Market Characterization of the U.S. Onboard Civil Aviation Fire Suppression Industry

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1. Summary

Onboard civil aviation fire suppression systems, which have historically used halons, are installed on mainline and regional passenger and freighter aircraft to protect valuable and sensitive assets (UNEP 2018, ICAO 2016, ICAO 2019a). Fire suppression systems onboard aircraft can be divided into two main product categories: total flooding systems and streaming applications; currently hydrofluorocarbons (HFCs), specifically HFC-236fa and HFC-227ea, have replaced halon 1301 in total flooding systems in lavatory trash receptacles (UNEP 2018, Robin 2011; Jensen Hughes, Inc. 2015). Due to weight and volume restrictions or penalties (e.g., increased fuel consumption), HFCs have not been popularized in other fire suppression systems onboard aircraft (ICAO 2016, ICAO 2019a).

In 2006, HFCs were used in lavatory trash receptacle fire suppression systems in new aircraft and over the period of 2006 to 2020, HFCs also replaced all halon 1301 lavatory trash receptacle fire suppression systems in existing aircraft. In 2020, approximately 0.38 metric tons (MT) of HFC-227ea and 0.30 MT of HFC-236fa were installed in new aircraft lavatory fire suppression systems[1]. This is estimated to be 0.009% of the total fire suppression market and 0.0004% of the total HFC use in the United States.

Industry has indicated that identifying, testing, and approving alternatives can take upwards of fifteen years (Boeing 2020b) and, thus, the use of HFCs in lavatory fire suppression systems is expected to continue as new aircraft are sold; in 2040, approximately 0.63 MT of HFC-227ea and 0.45 MT of HFC-236fa is estimated to be installed in new aircraft lavatory fire suppression systems. This is estimated to be 0.012% of the total fire suppression market and 0.0007% of the total HFC use in the United States.

2. Introduction

Onboard civil aviation fire suppression systems are installed throughout mainline and regional passenger and freighter aircraft, including engine nacelles, auxiliary power units (APUs),[2] lavatory trash receptacles, baggage/crew compartments, and handheld extinguishers (UNEP 2018). The total number of civil aircraft[3] in the United States in 2020 by type is shown in Table 1.

[1] Lavatory systems are assumed to have negligible annual leak rates and are sent offsite for servicing. Therefore, servicing is not explicitly accounted for in HFC use estimates.
[2] The APU is a small turbine engine installed near the rear of an aircraft and serves as an additional energy source normally used to start one of the main engines on an airliner or business jet. The APU is equipped with an extra electrical generator to create enough power to operate onboard lighting, galley electrics and cockpit avionics, usually while the aircraft is parked at the gate (FlyingMag 2018).
[3] Note that private and/or business aircraft are excluded in these estimates and the remainder of the market characterization. Because jets with less than 10 seats are not required to have lavatory trash receptacle systems, no HFCs are assumed to be in use in private and/or business aircraft (FAA 2020).

Table 1. Estimated Number of Aircraft Fleet in the United States in 2020

Total Number of Aircraft	2020
Mainline Passenger Aircraft	18,703
Regional Passenger Aircraft	1,577
Mainline Freighter Aircraft	692
Regional Freighter Aircraft	133

Source: Estimates were developed based on fleet and delivery estimates from Boeing (2017, 2020) and Airbus (2017, 2019).

Fire suppression systems onboard aircraft have historically used halons, a class of halogenated chemicals containing bromine, as clean extinguishing agents (i.e., those that do not leave residue following system discharge) to protect valuable and sensitive assets (UNEP 2018, ICAO 2016, ICAO 2019a). Halons have very high ozone depletion potentials (ODPs) because they contain bromine, which has a higher reactivity with ozone than chlorine.

Several alternatives to halons—including hydrofluorocarbons (HFCs) (i.e., HFC-236fa and HFC-227ea)—have been introduced in certain onboard civil aviation fire suppression applications. Similar to halons, HFCs are also effective, clean agents that are non-conductive.

The remainder of this report characterizes HFC use in the civil aviation fire suppression industry in the United States, including key market players and historical and current use of HFC fire suppressants in civil aircraft lavatory fire suppression systems.

3. Market Characterization

This section provides an overview of fire suppression systems used onboard civil aviation applications, as well as the current equipment market and key manufacturers.

3.1. Overview of Onboard Civil Aviation Fire Suppression Systems

Generally, fire suppression systems onboard aircraft can be divided into two main product categories: total flooding systems and streaming applications.

- **Total flooding systems** are designed to automatically discharge a fire extinguishing agent by detection and related controls (or manually by a system operator) and achieve a specified minimum agent concentration throughout a confined space (i.e., volume percent of the agent in air).
- **Streaming applications** use portable fire extinguishers that can be manually manipulated to discharge an agent in a specific direction and release a specific quantity of extinguishing agent at the time of a fire.

