United States
Environmental Protection
Agency

Multi-Industry Per- and Polyfluoroalkyl Substances (PFAS) Study – 2021 Preliminary Report

September 2021

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United States Environmental Protection Agency
Office of Water (4303T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460

EPA-821-R-21-004

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Abbreviations

ACC	American Chemistry Council
ADONA	trade name for ammonium 4,8-dioxa-3H-perfluorononanoate, one chemical used in a 3M fluoropolymer processing aid technology
AF&PA	American Forest and Paper Association
AFFF	aqueous film-forming foam
APFO	ammonium perfluorooctanoate (ammonium salt of PFOA)
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
ATSDR	United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry
BAF	bioaccumulation factor
BCF	bioconcentration factor
CAFE	National Oceanic and Atmospheric Administration Chemical Aquatic Fate and Effects database
CBI	confidential business information
CDR	Chemical Data Reporting
CFR	Code of Federal Regulations
CWA	Clean Water Act
DMR	discharge monitoring report
DOD	United States Department of Defense
DONA	trade name for 4,8-dioxa-3H-perfluorononanoic acid, one chemical used in a 3M fluoropolymer processing aid technology
DWTD	Drinking Water Treatability Database
DWTP	drinking water treatment plant
ELGs	Effluent Limitations Guidelines and Standards
EPA	United States Environmental Protection Agency
EPA OPPT	United States Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics
ETFE	ethylene tetrafluoroethylene
F-53B	trade name for chlorinated polyfluoroalkyl ether sulfonic acids, including 9Cl-PF3ONS (“F-53B major”), 11Cl-PF3OUdS (“F-53B minor”), and their potassium salts
FAA	United States Department of Transportation, Federal Aviation Administration
FASA	perfluoroalkane sulfonamide
FASAA	perfluoroalkane sulfonamido acetic acid
FASE	perfluoroalkane sulfonamido ethanol
FCN	food contact substance notification
FCS	food contact substance
FDA	United States Department of Health and Human Services, Food and Drug Administration
FR	Federal Register
FTCA	fluorotelomer carboxylic acid
FTOH	fluorotelomer alcohol
FTSA	fluorotelomer sulfonic acid
GAC	granular activated carbon
GenX	trade name for fluoropolymer processing aid technology that involves includes HFPO-DA and its ammonium salt
HFPO-DA	hexafluoropropylene oxide dimer acid, one chemical used in the GenX fluoropolymer processing aid technology
IWTT	Industrial Wastewater Treatment Technology
IX	ion exchange
K-9Cl-PF3ONS	potassium 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate (potassium salt of F-53B major)
K-11Cl-PF3OUdS	potassium 11-chloroeicosafluoro-3-oxaundecane-1-sulfonate (potassium salt of F-53B minor)
lb/year	pounds per year
LHA	lifetime health advisory
MCL	Maximum Contaminant Level

MI EGLE	Michigan Department of Environment, Great Lakes, and Energy
MGD	million gallons per day
NaDONA	sodium dodecafluoro-3H-4, 8-dioxanonanoate
NASF	National Association for Surface Finishing
NESHAP	National Emission Standards for Hazardous Air Pollutants
NFDHA	perfluoro-3,6-dioxaheptanoic acid
NEtFOSAA	N-ethyl perfluorooctane sulfonamido acetic acid
NEtFOSE	N-ethyl perfluorooctane sulfonamido ethanol
NEtPFOSA	N-ethyl perfluorooctane sulfonamide
ng/L	nanograms per liter
NIH	United States Department of Health and Human Services, National Institutes of Health
NJ DEP	New Jersey Department of Environmental Protection
NMeFOSAA	N-methyl perfluorooctane sulfonamido acetic acid
NMeFOSE	N-methyl perfluorooctane sulfonamido ethanol
NMePFOSA	N-methyl perfluorooctane sulfonamide
NOAA	United States Department of Commerce, National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OCPSF	organic chemicals, plastics, and synthetic fibers
PAC	powdered activated carbon
POTW	publicly owned treatment works
PFAA	perfluoroalkyl acid
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFCA	perfluoroalkyl carboxylic acid
PFDA	perfluorodecanoic acid
PFDS	perfluorodecane sulfonic acid
PFDoA	perfluorododecanoic acid
PFEA	per- and polyfluoroalkyl ether acid
PFECA	perfluoroalkyl ether carboxylic acid
PFECA-G	perfluoro-4-isopropoxybutanoic acid
PFESA	perfluoroalkyl ether sulfonic acid
PFESA-BP1	perfluoro-3,6-dioxa-4-methyl-7-octene-1-sulfonic acid
PFESA-BP2	Perfluoro-2-{[perfluoro-3-(perfluoroethoxy)-2-propanyl]oxy}ethane sulfonic acid
PFHpA	perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxDA	perfluorohexadecanoic acid
PFHxS	perfluorohexane sulfonic acid
PFMOAA	perfluoro-2-methoxyacetic acid
PFNA	perfluorononanoic acid
PFNS	perfluorononane sulfonic acid
PFOA	perfluorooctanoic acid
PFODA	perfluorooctadecanoic acid
PFO2HxA	perfluoro-3,5-dioxahexanoic acid
PFO3OA	perfluoro-3,5,7-trioxaoctanoic acid
PFO4DA	perfluoro-3,5,7,9-tetraoxadecanoic acid
PFO5DA	perfluoro-3,5,7,9,11-pentaoxadodecanoic acid
PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctane sulfonamide
PFPE	perfluoropolyether
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentane sulfonic acid
PFSA	perfluoroalkane sulfonic acid
PFTeA	perfluorotetradecanoic acid
PFTrA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid

PITT	PFAS Innovative Treatment Team
PMPA	perfluoromethoxypropyl carboxylic acid
PTFE	polytetrafluoroethylene
RfD	reference dose
RO	reverse osmosis
SIC	United States Department of Commerce Bureau of the Census Standard Industrial Classification system
SNUR	Significant New User Rule
TOXNET	National Institutes of Health Toxicology Data Network
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
WI DNR	Wisconsin Department of Natural Resources
µg/L	micrograms per liter
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (F-53B minor)
4:2 FTSA	4:2 fluorotelomer sulfonic acid
5:3 FTCA	2H, 2H, 3H, 3H-perfluorooctanoic acid
6:2 FTOH	6:2 fluorotelomer alcohol
6:2 FTSA	6:2 fluorotelomer sulfonic acid
7:3 FTCA	2H, 2H, 3H, 3H-perfluorodecanoic acid
8:2 FTSA	8:2 fluorotelomer sulfonic acid
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid (F-53B major)

1. Executive Summary

The purpose of this preliminary report is to summarize the readily available information and data the United States Environmental Protection Agency's (EPA) Office of Water collected and reviewed concerning industrial discharges of per- and polyfluoroalkyl substances (PFAS) from five industrial point source categories: organic chemicals, plastics, and synthetic fibers (OCPSF) manufacturing; metal finishing; pulp, paper, and paperboard manufacturing; textile mills; and commercial airports.[1]

PFAS are a family of thousands of synthetic organic chemicals that contain a chain of carbon-fluorine bonds, one of the strongest chemical bonds. Many PFAS are highly stable, water- and oil-resistant, and exhibit other properties that make them useful in a variety of consumer products and industrial processes. Owing to these properties, PFAS do not easily degrade naturally and thus accumulate over time. According to the United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR), the environmental persistence and mobility of some PFAS, combined with decades of widespread use, have resulted in their presence in surface water, groundwater, drinking water, rainwater, soil, sediment, ice caps, outdoor and indoor air, plants, animal tissue, and human blood serum across the globe. Exposure to certain PFAS can lead to adverse human health impacts (ATSDR, 2021).

The global regulatory community has historically been interested in two groups of PFAS: (1) long-chain perfluoroalkane sulfonic acids (PFSAs), including perfluorooctane sulfonic acid (PFOS); and (2) long-chain perfluoroalkyl carboxylic acids (PFCAs), including perfluorooctanoic acid (PFOA). Long-chain PFAS, including PFOA and PFOS, were manufactured and used in the United States since the 1940s. Due to evidence of long-term persistence and adverse health outcomes associated with long-chain PFAS, EPA implemented restrictions on the manufacture, use, and import of certain long-chain PFAS in the United States and some manufacturers have voluntarily phased out these chemicals. More recently, industry has developed and adopted alternative short-chain PFAS chemistries to replace long-chain PFAS. Many short-chain PFAS are structurally similar to their long-chain predecessors being replaced and are manufactured by the same companies. Publicly available health, toxicity, and hazard assessments of short-chain PFAS are limited. Available information suggests short-chain PFAS generally pose less risk to overall human health and exhibit lower persistence in humans than long-chain PFAS such as PFOA and PFOS. However, short-chain PFAS are environmentally persistent and some demonstrate potential to cause adverse effects on animal and human health.

This preliminary report summarizes the manufacture, use, and discharge of PFAS from facilities in the five industrial point source categories EPA reviewed. This preliminary report presents EPA's estimates of the types and concentrations of PFAS, including legacy long-chain PFAS and replacement short-chain PFAS, present in wastewater discharges from these facilities. Few facilities in these industries currently have monitoring requirements, effluent limitations, or pretreatment standards for PFAS in their wastewater discharge permits. EPA identified available wastewater treatment technologies, such as activated carbon, ion exchange, and membrane filtration, that may reduce PFAS in wastewater discharges from facilities in these industrial point source categories.

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[1] For this study, EPA focused on PFAS manufacturers and PFAS formulators for its review of the OCPSF point source category. "PFAS manufacturers" refers to facilities that manufacture PFAS through electrochemical fluorination, fluorotelomerization, or other processes. "PFAS formulators" refers to facilities that blend, convert, or integrate PFAS feedstocks with other materials to produce new commercial or intermediate products.

2. Multi-Industry PFAS Study Background

The Clean Water Act (CWA) directs EPA to promulgate Effluent Limitations Guidelines and Standards (ELGs) that specify the attainable effluent pollutant reduction based on performance of pollution control technologies which are, or can be, employed within each industrial point source category. EPA develops ELGs on an industry-by-industry basis. These national, technology-based controls apply to pollutants discharged from facilities directly into surface waters of the United States or to publicly owned treatment works (POTWs). EPA's goal in establishing ELGs is to ensure that industrial facilities with similar characteristics will, at a minimum, meet similar effluent limitations or pretreatment standards. These effluent limitations and pretreatment standards represent the performance of the "best" pollution control technologies, regardless of geography or the nature of their receiving water or POTW. Although the limitations are based on performance of specific technologies, the regulations do not require use of a specific control technology to achieve the limitations. Facilities may use any method or technology (other than dilution) to comply with the limitations. See EPA's Industrial Effluent Guidelines webpage for more information on ELGs.

To date, EPA has promulgated ELGs for 59 industrial point source categories. These ELGs apply to between 35,000 and 45,000 facilities that discharge to surface waters (direct dischargers), as well as another 129,000 facilities that discharge to POTWs (indirect dischargers), in the United States. The effluent limitations for direct dischargers are implemented through National Pollutant Discharge Elimination System (NPDES) permits issued by authorized states or EPA regional offices. The standards for indirect dischargers are implemented through pretreatment permits or other control mechanisms issued and enforced by POTWs, states, and EPA regional offices. EPA has not established any national technology-based numeric standards for PFAS in industrial wastewater discharges and none of the current ELGs establish effluent limitations or pretreatment standards for PFAS.[2]

As part of the statutorily required ELG planning process, EPA's Office of Water examined readily available public information about PFAS discharges. The *Preliminary Effluent Guidelines Program Plan 14* and a supporting report, *The EPA's Review of Per- and Polyfluoroalkyl Substances (PFAS) in Industrial Wastewater Discharge*, published in October 2019, describe the review activities and findings of the initial examination and identify several industries with facilities that are likely to be discharging PFAS in their wastewater (EPA, 2019a, 2019b). EPA determined that further data collection and study were necessary to inform decisions about how best to address industrial PFAS discharges and announced the Multi-Industry PFAS Study. The Multi-Industry PFAS Study focuses on continuing data collection and review of PFAS manufacture, use, control, and discharge by industries that EPA determined were likely to be discharging PFAS in their wastewater in the preliminary review. The objectives of the Multi-Industry PFAS Study are to:

- Examine specific industrial categories and facilities manufacturing or using PFAS.
- Identify specific industrial facilities discharging PFAS in their wastewater.
- Collect, compile, and review information and data on PFAS in industrial discharges.
- Determine the types and concentrations of PFAS discharged in wastewater, based on available data and information collected by EPA.
- Assess availability and feasibility of control practices and treatment technologies capable of reducing or eliminating PFAS in wastewater discharges.

EPA focused on five industrial point source categories in the Multi-Industry PFAS Study: organic chemicals, plastics, and synthetic fibers (OCPSF); metal finishing; pulp, paper, and paperboard; textile mills; and commercial airports.[3] Table 1 describes these five point source categories, applicable ELGs in the Code of Federal Regulations (CFR), and potential uses/sources of PFAS.

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[2] Where EPA has not promulgated an applicable ELG for direct or indirect dischargers, technology-based effluent limitations or pretreatment standards may be established based on the best professional judgement of the permitting authority.

[3] For this study, EPA focused on PFAS manufacturers and PFAS formulators for its review of the OCPSF point source category. "PFAS manufacturers" refers to facilities that manufacture PFAS through electrochemical fluorination, fluorotelomerization, or other processes. "PFAS formulators" refers to facilities that blend, convert, or integrate PFAS feedstocks with other materials to produce new commercial or intermediate products.

Table 1. Point Source Categories Included in Multi-Industry PFAS Study

Point Source Category	Description	Uses or Sources of PFAS [a]
Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF)	Industrial facilities that manufacture organic chemicals, plastics, synthetic fibers or resin products, including those that manufacture PFAS or process PFAS in production of such products. Subject to ELGs in 40 CFR Part 414.	- Manufacture PFAS through electrochemical fluorination, telomerization, or other processes. - Polymerization processing aids. - Production of plastic, rubber, and resin. - Present in manufacture of commercial chemical products (e.g., carpet cleaning sprays, cleaning agents, protective coatings).
Metal Finishing	Industrial facilities that change the surface of an object to improve its appearance or durability. Includes six primary operations: electroplating, electroless plating, anodizing, coating, printed circuit board manufacturing, and chemical etching and milling. Subject to ELGs in 40 CFR Part 433.	- PFAS-containing chemicals used as wetting agents, mist and fume suppressants to prevent air emissions of toxic metal fumes, agents to reduce mechanical wear, and surface coatings to impart certain characteristics (e.g., reduced corrosion, enhanced appearance).
Pulp, Paper, and Paperboard	Mills that convert wood into pulp, paper, paperboard, and other cellulose-based products. Subject to ELGs in 40 CFR Part 430.	- PFAS-containing chemicals used to impart products with water and grease repellency (e.g., food packaging, coated papers). - Recycling of paper and paperboard products treated with PFAS.
Textile Mills	Mills that receive and prepare fibers; transform materials into yarn, thread, or webbing; convert yarn and webbing into fabric or related products; or finish these materials to produce consumer products (e.g., thread, yarn, bolt fabric, hosiery, towels, sheets, carpet). Subject to ELGs in 40 CFR Part 410.	- PFAS-containing chemicals used to impart outdoor gear, clothing, household, and other textile products with water, oil, soil, and heat resistance.
Commercial Airports	Commercial facilities associated with commercial air transport or aircraft flight operations. Excludes facilities operated by the United States Department of Defense (DOD). Subject to ELGs in 40 CFR Part 449.	- PFAS are a component of aqueous film-forming foam (AFFF), used for exterminating hydrocarbon fuel fires and firefighting training.

a – In general, PFAS may be used as coatings or surfactants for mechanical components (e.g., semiconductors, wiring, tubing, piping, seals, gaskets, etc.) used at many types of industrial facilities.

3. PFAS Overview

This section provides background information on PFAS, with a focus on chemicals and classes discussed in this preliminary report, and discusses industrial trends in the manufacture, import, and use of certain PFAS; environmental fate and transport of PFAS; and PFAS exposure and health effects. This report focuses on 52 PFAS, listed in Table 2, for which EPA collected discharge data as part of the Multi-Industry PFAS Study and are included in EPA's Cross-Agency PFAS Research List. As of August 2021, EPA's Cross-Agency PFAS Research List comprises 199 PFAS compiled from public and internal sources and literature searches by EPA researchers and program office representatives (EPA, 2021a). This list includes the PFAS most frequently detected in organisms and the environment, those included in state or federal standards, and PFAS reported in EPA's national data sets.

3.1 PFAS Classifications and Characteristics

PFAS are a family of thousands of synthetic organic chemicals characterized by linear or branched carbon-fluorine chains connected to a functional group. For the Multi-Industry PFAS Study, EPA used the following technical definition for PFAS:

> *Per- and polyfluorinated substances that structurally contain the unit R-(CF_2)-C(F)(R')R'' where both the CF_2 and CF moieties are saturated carbons and none of the R groups (R, R', or R'') can be hydrogen.*

EPA's National Center for Computational Toxicology maintains a master list of more than 5,000 chemicals with defined structures that are potential PFAS (EPA, 2020a); however, it is likely that less than half of these are commercially active in the United States. PFAS vary widely in chemical and physical properties, behavior, and potential risks to human health and the environment. Differences in the chemical structure, carbon chain length, degree of fluorination, and chemical functional group(s) of individual PFAS have implications for their mobility, fate, and degradation in the environment, as well as uptake, metabolism, clearance, and toxicity in humans, plants, and animals.

Many PFAS are chemically and thermally stable, reduce surface tension, and are resistant to heat, water, and oil. These properties make PFAS useful in many consumer products and industrial processes, but also make PFAS persistent in the environment. The small size, high electronegativity, and low polarizability of the fluorine atom, and the strength of the carbon-fluorine covalent bond are responsible for many of the unique and desirable characteristics of PFAS. See EPA's 2019 report *The EPA's Review of Per- and Polyfluoroalkyl Substances (PFAS) in Industrial Wastewater Discharge* for a summary of potential industrial sources of PFAS identified during EPA's 2019 preliminary review (EPA, 2019b).

Two processes, electrochemical fluorination and fluorotelomerization, are commonly used to manufacture PFAS. PFAS have been manufactured and used in many industries in the United States and internationally since the 1940s, but were not widely documented in environmental samples until analytical methods became commercially available in the 2000s. Since that time, analytical methods have been continuously developed for different environmental media and PFAS chemicals, and to detect PFAS at lower concentrations. Today, PFAS are detected ubiquitously in the environment, biota, and humans, and in remote areas around the globe (Glüge et al., 2020; ITRC, 2020).

The thousands of chemicals that make up the PFAS family can be divided into two classes: nonpolymers and polymers. Each class may contain subclasses, groups, and subgroups. Figure 1, adapted from ITRC (2020), shows the PFAS classes and groups discussed in this preliminary report. Figure 1 is not an exhaustive list of chemical classes and groups that may be considered PFAS. This preliminary report focuses on nonpolymer PFAS with an emphasis on perfluoroalkyl acids (PFAAs), PFAAs precursors, and replacements for long-chain PFAS that have been or are being phased out.

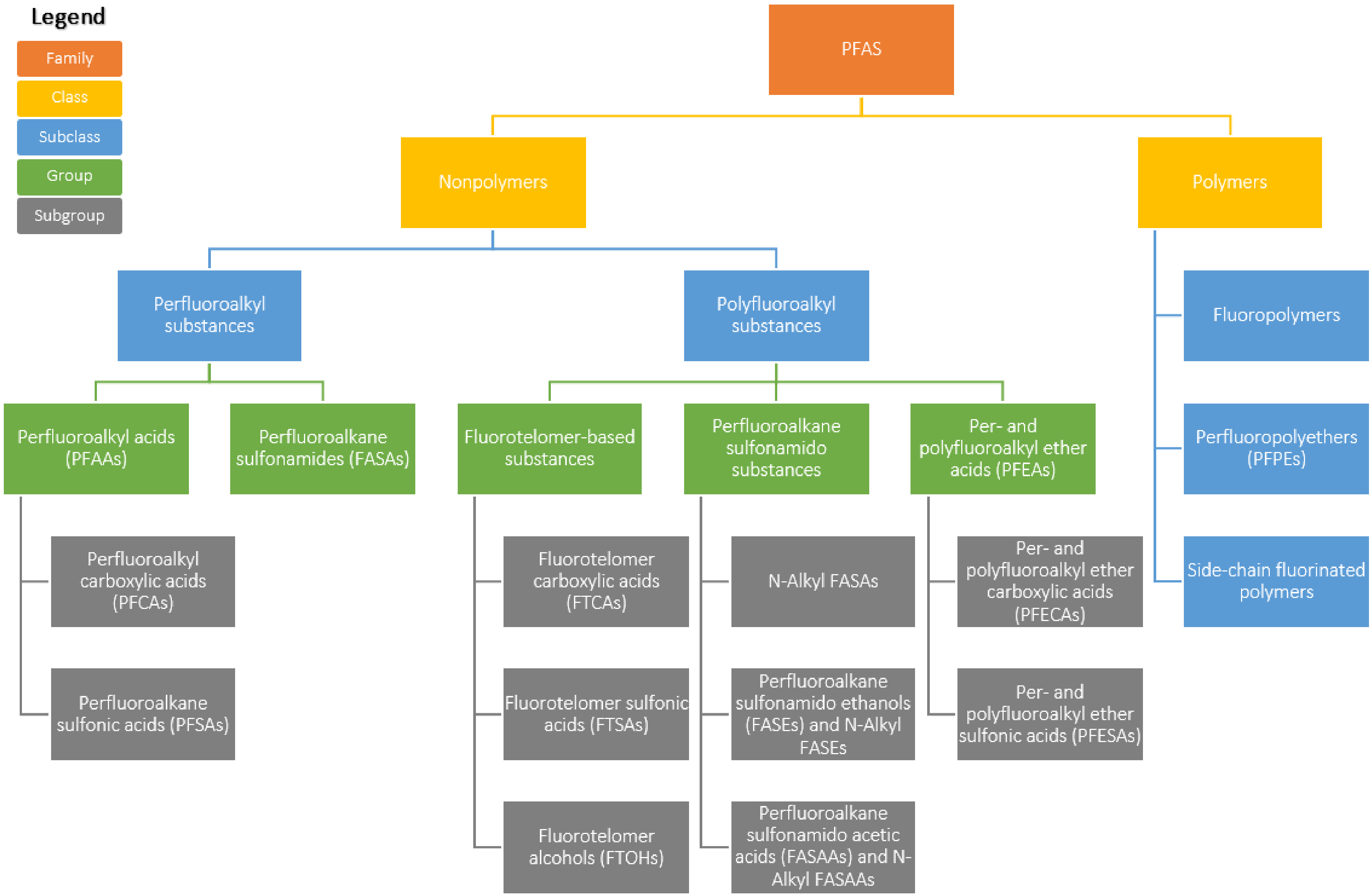

Figure 1. PFAS Classes and Groups Discussed in this Preliminary Report [4]

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[4] Figure 1 was adapted from ITRC (2020) and is not an exhaustive list of chemical classes and groups that may be considered PFAS.

