Section Number	Topic
1.1.1	Semiconductor Industry Uses
1.1.2	Less-publicized PFAS Sources
1.1.3	Less-studied PFAS

Information in these Priority Topics was prepared to supplement the information published in Section 2, which covers PFAS chemistry and naming conventions, history and use of PFAS, and sources of PFAS releases to the environment.

1.1.1 Semiconductor Industry Uses

This section provides more information on the uses of PFAS in the semiconductor industry and expands on the information presented in Section 2.6.1.6.

1.1.1.1 Background

Semiconductors, or chips, are small electronic devices used in a vast array of industries, including consumer electronics, manufacturing, medicine, commerce, military, artificial intelligence, and others. With the advent of artificial intelligence, data centers, and ever-expanding computational needs, chip manufacturing in the United States and around the world will continue to grow (SIA 2024). Many chip manufacturing processes rely on PFAS, some of which are proprietary, and other chemicals (for example, N-methylpyrrolidone, hydrochloric acid, and hydrofluoric acid) (NIST 2024), which may result in potential risks to workers and the environment. Figure 2-20 provides an example conceptual site model for industrial sites and can be useful in the evaluation of semiconductor PFAS uses and releases.

1.1.1.2 PFAS Uses

Because of the unique properties of PFAS (see Section 2), many PFAS from multiple classes are used during semiconductor manufacturing. For example, fluoropolymers are used to filter out small particles from fluids during chip production and are an important component during the photolithography process. No known alternatives exist for many of the industry's uses of fluorocarbon-containing materials (SIA 2023 , p. 3.), and once an alternative is invented, the process to qualify it for use is complex and may require many years to deploy for high-volume manufacturing (SIA 2023, p. 3.). Therefore, continued access to PFAS is currently a prerequisite for high-volume and advanced semiconductors. Given this, the focus on preventing exposures and the buildup of PFAS in the environment lies in materials management, particularly the management of wastes from semiconductor manufacturing, and perhaps even in the management of chips and semiconductor manufacturing equipment at the end of their service life.

When the bipartisan CHIPS and Science Act of 2022 was signed into law, it provided the Department of Commerce with $50 billion for a suite of programs to strengthen and revitalize the US position in semiconductor research, development, and manufacturing. The CHIPS Program Office's Final Programmatic Environmental Assessment contains tables describing the uses of PFAS in semiconductor manufacturing, Table C-4, (NIST 2024), and a list of chemicals used by the industry, Appendix D, (NIST 2024). The following subclasses, groups, or subgroups of PFAS were included on this list:

- fluorinated polymers, including polymeric perfluoropolyethers (PFPE), side-chain fluorinated polymers, and perfluoroalkoxy alkanes
- perfluoroalkane sulfonic acids (PFSAs) (for example, perfluorobutane sulfonic acid [PFBS], perfluorooctane sulfonic acid [PFOS])
- perfluoroalkane sulfonamides (FASAs) (for example, perfluorobutane sulfonamide [FBSA])
- perfluoroalkyl dicarboxylic acids (PFdiCAs) (for example, perfluorobutyl dicarboxylic acid [PFBdiCA])
- perfluoroalkane sulfonamido ethanols (FASEs) (for example, FBSE)
- perfluoroalkane sulfonamido acetic acids (FASAAs) (for example, perfluorobutane sulfonamido acetic acid [FBSAA])

More information about PFAS subclasses, groups, and subgroups is included in Section 2.2.2 and Figure 2-4.

The industry phased out the use of legacy PFAS, such as PFOS and perfluorooctanoic acid (PFOA), years ago, replacing them typically with C4-short chain replacement compounds (see bulleted list above), including PFBS (SIA 2023). These shorter chain compounds are now found in the wastewater from semiconductor fabrication plants (Chen et al. 2024; Jacob, Barzen-Hanson, and Helbling 2021; Jacob and Helbling 2023). In addition, fluorinated gases (see Section 1.1.3.4) are used as a plasma etchant in semiconductor manufacturing.

1.1.1.3 Exposure Pathways

In general, potential PFAS release mechanisms and pathways at semiconductor facilities include wastewater and stormwater discharges; on- and off-site disposal of solid wastes; accidental releases; and stack and fugitive emissions. Refer to Figure 2-20. The conceptual site model presents exposure routes and receptors that may be associated with semiconductor facilities. Semiconductor manufacturing is typically completed in a closed loop, where clean-room facilities may limit worker exposure. However, electronic waste recycling facilities may not provide such safeguards. Additional exposure pathways may include processing steps during materials recovery and scavenging during electronic waste recycling, including collection, processing, and disposal sites (Tansel 2022). Fluorinated gases (see Section 1.1.3.4) that are used in plasma etching processes are the largest source of greenhouse gas emissions from semiconductor production, and perfluorocarbons (PFCs) make up most of those releases (USEPA 2025).

Although often the focus is on industrial releases to wastewater treatment plants, the same chemicals could be released directly to land, surface water, groundwater, or air from leaks and spills. For example, GlobalFoundries' Essex Junction, Vermont, plant has a National Pollutant Discharge Elimination System (NPDES) permit to discharge directly into the Winooski River (Vermont DEC 2021). Although there are no regulations specific to discharges of PFAS from semiconductor wastewater, many states have regulations on industries or facilities with significant PFAS sources to perform and report discharge monitoring. Some of these states include Virginia, New Hampshire, and West Virginia. Missouri has a voluntary PFAS sampling program for facilities renewing existing wastewater or stormwater permits. Additional information is available in the Regulatory Programs Table and refer to the topic/focus area "Wastewater."

Many different types of solutions, rinses, inert equipment (such as molds and piping), and components are used in semiconductor manufacturing processes and have the potential to end up in waste streams. Studies have documented semiconductor waste streams containing PFAAs, including PFBS, perfluorohexane sulfonic acid (PFHxS), PFOS, perfluorohexanoic acid (PFHxA), PFOA, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and perfluorododecanoic acid (PFDoA) (see Section 2.6.1.6). A 2024 study identified effluent sample data from wastewater treatment plants associated with semiconductor facilities and identified perfluorobutane sulfonamido derivatives and ultra-short-chain PFAS (ultrashort PFAS) (see Section 1.1.3.1) as new trends associated with the semiconductor manufacturing industry (Chen et al. 2024). However, it should be noted that many of these newly identified PFAS are not included in typical commercial analytical laboratory PFAS methods; in addition, the toxicity or potential risk of these compounds is not known at this time.