Table 2 lists the national standards related to fire extinguishing products aboard aircraft. These standards include requirements, specifications, and recommendations for the design, installation, testing, maintenance, and safety factors for different types of fire suppression agents in total flooding systems and streaming applications.

Table 2. Standards for Fire Suppression Products Aboard Aircraft

Standard	Title	Description
NFPA 408	Standard for Aircraft Hand Portable Fire Extinguishers	• Requirements for type and size of portable fire extinguishers for all types of aircraft • Requirements for training flight-crew members on extinguisher use in the event of a fire onboard an aircraft
FAA Minimum Performance Standard (MPS) (DOT/FAA/AR-01/37)	Handheld Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft	• Specifies two extinguisher tests that replacement agents must pass in addition to requiring national certifications to ensure that replacement agents will meet or exceed performance of halon 1211 both in fighting fires and maintaining a safe breathing environment in aircraft cabins
FAA MPS (DOT/FAA/TC-TN12/11)	Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems	• Establishes the Minimum Performance Standards (MPS) that a halon 1301 replacement aircraft cargo compartment fire suppression system must meet as part of the aircraft certification procedures
FAA MPS	Fire Extinguishing Agents/Systems of Civil Aircraft Engine and APU Compartments	• Establishes the MPS that engine and APU compartment fire extinguishing systems must meet
FAA MPS (DOT/FAA/AR-96/122)	Lavatory Trash Receptacle Automatic Fire Extinguishers	• Establishes the MPS that an agent must meet and provides an equivalent level of safety to that of halon • Establishes the fire load, trash disposal receptacle test article, test procedures, and pass/fail criteria for built-in extinguishers for lavatory disposal receptacles

Sources: NFPA (2017), FAA (1997, 2002, 2012).

Fires are classified as Class A, B, or C, as defined in Table 2 (FEMA 2015).

Table 3. Classification of Fire Types in the United States Based on Fuel Hazard

Symbol	Fire Type Classification	Fuel
	Class A	Ordinary combustibles (e.g., wood, paper, plastics)
	Class B	Flammable liquids (e.g., gasoline, petroleum oil and paint) and flammable gases (e.g., propane, butane)
	Class C	Energized electrical equipment (e.g., motors, transformers, appliances)

Source: FEMA (2015).

3.1.1. Total Flooding Systems

Total flooding systems are used in both normally occupied and unoccupied areas in civil aviation applications (UNEP 2018). Total flooding systems are intended to provide a specified minimum agent concentration throughout a confined space to combat larger fires. Primary civil aviation applications for total flooding systems in the United States include:

- Engine nacelles,
- APUs,
- Cargo compartments, and
- Lavatory trash receptacles (Robin 2011; Jensen Hughes, Inc. 2015).

Total flooding systems in engine nacelles and APUs typically protect against Class B fires. Due to the proximity to fuels and other volatile fluids, the requirements for fire systems for engine nacelle and APUs are especially challenging (UNEP 2018). Total flooding systems in cargo compartments must be able to suppress Class A and Class B fires and must have sufficient ability to continue to provide fire suppression and safety from the initial fire warning through landing, often over 350 minutes (UNEP 2018). Total flooding systems in lavatory trash receptables are meant to extinguish receptacle fires in pressurized cabins' lavatories in the case of a Class A fire (ICAO 2016, ICAO 2019a).

Of these onboard aircraft applications, HFCs are currently used only in lavatory trash receptacle fire suppression systems. Boeing and Airbus are using HFC-227ea and HFC-236fa in their aircraft, respectively for these applications (ICAO 2016, ICAO 2019).

3.1.2. Streaming Applications

Streaming applications in onboard civil aviation applications, include portable fire extinguishers designed to protect against specific hazards. Portable fire extinguishers are intended as a first line of defense for fires of limited size. The selection and installation of extinguishers is independent of whether an area is equipped with a total flooding fire suppression system (NFPA 2013). Standards for handheld extinguishers aboard aircraft require the unit to be able to suppress hidden fires while not causing unsuitable visual obscuration, discomfort, or toxic effects where the space is occupied (UNEP 2018).

Currently, HFCs are not in use in streaming agents onboard aircraft.

3.2. Major Manufacturers

Major manufacturers for total flooding systems for aircraft within the United States include, but are not limited to:[4]

- BFPE International
- **FFE**
- Fike Corporation

[4] Manufacturers in bold manufacture HFC lavatory trash receptacle fire suppression systems.