3.1.1 Nonpolymer PFAS

The nonpolymer PFAS class includes two subclasses, perfluoroalkyl substances (fully fluorinated carbon chain) and polyfluoroalkyl substances (partly fluorinated carbon chain), which include various groups and subgroups of chemicals. Table 2, at the end of this section, presents the nonpolymer PFAS for which EPA collected discharge data for this study and are included in EPA's Cross-Agency PFAS Research List (EPA, 2021a).

Perfluoroalkyl Substances

Perfluoroalkyl substances are fully fluorinated alkane molecules consisting of a two-or-more carbon chain (tail) with a charged functional group (head). This preliminary report discusses two groups, PFAAs and perfluoroalkane sulfonamides (FASAs), but others exist and are receiving increasing attention as they are added to commercial laboratory target analyte lists and detected in the environment.

PFAAs are the simplest PFAS molecules and most frequently tested for in the environment. PFAAs do not degrade under ambient environmental conditions and are the terminal products of degradation of more complex PFAS (precursors). Longer chain PFAAs do not naturally degrade into PFAAs with a shorter carbon-fluorine chain length.

PFAAs are divided into two main subgroups: PFCAs and PFSAs. PFCAs may be manufactured using either electrochemical fluorination or fluorotelomerization, while PFSAs are only manufactured using electrochemical fluorination. The PFAAs group includes the two most studied PFAS: PFOA and PFOS. PFOA and PFOS are demonstrated to accumulate and remain in the human body for long periods of time, and to cause adverse health outcomes in animals and humans (EPA, 2016a, 2016b). Figure 2 illustrates the chemical structure of these two chemicals.

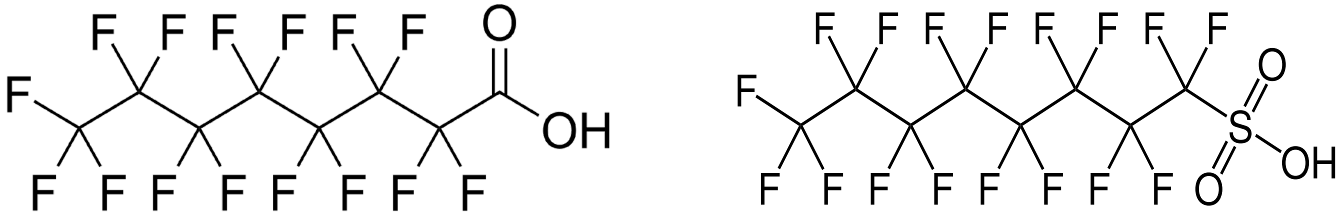

Figure 2. Molecular Structures of PFOA (left) and PFOS (right)

PFAAs are described as long-chain or short-chain PFAS as a shorthand to group PFCAs and PFSAs that may behave similarly in the environment. PFAAs are classified as either long-chain or short-chain depending on the number of carbons covalently bonded to fluorine. Long-chain PFCAs have eight or more carbons (seven or more carbons are perfluorinated) and long-chain PFSAs have six or more carbons (six or more carbons are perfluorinated) (ITRC, 2020). In terms of chemical behavior, PFCAs are more analogous to PFSAs that contain one more carbon than PFSAs that contain the same number of carbons because one carbon in the PFCA molecule is associated with the functional group rather than the fluoroalkyl tail (e.g., the eight carbon PFCA behaves more similar to a seven carbon PFSA than an eight carbon PFSA). Table 2 identifies short-chain PFCAs and PFSAs in blue text, while long-chain PFCAs and PFSAs are designated in red text. EPA notes that other factors besides carbon-fluorine chain length may affect behavior and bioaccumulation potential of PFAS.

FASAs are used as raw material in the electrochemical fluorination process to make perfluoroalkyl sulfonamido substances that are used for surfactants and surface treatments. FASAs may degrade to form PFAAs (ITRC, 2020).

Polyfluoroalkyl Substances

Polyfluoroalkyl substances are distinguished by not being fully fluorinated. Instead, they have a nonfluorine atom (typically hydrogen or oxygen) attached to at least one, but not all, carbon atoms, while two or more of the remaining atoms in the carbon chain tail are fully fluorinated. The nonfluorinated bond in polyfluoroalkyl molecules create a weak point that is susceptible to degradation, thus many of these PFAS have potential to be transformed into PFAAs. This preliminary report discusses three groups of polyfluoroalkyl substances: fluorotelomer-based substances, perfluoroalkane sulfonamido substances, and per- and polyfluoroalkyl ether acids (PFEAs).

Fluorotelomer-based substances are produced by fluorotelomerization and have an x:y naming convention whereby x identifies the number of fully fluorinated carbon atoms and y identifies the number of carbon atoms not fully fluorinated. Fluorotelomer-based substances are potential PFCA precursors but are not observed to transform into PFSAs (NASF, 2019a; Zhang et al., 2016). Three subgroups are discussed in this preliminary report: fluorotelomer carboxylic acids (FTCAs), fluorotelomer sulfonic acids (FTSAs), and fluorotelomer alcohols (FTOHs).

Perfluoroalkane sulfonamido substances have a fully fluorinated tail and also contain one or more methylene (CH_2) groups in the head of the molecule, attached to the sulfonamido spacer. Perfluoroalkane sulfonamido substances are manufactured by electrochemical fluorination and may degrade into PFCAs and PFSAs (ITRC, 2020). Three subgroups are discussed in this preliminary report: N-alkyl FASAs; perfluoroalkane sulfonamido ethanols (FASEs), and perfluoroalkane sulfonamido acetic acids (FASAAs).

PFEAs are manufactured by fluorotelomerization and include per- and polyfluoroalkyl ether carboxylic acids (PFECAs) and per- and polyfluoroalkyl ether sulfonic acids (PFESAs). Certain PFECAs and PFESAs have been developed and are used as replacements for phased out long-chain PFAAs such as PFOA and PFOS. The PFEAs gaining the most attention are hexafluoropropylene oxide dimer acid (HFPO-DA), 4,8-dioxa-3H-perfluorononanoic acid (DONA) and its ammonium salt (ADONA), and chlorinated PFESAs. See Section 3.2 for further discussion of these PFEAs.

Table 2. Nonpolymer PFAS Included in Collected Discharge Data and EPA's Cross-Agency PFAS Research List

Subclass	Group	Subgroup	General Chemical Structure[a] $C_nF_{2n+1}R$, where R =	PFAS Chemicals[a]
Perfluoroalkyl Substances	Perfluoroalkyl acids (PFAAs)	Perfluoroalkyl carboxylic acids (PFCAs)[b,c]	-COOH	- Perfluorobutanoic acid (PFBA) (C4) - Perfluoropentanoic acid (PFPeA) (C5) - Perfluorohexanoic acid (PFHxA) (C6) - Perfluoroheptanoic acid (PFHpA) (C7) - Perfluorooctanoic acid (PFOA) (C8) - Ammonium perfluorooctanoate (APFO) (C8) - Perfluorononanoic acid (PFNA) (C9) - Perfluorodecanoic acid (PFDA) (C10) - Perfluoroundecanoic acid (PFUnA) (C11) - Perfluorododecanoic acid (PFDoA) (C12) - Perfluorotridecanoic acid (PFTrA) (C13) - Perfluorotetradecanoic acid (PFTeA) (C14) - Perfluorohexadecanoic acid (PFHxDA) (C16) - Perfluorooctadecanoic acid (PFODA) (C18)
		Perfluoroalkane sulfonic acids (PFSAs)[b,c]	$-SO_3H$	- Perfluorobutane sulfonic acid (PFBS) (C4) - Perfluoropentane sulfonic acid (PFPeS) (C5) - Perfluorohexane sulfonic acid (PFHxS) (C6) - Perfluoroheptane sulfonic acid (PFHpS) (C7) - Perfluorooctane sulfonic acid (PFOS) (C8) - Perfluorononane sulfonic acid (PFNS) (C9) - Perfluorodecane sulfonic acid (PFDS) (C10)
	Perfluoroalkane sulfonamides (FASAs)[d]	*Not Applicable*	$-SO_2NH_2$	- Perfluorooctane sulfonamide (PFOSA)
Polyfluoroalkyl Substances	Fluorotelomer-based substances[e]	Fluorotelomer sulfonic acids (FTSAs)	$-CH_2CH_2SO_3H$	- 4:2 fluorotelomer sulfonic acid (4:2 FTSA) - 6:2 fluorotelomer sulfonic acid (6:2 FTSA) - 8:2 fluorotelomer sulfonic acid (8:2 FTSA)
		Fluorotelomer carboxylic acids (FTCAs)	$-CH_2COOH$	- 2H, 2H, 3H, 3H-perfluorooctanoic acid (5:3 FTCA) - 2H, 2H, 3H, 3H-perfluorodecanoic acid (7:3 FTCA)
		Fluorotelomer alcohols (FTOHs)	$-CH_2CH_2OH$	- 6:2 fluorotelomer alcohol (6:2 FTOH)
	Perfluoroalkane sulfonamido substances[d]	N-Alkyl FASAs	$-SO_2N(R')$ where $R' = C_mH_{2m+1}$ (m = 1, 2,4)	- N-methyl perfluorooctane sulfonamide (NMePFOSA) - N-ethyl perfluorooctane sulfonamide (NEtPFOSA)

Table 2. Nonpolymer PFAS Included in Collected Discharge Data and EPA's Cross-Agency PFAS Research List

Subclass	Group	Subgroup	General Chemical Structure [a] $C_nF_{2n+1}R$, where R =	PFAS Chemicals [a]
		Perfluoroalkane sulfonamido ethanols (FASEs) and N-Alkyl FASEs	$-SO_2N(R')CH_2CH_2OH$ where $R' = C_mH_{2m+1}$ (m = 0, 1, 2, 4)	- N-methyl perfluorooctane sulfonamido ethanol (NMeFOSE) - N-ethyl perfluorooctane sulfonamido ethanol (NEtFOSE)
		Perfluoroalkane sulfonamido acetic acids (FASAAs) and N-Alkyl FASAAs	$-SO_2N(R')CH_2COOH$ where $R' = C_mH_{2m+1}$ (m = 0, 1, 2, 4)	- N-methyl perfluorooctane sulfonamido acetic acid (NMeFOSAA) - N-ethyl perfluorooctane sulfonamido acetic acid (NEtFOSAA)
	Per- and polyfluoroalkyl ether acids (PFEAs)	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	*Varies by Chemical*	- Hexafluoropropylene oxide dimer acid (HFPO-DA) - 4,8-dioxa-3H-perfluorononanoic acid (DONA) - Ammonium 4,8-dioxa-3H-perfluorononanoate (ADONA) - Sodium dodecafluoro-3H-4, 8-dioxanonanoate (NaDONA) - Perfluoromethoxypropyl carboxylic acid (PMPA) - Perfluoro-2-methoxyacetic acid (PFMOAA) - Perfluoro-3,6-dioxaheptanoic acid (NFDHA) - Perfluoro-3,5-dioxahexanoic acid (PFO2HxA) - Perfluoro-3,5,7-trioxaoctanoic acid (PFO3OA) - Perfluoro-3,5,7,9-tetraoxadecanoic acid (PFO4DA) - Perfluoro-3,5,7,9,11-pentaoxadodecanoic acid (PF05DA) - Perfluoro-4-isopropoxybutanoic acid (PFECA-G)
		Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	*Varies by Chemical*	- 9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid (9Cl-PF3ONS) - Potassium 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate (K-9Cl-PF3ONS) - 11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS) - Potassium 11-chloroeicosafluoro-3-oxaundecane-1-sulfonate (K-11Cl-PF3OUdS) - Perfluoro-3,6-dioxa-4-methyl-7-octene-1-sulfonic acid (PFESA-BP1) - Perfluoro-2-{[perfluoro-3-(perfluoroethoxy)-2-propanyl]oxy}ethane sulfonic acid (PFESA-BP2)

Chemical Structure Abbreviations: C – carbon; H – hydrogen; N – nitrogen; O – oxygen; S – sulfur.

a – For purposes of this report, EPA presents all PFAS names and chemical structures as the neutral/acid form. Under typical environmental conditions, many PFAS are present in the anionic form.

b – PFCAs and PFSAs are denoted using the structural shorthand PFXY where: PF = perfluoro, X = length of the carbon chain (e.g., O for octane or 8 carbons), and Y = the functional group (e.g., A for carboxylic acids and S for sulfonic acids) (ITRC, 2020). The number of carbons in the chain is presented in parentheses.

c – The table identifies short-chain PFCAs (≤7 carbons) and short-chain PFSAs (≤5 carbons) in blue text, while long-chain PFCAs (≥8 carbons) and long-chain PFSAs (≥6 carbons) are designated in red text.

d – Potential PFCA and PFSA precursor.

e – Potential PFCA precursor.

3.1.2 Polymer PFAS

Polymer PFAS are large molecules formed by combining many identical smaller molecules (monomers) in a repeating pattern. Nonpolymer PFAS may be used in the manufacture of some polymer PFAS (either as raw materials or processing aids), included in polymer products as impurities, or released during incineration or degradation. This preliminary report discusses three subclasses of polymer PFAS: fluoropolymers, perfluoropolyethers (PFPEs), and side-chain fluorinated polymers.

Fluoropolymers contain a carbon-only polymer backbone with fluorine directly attached to the backbone. They are not typically made from nonpolymer PFAS raw materials; however, nonpolymer PFAS have been used as processing aids in the polymerization of certain fluoropolymers. Certain high-molecular weight fluoropolymers, including polytetrafluoroethylene (PTFE) and ethylene tetrafluoroethylene (ETFE), are chemically and thermally stable, insoluble in water, and less bioavailable. Based on current information, the molecules of these fluoropolymers are believed to be too large to cross cell membranes and are therefore believed to pose less risk to human and ecological health relative to nonpolymer PFAS (Chemours, 2021; Henry et al., 2018).

Perfluoropolyethers (PFPEs) contain carbon and oxygen polymer backbones with fluorine directly attached to the carbon. PFPEs are believed to have thermal and chemical stability and are not typically soluble in water. PFPEs are not made from long-chain PFAAs or their potential precursors, nor are long chain PFAAs involved in their manufacture.

Side-chain fluorinated polymers contain a nonfluorinated polymer backbone from which fluorinated side chains branch. Some may degrade to PFAAs when the point of connection of a fluorinated side-chain to the polymer is broken (OECD, 2013).

3.2 Phase Out and Replacement of Certain Long-Chain PFAS with Short-Chain PFAS

Until recently (early 2000s), industry primarily used long-chain PFAS, such as PFOS and PFOA, in the manufacture of commercial products. Due to evidence of long-term persistence and adverse health outcomes associated with long-chain PFAS, EPA's Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics (EPA OPPT) has taken a range of regulatory actions under the Toxic Substances Control Act (TSCA) to gather health and exposure information on, require testing of, and control PFAS in manufacturing and consumer products. EPA's efforts to address PFAS through TSCA include, but are not limited to, the following:

- In 2000, EPA worked with the 3M Company (3M) to support the company's voluntary phase out and elimination of PFOA, PFOS, and other specific long-chain PFAAs from production and use. 3M reported that it had completed most of the phase out by 2002, with full completion by 2008.
- In 2006, EPA launched the PFOA Stewardship Program which resulted in the voluntary phase out of long-chain PFCAs and their precursors (i.e., PFOA, higher homologues of PFOA, and their precursors) by eight major chemical manufacturers and processors by year-end 2015. Companies participating in the PFOA Stewardship Program were Arkema, Asahi Glass Company (AGC), Ciba/BASF Corporation, Clariant Corporation, Daikin Industries (Daikin), 3M/Dyneon, DuPont du Nemours (DuPont), and Solvay (formerly, Solvay Solexis).
- Between 2002 and 2020, EPA issued Significant New Use Rules (SNURs) to require manufacturers (including importers) and processors of certain long-chain PFAS to notify EPA at least 90 days before starting or resuming significant new uses of these chemicals. These SNURs prohibit companies from manufacturing, importing, or using certain long-chain PFAS in the United States without prior EPA review and approval.
- EPA's July 2020 SNUR closed an important loophole that previously allowed products containing certain PFAS that have been phased out in the United States to be imported into the nation. The SNUR leveled the playing field for companies that had already voluntarily phased-out the use of long-chain PFAS under EPA's PFOA Stewardship Program by preventing new uses of these phased-out chemicals.

Although manufacture and import of certain long-chain PFAS and precursors effectively ceased as result of EPA's actions under TSCA, products containing these chemicals that were manufactured or imported before 2020 may still be in use. While manufacture of long-chain PFAS is restricted in the United States, Europe, and Japan, their manufacture continues in China, India, Russia, and other countries.

EPA's TSCA Chemical Substance Inventory lists over 1,000 PFAS, approximately half of which are known to be commercially active within the United States in the last decade. As of February 2020, EPA reviewed more than 300 of the commercially active PFAS under the New Chemicals Program, and regulated about 200 PFAS with consent orders and/or new chemical SNURs (EPA, 2020b).

The phase out and increasing concerns regarding persistence, bioaccumulation, and health effects of certain long-chain PFAAs has led many manufacturers to develop replacement technologies. Manufacturers have developed alternative processes and chemistries to substitute for these long-chain PFAS, including nonfluorinated chemicals, short-chain PFCAs and PFSAs, and PFAS chemistries that do not degrade to long-chain PFAAs. The list below presents several examples of alternative short-chain PFAS that manufacturers have developed and used to replace long-chain PFAS:

- HFPO-DA (one chemical used in the DuPont/Chemours GenX technology) and ADONA (one chemical used in a 3M technology) are replacements for PFOA as a polymerization aid in the production of fluoropolymers and PFPEs.[5] Transition to the GenX- and ADONA-based processing aid technologies began in 2009 as part of industry's commitment under the PFOA Stewardship Program to work toward the elimination of certain long-chain PFAAs and precursors from emissions and products by 2015.
- Short-chain PFCAs (PFBA, PFPeA, PFHxA, PFHpA) and short-chain PFSAs (PFBS, PFPeS) are replacements for PFOA and PFOS in chemical coatings, additives, and surface treatments. For example, PFBS (a four-carbon homologue of the eight-carbon PFOS) replaced PFOS in 3M's Scotchgard™ stain repellent.
- Fluorotelomer-based substances with six or less fully fluorinated carbons (e.g., 6:2 FTSA, 6:2 FTOH) are replacements for long-chain PFAAs and their precursors in aqueous film-forming foam (AFFF) and food contact materials requiring water and oil resistance or nonstick properties.
- Fluorotelomer-based substances with six or less fully fluorinated carbons (e.g., 6:2 FTSA) and chlorinated PFESAs (e.g., 9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid and 11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid) are replacements of PFOS used as metal plating mist and fume suppressants. The substances 9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid (9Cl-PF3ONS), 11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS), and their potassium salts are also known as "F-53B" chemicals.[6]

Many short-chain PFAS-based replacement chemicals are structurally similar to their predecessors and manufactured by the same companies. Replacement short-chain PFAS may be used in higher quantities than long-chain PFAS to achieve the same desired properties (Blepp et al., 2017; Blum et al., 2015).

Chemical property information is publicly available for only a few alternative PFAS chemistries; very few health, toxicity, and hazard assessments have been performed for these chemicals (Blum et al., 2015). As part of this study, EPA conducted a preliminary review of four short-chain PFAS adopted by industry to replace PFOA and PFOS. Section 3.4 summarizes current information and data on advisory standards, toxicity, bioaccumulation and persistence, and degradation of PFOA, PFOS, PFBS, 6:2 FTSA, 6:2 FTOH, and HFPO-DA.

3.3 Environmental Fate and Transport of PFAS

Short- and long-chain PFAS enter the environment through manufacturing and during use and disposal of consumer items. According to ATSDR, PFAS have been found worldwide in surface water, groundwater, finished drinking water, rainwater, soils, sediments, ice caps, outdoor and indoor air, plants, animal tissue, and human blood serum. The highest environmental concentrations of long- and short-chain PFAS are found in surface water, groundwater, soils, and sediments around facilities that have produced or used PFAS (ATSDR, 2021). According to the Association of State and Territorial Solid Waste Management Officials (ASTSWMO), fresh waters near

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[5] The Chemours Company (Chemours) is a July 2015 spinoff of the former DuPont performance chemicals business unit. GenX is the trade name for a fluoropolymer processing aid technology that is associated with two chemicals, HFPO-DA and its ammonium salt, also referred to as "GenX" chemicals.