Wastewater from processes that use wet chemical formulations (for example, chip production) containing PFAS may be discharged to the publicly owned treatment works (POTWs) without substantive PFAS removal, and generally, treatment works are not typically equipped to measure or remove PFAS from their effluent or biosolids. However, some companies are considering segregating, storing, and sending PFAS-containing process wastes off-site for treatment (NIST 2024; NIST 2024). Fluorinated gases (see Section 1.1.3.4) that are used in plasma etching processes are the largest source of greenhouse gas emissions from semiconductor production, and PFCs make up most of those releases (USEPA 2025). Some of the more common PFCs used in the semiconductor industry include trifluoromethane (HFC-23), difluoromethane (HFC-32), tetrafluoromethane (PFC-14), hexafluoroethane (PFC-116), and octafluoropropane (PFC-218) (SIA 2023).

Semiconductor factories conduct wastewater pretreatment for other substances, such as acids, under wastewater discharge permits from POTWs. Pretreatment for PFAS at the end of a pipe, before the PFAS waste stream mixes with other wastes, could be an important component in addressing PFAS used in the production process.

1.1.2 Less-publicized PFAS Sources

As noted in Section 2.5.2, growing awareness of PFAS has led to both research and speculation about the use and occurrence of PFAS associated with an increasing number of products, and whether such occurrences may constitute a risk to human health and the environment. Although PFAS have been previously identified in applications mentioned in Section 2.5.1, this section expands on the knowledge of the application and use of PFAS in these areas. In addition, some other potential less-publicized sources are discussed.

1.1.2.1 Hydraulic Fluids

Hydraulic fluid has many purposes, including transferring forces, lubricating surfaces, and acting as a sealant and coolant. PFAS are used in these applications primarily for their unique combination of properties that are beneficial in high performance and extreme condition environments. Two important criteria for hydraulic fluids are viscosity and additives that provide resistance to corrosion. Hydraulic fluids use PFAS for corrosion, chemical, temperature, and wear resistance for machines to operate smoothly.

The Organisation for Economic Co-operation and Development (OECD) (2025) report on PFAS in hydraulic oils and lubricants provided a comprehensive overview of the use of PFAS in hydraulic fluids and lubricants, emphasizing their technical functions and the challenges of substitution. Although comprehensive, the authors noted that the report is not exhaustive or definitive. For example, hydraulic oil and lubricant formulations are typically considered confidential business information, often limiting the available details, such as the percent of PFAS in each formulation (see the example safety data sheets below).

PFAS are “notable for their oil- and water-repellent characteristics and high thermal stability, have effectively reduced friction and wear in diverse mechanical systems” (Dias et al. 2024). Tribology is the study of friction which “most often involves the control and reduction of friction” (Watterson 2019). “A popular use of PFAS in tribological applications is the use of polytetrafluoroethylene (PTFE) in coatings and lubricants, renowned for its lubricity, resilience at high temperatures, and resistance to chemical attacks” (Dias et al. 2024) and referenced therein as Yeo et al. (2012), Dubey et al. (2015), and Zheng et al. (2023). In lubricants, PFAS are used in base oils (for example, PFPEs, polychlorotrifluoroethylenes [PCTFEs]), additives (for example, micropowder PTFE), and solvents, contributing to durability, reduced maintenance, and compatibility with various materials (OECD 2025). Table 2.1 in the OECD report summarizes the PFAS used in specific functions and in which applications this use may apply.

Glüge et al. (2020) further stated: “anionic PFAS (largely those with a sulfonic acid group) are used as additives in brake and hydraulic fluids due to their ability to alter the electrical potential of the metal surface and thus, protect the metal surface from corrosion through electrochemical oxidation.”

Automotive Applications

In the automotive industry, PFAS-based lubricants are valued for their durability, low friction, and compatibility with diverse materials. They help reduce maintenance frequency and extend the lifespan of components such as gears and bearings. PFAS additives also support performance in high-temperature and high-load conditions (OECD 2025).

Zhu and Kannan (2020) stated that PFAS have been used as additives in automotive lubricant oils and hydraulic fluids, to reduce surface tension, and to prevent fires and evaporation. In the automotive sector, the use of PFAS has been noted in the development of some lubricants, engine oils, and hydraulic fluids (Wang et al. 2010; Rico et al. 2007). PFAS play a crucial role in supplying essential features such as anti-wear, anticorrosion, and antifoaming capabilities. The annual demand for vehicle lubricating oils in the United States is estimated at approximately 2.4 billion gallons (Research and Markets 2019).

Zhu and Kannan (2020) analyzed 18 lubricants purchased in the United States for PFAS; however, they noted that seven of the 18 lubricants were explicitly for use in aircraft applications. Several perfluoroalkyl carboxylic acids (PFCAs) and PFSAs were detected in the lubricants. They were analyzed before and after oxidation using the total oxidizable precursor (TOP) assay. Following oxidation, lubricant extracts yielded total perfluoroalkyl acid (PFAA) concentrations up to two orders of magnitude higher than before oxidation, as high as 8,300 nanogram/gram (ng/g) mean. Long-chain PFCAs were the majority of PFAS detected prior to oxidation; however, variable and poor recoveries were noted for some of the volatile precursors during the TOP assay procedure.

Aviation Applications

PFAS additives have been used in aircraft hydraulic fluids due to their flame resistance, and erosion- and corrosion-inhibiting properties, which are essential for maintaining system integrity under extreme temperatures and pressures (OECD 2025). Applications in the aviation industry may include flight control systems and landing gear (OECD 2025). In broader aerospace applications, PFAS-containing hydraulic fluids maintain performance at a broader range of temperatures, where petroleum-based fluids may underperform at either temperature extreme (OECD 2025).

One PFAS cited in papers as being used in hydraulic fluids is perfluoroethylcyclohexane sulfonate (PFECHS) (MPART 2020) (see Section 2.2.3.3). Multiple reports have linked the use of PFECHS in aviation applications to environmental contamination. PFAS have been used in aircraft hydraulic fluids since the mid-1960s (De Silva et al. 2011; de Solla et al. 2012; MacInnis et al. 2017). For more information on PFECHS, see Section 1.1.3.2.