- FireBoy-Xintex
- Firetrace International
- Meggitt
- Minimax
- **UTC (Kidde)**

Leading manufacturers of portable fire extinguishers for aircraft in the United States include, but are not limited to:

- BFPE International
- FireBoy-Xintex
- Gielle
- H3R Aviation, Inc.
- PyroChem
- TYCO (Ansul)
- UTC (Kidde)

4. Subsector Background and HFC Use

4.1. Fire Suppressants in Aircraft

Halons have a unique combination of characteristics including being electrically non-conductive, dissipating rapidly without residue (i.e., clean), efficiently extinguishing most types of fires, and low toxicity. While other sectors of use, including the military, have successfully adopted alternatives to halons, the efficiency of these agents has made finding alternatives for aviation, in response to the global halon phaseout, particularly difficult due to strict standards including weight restrictions aboard aircraft (Boeing 2020b, ICAO 2016, ICAO 2019a). ICAO Standards and Recommended Practices (SARPs) currently recommend the phase-out of halons in aircraft produced on or after December 31, 2011 for lavatory fire suppression systems and December 31, 2018 for hand-held fire extinguishers (ICAO N.d.). ICAO SARPs also recommend the use of an alternative in engine nacelle and APU systems or cargo compartment systems for any aircraft for which a type certificate[5] application will be submitted on or after December 31, 2014 or November 28, 2024, respectively (ICAO N.d.).

For an alternative to be approved for use in U.S. civil aviation applications, it must be first approved for use by EPA's Significant New Alternatives Policy (SNAP) program. The substitute must then be approved by the Federal Aviation Administration (FAA). In order to be approved by the FAA for use, a substitute must meet industry standards by being approved by either Underwriter's Laboratory, Factory Mutual Research Corporation, or the U.S. Coast Guard (FAA 2011).

Halon alternatives include hydrochlorofluorocarbons (HCFC), HFCs, and some not-in-kind (NIK) extinguishing agents. HFCs are considered to be clean fire suppressants and offer many of the same benefits as halons (e.g., fire suppression efficiency and lack of impact on equipment). In 2020, HFCs represent approximately 15 percent of the total halon alternative market in the United States, with CO_2 and inert gases accounting for most of the remainder, although HCFCs, perfluorocarbons (PFCs), fluoroketones (FKs), and iodinated fluorocarbons are also in use (EPA

[5] A type certificate designates that a general aircraft design meets design and safety requirements. The aircraft design must then also gain a certificate of airworthiness which designates a specific aircraft meets all additional requirements (ICAO 2019b).

2020). HFCs are estimated to represent only 0.05% of the total halon alternative market onboard civil aircraft in the United States, primarily HFC-227ea and HFC-236fa (ICAO 2016, ICAO 2019a).

4.1.1. Flooding Agents in Aircraft

In addition to continued use of halon 1301, the current market for total flooding systems also includes an HCFC, HFCs, and some not-in-kind (NIK) extinguishing agents (e.g., powdered aerosols, foams, water).

2-BTP, a non-HFC clean agent, was also approved by EPA's SNAP program for use in engine nacelles/APUs in 2016 and to date has not yet been widely adopted in civil aircraft (ICAO 2016, ICAO 2019a, UNEP 2018). Alternatives for cargo compartments have been particularly difficult to develop due to requirements to suppress Class A and Class B fires and sufficient ability to continue to provide fire suppression for the duration of the flight (UNEP 2018), with halons still being the main agent in use in new aircraft (ICAO 2016, ICAO 2019a).

In 2011, Boeing and Airbus began using HFC-227ea and HFC-236fa, respectively, in their lavatory trash receptacle systems. Regional aircraft manufacturers followed shortly after, installing HFC systems in new aircraft as of January 2013 (ICAO 2016). Although HFC-236fa and HFC-227ea have increased space and weight characteristics compared to halon systems, these issues are less of a concern for lavatory trash receptables due to their small size and charge size. The weight of the agent is estimated to be much smaller than that of the bottle itself and, thus, the slight increase necessary to accommodate for HFCs has minimal impact on the overall weight of the system (Jensen Hughes, Inc. 2021a). Table 4 summarizes the environmental characteristics, including ODP and GWP, for total flooding agents approved for use in aircraft.

Table 4. Environmental Characteristics of Total Flooding Agents Approved for Use Onboard Aircraft

Total Flooding Agent	Trade Name	Chemical Manufacturer	ODP[a]	GWP
Halon 1301[b]	Freon FE	DuPont and Great Lakes Chemical	10	7,140
HFC-227ea	FM-200	Chemours[c]	0	3,220
HFC-236fa	FE-36	Chemours[c]	0	9,810

Note: GWPs are aligned with the exchange values used in the American Innovation and Manufacturing (AIM) Act of 2020.
[a] Ozone Secretariat (1987).
[b] The production of Halon 1301 and Halon 2402 was banned in the United States in 1994 in compliance with the Montreal Protocol. Ongoing halon use is limited to recycled halon.
[c] Chemours was formerly a combination of DuPont and the fire suppressant division of Great Lakes Chemical.