[6] The trade name "F-53B" refers specifically to a single chemical, 9Cl-PF3ONS, but the name is often used to encompass 9Cl-PF3ONS, minor impurities such as the homologue 11Cl-PF3OUdS, and their potassium salts. The major and minor components of F-53B are sometimes referred to as "F-53B major" (9Cl-PF3ONS) and "F-53B minor" (11Cl-PF3OUdS).

industrial sites have documented PFAS concentrations ranging up to 1,000 nanograms per liter (ng/L). Oceanic concentrations of PFAS are several orders of magnitude lower, ranging from 0.01 to 0.1 ng/L (ASTSWMO, 2015).

EPA used the Unregulated Contaminants Monitoring Rule 3 (UCMR3) to collect data for contaminants suspected to be present in drinking water, but that do not have health-based standards set under the Safe Drinking Water Act. As part of UCMR3, EPA sampled drinking water for six PFAS (PFOS, PFOA, PFNA, PFHxS, PFHpA, and PFBS) between 2013 and 2015 (EPA, 2017a). EPA's UCMR3 monitoring indicated that public water systems in 33 states serving 16.5 million residents had detectable levels of long- and short-chain PFAS. Sixty-six public water systems serving more than 6 million people were found to have at least one sample above 70 ng/L, EPA's lifetime health advisory (LHA) value for the sum of PFOA and PFOS in drinking water (Hu et al., 2016). See Section 3.4 for more information regarding EPA's LHA values for PFAS.

Owing to their chemical and thermal stability, some long- and short-chain PFAS can withstand heat, acids, bases, reducing agents, and oxidants and, as a result, are not readily degradable by most natural processes. As discussed in Section 3.2, manufacturers that have phased out certain long-chain PFAS have replaced them with alternative PFAS chemistries, including short-chain PFCAs and PFSAs, and PFAS that do not degrade to long-chain PFAAs. Some short-chain PFAS are as persistent in the environment as their long-chain homologues (Wang et al., 2013) although other short-chains degrade much faster.

3.4 PFAS Exposure and Health Effects

This section summarizes information on exposure and adverse human health effects of certain PFAS. Research in this field is ongoing and information presented in this section represents the current state of knowledge based on EPA's review of technical literature, EPA toxicity assessments, ATSDR toxicological profiles, the United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) Chemical Aquatic Fate and Effects (CAFE) database (NOAA, 2019), and the United States Department of Health and Human Services National Institutes of Health (NIH) Toxicology Data Network (TOXNET) (NIH, 2019).

There are a variety of ways that individuals may be exposed to PFAS. Known exposure routes for PFAS include (ATSDR, 2021; EPA, 2016a, 2016b):

- Consumption of drinking water from contaminated public water systems or private wells.
- Consumption of contaminated fish.
- Consumption of crops grown in contaminated soils, particularly in agricultural areas that receive amendments of biosolids from POTWs.
- In utero exposure.
- Consumption of contaminated breast milk by infants.
- Inhalation and ingestion of contaminated indoor dust.
- Direct contact with products treated with PFAS, such as food papers/packaging and treated carpets.

For the general population, contaminated drinking water and food are the most frequently documented routes of exposure to long- and short-chain PFAS. There is evidence that exposure to certain PFAS can lead to adverse health outcomes in animals and humans. If animals or humans ingest PFAS-contaminated food or water, the PFAS are absorbed, and can accumulate in the body. Certain PFAS, such as PFOA and PFOS, may stay in the human body for longer than 10 years. As individuals become exposed to PFAS from different sources over time, the level of PFAS in their bodies may increase to the point where they suffer from adverse health effects (ATSDR, 2021).

In May 2016, EPA established an LHA value at 70 ng/L for the sum of PFOA and PFOS to protect the public from these potential adverse health effects resulting from exposure to PFOA and PFOS in drinking water. EPA's LHA values are based on the best available peer-reviewed studies of the effects of PFOA and PFOS on laboratory animals (rats and mice) and were also informed by epidemiological studies of human populations that have been exposed to PFAS (EPA, 2021d). EPA's LHA values are not legally enforceable; they provide technical information on drinking water contaminants to federal, state, and local officials, and managers of public or community water systems to assist them with protecting public health (EPA, 2018b). In 2021, EPA initiated a proposal to establish enforceable National Primary Drinking Water Regulations for PFOS and PFOA. This process will include evaluating the need for enforceable maximum contaminant levels (MCLs) for PFOA and PFOS.

As discussed in Section 3.2, industry has effectively ceased manufacturing and using certain long-chain PFAS and is substituting with short-chain PFAS. Less information about the toxicity and bioaccumulation of short-chain PFAS is available compared to long-chain PFAS. EPA reviewed information on the toxicity, bioaccumulation, and degradation potential for four short-chain PFAS (6:2 FTSA, 6:2 FTOH, PFBS, and HFPO-DA) adopted by industry to replace long-chain PFAS. Table 3 summarizes available information for these four short-chain PFAS, as well as for PFOA and PFOS for comparison. EPA notes that complete toxicity, bioaccumulation, and human half-life information is not available for all substances; EPA presents draft values where final values are not yet available (e.g., HFPO-DA toxicity values). See the *Short-Chain PFAS Review: Fact Sheet for 6:2 FTSA, 6:2 FTOH, PFBS, and HFPO-DA* for additional information (ERG, 2021d).

The informational categories in the first column of Table 3 are defined below:

- **Current Industrial Applications.** Describes use of the PFAS by the five point source categories assessed.
- **Chronic Reference Dose (RfD).** An estimate of the daily oral exposure for a chronic duration to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime. Generally used in EPA's noncancer health assessments and expressed in weight of substance per unit weight of organism per day (e.g., mg/kg-day). The lower the chronic RfD, the more toxic the substance.
- **Oral Median Lethal Dose (LD50).** A statistically derived single dose that can be expected to cause death in 50 percent of the test animals when administered by the route indicated (oral, dermal, inhalation). It is expressed as a weight of substance per unit weight of animal (e.g., mg/kg). The lower the LD50, the more acutely toxic the substance.
- **Toxicity Effects.** Describes types of adverse health effects observed in humans or test animals following exposure to the substance.
- **Bioaccumulation Factors (BAF).** The ratio of the concentration of a contaminant in an organism to the concentration in the ambient environment at steady state, where the organism can take in the contaminant through ingestion with its food as well as through direct contact. EPA OPPT characterizes a chemical as bioaccumulative if it has a bioconcentration factor (BCF) or BAF greater than or equal to 1,000. EPA OPPT characterizes a chemical as very bioaccumulative if it has a BCF or BAF greater than or equal to 5,000 (EPA, 2017b).
- **Human Half-Life.** The time required for human biological processes to naturally eliminate half the amount of a substance initially measured in blood serum.
- **Degradation Products.** Terminal products observed following degradation of the organic substance.

While information on human health effects of the four short-chain PFAS is limited, studies current when this preliminary report was written suggest 6:2 FTSA, 6:2 FTOH, PFBS, and HFPO-DA demonstrate less risk to overall human health and less potential for bioaccumulation, relative to PFOA and PFOS. However, EPA has documented these short-chain PFAS are present in industrial discharges, are environmentally persistent, and do demonstrate potential for adverse impacts to ecological and human health receptors. Additional findings from EPA’s preliminary review of these four short-chain PFAS, PFOA, and PFOS are listed below:

- PFBS, PFOA, and PFOS have lower reported minimum chronic RfD and oral LD50 values than 6:2 FTSA, 6:2 FTOH, and HFPO-DA. This suggests PFBS, PFOA, and PFOS may have higher chronic and acute toxicity.
- PFOA and PFOS meet EPA OPPT’s criteria for designation as “very bioaccumulative” and “bioaccumulative,” respectively. The four short-chain PFAS do not meet these criteria.
- Human half-life identified for PFBS is estimated as 43.8 days as compared to more than 2 years for PFOA and PFOS, which suggests PFBS is less bioaccumulative.
- Fluorotelomers readily degrade and transform through multiple complex mechanisms. Terminal end products for 6:2 FTSA and 6:2 FTOH include short-chain PFCAs and FTCAs (do not degrade to PFOA or PFOS); some of these degradation products may be environmentally and biologically persistent (Kabadi et al., 2018, 2020).
- Available information suggests PFBS and HFPO-DA are stable under ambient environmental conditions.

Table 3. Summary of Draft and Final Health Effects Information for Short-Chain PFAS, PFOA, and PFOS

	6:2 FTSA	6:2 FTOH	PFBS	HFPO-DA	PFOA	PFOS
Current Industrial Applications	Modern AFFF, food contact substances, and metal finishing mist and fume suppressants	Modern AFFF, food contact substances, and intermediate in chemical/resin manufacturing	Chemical coatings, additives and surface treatments (e.g., 3M Scotchgard™)	Polymerization aid in production of fluoropolymers and PFPEs	Manufacture, use, and import restricted in the United States	Manufacture, use, and import restricted in the United States
Chronic RfD (mg/kg-day)	*None identified*	*None identified*	0.0003	0.00008 [a]	0.00002	0.00002
Oral LD50 (mg/kg)	300 – 2,000	1,750 – 2,000	430	1,730 – 1,750 [b]	430 – 680	251 - 579
Toxicity Effects	Skin irritation, kidney and liver effects	Kidney, liver, immune system, and developmental effects	Thyroid, liver, kidney, developmental, and reproductive effects	Liver, kidney, immune system, hematological, developmental, and carcinogenic effects	Liver, kidney, reproductive, developmental, and carcinogenic effects	Liver, kidney, thyroid, immune system, developmental, cardiovascular, and carcinogenic effects
Bioaccumulation Factors (BAF)	*None identified*	*None identified*	< 10	< 10 (tissue value) [a]	7,670	1,900
Human Half-Life	*None identified*	*None identified*	43.8 days	*None identified*	2.1 – 10.1 years	3.3 – 27 years
Degradation Products	5:3 FTCA, PFPeA, PFHxA	5:3 FTCA, PFPeA, PFHxA	Environmentally stable (no natural degradation)	Environmentally stable (no natural degradation)	Environmentally stable (no natural degradation)	Environmentally stable (no natural degradation)
References	NASF, 2019a EPA 2021v	Kabadi et al., 2018, 2020 Rice et al., 2020 EPA, 2021v	AECOM, 2019 ASTDR, 2021 EPA, 2021u, 2021v	Dupont, 2008 EPA, 2018c	ATSDR, 2021 EPA, 2016a, 2018a, 2021v	ATSDR, 2021 EPA, 2016b, 2018a, 2021v

a – Draft values from EPA's 2018 draft *Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3)* (EPA, 2018c). Values subject to change; final GenX values anticipated in late 2021.

b – The oral median lethal doses (LD50s) were 1,730 mg/kg and 1,750 mg/kg in male rats and female rats, respectively. In these rat and mouse studies, animals received a single dose in the dose range of 175–5,000 mg/kg HFPO-DA and were assessed for effects for 14 days (DuPont, 2008; EPA, 2018c).

4. Data Collection Activities

This section describes the data sources EPA collected and evaluated as part of the Multi-Industry PFAS Study, provides information on data quality, and describes how EPA handles and safeguards confidential business information (CBI).

4.1 Data Sources and Quality

EPA gathered available data and reached out to stakeholders to identify facilities producing or using PFAS, determine wastewater characteristics, estimate PFAS in wastewater discharges, and identify effective PFAS control practices and treatment technologies. Table 4 describes each data source EPA consulted as part of the study and summarizes how each was used. EPA considered the accuracy, reliability, and representativeness of the data sources listed in Table 4 to assess their usability for the Multi-Industry PFAS Study, as described below.

Accuracy. EPA assumed that data and information contained in supporting government publications or databases, peer-reviewed journal articles, and other technical literature are sufficiently accurate to support the general characterization of industries, sources, wastewater discharges, and treatment associated with PFAS, as well as human health impacts and environmental fate, transport, and exposure pathways of PFAS. EPA considered the data and information obtained from direct correspondence with individual companies, industry trade associations, and state government representatives and regulators as sufficiently accurate to characterize and quantify specific PFAS wastewater discharges or related process operations from individual facilities.

Reliability. EPA used the following criteria to evaluate the reliability of available data and other information collected and used in its analyses:

- The work is clearly written, so that all assumptions and methodologies can be identified.
- The variability and uncertainty (quantitative and qualitative) of the information, or the procedures, measures, methods, or models used to compile the information, are evaluated and characterized.
- The assumptions and methods are consistently applied throughout the analysis, as reported in the source.
- Wastestreams, analytes, units, and analytical limitations (when appropriate) are clearly characterized.
- The contact is reputable and has knowledge of the industry, facility, processes, and/or wastestreams of interest.

EPA considered data sources that met these criteria sufficiently reliable to characterize and understand industries, sources, and wastewater discharges associated with PFAS.

Representativeness. EPA evaluated whether data and information were characteristic of PFAS discharges and impacts across industries or sources and were relevant to and representative of typical operations relevant to PFAS.

EPA considered data sources that met these criteria of being sufficiently accurate, reliable, and representative to characterize industries, sources, and wastewater discharges and treatment associated with PFAS, as well as human health impacts and environmental fate, transport, and exposure pathways of PFAS.

Table 4. Multi-Industry PFAS Study Data Sources

Data Source	Description	Use in Study
EPA Data Sets and Coordination		
2016 Chemical Data Reporting (CDR) Database	The CDR rule, under TSCA, requires manufacturers (including importers) to provide EPA with information on the production and use of chemicals in commerce. The information is collected every four years from manufacturers and importers of certain chemicals when production volumes exceed specified thresholds for a specific reporting year. EPA accessed CBI CDR data reported in 2016 for chemicals listed in EPA's Cross-Agency PFAS Research List, including facility names and locations and volumes of chemicals for production, import, and use of PFAS. The CDR information reported in 2016 reflects the most recent data set available and reflect production volumes from 2012 through 2015 (EPA, 2021b).	Estimate PFAS production volumes, identify companies and facilities manufacturing or importing PFAS, and identify industrial and commercial uses of PFAS.
2019 and 2020 Discharge Monitoring Reports (DMR)	EPA downloaded DMR data for PFAS from the Integrated Compliance Information System National Pollutant Discharge Elimination System for 2019 and 2020 using the online Water Pollutant Loading Tool. The data include pollutant discharge information (e.g., types and concentrations) and discharge flow rate data for direct dischargers with PFAS effluent limitations or monitoring requirements in their NPDES permits (EPA, 2020c, 2021c).	Evaluate wastewater characteristics, estimate facility and industry PFAS concentrations, and identify facilities with NPDES permit requirements for PFAS.
Industrial Wastewater Treatment Technology (IWTT) Database	EPA's IWTT database contains information on treatment technology advances identified through EPA's Annual Reviews. As part of its screening of industrial wastewater discharges, EPA reviews literature regarding the performance of new and improved industrial wastewater treatment technologies and enters the data into its IWTT database (EPA, 2021e).	Identify technologies used to remove PFAS from wastewaters.
Drinking Water Treatability Database (DWTD)	EPA's DWTD is a compilation of research articles on contaminants found in drinking water sources and treatment technologies for drinking water treatment plants. The DWTD includes PFAS removal performance data for an assortment of treatment technologies and 37 PFAS (EPA, 2021f).	Identify PFAS treatment technologies and assess PFAS removal performance.
EPA's Office of Enforcement and Compliance Assurance	EPA met with EPA's Office of Enforcement and Compliance Assurance and received industry data submittals, reports, and sampling data for three companies that manufacture or process PFAS (EPA, 2020d).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place. Used to determine wastewater characteristics and estimate PFAS in wastewater discharges.
EPA's Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics (EPA OPPT)	EPA met and coordinated with EPA's OPPT to discuss and collect PFAS data available in the TSCA Chemical Substance Inventory and 2016 CDR database (EPA, 2020f, 2021b).	Collect information on PFAS discussed in this report. Identify commercially active PFAS and companies and facilities manufacturing or importing these PFAS, as well as associated production volumes.

Table 4. Multi-Industry PFAS Study Data Sources

Data Source	Description	Use in Study
Previous Rulemaking Materials and EPA Publications	EPA obtained supporting documentation from previous EPA actions and rulemakings associated with PFAS and the industrial categories included in the Multi-Industry PFAS Study. These development documents contain findings, conclusions, and data on industry profiles, PFAS use and restrictions, and PFAS control and treatment technologies. Materials collected included, but are not limited to, existing ELGs, National Emission Standards for Hazardous Air Pollutants (NESHAP), SNURs, PFOA Stewardship Program status reports, EPA PFAS toxicology assessments, EPA's Interim Guidance on PFAS Disposal and Destruction, and technology technical briefs prepared by EPA's PFAS Innovative Treatment Team (PITT).	Background information on the population and processes of the five industrial point source categories and on the impacts of current government programs and regulations related to PFAS.
Information from Other Federal Agencies		
United States Department of Transportation, Federal Aviation Administration (FAA)	EPA met with the FAA to discuss PFAS-containing AFFF use at airports. EPA collected materials related to the military specifications for AFFF used at commercial airports and FAA guidance for AFFF use and control (ERG, 2020a).	Background on PFAS use by commercial airports and FAA activities to control PFAS.
United States Department of Health and Human Services, Food and Drug Administration (FDA)	EPA collected and reviewed FDA-funded studies and food contact substance notifications (FCNs) for PFAS approved for used in food contact materials (FDA, 2020, 2021; Kabadi et al., 2018, 2020; Rice et al., 2020).	Background information on the use of PFAS in food-contact materials.
Information from States and Regions		
National Pollutant Discharge Elimination System (NPDES) Permits, Permit Applications, and Fact Sheets	The CWA requires direct dischargers to control their discharges according to limitations, monitoring, and requirements included in NPDES permits. EPA obtained and reviewed copies of NPDES permits and, where available, accompanying permit applications and fact sheets for facilities discharging PFAS in the five industrial point source categories. Information contained in permit materials includes onsite wastewater treatment processes, outfall descriptions, and destinations of wastewater discharges.	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place.
Michigan Department of Environment, Great Lakes, and Energy (MI EGLE)	EPA met with MI EGLE and local wastewater authorities on several occasions between 2019 and 2021. EPA received or downloaded multiple documents and data sets including PFAS survey materials, reports summarizing MI EGLE's efforts to identify sources of and address PFAS, and effluent analytical data for direct and indirect discharges (ERG, 2019a, 2019b, 2019c; MI EGLE, 2020a, 2020b, 2020c, 2020d; MI GLWA, 2019).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place. Used to determine wastewater characteristics and estimate PFAS in wastewater discharges.
EPA Region 3	On February 26, 2020, EPA Region 3 submitted a field sampling investigation report containing effluent data for a Sartomer (a division of Arkema) PFAS production plant in West Chester, Pennsylvania. The sampling was performed to confirm PFAS levels in a surface water and determine if the Sartomer facility was the source of PFAS (EPA Region 3, 2019).	Determine wastewater characteristics and estimate PFAS in wastewater discharges.

Table 4. Multi-Industry PFAS Study Data Sources

Data Source	Description	Use in Study
New Jersey Department of Environmental Protection (NJ DEP)	EPA met with NJ DEP and received effluent analytical data and/or the NPDES permit materials for two facilities that manufacture or process PFAS (NJ DEP, 2015, 2018, 2020).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place. Used to determine wastewater characteristics and estimate PFAS in wastewater discharges.
Wisconsin Department of Natural Resources (WI DNR)	EPA met with the WI DNR to discuss sources of PFAS in the state of Wisconsin (ERG, 2020b).	Identify companies and facilities discharging PFAS in Wisconsin.
Information from Industry		
American Chemistry Council (ACC) and ACC FluoroCouncil	EPA met with the ACC and members of the ACC FluoroCouncil and collected materials relevant to the production and use of PFAS in the United States as well as assessments of certain PFAS (ERG, 2019d).	Background on PFAS manufacture and processing in the United States, to identify PFAS currently in the domestic market, and to identify specific companies and facilities that manufacture or process PFAS.
The Chemours Company (Chemours)	EPA met with Chemours (a July 2015 spinoff of the former DuPont performance chemicals business unit) and received materials from the company including presentations, technical papers, materials associated with a consent order for one Chemours PFAS manufacturing facility, and effluent analytical data and the NPDES permit for another Chemours PFAS manufacturing facility (ERG, 2019e; Chemours, 2020a; NJ DEP, 2018).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place. Used to determine wastewater characteristics and estimate PFAS in wastewater discharges.
3M	EPA met with 3M and received materials from the company, including an industry report on fluorochemical production, procedures for a direct injection analytical method for PFAS, wastewater treatment diagrams, NPDES permits, and effluent analytical data for three 3M facilities that manufacture or process PFAS (ERG, 2019f; 3M, 2020a, 2020b).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place. Used to determine wastewater characteristics and estimate PFAS in wastewater discharges.
Daikin	EPA met with Daikin America, a subsidiary of Daikin, to discuss manufacture, formulation, and discharge of PFAS (ERG, 2019g).	Identify unit operations, PFAS effluent limitations or monitoring requirements, and wastewater treatment in place.
AGC	EPA met with AGC Chemicals Americas, a wholly owned subsidiary of AGC, to discuss manufacture, formulation, and discharge of PFAS. AGC Chemicals Americas stated that they do not operate any facilities domestically that manufacture PFAS; however, they do have at least one facility that processes PFAS (ERG, 2019h).	Identify companies and facilities manufacturing or importing PFAS.
National Association for Surface Finishing (NASF)	EPA met with NASF and collected materials related to the use and toxicity of PFAS in metal finishing operations (ERG, 2020c; NASF, 2019a, 2019b, 2019c).	Background on PFAS use by the metal finishing industry and to assess toxicity, bioaccumulation, and persistence of PFAS.

