly, elements of this TRL have been already conducted, e.g. a flight test on the 2019 Boeing ECO Demonstrator.

The detailed TRL breakdown and criteria interpretation differ within the industry. This is why for one OEM, a certain TRL might be achieved and be still pending for another. However, the CCHRAG agrees that a robust TRL6 roadmap is in place for at least one agent which has passed the MPS test. Furthermore, CCHRAG agrees on the achievement of the initially defined main TRL criteria although a detailed assessment of additional, OEM-specific criteria might be outstanding.

TRL	Criterion	Achieved	Roadmap in place
6	Conduct FAA Minimum Performance Standard test	2/9 solutions	2/9 solutions
6	FAA and EASA approval of MPS test results	FAA test report to be issued	
6	Conduct final System robustness tests	ongoing	ongoing
6	Aircraft and prototype system interfaces validated	1/9 solutions	1/9 solutions
7	Install prototype system on aircraft	1/9 solutions	2/9 solutions
7	Perform ground testing to validate readiness for flight test	2/9 solutions	1/9 solutions
7	Begin technical discussions with EASA and FAA to gain general agreement on certification approach	1/9 solutions	
7	Gain preliminary approval of acceptable means of compliance	No	No

Table 3: CCHRAG TRL assessment

As a conclusion of Table 3 it can be stated that some but not all elements of TRL6 and TRL7 criteria as initially defined by the CCHRAG are fulfilled, so it is confirmed that TRL7 is actively being worked on at the time of the 41st Assembly.

12.3 Schedule Conclusive statement

CCHRAG concludes that at least one solution has a robust TRL6 roadmap in place.

13. Summary

Criterion	2019 Conclusion	2021 Conclusion	2022 status	Remarks
Cup burner fire extinction/suppression concentration established (ISO, NFPA)	Achievable	Achievable	Achieved	
FAA MPS testing concentration determined	Achievable on condition	Achievable	Achievable	2 agents have passed MPS testing, 2 show potential. Continued technology development is needed to guarantee successful certification.
Agent & System Weight is less than or equal to Halon system	Not Achievable	Not Achievable	Not Achievable	A weight increase is imminent for any of the halon replacement solutions presented. A consequence is an increased CO2 emission caused by higher fuel burn.
Clean agent (gaseous) - no clean up	Achievable	Achievable	Achievable	All relevant candidate agents MPS are gaseous - Material compatibility assessments ongoing.
Currently used in other industries and/or applications	Achievable	Achievable	Achievable	One solution is dedicated to the aircraft industry.
Risks for aircraft system adaptation/integration are mitigated or low	Achievable on condition	Achievable on condition	Risk to be anticipated	All solutions are pre-industrial / prototype. Integration risks to be mitigated.
Not Present on regulatory lists	Full compliance will take time and resources.	Achievable on condition	Risk to be mitigated	**High risk that candidate replacements will be regulated as PFAS.**
Toxicity is less than or equal to Halon 1301		Achievable on condition	Risk to be anticipated	Toxicity may be greater than Halon 1301.
Current TRL is equal or greater than 4	Achievable	Achievable	Achieved	
TRL6 Roadmap in place	-	Achievable on condition	Achieved	One solution has a robust TRL6 roadmap in place. Two additional solutions have TRL6 roadmaps in place.

Table 4: Summary table of technical assessment

Progress has been made for Halon replacement candidate agents. For some criteria, the status compared to previous assessments has changed from amber to green.

The risk for aircraft integration and toxicity have to be anticipated and mitigated. Higher toxicity might lead to additional measures to protect ground handling and maintenance staff. In this context, the previously assessed conditions turn into more tangible risks. The status of these criteria remains amber.

The system will be heavier and more integration space has to be allocated; and the status of this criteria remains red. The regulatory risk was non-existent at the time of the previous assessment cycles and the fact that promising candidate Halon Replacement agents might be regulated requires mitigation actions; therefore, the status compared to previous assessments has changed from amber to red.