4.1.2. Streaming Agents in Aircraft

In addition to continued use of halon 1211, the current market for streaming applications also includes HCFCs, HFCs, and other agents (e.g., dry chemical, CO_2, water) (UNEP 2018, ICAO

2016, ICAO 2019a). HCFC blends (e.g., Halotron I) and HFCs (largely HFC-236fa) replaced halon 1211 in various streaming agent applications following the production and import ban of halons in 1994 (UNEP 2014, UNEP 2018). HFC-236fa and HFC-227ea have both been listed as an acceptable replacement for halon 1211 by EPA's SNAP program and approved for use by the FAA onboard aircraft. Airframe manufacturers chose not to pursue these substitutes for use in streaming agent applications due to the space and weight characteristics paired with the concurrent ongoing development of an agent without these limitations (FAA 2013, ICAO 2016, ICAO 2019a, UNEP 2018). Since the approval and commercialization of 2-BTP the industry has, instead, turned to the use of 2-BTP as it is the closest direct replacement based on size and weight (ICAO 2019a).

Dry chemical, dry powder, and CO_2 handheld extinguishers have also been considered for replacement of halon 1211 for general streaming applications; however, according to FAA, these alternatives should not be used in aircraft due to corrosive and toxicological properties (FAA 2013). Table 5 summarizes the environmental characteristics, including ODP and GWP, for streaming agents approved for use in aircraft.

Table 5. Environmental Characteristics of Streaming Agents Approved by FAA for Handheld Fire Extinguishers for Use Onboard Aircraft

Streaming Agent	Trade Name	Chemical Manufacturer	ODP[a]	GWP
Halon 1211[b]	FREON™ 12B1	DuPont	3	1,890
HCFC Blend B[c, d]	Halotron I	American Pacific	0.01	222
HFC-236fa	FE-36	Chemours[e]	0	9,810
HFC-227ea	FM-200	Chemours[e]	0	3,220
2-bromo-3,3,3-trifluoropropene	2-BTP	American Pacific	0.0028	0.23-0.26

Note: GWPs are aligned with the exchange values used in the AIM act.
[a] Ozone Secretariat (1987).]
[b] The production of halon 1211 was banned in the United States in 1994 in compliance with the *Montreal Protocol*.
[c] HCFC Blend B contains greater than 93% HCFC-123 and less than 7% proprietary gas mixture (AMPAC 2016a).
[d] HCFCs are scheduled for phaseout under the Montreal Protocol. Starting in 2015, production and import of HCFCs (except in portable fire extinguishers for non-residential use and refrigeration and air conditioning equipment) are not allowed.
[e] Chemours was formerly a combination of DuPont and the fire suppressant division of Great Lakes Chemical.

4.2. Current and Projected Use of HFCs in the Civil Aviation Fire Suppression Subsector

As mentioned in Section 3.1 above, HFC use in civil aviation fire suppression applications are limited primarily to lavatory trash receptacle systems. Lavatory trash receptacle fire suppression systems are estimated to make up less than 0.5% of the total installed fire suppression base on aircraft (UNEP 2018). Lavatory trash receptacle fire suppression systems are hermetically sealed, expected to have negligible leak rates, and contain approximately 0.1 kilograms of HFC-227ea or HFC-236fa per system (Jensen Hughes, Inc. 2020). Lavatory systems must be punctured to remove agent and, thus, are not serviceable. At the end of the equipment lifetime, the lavatory system bottle is removed from the system and shipped to the manufacturer for replacement (Jensen Hughes, Inc 2020, Jensen Hughes, Inc. 2021b). HFCs from lavatory systems are removed and stored but are not currently used to fill new lavatory fire suppression systems. The average lifetime of lavatory fire suppression systems is ten years, whereas the average lifetime of civil aircraft is 25 to 30 years (Jensen Hughes, Inc. 2021b). Therefore, it is assumed that each aircraft lavatory would use three lavatory fire suppression system bottles over the lifetime of the aircraft.

It is estimated that HFC use in 2020 in U.S. civil aircraft lavatory trash receptacle systems is approximately 0.68 MT (0.38 MT HFC-227ea and 0.30 MT HFC-236fa). HFC estimates for the United States were developed based on fleet and delivery (i.e., sales) estimates from Boeing (2000, 2010, 2017, 2020) and Airbus (2000, 2009, 2017, 2019). In 2014, ICF received feedback from Airbus and Boeing representatives which allowed estimates for these two manufacturers' portion of the fleet to be refined. ICF then assumed that the remaining portion of the 2014 fleet consisted of various regional aircraft. These assumptions were used as a proxy for other fleet years.