Table 4. Multi-Industry PFAS Study Data Sources

Data Source	Description	Use in Study
American Forest and Paper Association (AF&PA)	EPA met with the AF&PA and several member companies to discuss sources and classifications of PFAS, including AF&PA member companies that use PFAS and the potential to discharge PFAS into the environment. AF&PA submitted information on the use and discharge of PFAS in four subsequent data submissions and facilitated outreach with specific member companies (ERG, 2020d; AF&PA, 2020a, 2020b, 2020c, 2020d).	Background on PFAS use by the pulp, paper, and paperboard industry, to identify unit operations and products associated with PFAS, and determine wastewater characteristics.
Ahlstrom-Munksjö USA Inc. (Ahlstrom-Munksjö)	EPA met with Ahlstrom-Munksjö to discuss use and discharge of PFAS by the company's pulp, paper, and paperboard facilities. Ahlstrom-Munksjö currently uses PFAS in the manufacture of food contact paper and packaging for five facilities in the United States. Ahlstrom-Munksjö is transitioning all production to PFAS-free formulations in the next few years (EPA, 2021g).	Background on PFAS use by the pulp, paper, and paperboard industry and to identify facilities using PFAS.
Georgia Pacific, LLC (Georgia-Pacific)	EPA met with Georgia-Pacific to discuss use and discharge of PFAS by the company's pulp, paper, and paperboard facilities. Georgia-Pacific discontinued application of PFAS to paper and packaging products more than a decade ago. In 2021, Georgia-Pacific completely discontinued purchase, conversion, and distribution of PFAS-treated paper and packaging products (EPA, 2021h).	Background on PFAS use by the pulp, paper, and paperboard industry and to identify facilities using PFAS.
Graphic Packaging International	EPA met with Graphic Packaging International to discuss use and discharge of PFAS by the company's pulp, paper, and paperboard facilities. Graphic Packaging International currently uses PFAS in the manufacture of food contact paper and packaging at a single facility in the United States, but will discontinue PFAS use at this facility by end of 2021 (EPA, 2021i).	Background on PFAS use by the pulp, paper, and paperboard industry and to identify facilities using PFAS.
WestRock Company	EPA met with WestRock Company to discuss use and discharge of PFAS by the company's pulp, paper, and paperboard facilities. WestRock Company discontinued application of PFAS to paper and packaging products across all United States mills in 2020 (EPA, 2021j).	Background on PFAS use by the pulp, paper, and paperboard industry and to identify facilities using PFAS.
Sappi North America, Inc. (Sappi)	EPA met with Sappi to discuss use and discharge of PFAS by the company's pulp, paper, and paperboard facilities. Sappi currently uses PFAS in the manufacture of food contact packaging at a single facility in the United States, but will discontinue use at this facility by 2024 (EPA, 2021m).	Background on PFAS use in the pulp, paper, and paperboard industry and to identify facilities using PFAS.
Domtar Corporation	Domtar Corporation submitted a letter to EPA with information on the use of PFAS by the company's pulp, paper, and paperboard facilities. Domtar Corporation notified EPA that one mill was using PFAS in the manufacture of food contact paper and packaging in 2021; however, this mill has closed and none of the remaining United States facilities use PFAS (Domtar Corporation, 2021).	Identify companies and facilities manufacturing or importing PFAS.

Table 4. Multi-Industry PFAS Study Data Sources

Data Source	Description	Use in Study
International Paper Company	Domtar Corporation submitted a letter to EPA confirming the company does not use PFAS in manufacturing products at United States mills and does not sell or import into the United States products with PFAS intentionally added (International Paper Company, 2021).	Identify companies and facilities manufacturing or importing PFAS.
Airport Council International – North America	EPA met with the Airport Council International – North America to discuss use and composition of PFAS-containing AFFF and efforts to reduce/control releases (ERG, 2020e).	Background on AFFF use at commercial airports and potential release of PFAS.
National Association of Clean Water Agencies (NACWA)	EPA met with the NACWA to discuss industrial producers and users of PFAS, treatment technologies, and POTW concerns related to PFAS (ERG, 2019i).	Background on organizations or companies collecting PFAS effluent and treatment technology data.
Other Sources		
Scientific and Academic Literature	As part of targeted literature reviews, EPA collected peer-reviewed and technical literature relevant to PFAS manufacture, release, sampling/analysis, treatment, toxicity, degradation, bioaccumulation, persistence, and other topics.	Obtain information on the five industrial point source categories, PFAS manufacture and use, and PFAS characteristics.
Conferences/Webinars	EPA participated in and obtained information from multiple conferences and virtual webinars relevant to PFAS manufacture, release, sampling/analysis, treatment, toxicity, degradation, bioaccumulation, persistence, and other topics.	Obtain information on the five industrial point source categories, PFAS manufacture and use, and PFAS characteristics.

4.2 Protection of Confidential Business Information

Certain data in the study record have been claimed as CBI or enforcement sensitive materials. As required by federal regulations at 40 CFR Part 2, EPA has taken precautions to prevent the inadvertent disclosure of this CBI. The agency has withheld CBI from the public docket in the Federal Docket Management System and available on www.regulations.gov. In addition, EPA has found it necessary to withhold from disclosure some data not claimed as CBI because the release of these data could indirectly reveal CBI. Where necessary, EPA has aggregated certain data in the public docket, masked plant identities, or used other strategies to prevent the disclosure of CBI. The agency's approach to protecting CBI ensures that the data in the public docket explain the basis for the study and provide the opportunity for public comment without compromising data confidentiality.

5. Review of the OCPSF Point Source Category

This section describes the OCPSF point source category, information and data EPA collected on its production and use of PFAS, and EPA's estimates of types and concentrations of PFAS discharged by OCPSF facilities that manufacture or formulate PFAS. EPA focused on PFAS manufacturers and PFAS formulators for its review of the OCPSF point source category in this study. EPA collected and reviewed information on PFAS manufacture, use, and discharge by this subset of OCPSF facilities from the sources below.

- Outreach with chemical manufacturers, industry trade associations, and state and local wastewater authorities.
- The agency's Chemical Data Reporting (CDR) database.
- Discharge Monitoring Report (DMR) data available in EPA's Water Pollutant Loading Tool.
- Reports and data collected from industry and state and local wastewater authorities.
- Wastewater discharge permits.
- Industry submissions associated with PFAS consent orders and enforcement activities.
- Publicly available technical literature.

5.1 Industry Description, Manufacture, and Use of PFAS

The OCPSF point source category includes more than 1,000 facilities that manufacture certain organic chemicals, plastics, and synthetic fibers and related products. The industry is diverse with many complex unit operations and specialized manufacturing facilities that process raw materials into thousands of different products. OCPSF facilities operate continuous processes as well as batch operations with a wide range of production volumes.

EPA promulgated the OCPSF Effluent Guidelines (40 CFR Part 414) in 1987, with technical amendments in 1989, 1990, 1992, and 1993. The OCPSF ELGs apply to process wastewater discharges resulting from the manufacture of seven products or product groups (40 CFR Part 414 Subparts B to H) at facilities included within specified United States Department of Commerce Bureau of the Census Standard Industrial Classification system (SIC) groups. Table 5 summarizes the manufactured products and SIC groups applicable to each subpart. The OCPSF ELGs apply to facilities that manufacture PFAS and may apply to facilities that use PFAS in production of applicable products or product groups; however, these regulations do not establish effluent limitations or pretreatment standards for any PFAS. See EPA's *Product and Product Group Discharges Subject to Effluent Limitations and Standards for the OCPSF Point Source Category – 40 CFR 414* report for additional information on applicability, effluent limitations and pretreatment standards, and wastewaters subject to the OCPSF ELGs (EPA, 2005).

Table 5. Applicability of 40 CFR Part 414 Subparts to Manufacture of Products and Product Groups

40 CFR Part 414 Subpart	Manufactured Products and Applicable SIC Groups [a]
B – Rayon Fibers	Applies only to cellulosic manmade fiber (Rayon) manufactured by the Viscose® process, generally classified and reported under SIC group 2823.
C – Other Fibers	Applies to all other synthetic fibers (except Rayon) generally classified and reported under SIC groups 2823 or 2824.
D – Thermoplastic Resins	Applies to any plastic generally classified and reported under SIC group 28213.
E – Thermosetting Resins	Applies to any plastic generally classified and reported under SIC group 28214.
F – Commodity Organic Chemicals	Applies to commodity organic chemicals and commodity organic chemical groups generally classified and reported under SIC groups 2865, 2869, or 2899.
G – Bulk Organic Chemicals	Applies to bulk organic chemicals and bulk organic chemical groups generally classified and reported under SIC groups 2865, 2869, or 2899.
H – Specialty Organic Chemicals	Applies to all other organic chemicals and groups not specifically listed in Subparts F or G that are classified and reported under SIC groups 2865, 2869, or 2899.

SIC group key: 28213 (Thermoplastic Resins); 28214 (Thermosetting Resins); 2823 (Cellulosic Man-Made Fibers); 2824 (Synthetic Organic Fibers, Except Cellulosic); 2865 (Cyclic Crudes and Intermediates, Dyes, and Organic Pigments); 2869 (Industrial Organic Chemicals, Not Elsewhere Classified); 2899 (Miscellaneous Chemicals).

a – This SIC group listing is provided as a guide. See 40 CFR Part 414 for precise applicability and definitions of the OCPSF regulations.

The OCPSF point source category includes a broad range of sectors, raw materials, and unit operations that may manufacture or use PFAS. EPA identified that some OCPSF facilities manufacture PFAS through electrochemical fluorination, fluorotelomerization, or other processes. EPA identified six facilities in the OCPSF point source category that manufacture PFAS. For purposes of the Multi-Industry PFAS Study, EPA refers to these facilities as "PFAS manufacturers." The PFAS feedstocks may be further processed on site or transferred to other facilities where they are blended, converted, or integrated with other materials to produce new commercial or intermediate products. EPA identified that some OCPSF facilities use PFAS feedstocks as polymerization processing aids or in the production of plastic, rubber, resin, coatings, and commercial cleaning products. For the purpose of this study, EPA refers to facilities that are the primary customers of PFAS manufacturers and that use PFAS feedstocks to produce commercial goods or intermediary products as "PFAS formulators."

EPA focused on PFAS manufacturers and PFAS formulators for its review of the OCPSF point source category in this study. Table 6 lists domestic OCPSF facilities that EPA identified as PFAS manufacturers or PFAS formulators through outreach and information collected from chemical manufacturers, industry trade associations, and state and local wastewater authorities (described in Section 5.2) and describes PFAS manufacturing operations for each. These facilities produce products that have broad application in the industrial and consumer market. EPA notes that Table 6 includes major PFAS manufacturing sites EPA has identified thus far and is not a comprehensive list of all OCPSF facilities manufacturing or using PFAS in the United States.

EPA evaluated available information and data on the number, type, and volume of PFAS that are manufactured or imported to the United States using data reported by industry to EPA under the TSCA and industry literature. As of February 2020, EPA's TSCA Chemical Substance Inventory of active chemicals contains a total of 606 active PFAS (EPA, 2020b, 2020g). However, the inventory reflects substances in commerce between 2006 and 2016 so it includes long-chain PFAS now restricted in the United States and does not include any PFAS that have entered commerce since. The CDR rule, under the TSCA, requires manufacturers (including importers) to provide EPA with information on the production, import, and use of chemicals in commerce.[7] EPA evaluated the 2016 CDR database for PFAS in EPA's Cross-Agency PFAS Research List and determined that 118 of these PFAS were reported between 2012 and 2015 (EPA, 2021a, 2021b). The six PFAS manufacturers presented in Table 6 reported domestic manufacture or import of 76 individual PFAS. EPA notes that the 2016 CDR database does not reflect a holistic view of the total United States volume of PFAS manufactured and used because these data are reported as ranges in the database and facilities are exempt from reporting requirements if they have annual sales below $4 million, do not meet the reporting threshold of 25,000 pounds, imported the chemical as part of an article, or manufactured the chemical in a manner described in 40 CFR 720.30(g) or (h).

EPA also evaluated industry literature to assess the number of PFAS that are currently manufactured. A recent study (Buck et al., 2021) conducted by representatives of three global fluorochemical producers – AGC, Chemours, and Daikin – concluded that 256 PFAS were offered for sale as commercial products, ingredients, or degradation products (including components and impurities) in December 2019. The study authors classified the majority of PFAS reported as PFEAs or PFPEs (34 percent); short-chain fluorotelomers or fluorotelomer-based side-chain fluorinated polymers (28 percent); or fluoropolymers (15 percent) (Buck et al., 2021). EPA determined the study did not provide a comprehensive account of the number, type, and volume of PFAS manufactured in or imported into the United States due to the following limitations:

- The results reflect only a subset of manufacturers which do not practice electrochemical fluorination (does not account for PFAS produced by other companies or by electrochemical fluorination).
- The list of 256 PFAS reported were not identified in the study and may include PFAS only in commerce outside of the United States.
- No production volume, commercial product names, use/functionality, or alternatives were assessed.

EPA contacted industry to seek more information on the list of 256 PFAS reported but did not receive additional information. However, the industry did provide EPA with an economic assessment of the United States

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[7] Manufacturers and importers must report to the CDR database if they meet certain annual volume thresholds, typically 25,000 pounds, but 2,500 pounds for chemicals subject to certain TSCA actions. The information is collected every four years. The CDR information reported in 2016 (2016 CDR) reflects the most recent data set available and includes production volumes from 2012 to 2015.

fluoropolymer industry, which estimated 85,000 tons of fluoropolymers are produced and 77,500 tons are sold in the United States each year (Wood, 2020a).

Based on information and data derived from the data sets described above, EPA estimates that at least 118 PFAS are active in the United States market and 85,000 tons of PFAS are produced domestically each year.

Table 6. OCPSF Facilities Identified as PFAS Manufacturers or PFAS Formulators

Facility Name	Location	Description of PFAS Manufacture
PFAS Manufacturers		
3M Cordova Plant	Cordova, Illinois	Manufactures specialty fluorochemicals used in electronics, cleaning supplies, lubricant depositions, and antistatic polymers.
3M Decatur Plant	Decatur, Alabama	Manufactures fluoropolymers, fluoroelastomers, fluoroplastics, and flame-retardant polymers.
Chemours Chambers Works	Deepwater, New Jersey	Manufactures fluoropolymers, fluoroelastomers, fluoromonomers, PFPEs, fluorotelomers, and PFAS intermediates.
Chemours Fayetteville Works	Fayetteville, North Carolina	Manufactures PFPEs, fluoropolymers, fluoromonomers, and polymerization aids used for the GenX technology.
Chemours Washington Works	Parkersburg, West Virginia	Manufactures fluoropolymers and fluorotelomers.
Daikin Decatur Plant	Decatur, Alabama	Manufactures fluoropolymers and fluorotelomer-based substances.
PFAS Formulators		
3M Cottage Grove Plant	Cottage Grove, Minnesota	Processes PFAS feedstocks from 3M’s Decatur, Alabama and Cordova, Illinois plants.
AGC Chemicals Americas	Thorndale, Pennsylvania	Processes fluoropolymers and fluorinated solvents that are manufactured internationally (no polymerization occurs in the United States).
DuPont Circleville Plant	Circleville, Ohio	Converts PFAS intermediates into fluoropolymer resin and film products.
DuPont Spruance Plant	Richmond, Virginia	Converts PFAS intermediates to produce PTFE fiber.
DuPont/Chemours Montague Plant	Montague, Michigan	*Unknown.*
Arkema/Sartomer Production Plant	West Chester, Pennsylvania	Processes fluoropolymers, such as PVDF.
Solvay Specialty Polymers USA, LLC	West Deptford, New Jersey	Processes fluoroelastomers and perfluoroelastomers.

5.2 Stakeholder Outreach

EPA met with industry stakeholders and state and local wastewater authorities, who voluntarily provided information on the manufacture, use, and discharge of PFAS by OCPSF facilities. EPA used this information to assess the volume and types of commercially produced PFAS and to understand better how to quantify and control PFAS discharges.

Outreach to the OCPSF industry included meeting with the American Chemistry Council (ACC) FluoroCouncil, a former subsidiary organization within the ACC that represented the world’s leading manufacturers of fluorinated chemistries, and member companies AGC, Chemours, Daikin, and Solvay (ERG, 2019d). ACC provided EPA with technical literature concerning PFAS terminology and classification, a list of short-chain fluorotelomers studies, an economic assessment of the United States fluoropolymer industry, and contacts at 3M, Chemours, and Daikin, which they identified as the only PFAS manufacturing companies in the United States. The ACC FluoroCouncil disbanded in April 2020 and was superseded by two new groups:

- The Performance Fluoropolymer Partnership, which represents the world's leading companies that manufacture, formulate, or process fluoropolymers, fluoroelastomers, and polymeric perfluoropolyethers. Members include AGC, Chemours, Daikin, and Gujarat Fluorochemicals.
- The Alliance for Telomer Chemistry Stewardship, which represents leading manufacturers of six-carbon fluorotelomer-based products in North America, Europe, and Japan. Members include AGC, Daikin, Dynax Corporation, and Johnson Controls, Inc.

EPA met with representatives of 3M, AGC, Chemours, and Daikin and each company provided EPA with information on PFAS manufacture as well as operations and wastewater treatment data for their United States facilities (ERG, 2019e, 2019f, 2019g, 2019h). EPA also contacted other chemical manufacturers that voluntarily participated in the phased elimination of specific long-chain PFAS through the PFOA Stewardship Program: Arkema, BASF Corporation, Clariant Corporation, and Solvay. Clariant Corporation notified EPA that in 2013 it divested its fluorotelomer business to an independent entity now known as Archroma and that Clariant Corporation no longer manufactures PFAS (ERG, 2020f). EPA did not receive any additional information from Archroma, Arkema, BASF Corporation, or Solvay.

EPA met with the wastewater permitting authorities from the Wisconsin Department of Natural Resources (WI DNR); New Jersey Department of Environmental Protection (NJ DEP); Michigan Department of Environment, Great Lakes, and Energy (MI EGLE); and two large wastewater authorities in Michigan with POTWs that are investigating potential sources of PFAS wastewater. All provided EPA with wastewater permit materials and/or PFAS sampling results from PFAS manufacturers and PFAS formulators operating in their jurisdictions (ERG, 2019a, 2019b, 2019c, 2020b; NJ DEP 2015, 2018, 2020).

5.3 PFAS Wastewater Regulatory Requirements and Controls

EPA collected and reviewed NPDES wastewater discharge permits for the PFAS manufacturers and PFAS formulators listed in Table 6. EPA also collected publicly available materials associated with PFAS-related consent orders for the Chemours Fayetteville Works and 3M Decatur facilities. EPA reviewed these materials to identify effluent limitations or monitoring requirements for PFAS and assess current practices for managing PFAS-containing wastewaters. Table 7 summarizes PFAS wastewater regulatory requirements and existing PFAS control technologies and practices.

The National Defense Authorization Act for Fiscal Year 2020 established reporting requirements for 172 PFAS under the Toxics Release Inventory (TRI) program. An additional three PFAS were added for reporting year 2021. By July 1, 2021, facilities will have to report PFAS releases, including discharges to water, of any of 175 PFAS that they manufacture, process, or use above a 100-pound reporting threshold. EPA will review 2020 TRI data reported for PFAS once this information is publicly available.

Table 7. PFAS Wastewater Regulatory Requirements and Controls for PFAS Manufacturers and PFAS Formulators

Facility Name	Location	PFAS Wastewater Regulatory Requirements	Existing PFAS Wastewater Controls [a]
PFAS Manufacturers			
3M Cordova Plant	Cordova, Illinois	- NPDES permit IL0003140 establishes quarterly monitoring requirements for 14 PFAS. [b] - No effluent limitations for PFAS.	- *No known PFAS wastewater controls.*
3M Decatur Plant	Decatur, Alabama	- NPDES permit AL0000205 establishes quarterly monitoring requirements for 11 PFAS. [b] - 2020 consent order will require monitoring requirements for 33 PFAS. - No effluent limitations for PFAS.	- Granular activated carbon (GAC) treatment for directly discharged process wastewater and indirectly discharged fluoroelastomer washing water, as required by 2020 consent order. - Developing wastewater minimization plan and evaluating PFAS control technologies to further reduce PFAS discharged to wastewater treatment plant, as required by 2020 consent order.
Chemours Chambers Works	Deepwater, New Jersey	- NPDES permit NJ0005100 establishes weekly monitoring requirements for 16 PFAS. - No effluent limitations for PFAS.	- Powdered activated carbon (PAC) systems are in place, but not actively used to treat directly discharged process wastewater.
Chemours Fayetteville Works	Fayetteville, North Carolina	- NPDES permit NC0003573 establishes monitoring requirements for PFOA. - 2019 consent order prohibits discharge of Chemours' process wastewaters. - NPDES permit NC0089915 establishes biweekly monitoring requirements for HFPO-DA, PFMOAA, PMPA, and 56 additional PFAS for nonprocess wastewaters discharged via an old process wastewater outfall. - NPDES permit NC0089915 establishes effluent limitations for HFPO-DA, PFMOAA, and PMPA for nonprocess wastewaters discharged via an old process wastewater outfall.	- Chemours' process wastewater is captured and disposed off site via deep well injection or incineration. The only process wastewater discharged comes from Chemours' tenants DuPont and Kuraray. - As of November 2020, the facility was conducting a pilot study to evaluate PFAS removal from process wastewater using a treatment train consisting of two-stage reverse osmosis (RO), GAC, and ion exchange (IX) (Chemours, 2020b). - GAC treatment for contaminated nonprocess wastewaters to achieve 99% reduction of certain PFAS, as required by 2019 consent order. - Thermal oxidizer and thermolysis reactor to control PFAS air emissions.
Chemours Washington Works	Parkersburg, West Virginia	- NPDES permit WV0001279 establishes effluent limitations for APFO and HFPO-DA. - NPDES permit WV0001279 establishes monitoring requirements for 8 PFAS.	- Thermal oxidizer to control PFAS air emissions. - GAC treatment for directly discharged process wastewater. - Plans to install additional treatment units to meet future PFAS effluent limitations.