— END —

Vintaging Model Peer Review: Fire Extinguishing

February 7, 2019

Presentation for the Halon Alternatives Research Corporation, Inc. (HARC)

United States Environmental Protection Agency

Outline

- VM Fire Extinguishing Peer Review Summary
- Updates to Assumptions
  - Market Penetration
  - Total Flooding Growth Rates
  - Lifetimes
  - Total Flooding Annual Emission Rates
- Final Results
- Contact Information

VM Fire Extinguishing Peer Review Summary

- ICF initiated peer review in March 2017
- Feedback from two peer reviewers received in April 2017
- ICF reached out with follow-up questions in February 2018
- Assumptions reviewed:
  - Market Penetration
  - Growth Rates
  - Lifetimes
  - Replacement Ratios
  - Annual Emission Rates
  - End of Life Emissions
- Public comments on fire extinguishing sector in 2015 U.S. GHG Inventory also received from 3M and HARC

Market Penetration Updates

- Flooding agents:
  - Implemented maximum market penetration values proposed to occur without HFC regulation
  - Updates increased the average market share of HFC-227ea from 1985-2050 from 10% to 23%
- Streaming agents:
  - Reduced maximum market penetration for HFC-236fa to 2.25%
  - Attributed remaining 0.875% to non-ODP/GWP

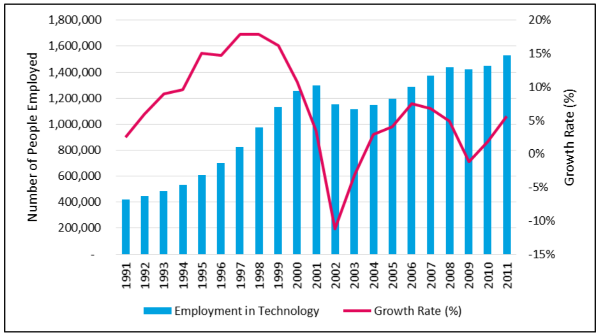
Updates to Flooding Agent Market Assumptions

	Primary Substitute				Secondary Substitute			
Initial Market Segment	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration	Name of Substitute	Start Date	Date of Full Penetration in New Equipment	Maximum Market Penetration
Flooding Agents (Previous)								
Halon-1301	Halon-1301	1994	1994	4%	Unknown			
	HFC-23	1994	1999	0.2%	None			
	HFC-227ea	1994	1999	18%	FK-5-1-12	2003	2010	10%
					HFC-125	2001	2008	10%
	Non-ODP/GWP	1994	1994	66%	FK-5-1-12	2003	2010	7%
	C_4F_{10}	1994	1999	0.5%	FK-5-1-12	2003	2003	100%
	HFC-125	1997	2006	11%	None			
Flooding Agents (New)								
Halon-1301	Halon-1301	1994	1994	4%	Unknown			
	HFC-23	1994	1999	0.2%	None			
	HFC-227ea	1994	1999	50%	FK-5-1-12	2003	2020	35%
					HFC-125	2001	2012	10%
					Inert Gas	2005	2020	10%
					Water Mist	2005	2020	3%
	NIK	1994	1994	22%	FK-5-1-12	2003	2020	7%
	Inert Gas	1995	2012	7%	None			
	CO_2	1998	2015	7%	None			
	C_4F_{10}	1994	1999	0.5%	FK-5-1-12	2003	2003	100%
	HFC-125	1997	2012	9%	FK-5-1-12	2003	2020	35%
					Inert Gas	2005	2020	10%
					Water Mist	2005	2019	3%