Examples of Corrosion-inhibitor Safety Data Sheets (SDS)

Corrosion inhibitors typically consist of fluorochemical surfactants which include PFAS. They may be used as additives to the acid media, or they may be applied as a thin, protective film on the metal prior to contact with the acid. Historical examples of fluorochemical surfactants used as corrosion inhibitors include FC-95, FC-98, FC-128, FC-134, and FX-161, FC-170, and FX-172 (3M Company 1963), and FC-5120 (3M Company 2012).

Safety Data Sheets reviewed (see call-out boxes) denote that the PFAS reported in fluorochemical surfactants used as corrosion inhibitors include salts of PFOS or PFECHS as more prevalent components, along with salts of other perfluoroalkyl sulfonates (for example, C4 through C7), including linear or cyclic isomers as minor components. More recently, PFBS-based surfactants are also reported, such as fluorosurfactant FC-5120 (3M Company 2012). Apart from salts of perfluoroalkylsulfonates, salts of perfluoroalkylcarboxylates appear to have also been used in some formulations of fluorochemical surfactants (see FC-118 example).

SDS for FC-118 FLUORAD Brand Fluorochemical surfactant
Issue Date: May 20, 1996

Source: Specialty Chemicals Division, 3M Company

The SDS includes the following ingredients:

- water (80%)
- ammonium perfluorooctanoate (18%–21%)
- ammonium perfluoroheptanoate (0.1%–1%)
- ammonium perfluorohexanoate (0–0.1%)
- ammonium perfluoropentanoate (0.1%–1%)

SDS for FC-135™ FLUORAD Brand Fluorochemical surfactant
Issue date: December 12, 2012

Source: Environmental Health and Safety Services Department, 3M Canada Company

The SDS includes the following ingredients:

- perfluoroalkylsulfonyl quaternary ammonium iodide (C8), which in water may produce PFOS (40%–44%)
- isopropyl alcohol (33%)
- fluoroalkyl quaternary ammonium iodides (C4, C5, C6, and C7) (0.1%–5%)
- methyl iodide (0.1%)

Cases for Continued Use

Despite the identification of several nonfluorinated chemical and technical alternatives, including silicone oils, esters, graphite, molybdenum disulfide, and boron nitride, none fully replicate the multifunctional performance of PFAS. The OECD (2025) report highlighted that while alternatives may be viable for some uses, they often require reformulation, increased maintenance, or compromise on performance. Moreover, no commercially viable alternatives are known to currently exist for PFAS in aviation hydraulic fluids. The report concluded that substitution is technically and economically challenging, and that regulatory drivers, rather than market forces, are likely to be the primary catalyst for change. Table 2.2 of the OECD report (2025) provides a list of silicone-based alternatives and which PFAS they would be intended to replace.

In Canada and the United States, use of FC-98 is permitted in the aviation industry based on the lack of alternatives, its critical role in the safe performance of aircraft, and anticipated minimal environmental release (USEPA 2005).

In the USEPA Docket control number OPPTS-50639, the Boeing Company submitted comments to USEPA’s PFAS proposed Significant New Use Rule, Supplemental Proposed Rule, published in the Federal Register on March 11, 2002 (67 Fed. Reg. 11014). Boeing mentioned the variety of commercial and military aircraft they manufacture and how many people they employ. They wrote in support of USEPA’s proposal to exclude from the definition of significant new use, “1) the manufacture or import of certain PFAS chemicals for use as an anti-erosion additive (i.e., FC-95 and FC-98) in fire-resistant phosphate ester aviation hydraulic fluids; and 2) the use of these PFAS chemicals as intermediates to produce other chemicals used solely for the excluded aviation hydraulic uses.”

In other sectors, the Association of Equipment Manufacturers (AEM) (www.aem.org) indicates PFAS are needed to meet objectives such as air quality, climate, safety, and sustainability and alternative power goals (AEM, 2024). The applications include such uses in seals, hoses, hydraulic systems, refrigerant, and alternative power technologies. Examples of machines and systems that use hydraulic power include excavators, cranes, forklifts, lifts, dozers, graders, loaders, shovels, trenchers, and concrete pumping systems, among others. Pinhole leaks, sudden drops in pressure, or contamination of the fluid can all cause serious safety issues for the operator or maintenance team (AEM 2024).

Additionally, the thinktank Industrial Resources Strategies issued a final report titled, “PFAS: Application, Technical Functions and Substitution Possibilities in the Industry” (Lang-Koetz, Hutschek, and Heil 2024), which examined suitable substitutes for various applications, including hydraulic fluids. To determine whether there are adequate substitutes that could replace PFAS, a specially developed artificial intelligence (AI) was used. Over 35,000 scientific documents were analyzed, and the AI-based system identified 420 materials and summarized them into 32 classes for five European companies. For the companies (which include an automobile company), the report claimed there were either none or only 2 to 3 identified materials that have the potential to replace PFAS in the future. “An adequate substitute that could be used immediately or in the near future was not found in any of the cases examined” (Lang-Koetz, Hutschek, and Heil 2024).

Canter (2024) provided information for companies involved in producing lubricants to minimize PFAS release and exposure. Canter (2024) recommended paying attention to the supply chain and establishing a system to determine the most likely source of PFAS. As well as a recommendation for a resource allocation plan, an assessment of all PFAS sources of contamination in water, fire suppression systems, and raw materials should be performed. Finally, Canter (2024) recommended that a lubricant manufacturer ask for a reformulated raw material without fluorine or find a supplier with a viable nonfluorine-containing alternative.

1.1.2.2 Pesticides

When identifying PFAS use in pesticides, it should be noted that organizations define PFAS differently. Refer to Table 2-1 for more information on the various definitions of PFAS. Pesticides can contain fluorinated compounds, but depending on what definition is used, they may or may not be identified as PFAS.