For the purposes of this analysis, it was assumed new aircraft from Boeing and Airbus employed HFC-227ea and HFC-236fa, respectively, in lavatory trash receptacle systems beginning in 2005 and 2011, respectively (ICAO 2016, ICAO 2019a). Furthermore, regional aircraft began installing HFC systems in new aircraft as of 2013 (ICAO 2016). Because the specific HFC in use in regional aircraft was not identified, it was assumed that 50% of regional aircraft employed HFC-227ea and 50% employed HFC-236fa. Additionally, it was assumed that, by 2020,[6] all existing aircraft had converted their halon lavatory systems to HFC systems. Delivery information from Boeing and Airbus was incorporated as totals across four time periods: 1999 to 2019, 2009 to 2029, 2016 to 2036, and 2019 to 2039, and it was assumed that annual deliveries were constant in each of these ranges. As noted above, it was also assumed that every 10 years, the lavatory trash receptacle system is replaced with a new system in existing aircraft.[7] Table 6, Figure 1, and Figure 2show the historic use of new HFC-227ea and HFC-236fa used in civil aviation lavatory system fire suppression applications in the United States from 2015 to 2020.

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[6] Based on expert opinion, all civil aviation lavatory receptable fire suppression systems have been converted to HFCs as of 2020. The completion of this conversion is not precisely known, however, and may have occurred earlier than 2020 (Jensen Hughes 2021).

[7] Aircraft lavatory systems which were transitioned from halon to HFCs were assumed to require two lavatory system bottles for the remaining lifetime of the aircraft.

Table 6. Historic HFC Use in Civil Aviation Fire Suppression Applications in the United States (2015-2020)

	2015	2016	2017	2018	2019	2020
HFC Use in Civil Aviation Fire Suppression Applications (MT)						
HFC-227ea	0.43	0.45	0.45	0.45	0.46	0.38
HFC-236fa	0.37	0.39	0.39	0.39	0.39	0.30
Total HFC	0.80	0.84	0.84	0.84	0.85	0.68
HFC Use in Civil Aviation Fire Suppression Applications (MMT CO_2 Eq.)						
HFC-227ea	0.001	0.002	0.002	0.002	0.002	0.001
HFC-236fa	0.004	0.004	0.004	0.004	0.004	0.003
Total HFC	0.005	0.005	0.005	0.005	0.005	0.004

Note: Totals may not sum due to independent rounding.

Figure 1. Historic HFC Use in Civil Aviation Fire Suppression Applications in the United States (2015-2020) (MT)

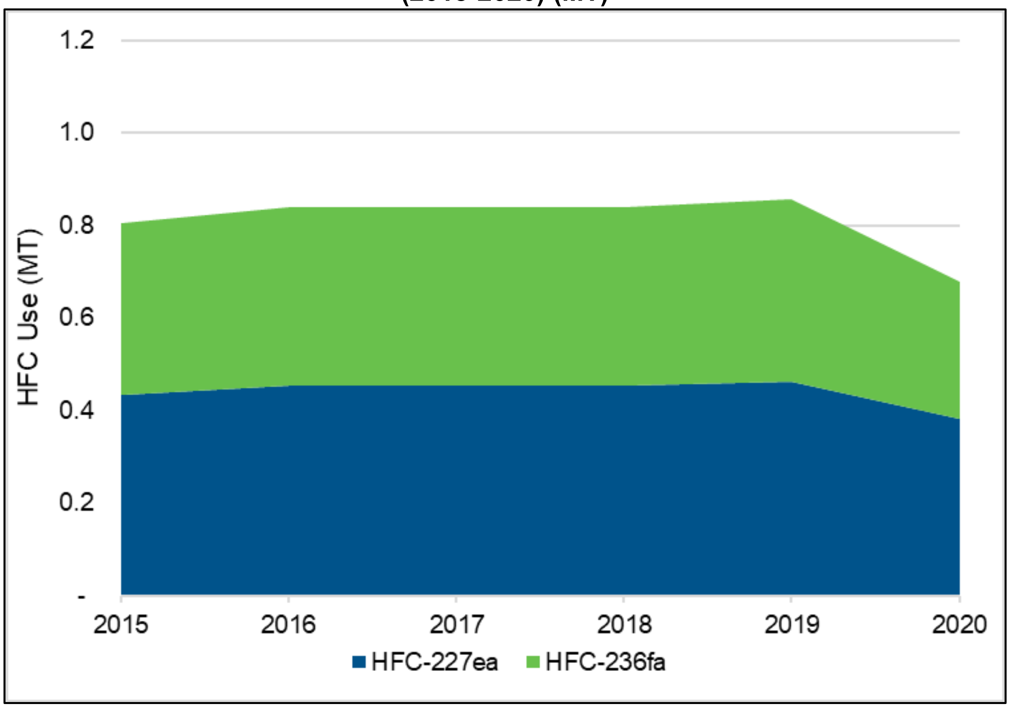


Figure 2. Historic HFC Use in Civil Aviation Fire Suppression Applications in the United States (2015-2020) (Million Metric Tons CO_2 Equivalent (MMT CO_2 Eq.))