Total Flooding Growth Rate Updates

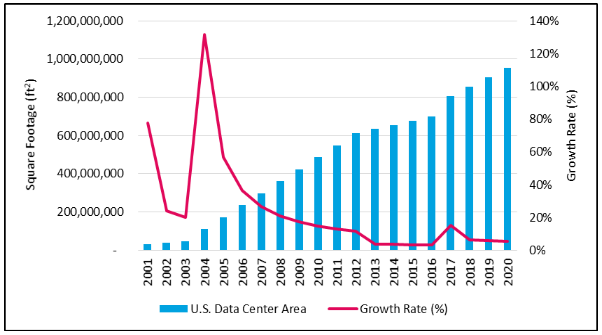
- Comments suggested total flooding market much larger than what VM modeled
- Growth rates updated to account for additional applications using HFC clean agents that were not originally using halon

Growth Rates of Employment in the Information Technology Industry



Source: Csorny (2013)

Growth Rates of Data Center Square Footage in the United States



Source: Koomey (2005), Mitchell-Jackson (2001), Sverdlik (2012)

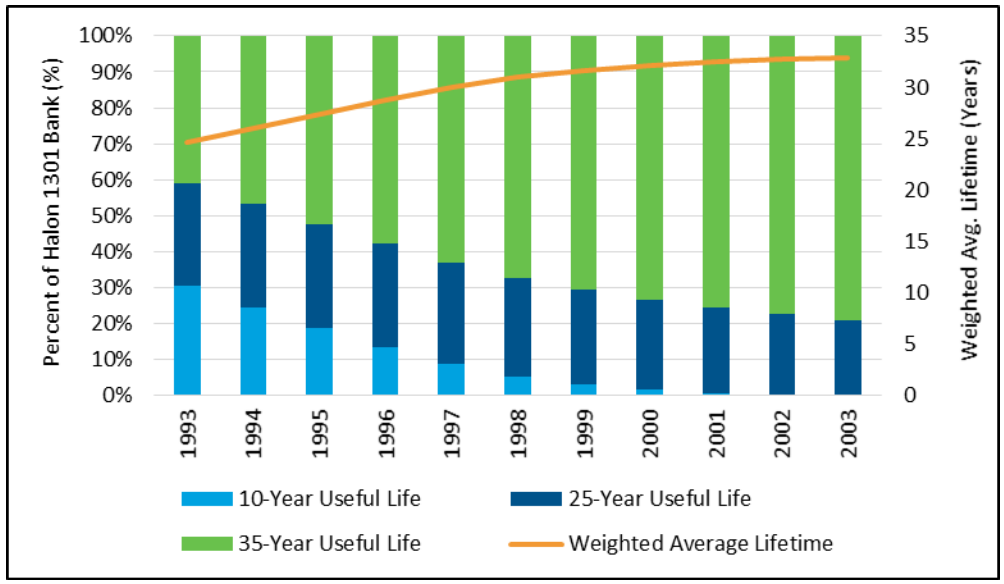
Updated Growth Rates for Total Flooding

Year	Updated Growth Rate
1996-1999	10%
2000-2003	-5.0%
2004-2009	2.5%
2010-2020	5.0%

Lifetime Updates

- Total Flooding
  - Extended lifetime from 20 years to 33 years
  - Based on improvement in useful life from 1993 to 2003
- Streaming
  - Extended lifetime from 12 years to 24 years
  - All portable units are recharged after 12 years and are in service for another 12 years

Market Penetration of Total Flooding Systems by Useful Life and Weighted Average Lifetime from 1993-2003

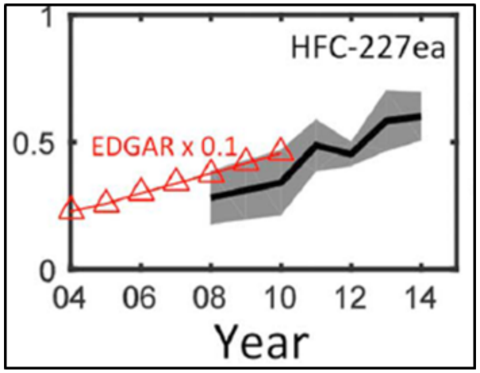


Source: Generated using data from Wickham (2002).