Two general categories of ingredients are used in pesticides: active and inert. Active ingredients are the primary elements that kill or suppress the targeted organisms, while the inert ingredients, including emulsifiers, fragrances, and dyes, are added to enhance the product and do not have to be disclosed (Donley et al. 2024). Donley et al. (2024) reported that several patents have identified fluorinated “inerts” as assisting with dispersal of spraying pesticides, preventing foaming, aiding in surfactancy, and penetrating organisms. Because the manufacturers of pesticides are not required to disclose when fluorinated substances are used as an inert ingredient, the full extent of PFAS in pesticides is uncertain.

Fluorination in pesticides can be used to modify chemical attributes such as stability and lipophilicity (Alexandrino et al. 2022). Active ingredients are often fluorinated in pesticides, with insecticides and acaricides (targeting ticks and mites) being highly fluorinated (Ogawa et al. 2020). Molecular stability can result from fluorination and can influence lipophilicity, allowing binding to target proteins (Alexandrino et al. 2022). The most common chemotype is a trifluoromethyl (CF3), followed by a monofluoromethyl group (CFH2) (Ogawa et al. 2020). Only a broad definition of PFAS would include these shorter chain chemicals under a PFAS classification. (Alexandrino et.al. 2022) discussed the increased use of fluorination in pesticides. It grew from 9% by the end of the twentieth century to over 50% between 2010 and 2020. Fluorinated pesticides made up nearly 70% of all new approved agrochemicals during the second half of 2010. Ogawa et al. (2020) said the difluoro[1]methyl group, CF2H, is emerging more rapidly than the CF3 group due to progress of synthetic methods.

Section 2.4.5 discusses the pesticide sulfluramid, which is manufactured in Brazil. The active ingredient in sulfluramid (a pesticide used for control of leaf-cutting ants) is n-ethyl perfluorooctane sulfonamide (EtFOSA), which is a direct precursor to PFOS. Although PFOS is listed under Annex B (restriction of use) in the UN Stockholm Convention on Persistent Organic Pollutants (POPs) (UNEP 2025), use of sulfluramid in insect bait has continued acceptable use in Argentina, Brazil, Costa Rica, and Vietnam from December 2020 onwards under the UN Stockholm Convention on POPs. Sulfluramid has prior registration for use in the United States in termite, ant, and roach bait stations (USEPA 2001). This may indicate prior potential for commercial and consumer use application both inside and outside of homes and buildings, as well as other locations.

A study in Denmark looked at worker exposure to PFAS-containing pesticides (including long-chain PFAS). This study, conducted between 1996 and 2001 on pregnant greenhouse workers, found elevated PFAS in their blood (Andersen et al. 2024), demonstrating higher exposure risk for this sector of people.

A study has identified PFAS as leaching from the coatings of pesticide containers (USEPA 2021). The practice of coating polyethylene plastic containers started as early as 1958 (Joffre 1957). Today this practice of coating agricultural containers continues (Rand and Mabury 2011). Often, molded plastic containers are treated under high temperature with fluorine gas (Kharitonov 2008).

Recent activity includes:

- July 2024: EPA Grants Petition on 3 PFAS Found in Fluorinated Plastic Containers (USEPA 2024)
- October 2024: EPA Issued Test Order for PFAS Used in Manufacturing Under National Testing Strategy (USEPA 2024). This action orders Innovative Chemical Technologies, Chemours Company, Daikin America, Sumitomo Corporation of Americas, and DuPont to conduct and submit testing on 6:2 FTAc (6:2 fluorotelomer acrylate), which is used in manufacturing plastics, resins, textiles, apparel, leather, and other chemicals.

More work is needed to study fluorinated coated containers in the agricultural industry and containers used in other sectors to understand the impact on the environment and human health.

1.1.2.3 Other Less-publicized Sources

Table 1-1 provides less-publicized sources, in addition to those presented in Table 2-7 in Section 2.5.

Table 1-1. Additional examples of PFAS claims in other less-publicized sources

Potential Use	Technical Basis	Documentation	Potential Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Commercial Car Washes	Analysis of PFAS in car wash products and other consumer products.	Borg and Ivarsson (2017) Glüge et al. 2020	PFAS are used in some car wash products and may leach into wastewater. PFAS presence in such products can be significant, depending on their concentration and usage patterns.
Concrete Sealers	Review of different types of penetrating concrete sealers and their chemical composition.	Concrete Sealers USA (2016)	Concrete sealers may contain PFAS to enhance water resistance. The significance depends on the type of sealer and its PFAS content, which varies by manufacturer.
Toilet Paper	Analysis of PFAS presence in toilet paper and its contribution to wastewater.	Thompson et al. (2023)	Toilet paper can be a significant source of PFAS in wastewater. The level of PFAS varies, and its contribution to overall PFAS pollution depends on the volume of toilet paper used and its PFAS concentration.
Fracking Fluids	Media reports describe a review of publicly reported data (FracFocus database: https://fracfocus.org/) detailing the use of nonionic fluorosurfactants used in injection fluids for fracking of hydrocarbons. These reports indicate PFAS or PFAS precursors in thousands of wells across a handful of states. Colorado has banned the use of PFAS in fracking fluids as of January 1, 2024.	FracFocus (2025) Horwitt (2021) Friday (2022) Connor et al. (2021) Horwitt and Gottlieb (2023) Colorado General Assembly (2022) Murphy and Hewat (2008) Schramm (2000)	The use of PFAS in fracking fluids is likely; however, due to limited details in the database, the exact type of PFAS and extent of PFAS, or PFAS precursors used in current or historical specific fracking operations is unknown. PTFE (Teflon) is a potential concern with use in fracking operations.