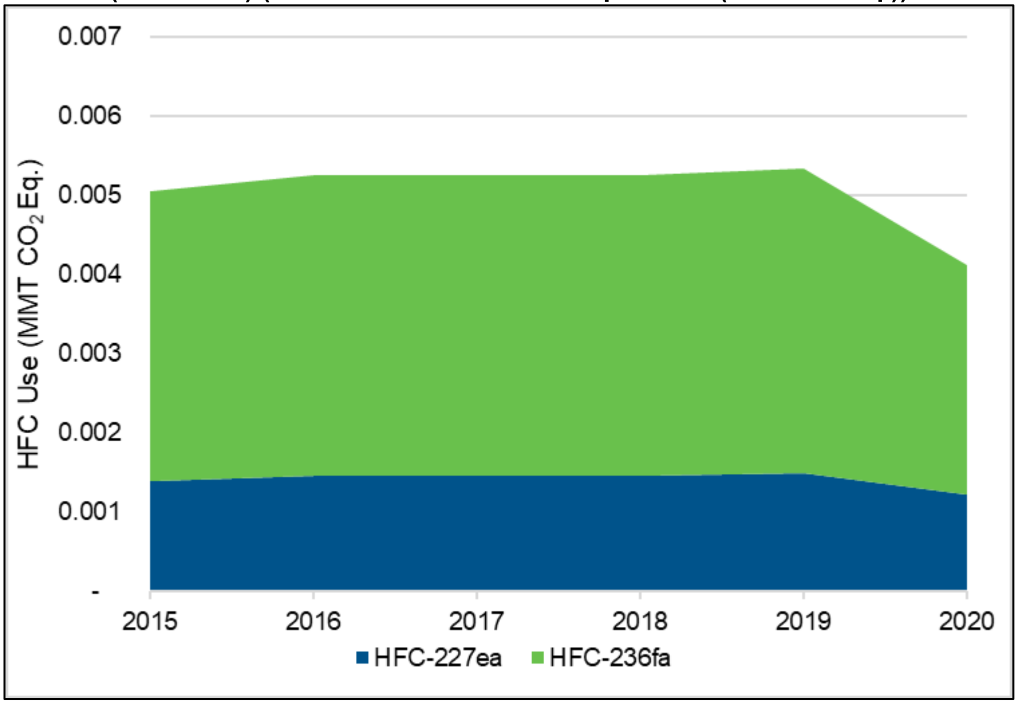


Figure 3 shows the projected use of HFCs in the total fire suppression market in the United States, and Table 7, Figure 4, and Figure 5 show the projected use of new HFC-227ea and HFC-236fa in onboard civil aviation fire suppression uses from 2020 to 2040. Estimates were developed assuming new aircraft continued to use HFC-227ea and HFC-236fa in lavatory trash receptacle systems. HFCs were not assumed to be in use in any other civil aviation fire suppression applications.

Projections of aircraft fleet and deliveries were adjusted to reflect preliminary observed changes in response to the COVID-19 pandemic. Aerospace Markets (2020) indicated there have been decreases in global aircraft fleet and deliveries in 2020, including an increase in early retirements of aircraft, particularly twin aisles. Global aircraft deliveries in 2020 have decreased by 33.1%, with full recovery not expected until after 2024 due to the COVID-19 pandemic. Full impacts for the United States are not yet known and may continue to fluctuate.

In 2020, the HFC use in the civil aviation market makes up 0.68 MT (0.38 MT HFC-227ea and 0.30 MT HFC-236fa) or 0.009% of the total fire suppression market and 0.0004% of total HFC use in the United States. Following the recovery of the civil aviation market from impacts due to the COVID-19 pandemic (i.e., 2025), HFC use in the civil aviation market is estimated to stabilize at 1.08 MT (0.63 MT HFC-227ea and 0.45 MT HFC-236fa) or 0.012% of the total fire suppression market and 0.0007% of total HFC use in the United States.