Total Flooding Annual Emission Rate Updates

- Annual leak rates for total flooding agents updated to decline over time to represent improved systems and practices
- Additional, higher leak rates are modeled for older systems

Annual HFC-227ea Emissions in the United States (Gg)



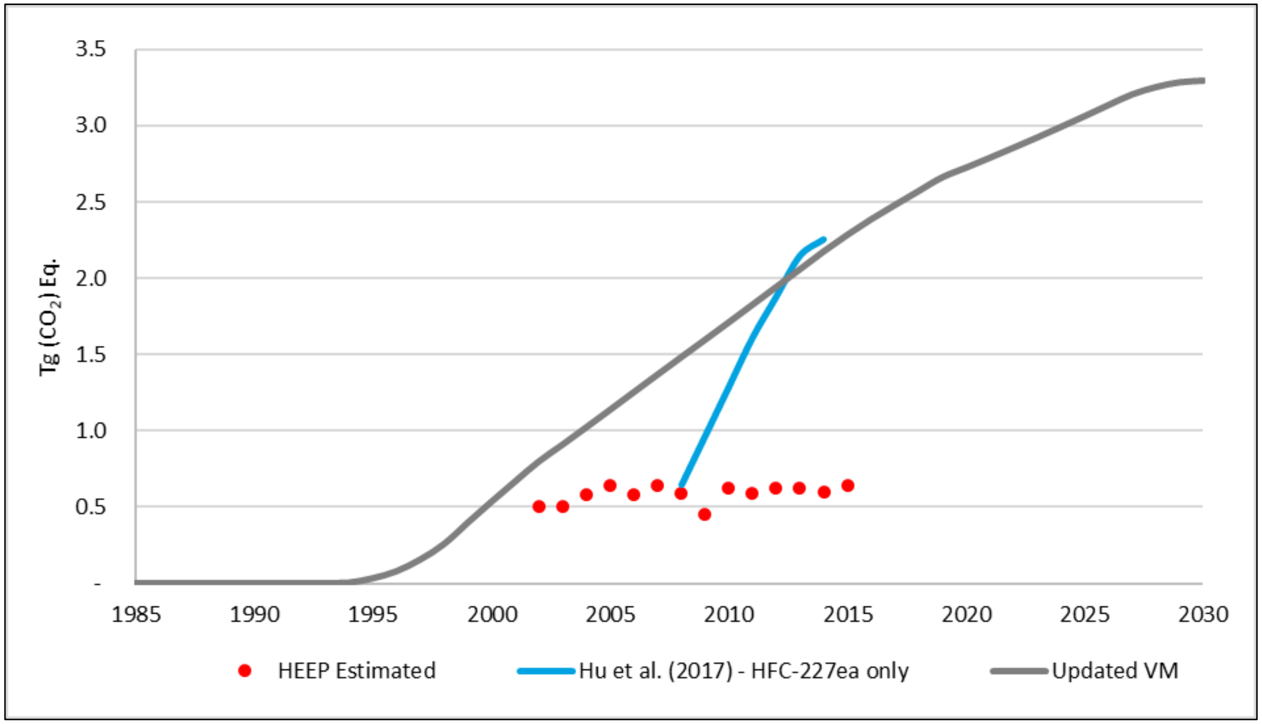
Source: Hu et al. (2017)

Comparison of Original and Updated Annual Leak Rate Assumptions for Total Flooding Agents