Potential Use	Technical Basis	Documentation	Potential Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Medical Devices	PFAS have widespread uses in medical devices and in vitro diagnostic reagents and instruments.[1] A consumer study[2] identified total organic fluorine content in 18 different soft contact lens products.	[1]PFAS Uses: Glüge et al. (2020) and Gaines (2022) [2]Contact Lenses Consumer Study: Segedie (2023) [3]Essential Uses, Patient Safety: Levy et al. (2023); Cousins et al. (2019); Spyrakis and Dragani (2023); Ozben et al. (2024); Rezvova et al. (2023) [4]Medical Testing and Safety: Henry et al. (2018); Maitz (2015); Ozben et al. (2024) [5]Polymer of Low Concern Analysis: Lohmann et al. (2020) [6]PFAS Serum Study: Kang et al. (2024)	Position papers[3] discuss the essential uses of some PFAS in medical devices (i.e., PTFE, polyvinylidene fluoride (PVDF) and volatile PFAS used as propellants in inhalers) and the impact that restrictions would have on patient safety. In a contact lens consumer study[2], organic fluorine levels ranged between 105 ppm to 20,700 ppm. Organic fluorine was detected in all 18 products; the study stated that the organic fluorine can be a marker for PFAS. Proponents[4] argue that PFAS—fluoropolymers in particular—are chemically and biologically inert and have a robust clinical history and testing of implanted medical devices supporting their safety in medical applications. However, others[5] point to new research in animals showing the potential for some fluoropolymers to be bioavailable. One US study[6] of young adults (aged 20—39 years) estimated a statistically significant increase in the body burden of PFAS in contact lens users as compared to non-contact lens users. No statistically significant difference in PFAS body burden was observed in a supplemental analysis of older adults aged 40–59 years. The study authors noted that not all potential confounders could be adjusted in the model and identified several limitations when interpreting the age-dependent observations.

Potential Use	Technical Basis	Documentation	Potential Conflicting Perceptions on Presence of PFAS and Significance of PFAS
Lithium-Ion Batteries	PFAS are widely reported components in lithium-ion batteries, including in the electrodes (cathode and anode), binder, electrolyte (main component and additives), and separator (porous membrane). The global clean energy sector may be an unrecognized and potentially growing source of international PFAS release into the environment, highlighting a need to evaluate clean energy impacts beyond just carbon dioxide emissions. A fire on Long Island at the largest utility-scale storage facility of lithium salt and battery cells burned on May 21, 2023. Elevated PFAS concentrations were detected in the extinguishing water concentrations. The concern over fluorinated compounds in lithium-ion batteries has led to research on fluorine-free batteries: Ma et al. (2024); Ma et al. 2024.	Vamosi (2023) Quant et al. (2023) Rensmo et al. (2023) Guelfo et al. (2024) Willstrand, Quant, and Hynynen (2025)	Savvidou et al. (2024) suggested PFAS-free alternatives are available in electrodes and electrolytes. PFAS-free lithium-ion batteries: Ma et al. (2024); Ma et al. 2024.
Dry Cleaners	PFAS may be used in dry-cleaning systems as replacements for tetrachloroethene-based systems. PFAS may also be in waste discharges from dry cleaners as a result of PFAS in the materials being laundered.	Gaines (2022) CA ARB (2006) FL DEP (2021)	Existing patents show the use of hydrofluoroethers with other PFAS as an alternative to tetrachloroethene or other solvents used in dry cleaning. Another patent mentions the use of carbon dioxide and a surfactant; fluoroalkyl substances are mentioned as a potential surfactant. The Zonyl series by DuPont is mentioned as a source of fluorinated compounds. California report discusses a replacement for tetrachloroethene called PureDry, which contains HFE-7200, FC-43, PF-5070, and PF-5060.
Explosives, Pyrotechnics, and Propellants	Published information on composition of explosives, propellants, and pyrotechnics is available.	Valluri, Schoenitz, and Dreizin (2019)	Although certain fluoropolymers are known to be components of some explosives, propellants, and pyrotechnics, data are not available on the fate and transport of fluoropolymers associated with these items. Research is underway to address data gaps.

1.1.3 Less-studied PFAS

Section 2 provides a summary of different PFAS classes, subclasses, and groups. This section expands on that discussion to provide information on some of the less-studied PFAS, including ultrashort PFAS, cyclic PFAS, volatile PFAS, and fluorinated gases.

1.1.3.1 Ultrashort PFAS

Ultra-short-chain PFAS (ultrashort PFAS) are generally described as having ≤3 carbons (Zheng, Eick, and Salamova 2023; Neuwald et al. 2022). Common examples of ultrashort PFAS include trifluoroacetic acid (TFA, C2), perfluoropropanoic acid (PFPrA, C3), perfluoropropanesulfonic acid (PFPrS, C3), and 1,1,1-trifluoro-N-[(trifluoromethyl)sulfonyl] methanesulfonamide (TFSI, C2) (Table 1-2). Some fluorinated gases may also be considered ultrashort PFAS (Section 1.1.3.4). Zhi et al. (2024) identified ultrashort PFAS found in environmental samples, including PFPrA, trifluoromethanesulfonic acid (TFMS, C1), perfluoroethane sulfonic acid (PFEtS, C2), and PFPrS. Ultrashort PFAS are known to be industrial chemicals used for a variety of direct applications or may be byproducts from the construction of complex chemicals. As examples, TFA and PFPrA are common reagents and catalysts used in laboratories (Zheng, Eick, and Salamova 2023), and TFSI is used in the production of lithium-ion batteries and as an additive to biodegradable natural rubber matrixes (Sowińska et al. 2021).

Existing studies have shown ultrashort PFAS tend to be as persistent as their longer chain homologues and are more mobile in the environment. In some cases, ultrashort PFAS may have higher acute ecological toxicity than short- and long-chain PFAS (Wang et al. 2014) and can be more difficult to remove from water (Ateia et al. 2019; Neuwald et al. 2022). Ultrashort PFAS are not typically included in studies focusing on capture and destruction of PFAS. Human health–related toxicological effects of ultrashort PFAS are discussed in Section 1.4.4 on health effects of ultrashort PFAS.

Although TFA is a common example of a C2 ultrashort-chain PFAS, it is worth noting that under some existing definitions of PFAS, it would not be considered a PFAS (refer to Section 2.2). TFA has been found in the environment at concentrations orders of magnitude higher than other PFAS. TFA was found at higher occurrence in residential house dust and tap water in a study in Indiana (Zheng, Eick, and Salamova 2023). In Zhi et al. (2024), the authors noted the elevated TFA levels and that levels are increasing in the global environment. This paper also identified four additional ultrashort PFAS found in environmental samples, including PFPrA, TFMS, PFEtS, and PFPrS. In addition, large amounts of TFA are produced for use as an intermediate in chemical manufacturing and for other purposes (National Center for Biotechnology Information 2025, PubChem website).