Figure 3. Projected HFC Use in Fire Suppression Applications in the United States (2020-2040) (MT)

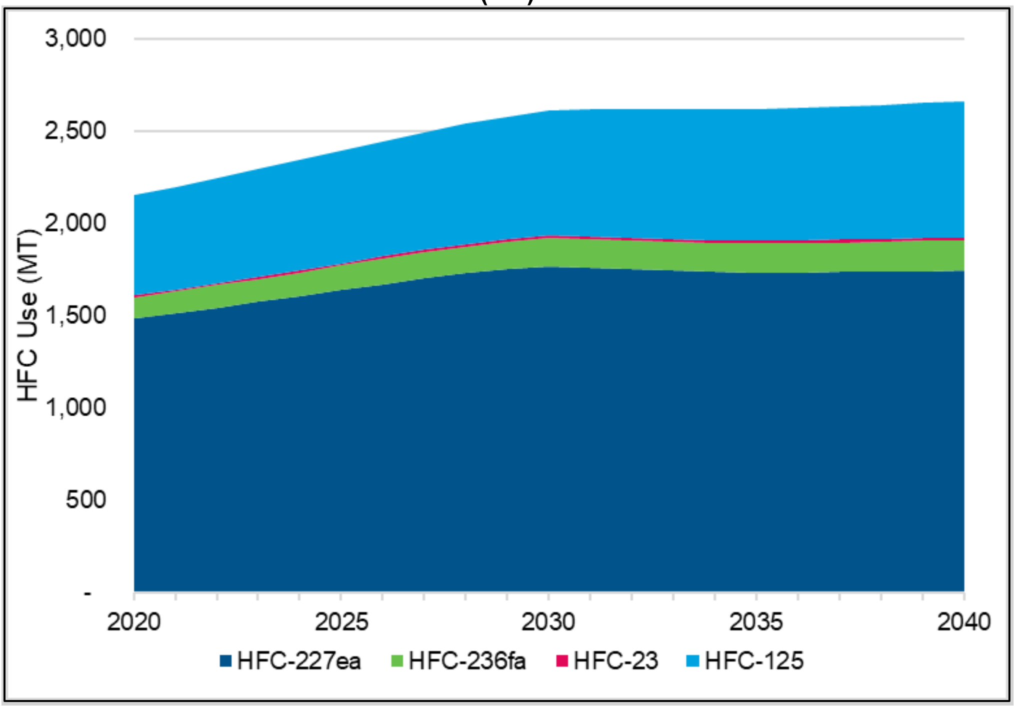


Table 7. Projected HFC Use in Civil Aviation Fire Suppression Applications in the United States (2020-2040)

	2020	2025	2030	2035	2040
HFC Use in Civil Aviation Fire Suppression Applications (MT)					
HFC-227ea	0.38	0.67	0.62	0.67	0.63
HFC-236fa	0.30	0.46	0.43	0.48	0.45
Total HFC	0.68	1.13	1.04	1.16	1.08
HFC Use in Civil Aviation Fire Suppression Applications (MMT CO_2 Eq.)					
HFC-227ea	0.001	0.002	0.002	0.002	0.002
HFC-236fa	0.003	0.005	0.004	0.005	0.004
Total HFC	0.004	0.007	0.006	0.007	0.006

Note: Totals may not sum due to independent rounding.

Figure 4. Projected HFC Use in Civil Aviation Fire Suppression Applications in the United States (2020-2040) (MT)