Table 7. PFAS Wastewater Regulatory Requirements and Controls for PFAS Manufacturers and PFAS Formulators

Facility Name	Location	PFAS Wastewater Regulatory Requirements	Existing PFAS Wastewater Controls [a]
Daikin Decatur Plant	Decatur, Alabama	- NPDES permit AL0064351 establishes quarterly monitoring requirements for 7 PFAS. [b] - No effluent limitations for PFAS.	- GAC treatment for directly discharged fluoropolymer/polymerization process wastewater. - Fluorotelomerization process wastewater is incinerated off site (no discharge).
PFAS Formulators			
3M Cottage Grove Plant	Cottage Grove, Minnesota	- NPDES permit MN0001449 establishes monthly monitoring requirements for 14 PFAS. - No effluent limitations for PFAS.	- Hazardous waste incinerator. - Regenerative thermal oxidizer and scrubber to control PFAS air emissions. - GAC treatment for process wastewaters.
AGC Chemicals Americas	Thorndale, Pennsylvania	- *Unknown.*	- *No known PFAS wastewater controls.*
DuPont Circleville Plant	Circleville, Ohio	- NPDES permit OH0006327 establishes monitoring requirements for PFOA. - No effluent limitations for PFAS.	- *No known PFAS wastewater controls.*
DuPont Spruance Plant	Richmond, Virginia	- NPDES permit VA0004669 establishes quarterly monitoring requirements for PFOA. - No effluent limitations for PFAS.	- *No known PFAS wastewater controls.*
DuPont/Chemours Montague Plant	Montague, Michigan	- NPDES permit MI0000884 establishes quarterly monitoring requirements for 4 PFAS. - No effluent limitations for PFAS.	- *No known PFAS wastewater controls.*
Arkema/Sartomer Production Plant	West Chester, Pennsylvania	- No monitoring requirements or effluent limitations for PFAS.	- *No known PFAS wastewater controls.*
Solvay Specialty Polymers USA, LLC	West Deptford, New Jersey	- NPDES permit NJ0005185 establishes weekly monitoring requirements for 12 PFAS. - No effluent limitations for PFAS.	- *No known PFAS wastewater controls.*

a – Conventional wastewater treatment methods (e.g., primary settling, physical-chemical treatment, neutralization, biological treatment, clarification) are not demonstrated to be effective controls for PFAS and are not presented in this table. See Section 10 for additional information on performance of wastewater treatment technologies.

b – The referenced NPDES permit has an expiration date that has passed but the permit is administratively extended.

5.4 Wastewater Characteristics

EPA evaluated available data on types and concentrations of PFAS in wastewater discharged from PFAS manufacturers and PFAS formulators. EPA summarized the limited information available and calculated average PFAS concentrations in effluent from these facilities based on 2019 DMR, 2020 DMR, industry-submitted, enforcement, and state and regional permitting authority data.

EPA identified analytical data that meet EPA's acceptance criteria for inclusion in analyses for characterizing PFAS in industrial wastewater discharges. EPA's acceptance criteria are presented in the memorandum "Development of the Multi-Industry PFAS Study Analytical Database" (ERG, 2021a). EPA identified seven sources of effluent sampling and monitoring data from PFAS manufacturers and OCPSF PFAS formulators that meet EPA's acceptance criteria:

- PFAS monitoring results reported in 2019 and 2020 DMRs (EPA, 2020c, 2021c).
- 2018 – 2019 PFAS monitoring results for three 3M facilities (3M, 2020a).
- 2020 PFAS monitoring results for Chemours Chambers Works (Chemours, 2020a).
- MI ELGE 2020 PFAS monitoring results for direct discharge facilities (MI EGLE, 2020b).
- NJ DEP PFAS monitoring data for Solvay Specialty Polymers USA, LLC in West Deptford, New Jersey (NJ DEP, 2020).
- An EPA Region 3 field sampling investigation report titled *PFAS Screening of Goose Creek & Goose Creek Industrial Users* (EPA Region 3, 2019).
- PFAS effluent sampling results submitted by PFAS manufacturers to EPA's Office of Enforcement and Compliance (EPA, 2020d).

EPA included 6,006 PFAS sample results representing all six PFAS manufacturers and 735 PFAS sample results representing six of seven PFAS formulators in its analysis characterizing PFAS in effluent from PFAS manufacturers and PFAS formulators. EPA calculated facility-level average, minimum, and maximum concentrations for each PFAS with available data using the following assumptions and limitations:

- EPA assumed all nondetection results and results below the level of quantification (i.e., the reporting or quantification limitation) were zero.[8]
- EPA did not have information on analytical method sensitivity and level of quantification for all data.
- EPA did not know the operations or treatment processes online at the facilities at the time of sampling.
- EPA does not have information on whether the observed PFAS concentrations are from legacy use of PFAS, current use of PFAS, or formation from degradation of more complex PFAS.

EPA calculated an overall average, minimum, and maximum concentration for each PFAS based on the facility-level results. EPA did not estimate average concentrations for any PFAS that were not detected at or above the level of quantification across all facilities or did not have any data.

Table 8 presents the average, minimum, and maximum concentrations for each PFAS in PFAS manufacturer and PFAS formulator effluent. As illustrated in the table, average PFAS concentrations in PFAS manufacturer effluent were higher than in PFAS formulator effluent for all PFAS except PFNA and PFUnA. Average concentrations for short-chain PFCAs and PFSAs were generally higher relative to long-chain PFCAs and PFSAs for both PFAS manufacturers and formulators.

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[8] The lower level of quantification is the lowest concentration that the analytical method being used can measure accurately.

Table 8. PFAS Manufacturer and PFAS Formulator PFAS Wastewater Concentrations

PFAS Subgroup	Analyte [a,b]	PFAS Manufacturers			PFAS Formulators		
		Quantified Detections/ Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]	Quantified Detections/ Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]
PFCAs	PFBA	68/71	ND – 2,390	153	24/25	ND – 177	41.7
	PFPeA	78/95	ND – 20	2.49	24/24	0.169 – 4.08	0.829
	PFHxA	234/255	ND – 45	6.93	50/50	0.0022 – 0.519	0.111
	PFHpA	220/246	ND – 26	1.50	34/62	ND – 0.112	0.0167
	PFOA	1,235/1,367	ND – 430	3.77	60/73	ND – 1.6	0.116
	APFO	709/747	ND – 450	3.27	1/2	ND – 0.013	0.0065
	PFNA	145/164	ND – 1.19	0.224	26/62	ND – 14	0.883
	PFDA	120/125	ND – 1.5	0.271	25/50	ND – 0.088	0.0112
	PFUnA	32/74	ND – 0.09	0.0129	26/49	ND – 0.27	0.0401
	PFDoA	96/125	ND – 0.14	0.0182	0/50	ND	ND
	PFTrA	39/74	ND – 0.039	0.00416	2/50	ND – 0.0011	0.0000404
	PFTeA	31/58	ND – 0.04	0.00315	0/26	ND	ND
	PFHxDA	5/13	ND – 0.012	0.00218	*No Data*		
	PFODA	4/13	ND – 0.0044	0.000892	*No Data*		
PFSAs	PFBS	188/194	ND – 777	6.49	26/62	ND – 17.6	2.77
	PFPeS	4/14	ND – 0.013	0.000901	*No Data*		
	PFHxS	214/245	ND – 28.6	0.510	26/62	ND – 0.466	0.057
	PFHpS	1/14	ND – 0.0022	0.0000917	*No Data*		
	PFOS	58/76	ND – 21.2	3.37	49/63	ND – 0.153	0.034
	PFNS	0/14	ND	ND	*No Data*		
	PFDS	0/14	ND	ND	*No Data*		
FASAs	PFOSA	97/169	ND – 76.3	0.756	0/24	ND	ND
FTSAs	4:2 FTSA	0/14	ND	ND	*No Data*		
	6:2 FTSA	3/14	ND – 0.022	0.00177	*No Data*		
	8:2 FTSA	0/14	ND	ND	*No Data*		
N-Alkyl FASAs	NMePFOSA	0/13	ND	ND	*No Data*		
	NEtPFOSA	0/13	ND	ND	*No Data*		
FASEs and N-Alkyl FASEs	NMeFOSE	0/13	ND	ND	*No Data*		
	NEtFOSE	0/13	ND	ND	*No Data*		
FASAAs and N-Alkyl FASAAs	NMeFOSAA	70/107	ND – 112	2.92	*No Data*		
	NEtFOSAA	70/107	ND – 118	3.21	*No Data*		

Table 8. PFAS Manufacturer and PFAS Formulator PFAS Wastewater Concentrations

PFAS Subgroup	Analyte [a b]	PFAS Manufacturers			PFAS Formulators		
		Quantified Detections/ Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]	Quantified Detections/ Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]
PFECAs	HFPO-DA	1,098/1,180	ND – 530	8.00	*No Data*		
	NaDONA	0/13	ND	ND	*No Data*		
	PMPA	0/3	ND	ND	*No Data*		
	PFMOAA	5/31	ND – 0.34	0.123	*No Data*		
	NFDHA	0/3	ND	ND	*No Data*		
	PFO2HxA	0/31	ND	ND	*No Data*		
	PFO3OA	0/31	ND	ND	*No Data*		
	PFO4DA	0/31	ND	ND	*No Data*		
	PFO5DA	0/31	ND	ND	*No Data*		
	PFECA-G	0/31	ND	ND	*No Data*		
PFESAs	K-9Cl-PF3ONS	0/13	ND	ND	*No Data*		
	K-11Cl-PF3OUdS	0/13	ND	ND	*No Data*		
	PFESA-BP1	0/31	ND	ND	*No Data*		
	PFESA-BP2	0/31	ND	ND	*No Data*		

Sources: ERG, 2021b.

Abbreviations: ND – nondetection; µg/L – micrograms per liter.

a – This table presents data for all PFAS listed in Table 2 for which sample results are available and meet EPA's acceptance criteria. See the PFAS Analytical Database for additional results for the following 11 PFAS not discussed in this preliminary report: 10:2 FTSA, PFEESA, FBSA, PFDoS, Hydro-EVE Acid, EVE Acid, PEPA, NVHOS, PFESA Byproduct 4, PFESA Byproduct 5, PFESA Byproduct 6.

b –The table identifies short-chain PFCAs (≤7 carbons) and short-chain PFSAs (≤5 carbons) in blue text, while long-chain PFCAs (≥8 carbons) and long-chain PFSAs (≥6 carbons) are designated in red text.

c – In this analysis, EPA treated all nondetection results as zero for the purpose of estimating concentrations. All concentration values are rounded to three significant figures.

5.5 OCPSF Point Source Category Summary

Based on information and data EPA collected for the Multi-Industry PFAS Study, EPA documented that PFAS have been, and continue to be, manufactured and used by OCPSF facilities in the United States. The type and quantity of PFAS manufactured and used vary by facility and have changed over time. Through outreach and data collected from industry, EPA identified six OCPSF facilities that manufacture PFAS in the United States through electrochemical fluorination, fluorotelomerization, or other processes. The PFAS feedstocks may be further processed on site or transferred to other facilities where they are blended, converted, or integrated with other materials to produce new commercial or intermediate products such as plastic, rubber, resins, coatings, and cleaning products. EPA identified seven additional OCPSF facilities that use PFAS feedstocks to formulate other products. EPA has not developed a comprehensive list of all PFAS manufacturers and formulators in the United States and considers it probable that there are more OCPSF facilities using PFAS that EPA has not yet identified. Based on limited information available, EPA estimates that the OCPSF facilities in the United States manufacture or use at least 118 PFAS and produce 85,000 tons of fluoropolymers annually.

EPA documented that the manufacture or formulation of PFAS by OCPSF facilities may generate PFAS-containing wastewaters. EPA verified that PFAS, including legacy long-chain PFAS and replacement PFAS, are present in wastewater discharges from PFAS manufacturers and PFAS formulators to surface waters and POTWs. Using available PFAS monitoring data, EPA estimated the average PFAS concentrations in PFAS manufacturer effluent were higher than average PFAS concentrations in effluent from PFAS formulators. Average concentrations for short-chain PFCAs and PFSAs were generally higher than the average concentrations of long-chain PFCAs and PFSAs; this was true for both PFAS manufacturers and formulators.

PFAS manufacturers and formulators have few monitoring requirements, effluent limitations, or pretreatment standards for PFAS in their wastewater discharge permits and may continue to discharge PFAS to POTWs or surface waters unless effective controls are in place. EPA identified some PFAS manufacturers and formulators successfully controlling PFAS in wastewater using granular activated carbon (GAC), ion exchange (IX), reverse osmosis (RO), and thermal treatment systems. Based on EPA's Drinking Water Treatability Database (DWTD), these technologies are able to remove more than 99 percent on some PFAS in industrial wastewater, or completely eliminate the discharge of wastewater containing PFAS (EPA, 2021f). See Section 10 for more information on PFAS discharge control technologies.

6. Review of the Metal Finishing Point Source Category

This section describes the metal finishing point source category, information and data EPA collected on its PFAS use and discharge, and EPA's estimates of types and concentrations of PFAS discharged by facilities within the category. EPA collected and reviewed information on PFAS use and discharge by metal finishing facilities from the following sources:

- Outreach with an industry trade association and state and local wastewater authorities.
- Reports and data collected from industry and state and local wastewater authorities.
- Publicly available technical literature.

6.1 Industry Description and Use of PFAS

Metal finishing refers to changing the surface of an object to improve its appearance and/or durability. EPA promulgated the Metal Finishing Effluent Guidelines (40 CFR Part 433) in 1983, with technical amendments in 1984 and 1986. The regulations cover wastewater discharges from facilities that perform one or more of the following six metal finishing operations on any basis material:

- Electroplating.[9]
- Electroless plating.
- Anodizing.
- Coating (phosphating, chromating, and coloring).
- Chemical etchings and milling.
- Printed circuit board manufacture.

If a facility performs any of these six core operations, then discharges from the 46 operations listed in 40 CFR Part 433.10(a) are covered by the Metal Finishing ELGs. EPA estimates about 44,000 facilities perform metal finishing operations and discharge process wastewater directly to United States surface waters or indirectly to surface waters through POTWs.

The metal finishing point source category includes a broad range of sectors, raw materials, and unit operations that may use PFAS. EPA identified that some metal finishing facilities have used, and continue to use, nonpolymer PFAS and related products as wetting agents, mist and fume suppressants (to prevent emissions of toxic metal fumes to air), agents to reduce mechanical wear, and surface coatings to impart specific characteristics (e.g., reduced corrosion, enhanced aesthetic appearance). EPA also identified that some polymer PFAS, such as PTFE, may be used in electroless nickel plating operations (NASF, 2019b; MI EGLE, 2020d; ITRC, 2020; Glüge et al., 2020). PFAS used by metal finishing facilities may be transferred to wastewater streams generated by the facility and ultimately discharged to surface waters or POTWs.

Based on studies conducted by EPA and states since 2007, the agency identified chromium electroplating and chromium anodizing operations (collectively referred to as "chromium electroplating facilities") as the most significant source of PFAS, particularly PFOS, in the metal finishing point source category (MPCA, 2006; EPA Region 5, 2009; MI EGLE, 2020d). Thus, EPA focused on chromium electroplating facilities for its review of the metal finishing point source category in this study.

Since the 1980s, mist and fume suppressants containing 5 to 10 percent PFOS by weight were frequently used by United States chromium electroplating facilities to control hexavalent chromium emissions (a known human carcinogen and inhalation hazard), as required under the Clean Air Act by the National Emission Standards for

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[9] Metal finishing is related to electroplating, which is the production of a thin surface coating of the metal upon another by electrodeposition. Certain electroplating processes are covered by the ELGs for the Electroplating Category (40 CFR Part 413), rather than the ELGs for the Metal Finishing Category. These include job shop electroplaters, independent printed circuit board manufacturers, indirect discharge electroplating facilities, and electroplating facilities in operation before July 15, 1983.

Hazardous Air Pollutants (NESHAP) for Chromium Emissions from Hard and Decorative Chromium Electroplating and Chromium Anodizing (40 CFR Part 63, Subpart N). The surfactant properties of PFOS reduce the surface tension of the electrolyte solution, which limits the release of hexavalent chromium vapors to the air and thereby reduces worker exposure. Due to concerns about human health and environmental impacts of PFOS, in 2012 EPA amended the NESHAP to phase out the use of mist and fume suppressants containing more than 1 percent PFOS by weight in chromium electroplating by September 21, 2015 (ITRC, 2020; NASF, 2019b; EPA, 2012a). EPA identified the following alternative technologies adopted by industry following the restriction on PFOS-based agents:

- Replacing PFOS-based mist and fume suppressants with fluorotelomer-based substances (e.g., 6:2 FTSA) and chlorinated PFESAs (e.g., F-53B).[10]
- Replacing PFOS-based mist and fume suppressants with nonfluorinated mist and fume suppressants.
- Using mechanical controls such as enclosed lines, air jet systems, air pollution scrubbers, and closed-loop systems to manage hexavalent chromium emissions.
- Transitioning to trivalent chromium rather than hexavalent chromium for decorative chromium electroplating. Trivalent chromium is considered less toxic and less bioavailable relative to hexavalent chromium. However, trivalent chromium generally cannot be used for hard chromium electroplating because of quality differences and cost (MI ELGE, 2020a).

Once the electroplating bath liquid can no longer be used, it may be treated to remove chromium and other metals, but PFAS may remain present and be discharged in effluent from chromium electroplating facilities still using PFAS-based mist and fume suppressants. Most metal finishing facilities, including those that perform chromium electroplating, discharge wastewater to their local sewer system rather than to surface waters.

In developing the 2012 NESHAP, EPA developed a profile of the 1,339 chromium electroplating facilities operating in the United States (652 hard chromium electroplating, 517 decorative chromium electroplating, 170 chromium anodizing) (EPA, 2012a). Approximately 50 percent of chromium electroplating facilities apply PFAS-based mist and fume suppressants, based on information from the 2020 MI EGLE report titled *Identified Industrial Sources of PFOS to Municipal Wastewater Treatment Plants* (MI EGLE, 2020d).

6.2 Stakeholder Outreach

EPA met with the National Association for Surface Finishing (NASF) and Michigan wastewater authorities, who voluntarily provided information on the use and discharge of PFAS by metal finishing facilities. NASF is a trade association that represents the United States surface coating industry and provided EPA with information to categorize PFAS historically and currently used in the industry. NASF estimates that 30 to 40 percent of surface finishing facilities have chromium electroplating processes, but not all facilities have used or currently use PFAS-based mist and fume suppressants (NASF, 2019c). Representatives from MI EGLE and two large Michigan wastewater authorities investigating potential sources of PFAS wastewater provided EPA with information on current efforts to regulate and control PFAS discharges and/or PFAS sample results for metal finishing facilities operating in those jurisdictions. As part of ongoing investigations, MI EGLE (2020d) determined that approximately two-thirds of sampled chromium electroplating facilities discharged PFOS exceed the Michigan water quality standard of 12 ng/L even though mist and fume suppressants containing more than 1 percent PFOS are no longer in use. MI EGLE also found no detectable amounts of PFOS precursors or PFOA precursors in mist and fume suppressant samples from 11 chromium electroplating facilities. The presence of PFOS may be due to legacy issues, trace levels (less than 1 percent) of PFOS in modern suppressants, or, to a lesser degree, due to degradation of other more complex PFAS (MI EGLE, 2020a, 2020d).

6.3 PFAS Wastewater Regulatory Requirements and Controls

EPA did not identify any chromium electroplating facilities with PFAS effluent limitations or pretreatment standards in their wastewater discharge permits. As part of Michigan's Industrial Pretreatment Program PFAS Initiative, MI EGLE required 95 POTWs to evaluate their industrial users as potential sources of PFOS and PFOA. These local POTWs implemented requirements for industrial users discharging to their system to monitor for

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[10] EPA and MI EGLE analysis of modern mist and fume suppressants used by 11 chromium electroplaters in Michigan showed that 6:2 FTSA was the only detectable PFAS; PFOS and PFOS precursors were not detected in any suppressant samples evaluated (MI EGLE, 2020a).

PFOA and PFOS and, if effluent PFOS concentrations exceeded Michigan's screening value of 12 ng/L, implement PFOS reduction programs. MI EGLE reports that numerous POTWs identified chromium electroplating facilities as sources of PFOS discharges and have required these sources to install PFAS pretreatment, such as GAC. MI EGLE identified six Michigan chromium electroplating facilities have lowered effluent concentrations of PFAS using GAC (MI EGLE, 2020d).

6.4 Wastewater Characteristics

EPA evaluated available data on types and concentrations of PFAS in wastewater discharged from chromium electroplating facilities. EPA has not identified any facilities with PFAS monitoring requirements or effluent limitations; therefore, no DMR data are available for PFAS. EPA summarized the limited information available and calculated average PFAS concentrations in effluent from chromium electroplating facilities based on Michigan permitting authority data.

EPA identified analytical data that meet EPA's acceptance criteria for inclusion in analyses for characterizing PFAS discharges in industrial wastewater discharges. EPA's acceptance criteria are presented in the memorandum "Development of the Multi-Industry PFAS Study Analytical Database" (ERG, 2021a). EPA identified two sources of analytical data for chromium electroplating, both of which meet EPA's acceptance criteria: *Targeted and Nontargeted Analysis of PFAS in Fume Suppressant Products at Chrome Plating Facilities* (2020 chromium electroplating report) (MI EGLE, 2020a) and MI EGLE PFAS monitoring results for indirect discharge facilities (MI EGLE, 2020c). EPA included 1,137 PFAS sample results representing 47 chromium electroplating facilities in its analysis characterizing PFAS in chromium electroplating wastewater.