Although TFA is extremely persistent, this ultrashort PFAS does not have well-established drinking water health advisories or regulatory limits (Arp et al. 2024). However, it should be noted that the Netherlands National Institute for Public Health and the Environment (RIVM) and the German Environment Agency (UBA) have developed drinking water guidelines for TFA of 2.2 ug/L (RIVM 2023) and 60 ug/L (UBA 2020), respectively.

Ultrashort PFAS are less studied than short- and long-chain PFAS and are often not included in analytical methods used for other PFAS because their highly polar characteristics make them difficult to analyze with current analytical methods (Björnsdotter et al. 2020; Liang, Steimling, and Chang 2023; Neuwald et al. 2022). Additional information about ultrashort PFAS analysis is found in Section 1.5.3. However, studies evaluating transformation of PFAA precursors suggest their contribution to human exposure to ultra-short-chain PFAS—specifically, polyfluoroalkyl carboxamides, polyfluorinated phosphate esters (PAP), FOSAs, FOSEs, FTOHs, and FTACs, among others (Zheng, Eick, and Salamova 2023).

TFA has been documented to form through the atmospheric degradation of several F-gases, including hydrofluorocarbons and hydrochlorofluorocarbons used in refrigerants (Jordan and Frank 1999; Liang, Steimling, and Chang 2023). Similarly, ultrashort PFAS such as PFPrA and TFA can be produced through the breakdown of pharmaceuticals, pesticides, and polymers (Jordan and Frank 1999; Liang, Steimling, and Chang 2023). Ultrashort PFAS are also included in formulations of aqueous film-forming foam (AFFF) or are the result of the breakdown of other PFAS in AFFF. For example, PFPrA and TFA are breakdown products of perfluoro-2-methyl-3-pentanone (PFMP), which was marketed by 3M as a fire protection fluid replacement for chlorofluorocarbons and halons (Jackson et al. 2011), while other ultrashort PFAS (PFPrS and PFEtS) have been quantified in AFFF formulations manufactured between 1989 and 2001 (Barzen-Hanson and Field 2015). For additional examples and occurrences and health effects associated with ultrashort PFAS, see Section 1.4.4. In addition, see the updated Table 4-1 for physical and chemical properties of some ultrashort PFAS.

Table 1-2 summarizes some ultrashort PFAS examples, with a notation of those covered in Table 4-1 as well as those that can be currently analyzed by some environmental laboratories, see Section 1.5.3 for more information about analysis of ultrashort PFAS. Note: The USEPA’s CompTox Chemicals Dashboard (CompTox Chemicals Dashboard (epa.gov)) was used to standardize naming conventions and CAS numbers for ultrashort PFAS throughout the different sections of the Priority Topics documents.

Table 1-2. Ultrashort PFAS examples

CAS No.	**Chemical Name**	**Included in Table 4-1**	**Included on Current Commercial Lab Lists**
381-73-7	Difluoroacetic acid (DFA)		
76-05-1	Trifluoroacetic acid (TFA)	X	X
422-64-0	Perfluoropropanoic acid (PFPrA)	X	X
421-85-2	Trifluoromethylsulfonamide		
78491-70-0	Perfluoroethanesulfonamide		
152894-03-6	Perfluoropropanesulfonamide		
423-41-6	Perfluoropropanesulfonic acid (PFPrS)	X	X
354-88-1	Perfluoroethanesulfonic acid (PFEtS)	X	X
1493-13-6	Trifluoromethanesulfonic acid (TFMS)	X	X
344324-36-3	Perfluoroethane-1-sulfinic acid		
359868-84-1	Perfluoropropane-1-sulfinic acid		
34642-42-7	Perfluoromethane-1-sulfinic acid		
674-13-5	Perfluoro-2-methoxyacetic acid (PFMOAA)	X	X
1036-91-3	Perfluoro-2-(trifluoromethoxy)ethanesulfonic acid		
374-09-4	Trifluoromethylphosphonic Acid		
103305-01-7	Pentafluoroethylphosphonic acid		
82113-65-3	1,1,1-trifluoro-N-[(trifluoromethyl)sulfonyl] methanesulfonamide (TFSI)	X	
90076-65-6	Lithium bis[(trifluoromethyl)sulfonyl]azanide (HQ-115)	X	X
34642-43-8	Perfluorobutane-1-sulfinic acid (PFBSi)		X
756-09-2	2,2,3,3-Tetrafluoropropanoic acid (2,2,3,3-TFPA)		X
359-49-9	2,3,3,3-Tetrafluoropropanoic acid (2,3,3,3-TFPA)		X

1.1.3.2 Cyclic PFAS

Cyclic PFAS include a carbon ring that may be partially or fully fluorinated or aromatic substances that have a fluorinated side chain. Although cyclic PFAS are not commonly tested for by USEPA standard test methods (for example, USEPA Method 1633A), some are included in ASTM methods such as D7979. Classification of these fluorinated compounds as PFAS is dependent on the definition of PFAS used.
Examples of cyclic PFAS include:

- perfluorocycloalkyl sulfonates such as perfluoromethylcyclohexane sulfonate (PFMeCHS), perfluoropropylcyclopentanesulfonate (PFPCPeS), and perfluoroethylcyclohexane sulfonate (PFECHS)
- perfluorotoluene
- (perfluoropropyl)benzene
- fipronil

Certain cyclic structures can have much in common with noncyclic PFAS analogs and have been used in replacement chemistry. See Section 2.2.3.3.

Of the examples of cyclic PFAS, PFECHS is among those with the most available published peer-reviewed research. PFECHS is an 8-carbon cyclic PFAS that was produced by 3M and sold commercially as FC-98 as a corrosion inhibitor in some hydraulic fluid formulations (see Section 1.1.2.1) (de Silva et al. 2011). For example, PFECHS is considered an analog for PFOS and has been documented as a replacement compound for PFOS in some hydraulic fluids (O'Rourke et al. 2024). This is further supported by a multivariate statistical analysis demonstrating a positive correlation between PFECHS and PFOS

(O’Rourke et al. 2024). In 2020, the Michigan PFAS Action Response Team (MPART), in conjunction with the Michigan Department of Health and Human Services, prepared a study noting occurrence of PFECHS in multiple media, including drinking water, surface water, sediment, marine organisms, and human blood (MPART 2020). Further, MPART noted the documented use of PFECHS and other perfluorocycloalkyl sulfonates in commercially available fluorochemical surfactants (MPART 2020). 3M phased out production of PFECHS and other perfluorooctyl-based compounds; however, it remains a permitted chemical in the United States and Canada due to “the lack of alternatives, its critical role in the safe performance of aircraft, and anticipated minimal environmental release” (de Silva et al. 2011).