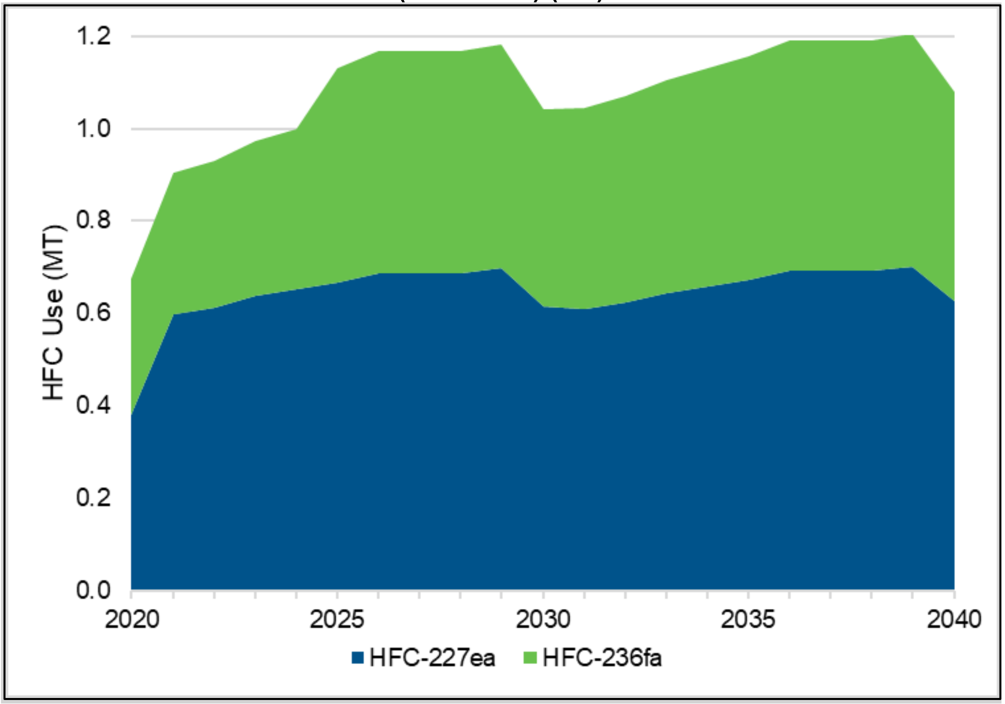
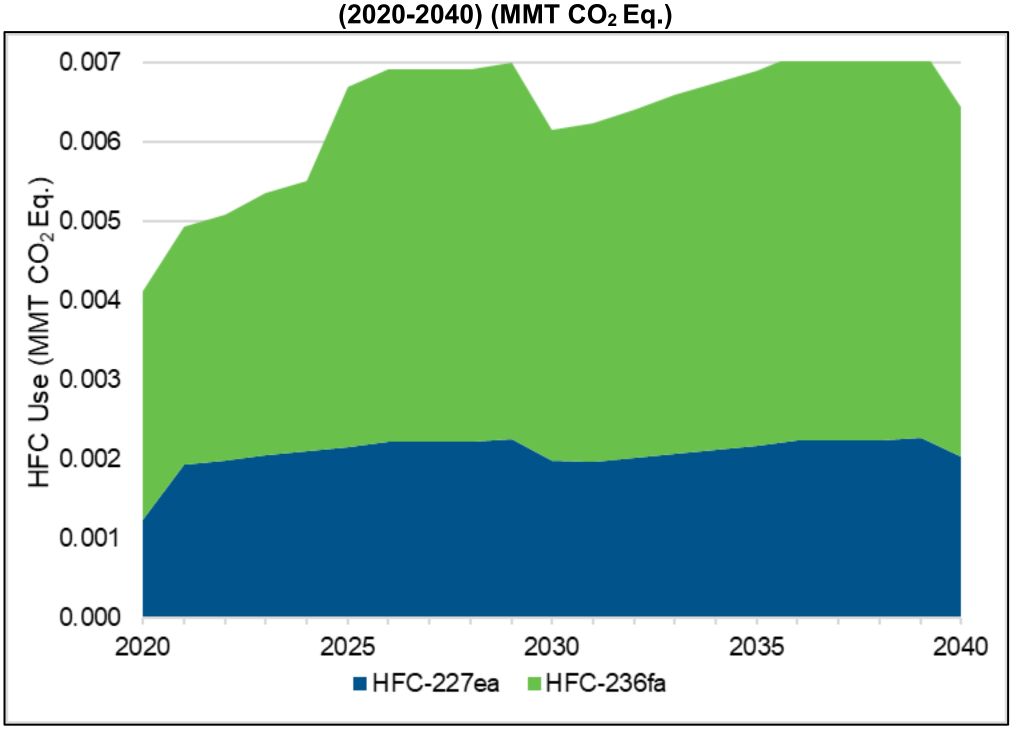


Figure 5. Projected HFC Use in Civil Aviation Fire Suppression Applications in the United States (2020-2040) (MMT CO_2 Eq.)



As additional alternatives are identified and tested for engine nacelle, APU, and cargo compartment use, use of HFCs could increase; however, HFCs are not being heavily considered by industry in these applications at this time due to the limitations for use in most civil aviation applications (e.g., weight restrictions) (ICAO 2016, ICAO 2019a). HFC use in lavatory systems could decrease as alternatives become available; however, there are no known alternatives for lavatory systems currently in development. Future HFC use in civil aviation applications would vary based on actual annual aircraft growth rates, which could vary due to unexpected events (e.g., COVID-19 pandemic).

4.3. Imports and Exports of Civil Aviation Fire Suppression Systems in the United States

HFC-227ea and HFC-236fa are produced in the United States; however, HFC-236fa lavatory fire suppression systems are exclusively manufactured by FFE Ltd., a UK-based company (Jensen Hughes, Inc. 2021). Therefore, it assumed that HFC-236fa lavatory systems are imported pre-charged for use in Airbus and regional aircraft. HFC-227ea lavatory fire suppression systems are assumed to be manufactured in the United States.

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