Some wastewater sample data from the 2020 chromium electroplating report (MI EGLE, 2020a) were collected before adsorption treatment processes that target PFAS. EPA included these data in this preliminary analysis because most chromium electroplating facilities do not have dedicated treatment for PFAS in place and, thus, the samples are representative of effluent from most facilities. During discussions with EPA, NASF representatives stated that the MI EGLE (2020a) data are a fair representation of the industry as a whole (ERG, 2020c).

EPA calculated facility-level average, minimum, and maximum concentrations for each PFAS with available data using the following assumptions and limitations:

- EPA assumed all nondetection results and results below the level of quantification (i.e., the reporting or quantification limitation) were zero.[11]
- EPA did not have information on analytical method sensitivity and level of quantification for all data.
- EPA did not know the operations or treatment processes online at the facilities at the time of sampling.
- EPA does not have information on whether the observed PFAS concentrations are from legacy use of PFAS, current use of PFAS, or form from degradation of more complex PFAS.

EPA calculated an overall average, minimum, and maximum concentration for each PFAS based on the facility-level results. EPA did not estimate average concentrations for any PFAS that were not detected at or above the level of quantification across all facilities or did not have any data.

Table 9 presents the average, minimum, and maximum concentrations for each PFAS observed in chromium electroplating facility effluent. As illustrated in the table, EPA estimated the average wastewater concentration of 6:2 FTSA was more than 100 times greater than any other PFAS detected in chromium electroplating wastewater. Despite the phase out of PFOS-based mist and fume suppressants, some chromium electroplating facilities still report detectable levels of PFOS in their wastewater.

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[11] The lower level of quantification is the lowest concentration that the analytical method being used can measure accurately.

Table 9. Chromium Electroplating Wastewater PFAS Concentrations

PFAS Subgroup	Analyte [a b]	Facilities with Data	Quantified Detections/Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]
PFCAs	PFBA	11	5/12	ND – 4.71	0.492
	PFPeA	11	5/12	ND – 0.93	0.108
	PFHxA	11	8/12	ND – 0.34	0.0703
	PFHpA	11	8/12	ND – 0.49	0.0687
	PFOA	47	51/406	ND – 0.74	0.00770
	PFNA	11	0/12	ND	ND
	PFDA	11	0/12	ND	ND
	PFUnA	11	0/12	ND	ND
	PFDoA	11	0/12	ND	ND
	PFTrA	11	0/12	ND	ND
	PFTeA	11	0/12	ND	ND
PFSAs	PFBS	10	7/11	ND – 19.8	2.09
	PFPeS	11	2/12	ND – 0.088	0.015
	PFHxS	11	8/12	ND – 1.22	0.147
	PFHpS	11	7/12	ND – 0.323	0.0595
	PFOS	47	412/456	ND – 240	4.86
	PFNS	11	3/12	ND – 0.043	0.00636
	PFDS	11	1/12	ND – 0.014	0.00127
FASAs	PFOSA	11	0/12	ND	ND
FTSAs	4:2 FTSA	11	8/12	ND – 1.39	0.229
	6:2 FTSA	11	11/12	ND – 3,140	532
	8:2 FTSA	11	7/12	ND – 0.237	0.0633
FASAAs and N-Alkyl FASAAs	NMeFOSAA	11	0/12	ND	ND
	NEtFOSAA	11	0/12	ND	ND
PFECAs	HFPO-DA	11	5/12	ND – 0.065	0.0124

Sources: ERG, 2021b.

Abbreviations: ND – nondetection; µg/L – micrograms per liter.

a – This table presents data for all PFAS listed in Table 2 for which sample results are available and meet EPA's acceptance criteria. EPA does not have any sample results PFAS note listed.

b –The table identifies short-chain PFCAs (≤7 carbons) and short-chain PFSAs (≤5 carbons) in blue text, while long-chain PFCAs (≥8 carbons) and long-chain PFSAs (≥6 carbons) are designated in red text.

c – In this analysis, EPA treated all nondetection results as zero for the purpose of estimating concentrations. All concentration values are rounded to three significant figures.

6.5 Metal Finishing Point Source Category Summary

Based on information and data EPA collected for the Multi-Industry PFAS Study, EPA documented that PFAS have been, and continue to be, used by metal finishing facilities in the United States. EPA identified chromium electroplating facilities as the most significant source of PFAS in the metal finishing point source category. Chromium electroplating facilities use PFAS-based mist and fume suppressants to control toxic hexavalent chromium emissions. PFOS-based mist and fume suppressants were frequently used until 2015, when EPA's revisions to the chromium electroplating NESHAP required chromium electroplating facilities to phase out mist and fume suppressants containing more than 1 percent PFOS by weight. Chromium electroplating facilities have adopted alternative technologies, including mist and fume suppressants containing fluorotelomer-based substances (e.g., 6:2 FTSA) and chlorinated PFESAs (e.g., F-53B), to replace use of PFOS-based products. EPA estimates that approximately half of the 1,339 chromium electroplating facilities in the United States still apply some type of PFAS-based mist and fume suppressant.

EPA documented that the use of PFAS-based mist and fume suppressants may generate wastewaters containing PFAS. EPA verified that PFAS, including legacy long-chain PFAS and replacement PFAS, are present in wastewater discharges from chromium electroplating facilities to surface waters and POTWs. Using available sampling data, EPA estimated the average wastewater concentration of 6:2 FTSA was more than 100 times greater than any other PFAS evaluated. 6:2 FTSA was the only PFAS detected in a 2020 MI EGLE targeted analysis of PFAS in mist and fume suppressants used by several facilities included in this analysis. Despite the phase out of PFOS-based mist and fume suppressants, some chromium electroplating facilities still report detectable levels of PFOS in their wastewater. MI EGLE (2020d) determined that approximately two-thirds of the evaluated chromium electroplating facilities discharged PFOS exceed the Michigan water quality standard of 12 ng/L even though mist and fume suppressants containing more than 1 percent PFOS are no longer in use. As part of a separate study, EPA and MI EGLE found no detectable amounts of PFOS precursors or PFOA precursors in mist and fume suppressant samples from 11 facilities. The presence of PFOS may be due to legacy issues, trace levels (less than 1 percent) of PFOS in modern suppressants, or, to a lesser degree, due to degradation of other more complex PFAS (MI EGLE, 2020a, 2020d).

EPA did not identify any chromium electroplating facilities with PFAS effluent limitations or pretreatment standards in their wastewater discharge permit and estimates that less than 5 percent of chromium electroplating facilities monitor for PFAS. Most chromium electroplating facilities are not monitoring for PFAS and are likely to continue to discharge PFAS to POTWs or surface waters unless effective controls are in place. EPA identified that at least six Michigan chromium electroplating facilities have lowered effluent concentrations of PFAS using GAC.

7. Review of the Pulp, Paper, and Paperboard Point Source Category

This section describes the pulp, paper, and paperboard point source category; information and data EPA collected on the category's PFAS use and discharge; and EPA's estimates of types and concentrations of PFAS discharged by the category. EPA collected and reviewed information on PFAS use and discharge by pulp, paper, and paperboard facilities from the following sources:

- Outreach with pulp and paper companies, an industry trade association, and state and local wastewater authorities.
- Reports and data collected from industry and state and local wastewater authorities.
- Publicly available technical literature.

7.1 Industry Description and Use of PFAS

The pulp, paper, and paperboard point source category includes companies and facilities that convert wood into pulp, paper, paperboard, and other cellulose-based products. Facilities that convert wood to pulp, paper, or paperboard are generally classified as integrated mills or nonintegrated mills. Integrated mills have the onsite capability to convert wood into pulp, and then into paper, while nonintegrated mills only manufacture paper or paperboard from purchased pulp. There are additional types of mills that manufacture only pulp or recycled fiber for manufacture of various good elsewhere (e.g., market pulp mills, dissolving pulp mills, fluff pulp mills, recycled fiber mills). There are also converting facilities which cut, fold, or otherwise convert manufactured paper into commercial products.

EPA promulgated the Pulp, Paper, and Paperboard Effluent Guidelines (40 CFR Part 430) in 1974 and 1977, with numerous technical amendments and revisions between 1982 and 2007. EPA estimated approximately 565 pulp, paper, and paperboard mills operated in the United States in 1997, the time of the most recent major ELGs rulemaking. The ELGs cover wastewater discharges from facilities which perform specified pulping processes or manufacture specified paper products and are typically classified under four SIC groups: 2621, 2631, 2641, and 2661. The existing ELGs do not establish effluent limitations or pretreatment standards for PFAS.

PFAS have been used by pulp, paper, and paperboard facilities as an additive or coating to impart certain surfactant qualities to finished paper products. Some facilities have manufactured high-performance paper products, such as those requiring oil, grease, and/or moisture resistance, using additives mixed with the pulp before it is formed into paper. Other facilities have applied coatings containing PFAS to the finished paper. PFAS are primarily used by facilities that manufacture food contact papers and packaging (e.g., fast food wrappers, take-out containers, bakery bags, popcorn bags, pizza boxes), but also have limited applications for specialty paper products (e.g., carbonless forms, masking paper) (AF&PA, 2020a; WA DEC, 2021).

Chemicals used in food contact paper and packaging are regulated by the United States Department of Health and Human Services, Food and Drug Administration (FDA) because of their potential to migrate to food. All food contact substances (FCSs) must be approved through the food contact substance notification (FCN) program, under which the FDA will review available migration, exposure, and human health risk data to ensure an FCS is safe for its intended use prior to approving it for use in market. Manufacturers of chemicals approved to be used as an FCS are permitted to market and sell these chemicals to food contact paper and packaging producers who will use them in their products (FDA, 2020).

Since the 1960s, the FDA has authorized several broad classes of PFAS for use as FCSs, including long-chain PFAS such as PFOS and PFOA, and more recently short-chain, fluorotelomer, and side-chain polymer PFAS. As of December 2020, there are 17 distinct PFAS approved by the FDA for use to provide oil and grease resistance in food contact applications. All approved PFAS are for polyfluorinated polymers, with the majority being six-carbon side-chain fluorinated polymers and the rest being perfluoropolyethers (FDA, 2021; WA DEC, 2021).

When the FDA identifies potential safety concerns with an FCS, the agency may work with industry to reach voluntary market phase out agreements or revoke food contact authorizations. In 2011, the FDA worked with three manufacturers (DuPont, Clariant Corporation, and BASF Corporation) to voluntarily end sale of several long-chain PFAS for food contact applications. In 2016, the FDA revoked authorization for the remaining uses of long-chain PFAS and these chemicals are no longer approved for use in food contact applications in the United States. In July 2020, the FDA announced that four manufacturers will voluntarily phase out the use of PFAS containing or degrading to 6:2 FTOH. The market phase out is a response to FDA research that raised questions about human health risks for 6:2 FTOH. The four manufacturers (AGC, Chemours, Daikin, and Archroma) hold FCNs for approximately 11 PFAS containing or degrading to 6:2 FTOH. AGC, Daikin, and Archroma agreed to a complete market phase out of PFAS containing 6:2 FTOH by December 31, 2023; Chemours has already stopped sales of 6:2 FTOH-containing products in the United States (FDA, 2020; WA DEC, 2021).

In recent years, an increasing number of major food distributers and retailers (e.g., Sweetgreen, Chipotle, McDonald's, Taco Bell, Whole Foods Market, Trader Joes, Kroger, Panera Bread) have announced plans to phase out all PFAS in food contact papers and packaging in response to consumer and regulatory pressures. Several states, including California, Maine, New York, Vermont, and Washington, are also acting to restrict use of PFAS in these materials and identify alternative substances that provide comparable performance without use of PFAS. Washington Department of Ecology identified the following FDA-approved alternatives to PFAS coated food contact paper (WA DEC, 2021):

- Uncoated paper.
- Wax coated paper.
- Clay coated paper.
- Siloxane coated paper.
- Polyvinyl alcohol (PVOH) or ethylene vinyl alcohol (EVOH) copolymer coated paper.
- Polylactic acid (PLA) and PLA coated paper.
- Polyethylene (PE) or polyethylene terephthalate (PET) coated paper.

7.2 Stakeholder Outreach

EPA met with industry stakeholders and state and local wastewater authorities, who voluntarily provided information on the use and discharge of PFAS by pulp, paper, and paperboard facilities. EPA used this information to categorize PFAS being used in the industry, quantify PFAS in discharges, and to learn how the industry controls PFAS discharges.

Outreach to the industry included contact with the American Forest and Paper Association (AF&PA) and companies that historically or currently manufacture food contact paper/packing or specialty paper products. AF&PA is a national trade association for the forest, pulp, and paper industry; its 38 member companies represent approximately 85 percent of the pulp, paper, tissue, and paper-based packaging products manufactured in the United States. EPA met with the AF&PA and 10 member companies in March 2020 (ERG, 2020d). AF&PA provided four letters to EPA containing information on the use and discharge of PFAS in the pulp and paper industry (AF&PA, 2020a, 2020b, 2020c, 2020d).

AF&PA reported that the pulp, paper, and paperboard industry phased out the use of PFOA and PFOS approximately 10 years ago, but continues to use FDA-approved short-chain PFAS in the manufacture of food contact packaging and specialty paper products to enhance resistance to water, oil, and grease. According to AF&PA, PFAS is not integral to or used in the pulping process (including pulp brightening or bleaching), recycling of paper and packaging, or manufacture of products requiring absorbency, publishing papers, newsprint, and conventional packaging (e.g., standard corrugated boxes). AF&PA states certain PFAS may be present in process equipment components (e.g., PTFE piping or valves), cleaners, and firefighting foam used at pulp, paper, and paperboard facilities; however, these substances are used infrequently and in small volumes compared to raw materials used in pulp and paper manufacturing. Additionally, AF&PA reported that some PFAS may enter the facility through intake water or from recycled paper products that are used to create recovered pulp and fiber.

Whether PFAS are in an additive mixed with the pulp prior to forming it into paper, or in a coating applied to the surface of the paper after the paper is formed, AF&PA reports the majority of PFAS would remain in the final product and not be transferred to a wastewater stream. AF&PA stated that the PFAS chemistries may be expensive, so there is economic incentive for facilities to minimize PFAS use, minimize loss to process wastewater, and retain as much PFAS as possible in the final product.

In 2020, AF&PA conducted a survey of their member companies regarding their use of PFAS. Nineteen AF&PA member companies responded to the survey, representing 146 of the 171 mills operated by members. Five of the 146 mills covered by the respondents reported they intentionally use PFAS in the manufacture of pulp and paper products as of July 2020. The five mills are operated by different companies and all reported that PFAS would be phased out of production processes in the next three to four years. Table 10 summarizes the PFAS-containing products produced by these mills and company plans to reduce or alter PFAS use.

Table 10. Summary of AF&PA Member Company Mills Using PFAS

Mill ID	Products and Processes Using PFAS	PFAS Phase Out Steps
A	Uses FDA-approved PFAS in products with food service applications.	Products to be phased out in 2021, so no alternatives to PFAS under consideration.
B	Uses FDA-approved PFAS in food packaging.	Commercial alternatives under evaluation. Other coatings in development.
C	Uses FDA-approved PFAS in paper for food packaging and other specialty packaging.	Production-scale trials expected for two PFAS-free product designs.
D	Uses FDA-approved PFAS in coatings on bleached kraft paper for specialty business forms.	Alternative materials have been evaluated in lab, with plans to move forward on pilot testing and manufacturing trials.
E	Uses FDA-approved PFAS in food packaging.	Facility closed in 2021 with no plans to move manufacture to another site in the United States.

Source: AF&PA, 2020a, 2020b, 2020c, 2020d.

The total production of paper containing PFAS for the five mills (85,000 tons) accounts for 4.3 percent of these five mills' total paper production and roughly 0.14 percent of the mill production of all AF&PA members. AF&PA stated that one mill, Mill E, closed in 2021 and the company no longer uses PFAS at any United States mills. AF&PA also confirmed that no PFOA, PFOS, or GenX chemicals (including HFPO-DA) are intentionally added to the products at the four mills that remain active. The four active mills indicated that they are either actively seeking nonPFAS alternatives for their coatings or ending production of PFAS-containing product lines, a decision driven by public opinion, market pressure, and regulatory measures.

AF&PA identified major producers of food contact paper and packaging or specialty paper products and provided EPA with contact information for representatives of these companies. EPA met separately with representatives of Ahlstrom-Munksjö USA, Inc. (Ahlstrom-Munksjö); Georgia-Pacific, LLC (Georgia-Pacific); Graphic Packaging International, Inc. (Graphic Packaging); WestRock Company; and Sappi North America, Inc. (Sappi). Each company provided EPA with information on their historical and current PFAS use, as well as operations and wastewater treatment data for their United States facilities.

EPA and representatives from Ahlstrom-Munksjö discussed the company's operations at two pulp and paper mills and two specialty paper manufacturing facilities in Wisconsin. Ahlstrom-Munksjö became a member of AF&PA after the trade association's PFAS survey was conducted and their facilities are not included the survey results. As of July 2021, the four Ahlstrom-Munksjö Wisconsin facilities are applying coatings containing PFAS to impart oil and grease resistance to food service products. Two copolymer coatings, supplied by Daikin and Solvay, contain FDA-approved PFAS and are applied to finished sheets in a closed-loop, recirculating system (excess coating is captured and reused). To Ahlstrom-Munksjö's knowledge, no wastewaters are generated during the coating process. Ahlstrom-Munksjö estimated that approximately 10 percent of production at the four Wisconsin plants is manufactured using PFAS; however, Ahlstrom-Munksjö is transitioning all Wisconsin facilities to FluoroFree® technology and 100 percent PFAS-free products, with a goal to eliminate PFAS use by end of 2023. Ahlstrom-Munksjö stated the company also operates five additional pulp, paper, or paperboard manufacturing facilities in other states. Of these five facilities, only one site, in Windsor Locks, Connecticut is using significant volumes of

FDA-approved PFAS. Ahlstrom-Munksjö did not provide additional information on PFAS use at the Windsor Locks, Connecticut facility or other facilities in the United States (Ahlstrom-Munksjö, 2021; EPA, 2021g).

Georgia-Pacific has not directly purchased or applied PFAS to paper products since 3M phased out production of PFOA, PFOS, and other long-chain PFAS in the 2000s. Until April 2021, Georgia-Pacific continued to purchase, cut, fold, and otherwise convert paper treated with FDA-approved PFAS into food contact products, including sandwich wraps, take-out containers, and food trays. In April 2021, Georgia-Pacific discontinued purchasing PFAS-treated paper, and switched to paper treated with a nonPFAS polymer blend. Based on the company's estimate at the time, the inventory of PFAS-treated paper in the supply chain would be distributed by July 2021. Georgia-Pacific indicated that the transition to nonPFAS alternatives was influenced by customer interest in PFAS-free products and the company's forecast of market demand for such products. Georgia-Pacific confirmed that the company does not own or operate any of the five mills presented in Table 10; however, the company reported that their Packerland Plant in Green Bay, Wisconsin, purchased and converted PFAS-treated paper in 2020. Georgia-Pacific provided EPA with PFAS monitoring data, representing effluent from two pulp, paper, and paperboard mills in Green Bay, Wisconsin (not the Packerland Plant) and also confirmed that the company operated two facilities represented in a sampling data set previously provided by AF&PA (EPA, 2021h).

As of June 2021, Graphic Packaging was intentionally applying PFAS-based coatings in the manufacture of food contact paper and packaging at one facility, the Texarkana Mill in Queen City, Texas. Graphic Packaging estimates 15,000 tons of PFAS-treated product is manufactured at the Texarkana Mill annually, accounting for less than 2 percent of the mill's total annual production and less than 1 percent of the total annual production across all Graphic Packaging facilities. Wastewater generated during the papermaking process and washing equipment is treated at an onsite wastewater treatment plant before it is discharged to the Sulphur River. Graphic Packaging reported that the Battle Creek Mill in Battle Creek, Michigan also intentionally applied PFAS until 2018 (zero PFAS use since 2018). Graphic Packaging further reported that all PFAS use will be discontinued by January 1, 2022 (this inventory will be exhausted by end of March 2022) and PFAS-based coatings will be substituted with alternative technologies such as polymer resins and proprietary nonfluorinated coatings (EPA, 2021i).

WestRock Company historically used FDA-approved PFAS in production of food contact papers and packaging. As of 2021, WestRock Company no longer intentionally uses PFAS in pulp, paper, and paperboard production at any of the company's 28 mills and more than 200 converting facilities in the United States. WestRock Company completed transition of the last facility using PFAS to nonfluorinated technologies in 2020 (EPA, 2021j).

As of July 2021, Sappi was intentionally using PFAS-based additives in food packaging applications at their Somerset Mill, one of the company's three United States mills. The Somerset Mill is an integrated pulping and papermaking mill in Skowhegan, Maine that uses FDA-approved PFAS to enhance grease-resistance of specialty food packaging products. The company reported that less than 2 percent of the Somerset Mill's annual production is manufactured using PFAS-based additives and that they account for less than 1 percent of the weight of the food packaging products in which they are used. The PFAS additives are applied at the wet-end of the papermaking process in one product line of grease-proof food packaging products. Wastewater generated during the process is captured and treated at the Somerset Mill's onsite wastewater treatment plant prior to being discharged to the Kennebec River. This treatment includes primary settling, activated sludge, and a polishing pond prior to discharge, and does not include any treatment for PFAS chemicals specifically. Sappi reports that the company is developing nonfluorinated additive alternatives and will eliminate PFAS use across all product lines by 2024 (EPA, 2021m).