SDS for FC-98 FLUORAD Brand Fluorochemical surfactant
Issue Date: September 10, 2002

The SDS includes the following ingredients:

- potassium perfluoroethyl cyclohexyl sulfonate (66%–70%)
- potassium perfluoromethyl cyclohexyl sulfonate (18%–22%)
- potassium perfluorodimethyl cyclohexyl sulfonate (9%–13%)
- potassium perfluorocyclohexyl sulfonate (1%–3%)
- residual organic fluorochemicals (not known)

Three studies cited by MPART (2020)—Wang et al. 2016, de Solla, De Silva, and Letcher (2012), and Letcher et al. (2015)—documented the greatest concentrations of PFECHS near airports. A review paper by Mahoney et al. (2022) discussed available information about PFECHS detection in environmental samples. PFECHS has been detected in surface water, herring gull eggs, and predator fish from the Great Lakes and other freshwater bodies (Mahoney et al. 2022; Muir et al. 2019; De Silva et al. 2011). Data reported by Szabo et al. (2022) indicate PFECHS in black swan serum and excrement and associated aquatic environmental media samples.

O’Rourke et al. (2024) noted that the similarity in persistence within living organisms to that of long-chain legacy PFAS may indicate that PFECHS and other replacement compounds such as F-53B are being used as substitutes for PFOS, suggesting comparable transportation pathways of environmental contamination in freshwater systems. Miaz et al. (2020) reported on analyses of serum samples from Swedish women collected from 1996 to 2017. Their study showed a declining trend in serum concentrations since 2000, with detectable concentrations of PFECHS of 0.06–0.28 ng/g. More research is needed to fully understand the toxicity and bioaccumulation properties of PFECHS.

PFECHS has biomagnification potential and is moderately bioaccumulative in the estuarine and marine food web (Wang et al. 2023). Although Mahoney et al. (2022) concluded PFECHS had a lower bioconcentration potential than PFOS in a trout cell assay, in 2023 Mahoney et al. (2023) found that PFECHS has potential to cause adverse effects at the cellular level in the marine system. Szabo et al. (2022) calculated a bioaccumulation factor for PFECHS of 593 L/kg versus the bioaccumulation factor for PFOS of 1,097 L/kg. In a study published by Wang et al. (2016), PFECHS and PFPCPeS were found to accumulate most significantly in the liver, kidney, blood, and bladder, with estimated average whole body bioaccumulation factors (log $\text{BAF}_{\text{whole-body}}$) of 2.7 and 1.9, respectively. Currently, PFECHS is thought to have a lower toxic potency than PFOS, but there is a need for additional research (Mahoney et al. 2023).

1.1.3.3 Volatile PFAS

Refer to the PFAS-Vapor Intrusion Fact Sheet for a discussion of the current state of the science for vapor-forming PFAS and their potential role in the vapor intrusion pathway. In addition, refer to Section 4.2 for an introduction to the physical properties of volatile PFAS. USEPA vapor intrusion guidance (2015) considers a compound to be volatile if it has a vapor pressure greater than 1 millimeter of mercury (mm Hg) or a Henry’s law coefficient greater than 10^{-5} atmosphere-meter cubed per mole (atm m^3 mol^{-1}). Numerous PFAS meet this volatility criteria, including both anionic and neutral PFAS (Abusallout et al. 2022; Schumacher et al. 2024).

As discussed in greater detail in Section 4.2, there are limited reliable data on the physical and chemical properties related to PFAS volatilization. For example, reported Henry’s law coefficients can span multiple orders of magnitude for a single PFAS (see Table 4-1), making it difficult to know which values are most representative of the compound’s behavior in the environment. Thus, it is not always clear whether certain compounds meet the USEPA volatility definition when the range of estimated or measured vapor pressures and/or Henry’s law coefficients extends both below and above the thresholds. The

PFAS listed in Table 4-1 with sufficient vapor pressure and/or Henry's Law coefficient to be considered volatile are summarized in Table 1-3.

Table 1-3. PFAS listed in Table 4-1 with sufficient vapor pressure and/or Henry's law coefficient to be considered volatile

PFAS	**Sufficient Vapor Pressure per Table 4-1**	**Sufficient Henry's Law Coefficient per Table 4-1**
Perfluorocarboxylic acids (PFCAs)		
Perfluorobutanoic acid (PFBA)	X	X
Perfluoropentanoic acid (PFPeA)	X	
Perfluoroalkane sulfonamides (FASAs)		
FBSA	X	
MeFOSA		X
EtFOSA		X
Perfluoroalkane sulfonamido ethanols (FASEs)		
N-methyl perfluorooctane sulfonamide ethanol (MeFOSE)		X
N-ethyl perfluorooctane sulfonamido ethanol (EtFOSE)		X
Fluorotelomer alcohols (FTOHs)		
4:2 FTOH	X	X
6:2 FTOH	X	X
8:2 FTOH	X	X
10:2 FTOH	X	X
Perfluoroalkyl ether carboxylic acids (PFECAs)		
Hexafluoropropylene oxide dimer acid (HFPO-DA)	X	X
PFMPA	X	
PFMBA	X	X

At this time, vapor-phase occurrence is mostly commonly associated with neutral PFAS, such as fluorotelomer alcohols (FTOHs), perfluorooctane sulfonamido ethanol (FOSE), perfluorooctane sulfonamide (PFOSA), and ultrashort-chain PFAS (considered to include 3 or fewer carbon atoms) (See Section 1.1.3.1). However, it should be noted that nonvolatile terminal PFAS, such as PFNA, PFOA, and perfluoroheptanoic acid (PFHpA), can also be formed from transformation of FTOHs, and PFOS can be released from transformation of FOSE. (See Section 2.2.4 for more information about polyfluoroalkyl substances).