Total Flooding Agent	Original Annual Leak Rate (% of charge)	Updated Annual Leak Rate (% of charge)
Halon 1301	1985-1993: 9.2% 1994-on: 4.5%	1994-1998: 4.5% 1998-2002: 2.5%[a]
HFC-23	1994-on: 2.5%	2003-2019: 1.5% 2020-on: 1.0%
HFC-227ea	1994-on: 2.5%	2003-2019: 1.5% 2020-on: 1.0%
No GWP/ODP	1994-on: 2.5%	2003-2019: 1.5% 2020-on: 1.0%
C_4F_{10}	1994-on: 2.5%	1994-on: 2.5%
HFC-125	1997-on: 2.5%	2003-2019: 1.5% 2020-on: 1.0%
Novec™ 1230	2003-on: 2.5%	2003-2019: 1.5% 2020-on: 1.0%

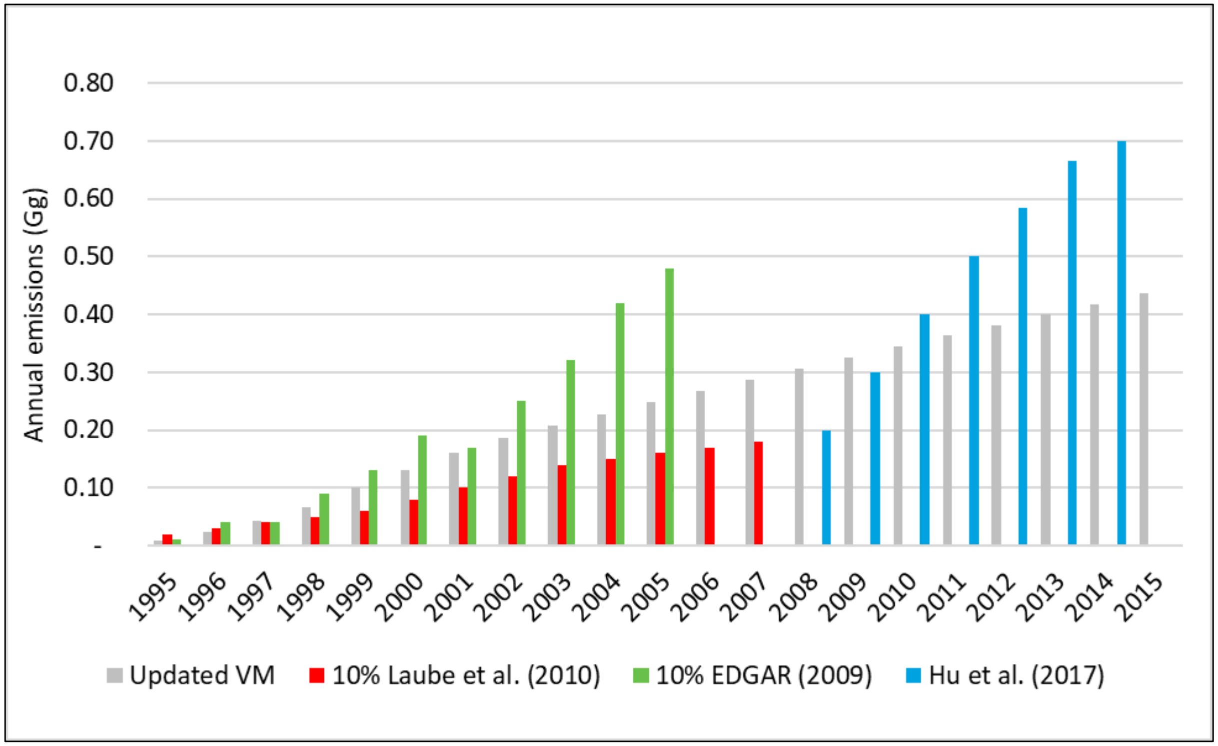
Final Results

Total HFC and PFC Emissions from the Fire Extinguishing Sector in the Updated VM Compared to HEEP Emission Estimates and Hu et al. (2017) (Tg $CO\text{-}_2$ Eq.)



Final Results

HFC-227ea Emissions (Gg) in the United States Modeled in the Updated VM in Comparison to Literature Estimates



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