EPA also contacted Kimberly-Clark Corporation, Domtar Corporation, and International Paper Company to discuss potential use of PFAS at pulp, paper, and paperboard facilities. Kimberly-Clark Corporation notified EPA that PFAS would inhibit the high absorbency of their products and that the specialty paper business unit was spun off as a separate entity known as Neenah Paper in 2004 (EPA, 2021l). EPA attempted to contact Neenah Paper to discuss potential use of PFAS and received no response (EPA, 2021n). Neither Kimberly-Clark Corporation or Neenah Paper are members of AF&PA. In a June 2021 letter, Domtar Corporation notified EPA that the company's Port Huron Mill, in Port Huron, Michigan, used FDA-approved short-chain PFAS to manufacture food contact paper and packaging until the facility closed in March 2021. None of Domtar Corporation's remaining nine pulp, paper, and paperboard manufacturing facilities use PFAS in production of paper-based products (Domtar Corporation, 2021). In a July 2021 letter, International Paper Company confirmed the company does not use PFAS in manufacturing products at United States mills and does not sell into the United States products with PFAS intentionally added (International Paper Company, 2021).

7.3 PFAS Wastewater Regulatory Requirements and Controls

As part of the Multi-Industry PFAS Study, EPA did not identify any pulp, paper, and paperboard facilities with PFAS effluent limitations or pretreatment standards in their wastewater discharge permits. As part of Michigan's Industrial Pretreatment Program PFAS Initiative, MI EGLE required 95 POTWs to evaluate their industrial users as potential sources of PFOS and PFOA. These local POTWs implemented requirements for industrial users discharging to their system to monitor for PFOA and PFOS and, if effluent PFOS concentrations exceeded Michigan's screening value of 12 ng/L, implement PFOS reduction programs. MI EGLE reports that POTWs identified approximately ten pulp, paper, or paperboard manufacturing facilities as sources of PFOS discharges and are collaborating with these sources to further investigate and reduce PFOS concentrations (MI EGLE, 2020d).

7.4 Wastewater Characterization

EPA evaluated the available data on types and concentrations of PFAS in wastewater discharged from pulp, paper, and paperboard facilities. EPA has not identified any facilities with PFAS monitoring requirements or effluent limitations; therefore, no DMR data are available for PFAS. EPA summarized the information available and calculated average PFAS concentrations in effluent from pulp, paper, and paperboard facilities based on industry and state permitting authority data.

EPA identified analytical data that meet EPA's acceptance criteria for inclusion in analyses for characterizing PFAS discharges in industrial wastewater discharges. EPA's acceptance criteria are presented in the memorandum "Development of the Multi-Industry PFAS Study Analytical Database" (ERG, 2021a). EPA identified four sources of PFAS analytical data for pulp, paper, and paperboard effluent:

- MI ELGE 2020 PFAS monitoring results for direct and indirect discharge facilities (MI EGLE, 2020b, 2020c).
- 2019 study of PFAS in industrial, municipal, and landfill leachate discharges commissioned by the Vermont Department of Environmental Conservation (VT DEC, 2020).[12]
- PFOA and PFOS sampling results for Georgia-Pacific facilities located in Green Bay, Wisconsin (EPA, 2021h).
- AF&PA summary of PFAS concentrations in effluent from six unidentified pulp and paper mills, originally collected by the National Council for Air and Stream Improvement (AF&PA, 2020c).

EPA determined that the AF&PA submission did not meet all of EPA's acceptance criteria for inclusion in analyses for characterizing PFAS in pulp, paper, and paperboard facility discharges because results were not reported as individual or average concentration results. EPA determined that all individual sample results in the other three data sources did meet EPA's acceptance criteria. EPA included 358 PFAS sample results representing 23 facilities from these sources in its analysis characterizing PFAS in pulp, paper, and paperboard effluent.

EPA calculated facility-level average, minimum, and maximum concentrations for each PFAS with available data using the following assumptions and limitations:

- EPA assumed all nondetection results and results below the level of quantification (i.e., the reporting or quantification limitation) were zero.[13]
- EPA did not have information on analytical method sensitivity and level of quantification for all data.
- EPA did not know the operations or treatment processes online at the facilities at the time of sampling.

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[12] AF&PA excluded the PFAS sample results from this 2019 study from its data submittal to EPA. AF&PA and the National Council for Air and Stream Improvement asserted the data in the report "may be imprecise as evidenced by the high degree of variability" and "split samples collected by one of the facilities and analyzed at a separate laboratory showed much lower concentrations" (AF&PA, 2020c). Based on discussions with WestRock Company and the Vermont Department of Environmental Conservation, EPA determined the effluent data for the two pulp, paper, and paperboard facilities in the report met EPA's acceptance criteria and were of sufficient quality for a preliminary review of PFAS concentrations in industry discharges (EPA, 2021j; VT DEC, 2021).

[13] The lower level of quantification is the lowest concentration that the analytical method being used can measure accurately.

- EPA does not have information on whether the observed PFAS concentrations are from legacy use of PFAS, current use of PFAS, or form from degradation of more complex PFAS.

EPA calculated an overall average, minimum, and maximum concentration for each PFAS based on facility-level results. EPA did not estimate average concentrations for any PFAS that were not detected at or above the level of quantification across all facilities or did not have any data.

Table 11 presents the average, minimum, and maximum concentrations for each PFAS observed in effluent from the 23 pulp, paper, and paperboard facilities. As illustrated in the table, EPA estimated the average concentrations for 6:2 FTSA and short-chain PFCAs (both degradation products of FDA-approved PFAS used in food packaging) were generally higher relative to PFSAs and long-chain PFCAs. Despite the phase out of long-chain PFAAs, some pulp, paper, and paperboard facilities still report detectable levels of PFOA and PFOS in their wastewater.

Table 11. Pulp, Paper, and Paperboard Wastewater PFAS Concentrations

PFAS Subgroup	Analyte [a b]	Facilities with Data	Quantified Detections/Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]
PFCAs	PFBA	2	8/8	0.149 – 0.638	0.377
	PFPeA	2	8/8	0.0308 – 0.246	0.145
	PFHxA	2	8/8	0.0841 – 0.64	0.250
	PFHpA	2	8/8	0.0235 – 0.206	0.118
	PFOA	23	55/79	ND – 0.68	0.0377
	PFNA	2	8/8	0.00592 – 0.0526	0.0235
	PFDA	2	4/8	ND – 0.0197	0.00501
	PFUnA	2	4/8	ND – 0.0153	0.00441
	PFDoA	2	4/8	ND – 0.0203	0.00496
	PFTrA	2	4/8	ND – 0.0249	0.00579
	PFTeA	2	4/8	ND – 0.023	0.00493
PFSAs	PFBS	2	4/8	ND – 0.254	0.0343
	PFPeS	2	0/8	ND	ND
	PFHxS	2	0/8	ND	ND
	PFHpS	2	0/8	ND	ND
	PFOS	23	56/80	ND – 0.41	0.0318
	PFNS	2	1/8	ND – 0.00217	0.000271
	PFDS	2	1/8	ND – 0.00517	0.000646
FASAs	PFOSA	2	0/8	ND	ND
FTSAs	4:2 FTSA	2	0/8	ND	ND
	6:2 FTSA	2	7/8	ND – 0.284	0.0691
	8:2 FTSA	2	0/8	ND	ND
FASAAs and N-Alkyl FASAAs	NMeFOSAA	2	0/8	ND	ND
	NEtFOSAA	2	0/8	ND	ND

Sources: ERG, 2021b.

Abbreviations: ND – nondetection; µg/L – micrograms per liter.

a – This table presents data for all PFAS listed in Table 2 for which sample results are available and meet EPA’s acceptance criteria. EPA does not have any sample results for PFAS not listed.

b –The table identifies short-chain PFCAs (≤7 carbons) and short-chain PFSAs (≤5 carbons) in blue text, while long-chain PFCAs (≥8 carbons) and long-chain PFSAs (≥6 carbons) are designated in red text.

c – In this analysis, EPA treated all nondetection results as zero for the purpose of estimating concentrations. All concentration values are rounded to three significant figures.

7.5 Pulp, Paper, and Paperboard Point Source Category Summary

Based on information and data EPA collected for the Multi-Industry PFAS Study, EPA documented that PFAS have been, and continue to be, used by pulp, paper, and paperboard facilities in the United States; however, only a small subset of facilities are actively applying PFAS and it appears the production of paper products containing PFAS at these facilities is a small percentage of the overall production. Additionally, the industry has indicated they plan to eliminate PFAS use by 2024. Information collected from one trade association and eight major companies indicates the industry phased out the use of PFOA and PFOS approximately 10 years ago, but continues to use FDA-approved short-chain PFAS in limited quantities in the manufacture of food contact packaging and specialty paper products. PFAS may be in additives mixed with the pulp prior to forming it into paper or in coatings applied to the surface of the paper after the paper is formed to enhance resistance to water, oil, and grease. Based on outreach and a trade association survey of companies representing 85 percent of United States production, EPA identified 10 pulp, paper, and paperboard facilities operated by six companies that have applied PFAS since 2020. The PFAS-based production volume of these 10 mills represents less than 10 percent of their total production and less than 1 percent of the total produced by this industry in the United States. The companies operating all 10 facilities reported to EPA that they will transition to PFAS-free technologies and eliminate all application of PFAS in their United States pulp and papermaking operations by 2024. This schedule coincides with an FDA agreement with chemical manufacturers to voluntarily phase out use of PFAS that contain or may degrade to 6:2 FTOH in food contact applications by 2024.

EPA did not identify any pulp, paper, and paperboard facilities with PFAS effluent limitations or pretreatment standards in their wastewater discharge permit and estimates that only a small fraction of pulp, paper and paperboard facilities monitor for PFAS. EPA did not identify any pulp, paper, and paperboard facilities employing wastewater treatment systems known to effectively reduce PFAS in industrial wastewater. Although industry reports the application of PFAS to pulp, paper, and paperboard products is typically a dry or closed-loop process and may not generate a wastewater stream, EPA documented PFAS, including legacy long-chain PFAS and replacement PFAS, are present in wastewater discharges from pulp, paper, and paperboard facilities to surface waters and POTWs. Using available sampling data, EPA estimated average concentrations for 6:2 fluorotelomers and short-chain PFCAs (both degradation products of FDA-approved PFAS used in food packaging) were generally higher relative to PFSAs and long-chain PFCAs. The presence of PFOA, PFOS, and other long-chain PFAAs may be due to legacy issues or degradation of other more complex PFAS.

8. Review of the Textile Mills Point Source Category

This section describes the textile mills point source category and information and data that EPA collected on its PFAS use and discharge. EPA collected and reviewed information on PFAS use and discharge by textile mills from the following sources:

- Outreach to textile manufacturing companies, carpet manufacturing companies (a subset of the category), industry trade associations, and state and local wastewater authorities.
- Publicly available technical literature.

8.1 Industry Description and Use of PFAS

Textile mills receive and prepare fibers; transform fibers into yarn, thread, or webbing; convert yarn and webbing into fabric or related products; or finish these materials. Many facilities produce a final consumer product such as thread, yarn, fabric, hosiery, towels, sheets, and carpet while the rest produce an intermediate product for use by other establishments in the industry. As part of EPA's 1996 *Preliminary Study of the Textile Mills Category*, EPA estimated that approximately 6,000 establishments in the United States manufactured textile products. The majority of United States textile mills, including carpet manufacturers, are concentrated in the southeastern United States (EPA, 1996). The city of Dalton, Georgia contains over 150 carpet manufacturing plants, and more than 90 percent of the world's carpeting is produced within a 65-mile radius of the city (Town of Centre AL v. Dalton GA Manufacturers, 2017).

EPA promulgated the Textile Mills Effluent Guidelines (40 CFR Part 410) in 1974, with technical amendments in 1977 and 1982. The regulations cover wastewater discharges generated from textile mills using the following processes:

- Wool scouring, topmaking, and general cleaning of raw wool.
- Wool finishing, including carbonizing, fulling, dyeing, bleaching, rinsing, and fireproofing.
- Yarn manufacture, unfinished fabric manufacture, fabric coating, fabric laminating, tire cord and fabric dipping, carpet tufting, and carpet backing.
- Woven fabric finishing, including desizing, bleaching, mercerizing, dyeing, printing, resin treatment, waterproofing, flameproofing, application of soil repellent, and other special finishes.
- Knit fabric finishing, including bleaching, mercerizing, dyeing, printing, resin treatment, waterproofing, flameproofing, application of soil repellent, and other special finishes.
- Carpet finishing, including bleaching, scouring, carbonizing, fulling, dyeing, printing, resin treatment, waterproofing, flameproofing, application of soil repellent, looping, and backing with latex and jute.
- Stock and yarn finishing, including cleaning, scouring, bleaching, mercerizing, dyeing, and finishing.
- Manufacturing of nonwoven textile products of wool, cotton, synthetics, or blends of such fabrics.

The current ELGs do not establish effluent limitations or pretreatment standards for PFAS.

Textile mills use PFAS to impart outdoor gear, clothing, household fabrics, carpets, and other textile products with water, oil, soil, and heat resistance; improve cleanability of oil- and water-based stains; as a wetting or antifoaming agent when dyeing and bleaching, and as a breathable moisture barrier to wind and rain (NCTO, 2016; Wood, 2020b; Glüge et al., 2020). Some textile products that may contain PFAS include consumer apparel and accessories, professional apparel (including medical and firefighter uniforms and personal protection equipment), sportswear, outdoor gear, heat-resistant gloves, footwear, carpeting and rugs, backpacks, swimwear, and upholstery (NRDC, 2021; SAICM, 2021). Fluoropolymer PFAS are most commonly used as breathable membranes, while side-chain fluorinated polymers are used as long-lasting durable water repellent finishes (Wood, 2020b; Glüge et al., 2020). During fabric and carpet manufacturing, PFAS can either be incorporated as an additive mixed into the individual fibers or sprayed as a coating onto finished fabrics, either during manufacturing or after sale (GSPI, 2021).

A National Resources Defense Council (NRDC) analysis of a 2016 fluorotelomer market study concluded the global textile industry was the largest user of fluorotelomers (relative to the volumes used in firefighting foams, food packaging, stain resistance chemicals, and other products), making up approximately 36 percent of the total market (NRDC, 2021; Ahuja and Mamtani, 2016).

Some retailers and textile companies have committed to eliminating the sale or manufacture of PFAS-containing textile products in the coming years, including Interface, Tarkett, IKEA, Herman Miller, Crate and Barrel, Room and Board, Engineered Floors, Lowes, and Home Depot. Fashion, apparel, and home textile brands are currently the most common adopters of PFAS-free commitments. Sports and outdoor brands face more challenges to phase out PFAS while keeping the current level of product performance and functionality because there are no technologies which can repel oil-based materials to the same levels that PFAS achieve, and which are acceptable to the industry. (NRDC, 2021; NCTO, 2018; GSPI, 2021). At least one state, California, is in the process of regulating PFAS in carpets, rugs, and after-market treatments. The major categories of nonfluorinated water-repellant alternatives available on the market include hydrocarbons, silicones, dendrimers, polyurethanes, and nanomaterials (Wood, 2020b).

8.2 Stakeholder Outreach

EPA attempted to meet with industry stakeholders and state and local wastewater authorities to collect, on a voluntary basis, information on the use and discharge of PFAS for textile and carpet mills.

EPA reached out to two trade associations and three textile or carpet manufacturing companies that the agency considered possible users of PFAS. The trade associations and companies that EPA contacted are listed below:

- **National Council of Textile Organizations (NCTO).** A national trade association representing more than 150 companies across the entire spectrum of the United States textile industry and comprising four councils: the fiber council, the yarn council, fabric and home furnishing council, and the industry support council.
- **Carpet and Rug Institute (CRI).** A trade association for the North American carpet industry, providing carpeting-related informational tools, programs, and research resources. CRI represents manufacturers producing 94 percent of carpet in the United States, suppliers of raw materials, and services to the industry.
- **Milliken and Company (Milliken).** Global manufacturer and supplier of household textiles (including carpets), performance and protective textiles, specialty chemicals, and other industrial textiles.
- **Shaw Industries Group, Inc. (Shaw).** Global manufacturer of carpets, rugs, and household textiles.
- **W.L. Gore and Associates (Gore).** Global manufacturer of industrial and commercial fluoropolymer-based products, including waterproof, breathable fabrics (e.g., GORE-TEX) used in apparel, footwear, workwear/technical wear, and outdoor textiles.

NCTO, CRI, and their member companies declined to meet with EPA and did not provide any information on PFAS use in the industry (EPA, 2021o, 2021p). Milliken informed EPA that they are not in a position to discuss PFAS due to ongoing litigation involving claims against multiple defendants related to alleged discharge of PFAS from carpet manufacturing facilities in and around Dalton, Georgia.[14] Milliken explained that the Milliken facility at issue in that litigation was operated by Milliken for only a short time, from October 2009 to November 2012. Milliken also stated that none of the current NPDES permits held by the company's textile mills have any monitoring requirements for PFAS (EPA, 2021q). EPA did not receive responses or any additional information from Shaw or Gore (EPA, 2021r, 2021s).

8.3 PFAS Wastewater Regulatory Requirements and Controls

As part of the Multi-Industry PFAS Study, EPA did not identify any textile mills with PFAS effluent limitations, pretreatment standards, or monitoring requirements in their wastewater discharge permits. EPA identified a draft

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[14] The plaintiff of this litigation, the Water Works and Sewer Board of the City of Centre, brought a complaint against owners, operators, and/or chemical suppliers to manufacturing facilities (including textile and carpet manufacturers) located in and around Dalton, Georgia. The plaintiff claims that they have and continue to be damaged due to the past and present release of toxic chemicals, including PFOA, PFOS, precursors to PFOA and PFOS and related chemicals released during manufacturing operations (Town of Centre AL v. Dalton GA Manufacturers, 2017).

NPDES permit for one textile mill in Georgia which, if finalized, would require the company to determine if the facility has potential to release PFAS to the environment through discharge of wastewater effluent or industrial sludge disposal (GA DNR, 2020).

8.4 Wastewater Characteristics

EPA evaluated the available data on types and concentrations of PFAS in wastewater discharged from textile mills. As of July 2021, EPA has not identified any textile mills with PFAS monitoring requirements or effluent limitations; therefore, no DMR data is available for PFAS. EPA summarized the information available and calculated average PFAS concentrations in effluent from textile mills based on Michigan permitting authority data.

EPA identified analytical data that meet EPA's acceptance criteria for inclusion in analyses for characterizing PFAS discharges in industrial wastewater discharges. EPA's acceptance criteria are presented in the memorandum "Development of the Multi-Industry PFAS Study Analytical Database" (ERG, 2021a). EPA identified one source of analytical data of textile mill effluent and determined that all individual sample results in the source met EPA's acceptance criteria, MI EGLE PFAS monitoring results for indirect discharge facilities (MI EGLE, 2020c). EPA included 16 PFAS sample results representing three indirect discharge mills in its analysis characterizing PFAS in textile mill effluent.

EPA calculated facility-level average, minimum, and maximum concentrations for each PFAS with available data using the following assumptions and limitations:

- EPA assumed all nondetection results and results below the level of quantification (i.e., the reporting or quantification limitation) were zero.[15]
- EPA did not have information on analytical method sensitivity and level of quantification for all data.
- EPA did not know the operations or treatment processes online at the facilities at the time of sampling.
- EPA does not have information on whether the observed PFAS concentrations are from legacy use of PFAS, current use of PFAS, or formation from degradation of more complex PFAS.

EPA calculated an overall average, minimum, and maximum concentration for each PFAS based on the facility-level results. Table 12 presents the average, minimum, and maximum concentrations for each PFAS observed in effluent the three indirect discharge textile mills.

Table 12. Textile Mill Wastewater PFAS Concentrations

PFAS Subgroup	Analyte [a b]	Facilities with Data	Quantified Detections/Total Sample Results	Concentration Range (µg/L) [c]	Average Concentration (µg/L) [c]
PFCAs	PFOA	3	4/8	ND – 0.114	0.00807
PFSAs	PFOS	3	4/8	ND – 0.0361	0.00249

Source: ERG, 2021b.

Abbreviations: ND – nondetection; µg/L – micrograms per liter.

a – This table presents data for all PFAS listed in Table 2 for which sample results are available and meet EPA's acceptance criteria. EPA does not have any sample results for PFAS not listed.

b –The table identifies long-chain PFCAs (≥8 carbons) and long-chain PFSAs (≥6 carbons) in red text.

c – In this analysis, EPA treated all nondetection results as zero for the purpose of estimating concentrations. All concentration values are rounded to three significant figures.

8.5 Textile Mills Point Source Category Summary

Based on information and data EPA collected for the Multi-Industry PFAS Study, EPA documented that PFAS have been, and continue to be, used by textile mills in the United States. Textile mills use PFAS to enhance resistance to water, oil, soil, and heat; improve cleanability of oil- and water-based stains; as a wetting and antifoaming agency; and in the breathable moisture barrier to wind and rain. PFAS have been applied in a wide range of textiles

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[15] The lower level of quantification is the lowest concentration that the analytical method being used can measure accurately.

including but not limited to clothing, footwear, carpets and rugs, household fabrics, upholstery, medical garments, firefighting gear, luggage, and outdoor gear (e.g., jackets, hats, gloves, tents). During fabric and carpet manufacturing, PFAS can either be incorporated as an additive mixed into the individual fibers or sprayed as a coating onto finished fabrics during manufacturing or after sale.

EPA's review of PFAS use and discharge by the textile mills point source category is largely based on publicly available information and literature. EPA attempted to meet with representatives of industry trade associations and companies to collect, on a voluntary basis, information on the use and discharge of PFAS at textile and carpet mills. Ultimately, EPA did not meet or receive additional information from these entities.

EPA did not identify any textile mills with PFAS effluent limitations or pretreatment standards in their wastewater discharge permit and estimates that only a small fraction of textile mills monitor for PFAS. EPA did not identify any textile mills employing wastewater treatment systems known to effectively reduce PFAS in industrial wastewater. Based on a small number of sample results, EPA has observed that PFAS, including legacy long-chain PFAS, are present in wastewater discharges from textile mills to POTWs. Most textile mills are not monitoring for PFAS and may continue to discharge PFAS to POTWs or surface waters unless effective controls are in place.