Some example uses of volatile PFAS include the following:

- fluorotelomer alcohols in paints (Cahuas et al. 2022).
- textile and leather production (MPCA 2023). FTOHs, N-EtFOSE, and MeFOSE are commonly used in textile manufacturing and in impregnation treatments for textiles and leather (MPCA 2023).
- medical industry as propellants in inhalers (Gaines 2022).

1.1.3.4 Fluorinated Gases

Fluorinated gases (F-gases) are humanmade, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride, and other fluorinated compounds, and are used (both historically and currently) in a variety of industrial applications (Table 1-4). Under the very broad definition of PFAS recommended by the Organisation for Economic Co-operation and Development (OECD), fluorinated gases are considered PFAS (OECD 2021), fluorinated gases are considered PFAS. HFCs represent approximately 90% of all F-gases (European Commission n.d.). F-gases under the definition of PFAS typically contain between 1 and 7 carbons; some examples of F-gases are provided in Table 1-4 (MPCA n.d.). The broad

OECD PFAS definition encompasses many of the PFC and HFC gases used in semiconductor device manufacturing (see Section 1.1.1), as well as fluorinated heat transfer fluids (SIA 2023). As noted in Section 1.1.3.1, TFA has been documented to form through the atmospheric degradation of several F-gases, including hydrofluorocarbons and hydrochlorofluorocarbons used in refrigerants (Jordan and Frank 1999; Liang, Steimling, and Chang 2023).

F-gases are often used as replacements for ozone-depleting substances (such as halons), as these gases are not typically as harmful to the atmospheric ozone layer. However, F-gases are still highly regulated because they are strong greenhouses gases with a higher potential to contribute to global warming than carbon dioxide. Some of these regulations have banned F-gases such as HFC-23 due to their high potential to contribute to global warming (European Environment Agency 2025; EFCTC n.d.). F-gases are highly regulated by the US Clean Air Act, the Montreal Protocol for Greenhouse Gases, the Paris Agreement, and European Union air regulations. However, the World Meteorological Organization (UNEP 2018) estimates the global warming potential of some of these F-gases to be lower than carbon dioxide over a 100-year time horizon (it depends on the F-gas) and lists the ozone depletion potential of many F-gases to be 0. The atmospheric half-life of many of these compounds is on the order of days to years, depending on the chemical, via oxidation or photolysis in the atmosphere.

F-gases are used in many different products, equipment, and processes, such as refrigeration, air conditioning, heat pumps, insulation, fire protection, power lines, and aerosol propellants, as well as in industrial processes (European Commission n.d. ; EFCTC n.d.). Electronics and aerospace industries use solvents containing F-gases to clean components (NetRegs n.d.). Several industries rely on F-gases for safe and reliable operations, including food storage, distribution to pharmaceutical production, and home heating and cooling. Benefits of F-gases include energy efficiency and less reliance on fossil fuels (Chemours n.d.).

Refer to EFCTC (n.d.) for additional information on the F-gases.

Table 1-4. Examples of fluorinated gases

Source: MPCA (n.d.) "Table of HFCs and PFCs and Pounds of Chemicals that Trigger Reporting Requirements"

F-Gas	CAS No.	Chemical Name	Use
HFC-23	75-46-7	Trifluoromethane	Refrigerant, fire extinguisher, semiconductor manufacturing
HFC-32	75-10-5	Difluoromethane	Refrigerant
HFC-41	593-53-3	Fluoromethane	
HFC-43-10mee	138495-42-8	Decafluoropentane	Cleaning solvent
HFC-125		Pentafluoroethane	Fire extinguisher
HFC-134	359-35-3	1,1,2,2-Tetrafluoroethane	
HFC-134a	811-97-2	1,1,1,2-Tetrafluoroethane	Refrigerant, fire extinguisher, foaming agent, medical propellants, aerosol propellants
HFC-143	430-66-0	1,1,2-Trifluoroethane	
HFC-143a	420-46-2	1,1,1-Trifluoroethane	Refrigerant
HFC-152	624-72-6	1,2-Difluoroethane	
HFC-152a	75-37-6	1,1-Difluoroethane	Refrigerant, foaming agent, aerosol propellant, temperature sensing agent
HFC-161	353-36-6	Fluoroethane	
HFC-227ea	431-89-0	Heptafluoropropane	Refrigerant, fire extinguisher, medical propellant
HFC-236cb	677-56-5	1,1,1,2,2,3-Hexafluoropropane	
HFC-236ea	431-63-0	1,1,1,2,3,3-Hexafluoropropane	

F-Gas	**CAS No.**	**Chemical Name**	**Use**
HFC-236fa	690-39-1	1,1,1,3,3,3-Hexafluoropropane	Refrigerant, fire extinguisher, foaming agent, medical propellant
HFC-245ca	679-86-7	1,1,2,2,3-Pentafluoroproane	Refrigerant
HFC-245fa	460-73-1	1,1,1,3,3-Pentafluoropropane	Refrigerant, foaming agent
HFC-365mfc	406-58-6	Pentafluorobutane	Refrigerant, foaming agent
PFC-14	75-73-0	Perfluoromethane; tetrafluoromethane	Plasma etchant, semiconductor manufacturing, refrigerant
PFC-116	76-16-4	Perfluoroethane; hexafluoroethane	Plasma etchant, semiconductor manufacturing
PFC-218	76-19-7	Perfluoropropane; octafluoropropane	Plasma etchant, semiconductor manufacturing, refrigerant, fire extinguisher
PFC-318	115-25-3	Perfluorocyclobutane; octafluorocyclobutane	Plasma etchant, cleaning agent, refrigerant, propellant in food industry
PFC-3-1-10	355-25-9	Perfluorobutane; decafluorobutane	Refrigerant, fire extinguisher
PFC-4-1-12	678-26-2	Perfluoropentane; dodecafluoropentane	Refrigerant, cleaning solvent
PFC-5-1-14	355-42-0	Perfluorohexane; tetradecane fluorohexane	Refrigerant, cleaning solvent, fire extinguisher
PFC-9-1-18	306-94-5	Perfluorodecalin	
c-C3F6	931-91-9	Perfluorocyclopropane	

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Updated January 2026.