9. Review of the Commercial Airport Point Source Category

This section describes the commercial airport point source category, the use of PFAS-containing firefighting foam (i.e., AFFF) for firefighting activities and certification exercises, and mechanisms for PFAS release to the environment. EPA collected and reviewed information on PFAS use and discharge by commercial airports from outreach with the United States Department of Transportation, Federal Aviation Administration (FAA) and an industry trade association; government reports and databases; a survey and report published by the Airport Cooperative Research Program (ACRP); and publicly available technical literature.

9.1 Industry Description and Use of PFAS

The FAA and Airport and Airway Improvement Act (AAIA) (49 U.S.C. Chapter 471) classify commercial airports by size based on volume of commercial traffic. Commercial airports are defined by the FAA and AAIA as publicly owned airports that have at least 2,500 passenger boardings (number of passengers boarding a plane for departure) each calendar year and receive scheduled passenger service (EPA, 2012b). As of April 2021, the FAA has certified 519 commercial airports (FAA, 2021a). Military installations and other facilities operated by the United States Department of Defense (DOD) are not considered commercial airports; therefore, PFAS use and discharge by DOD facilities are outside the scope of this study.

14 CFR Part 139 contains the regulations pertaining to certification of airports and requires commercial airports to conduct periodic testing of certain equipment and train personnel to perform aircraft rescue and firefighting (ARFF) operations. In 2006, the FAA required that commercial airports certified under 14 CFR Part 139 purchase only firefighting foams that conform to military specification (Mil-Spec) MIL-PRF-24385 for performance and procurement, which required that AFFF liquid concentrates contain fluorocarbon (i.e., PFAS) surfactants (FAA, 2006). In May 2019, the DOD amended Mil-Spec MIL-PRF-24385 to remove the Mil-Spec's requirement that AFFF contain fluorocarbon surfactants (DOD, 2019). However, as of June 2021, all firefighting foam formulations that meet MIL-PRF-24385 contain PFAS in concentrations less than 800 parts-per-billion (ACRP, 2017; ERG, 2020a).

AFFF is produced by mixing PFAS-containing concentrate with water at the specified proportion, typically 3 or 6 percent ratio to water. AFFF has been, and continues to be, stored and used at military installations, industrial facilities, petroleum refineries, and airports to prevent, extinguish, or control Class B flammable fuel fires and for firefighter training. When mixed with water, AFFF concentrate generates an aqueous film and foam solution that spreads across the surface of a hydrocarbon (e.g., grease, oil, gasoline, solvent) fire to extinguish the flames and form a vapor barrier separating fuel and atmospheric oxygen to prevent reignition. Military and commercial airport AFFF applications subject to the Mil-Spec MIL-PRF-24385 account for more than 75 percent of AFFF used in the United States (ACRP, 2017).

The FAA requires periodic testing of foam proportioning system performance in ARFF vehicles, as prescribed in 14 CFR Parts 139.315 to 139.319. The number of ARFF vehicles and amount of AFFF present at each airport is based on the length of aircraft and average number of daily departures from the airport. Until recently, foam proportioning system testing required airports to perform output-based testing, in which AFFF is sprayed from the ARFF vehicle for at least 30 seconds to demonstrate that the firefighting equipment operates correctly. During output-based testing, safeguards, such as capture containers, containment basins, absorbent pads, and use separator/scrubbing systems may be used to prevent the release of PFAS to the environment (ACRP, 2017; FAA, 2021b). 14 CFR Part 139 also permits input-based testing, a method that requires additional equipment but allows for a substitute (typically water) to be sprayed instead of AFFF. Input-based testing requires the establishment of a baseline by spraying foam from the ARFF vehicles. Once a baseline is established, the test can be run using water rather than foam. As of June 2021, the FAA has approved and encourages use of four different types of AFFF testing equipment that do not require dispensing AFFF. The FAA and some states are providing funding for the purchase of input-based testing equipment that does not require foam to be dispensed onto the ground (FAA, 2019a, 2019b, 2021b). Commercial airports that use input-based testing equipment will eliminate potential discharges of wastewater containing PFAS during periodic testing of foam proportioning system performance in ARFF vehicles.

The FAA also requires all airport firefighting personnel to complete an annual live-fire fighting training as dictated in 14 CFR Parts 139.315 to 139.319. Live firefighting training involves extinguishing a pit fire with an aircraft mockup using enough fuel to simulate the type of conditions that could be encountered during a rescue situation. If training of airport firefighting personnel does not occur within a 12-month period, an airport will be considered out of compliance with 14 CFR Part 139. Commercial airports are not required to use AFFF during live firefighting testing (water solutions or alternative methods may be used). Some airports have a designated firefighting training area to perform training, while others do not (ACRP, 2017).

Until application, AFFF is managed as a concentrated product containing less than 2 percent PFAS by weight. PFAS account for less than 1 percent of AFFF after the concentrate is mixed with water to create the firefighting solution. AFFF formulations are generally categorized into three groups, based on the PFAS type included:

- **Legacy PFOS-based AFFF.** First-generation AFFF formulations where PFOS is an active ingredient. Manufactured by 3M via electrochemical fluorination and sold under the brand name Light Water™ in the United States from 1970s to 2002.
- **Legacy fluorotelomer-based AFFF.** Second-generation AFFF formulations containing precursors to long-chain PFCAs (e.g., PFOA) and manufactured via fluorotelomerization in the United States from 1970s to 2016.
- **Modern fluorotelomer-based AFFF.** Modern AFFF formulations containing four- and six-carbon fluorotelomer chemistries (e.g., 6:2 FTSA) and developed in response to the PFOA Stewardship Program. These AFFF formulations are currently being commercially sold in the United States market.

While modern fluorotelomer-based AFFF formulations have the potential to be less harmful to human health and the environment than legacy formulations, much remains unknown about the short-chain PFAS used. Four- and six-carbon chain fluorotelomers degrade into short-chain PFCAs and other short-chain PFAS, as discussed in Section 3.4. Since certain short-chain PFAS are less effective surfactants than their long-chain counterparts, greater quantities of short-chain PFAS may be required to provide equivalent performance (ACRP, 2017).

PFAS contamination has been observed in surface water, groundwater and drinking water in proximity to airports that use AFFF (Hu et al., 2016; Gewurtz et al., 2014; ITRC, 2020). Due to growing concerns related to PFAS use and release at airports, the FAA Reauthorization Act of 2018 (enacted October 5, 2018) mandates that the FAA can no longer require the use of AFFF by 14 Part 139 airports no later than three years from the date of enactment (October 4, 2021). As a result, the FAA has approved, encourages use of, and, in some cases, funds technologies that do not require dispensing AFFF when airports conduct periodic equipment testing and training. While the FAA Reauthorization Act of 2018 will end the requirement for use of AFFF, it does not prohibit its use by commercial airports (FAA, 2018, 2019c, 2021b).

The National Defense Authorization Act of fiscal year 2020 (enacted December 20, 2019) requires the DOD to phase out its use of AFFF at all military installations by October 2024, with limited exceptions, and immediately stop military training exercises with AFFF. The Secretary of the Navy must publish specifications for PFAS-free firefighting foam at all military installations and ensure that the foam is available for use by October 2023 (ITRC, 2020). These mandates do not apply to commercial airports and the FAA has not yet announced plans to require exclusive use of PFAS-free formulations at commercial airports.

Despite discontinued manufacture of legacy AFFF formulations with long-chain PFAS chemistries, many airports have AFFF in service or in stockpiles and are not prohibited from using legacy or modern AFFF. AFFF has a long shelf life; some manufacturers claim PFAS-containing AFFF can remain viable up to 25 years if stored properly (ACRP, 2017). This means that PFAS-containing AFFF, including legacy PFOS-based products, still exist in United States inventories and ongoing permitted use of AFFF at commercial airports can still result in PFAS releases. The current volume of AFFF in commercial airport stockpiles or used annually is not known.

The DOD, states, and other organizations recommend the complete replacement of legacy AFFF and have launched proper disposal and take-back programs. As of January 2020, EPA has identified eleven states with AFFF procurement, use, storage, and/or disposal regulations: Arizona, Colorado, Georgia, Kentucky, Michigan, Minnesota, New Hampshire, New York, Virginia, Washington, and Wisconsin (ACRP, 2017; ERG, 2020a; Bloomberg Law, 2020).

Many firefighting foam manufacturers now offer Class B fluorine-free foam products. A 2020 literature review and market study found that fluorine-free alternative foams, including hydrocarbon- and detergent-based foams, are generally available and technically feasible, and have been successfully implemented in many industrial sectors in Europe (Wood, 2020c).

As of June 2021, the FAA has not identified any fluorine-free foams on the market that provide the same level of fire suppression, flexibility, and scope of usage as MIL-PRF-24385 AFFF and therefore they are not used at DOD- and FAA-regulated facilities. To aid in the transition to nonfluorinated AFFF, the FAA, the DOD, Airports Council International – North America, firefighting foam manufacturers/developers, and other organizations are researching and testing at least 15 commercially available fluorine-free AFFF alternatives to identify formulations that are environmentally friendly and provide the same level of safety currently offered by the Mil-Spec MIL-PRF-24385. The FAA has built a research testing facility and conducted over 400 tests in an effort to find a new fluorine-free alternative firefighting extinguishing agent (ERG, 2020a; FAA, 2019a, 2021b; SERDP, 2020).

9.2 Stakeholder Outreach

EPA met with the FAA and the Airports Council International – North America to collect, on a voluntary basis, information on the use and release of PFAS-containing AFFF by commercial airports. FAA representatives provided EPA with an overview of firefighting requirements for commercial airports to maintain 14 CFR Part 139 certification. EPA collected information on the Mil-Spec MIL-PRF-24385, FAA development and approval of input-based testing systems, and the FAA's guidance to commercial airports to control release of AFFF. EPA continues to coordinate with the FAA to understand the status of research on fluorine-free formulations and actions taken to address AFFF. The Airports Council International – North America is a trade association for the North American airport industry and provided EPA with information on its members' practices for using and capturing AFFF.

9.3 PFAS Wastewater Regulatory Requirements and Controls

As part of the Multi-Industry PFAS Study, EPA did not identify any commercial airports with PFAS effluent limitations, pretreatment standards, or monitoring requirements in their wastewater discharge permits.[16]

9.4 PFAS Releases Associated with AFFF Use

Commercial airports have historically generated PFAS-containing wastewater during periodic testing of ARFF equipment, live-fire firefighting training, emergency response activities, rinsing ARFF equipment, and accidental leaks. The volume of PFAS released to the environment can vary depending on the activity and types of controls employed by the airport. A 2016 survey of 167 airports across the United States and Canada indicated that nearly 80 percent of respondents sprayed AFFF directly on the ground rather than an engineered containment system. Most airports which reported directly spraying AFFF onto the ground also reported that AFFF was left to evaporate, dissipate, dilute, or infiltrate into the ground. Most airports that reported capturing AFFF in a containment system or cleaning up AFFF sprayed onto the ground ultimately discharged the solution to POTW via a sewer or to a surface water (ACRP, 2017). Most on-site airport wastewater treatment systems and POTWs are not capable of effectively removing PFAS. Once released, AFFF foam can contaminate soil, surface water, and groundwater.

To minimize AFFF releases, the FAA and Airports Council International – North America are working with airports to enhance education of AFFF issues; reduce AFFF release during periodic testing and training activities; and promote practices and technologies used for the capture of AFFF, and subsequent treatment at municipal wastewater treatment plants (ERG, 2020a; FAA, 2021b). Since 2019, the implementation of input-based testing and PFAS control processes and technologies have reduced AFFF releases by commercial airports. Releases to the environment will be further reduced based on federal actions to review and revise mandates to use PFAS-containing AFFF and proliferation of fluorine-free firefighting foams alternatives. The FAA states that approval of input-based testing and updated guidance has eliminated the need for commercial airports to discharge

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[16] The FAA requires commercial airports and air carriers to conduct deicing and anti-icing of aircraft and airfield pavement to ensure safety of flights. In 2012, EPA promulgated the Airport Deicing ELGs (40 CFR Part 449), which address control of wastewater generated by deicing. The ELGs do not apply to wastewater generated by AFFF use at commercial airports, nor do they establish PFAS requirements or effluent limitations (EPA, 2012b).

wastewater contaminated with AFFF except during actual emergency response situations (i.e., AFFF should not be released during periodic testing of ARFF equipment .

9.5 Commercial Airports Point Source Category Summary

The FAA Reauthorization Act of 2018 (enacted October 5, 2018) mandates that the FAA can no longer require the use of PFAS-based AFFF by 14 CFR Part 139 airports no later than three years from the date of enactment (October 4, 2021). As a result, the FAA has approved, encourages use of, and in some cases funds four different types of AFFF testing equipment that do not require dispensing AFFF when airports conduct periodic equipment testing and training (FAA, 2021b). The FAA has also built a research testing facility and has conducted over 400 tests in an effort to find a new fluorine-free alternative firefighting extinguishing agent (FAA, 2019b).

Historically, the FAA required that commercial airports certified under 14 CFR Part 139 purchase only firefighting foams that conform to Mil-Spec MIL-PRF-24385 for performance and procurement (FAA, 2006). In May 2019, the DOD amended Mil-Spec MIL-PRF-24385 to remove the requirement that AFFF must contain PFAS. As of July 2021, all firefighting foam formulations that meet MIL-PRF-24385 contain less than 800 parts-per-billion of PFAS. The FAA and the DOD are continuing to collaborate on research and to test fluorine-free alternatives that provide the same level of safety currently offered by Mil-Spec MIL-PRF-24385.

Based on this information, EPA determined that commercial airports may generate PFAS-containing wastewater from live-fire firefighting training, emergency response activities, and accidental leaks from stockpiles of AFFF. The volume of PFAS released to the environment can vary depending on the activity, types of controls employed by the airport, and type and volume of AFFF released.

10. Review of PFAS Treatment Technologies

This section summarizes information and performance data EPA collected on treatment technologies capable of removing or destroying PFAS in water streams. For the purposes of this preliminary report, PFAS destruction (sometimes referred to as mineralization) is the complete chemical degradation of PFAS molecules into base elements or compounds such as carbon dioxide (CO_2), water (H_2O), and fluorine ions (F^-). Incomplete destruction leaves behind partially degraded PFAS, resulting in increased concentrations of PFAAs or precursors. Removal is the physical separation of PFAS from an influent wastestream, but does not imply chemical transformation. Removal technologies result in PFAS being concentrated into another wastewater stream or solid waste.

EPA reviewed technical literature, Industrial Wastewater Treatment Technology (IWTT) database (EPA, 2021e), and EPA's Drinking Water Treatability Database (DWTD) (EPA, 2021f) to identify technologies capable of removing or destroying PFAS in industrial wastewater, drinking water, and municipal wastewater. The following treatment types are presented in this preliminary report:

- **Conventional Water Treatment.** Physical, biological, and chemical processes which are commonly applied in drinking water treatment plants (DWTPs) or POTWs to remove organic pollutants, solids, nutrients, and provide disinfection (see Section 10.1).
- **Adsorption.** Removal by transfer of contaminants from a liquid phase onto the surface of a solid adsorbent through hydrophobic partitioning or electrostatic interactions with active sites (see Section 10.2).
- **Membrane Filtration.** Removal of contaminants from a solution into a concentrated liquid wastestream using a selective barrier (see Section 10.3).
- **Incineration/Thermal Treatment.** Destruction by application of heat to break down the chemical structure of contaminants (i.e., breaking chemical bonds of PFAS molecules using extremely high temperatures) (see Section 10.4).
- **Advanced Oxidation and Reduction Processes.** Destruction using oxidizing or reducing agents and processes to break down the chemical structure of contaminants (i.e., breaking chemical bonds of PFAS molecules through a series of oxidation-reduction reactions) (see Section 10.5).
- **Emerging Technologies for PFAS Treatment.** Additional technologies being studied for PFAS removal or destruction but not yet widely implemented or demonstrated (see Section 10.6).

Table 13 summarizes demonstrated PFAS technologies identified through EPA's review. Where available, treatment capabilities reported in literature or EPA's DWTD are provided for six PFAS representing a range of chain length, functional group, and level of fluorination (PFOA, PFOS, PFBA, PFBS, 6:2 FTSA, HFPO-DA). See EPA's 2021 *Evaluation of Industrial Wastewater Treatment Technologies* report for additional information and data on these and additional PFAS treatment technologies (ERG, 2021c).

Table 13. Summary of Available PFAS Treatment Technologies

Treatment Technology	Treatment Description	Observed PFAS Removal Level [a]	Considerations for Use
Conventional Drinking Water and Wastewater Treatment	Water treatment processes commonly used by DWTPs or POTWs including filtration, coagulation, sedimentation, biological treatment, clarification, and disinfection.	Marginal reduction (< 25%) in concentration for most PFAS.	• PFAS removal limited to compounds adsorbed onto solids (i.e., dissolved PFAS are not removed). • May increase effluent concentrations of PFCAs and PFSAs through transformation of precursors.
Activated Carbon	Transfers PFAS from a liquid wastestream onto a solid powdered or granulated carbon-based adsorbent. Includes granular activated carbon (GAC) and powdered activated carbon (PAC).	PFOA: Up to 99% [a] PFOS: Up to 99% [a] PFBA: Up to 99% [a] PFBS: Up to 99% [a] HFPO-DA: Up to 93% [a] 6:2 FTSA: Up to 88% [a]	• Short-chain PFAS have lower removal rates than long-chain PFAS. • PFCAs have lower removal rates than PFSAs. • Sorption rates sensitive to water solution chemistry (e.g., greater pH or higher organic content of wastewater is linked to lower sorption rates). • Requires thermal regeneration or disposal of spent adsorbent media. • GAC is commercially available and has been implemented at OCPSF and chromium plating facilities to capture PFAS.
Ion Exchange Resin	Synthetic resins used to remove charged PFAS. Can be used in batch or flow-through reactors.	PFOA: Up to 99% [a] PFOS: 90-99% [a] PFBA: Up to 99% [a] PFBS: Up to 99% [a] HFPO-DA: Up to 99% [a] 6:2 FTSA: Up to 99% [a]	• Can be tailored to target electrostatically charged PFAS. • PFAS selective resins are more expensive but demonstrate higher removal capacities than activated carbon treatment for certain PFAS. • Rate of exchange depends on PFAS type, influent PFAS concentration, resin properties, and solution ionic strength. • Requires chemical generation or disposal of spent resin. Single-use resins create a solid waste stream onto which PFAS is absorbed. Regeneration of a reusable resin with a chemical solution generates a concentrated PFAS liquid wastestream. Regenerable resin cannot be infinitely regenerated and will create a solid wastestream onto which PFAS is adsorbed. • Commercially available for wastewater treatment.
Membrane Separation	Separation treatment that pushes water molecules through a semi-permeable membrane while rejecting larger PFAS molecules. Includes nanofiltration (NF) and reverse osmosis (RO).	PFOA: Up to 99% [a] PFOS: Up to 99% [a] PFBA: Up to 99% [a] PFBS: Up to 99% [a] HFPO-DA: Up to 99% [a] 6:2 FTSA: Up to 99% [a]	• Higher capital cost and energy demand than conventional treatments or adsorption. • Effective in removing most PFAS from water solutions. • Susceptible to fouling without pretreatment. • Generates a concentrated PFAS wastestream that must be treated or disposed.

Table 13. Summary of Available PFAS Treatment Technologies

Treatment Technology	Treatment Description	Observed PFAS Removal Level [a]	Considerations for Use
Incineration/ Thermal Treatment	Process of applying high temperatures to chemically break down PFAS molecules.	Complete PFAS destruction at temperatures ranging 200 – 1,400°C (varies from one PFAS to another).	• Can be used to regenerate solid adsorbents, such as GAC, while also destroying PFAS. However, high heat required to break carbon-fluorine bond can destroy adsorbent as well. • Incomplete destruction of PFAS may result in increased PFAA and precursor concentrations.
Advanced Oxidation/ Reduction Processes	Use of chemical or electrochemical catalyst to break down PFAS molecules.	Up to 99% PFAS destruction.	• Requires high energy or chemical catalyst input to initiate reactions. • Pretreatment to create a concentrated PFAS influent will reduce energy demand. • Incomplete destruction of PFAS may result in increased PFAA and precursor concentrations. • Advanced reduction requires strong alkaline systems.

a – Potential removal rates are based on reported data from EPA's DWTD for PFAS. See the DWTD for removal rates for additional PFAS (EPA, 2021f).

10.1 Conventional Treatment Technologies

Treatment methods commonly found in DWTPs include coagulation, sand or multimedia filtration, and disinfection involving ultraviolet light or chemicals. POTWs typically treat wastewater using primary screening, sedimentation, secondary biological treatment (e.g., suspended growth or fixed-film biological processes), clarification, filtration, and/or disinfection. These conventional treatment processes used in POTWs and DWTPs do not degrade the carbon-fluorine bond and are ineffective at removing PFAS. No or inconsistent removal of PFAS has been observed, with most studies reporting less than 25 percent removal of total PFAS. PFAS removal for these treatments is limited to physical removal of PFAS bound to filtered solids, leaving behind dissolved PFAS (Appleman et al., 2014; Rahman et al., 2014; EPA, 2021f). Nonpolymer polyfluorinated PFAS and polymer PFAS may be partially degraded in drinking water or wastewater treatment processes, leading to increased PFAA detections in effluent and sludge (Pan et al., 2016; Hamid and Li, 2016).

10.2 Adsorption

Adsorption is a demonstrated process for contaminant removal in water and wastewater and is the most common treatment method for PFAS. Adsorption is both a physical and chemical process that removes a compound in an aqueous solution (adsorbate) through association to a solid phase (adsorbent). Adsorption does not chemically alter or destroy PFAS; rather, compounds are transferred from the liquid phase to a solid when they adhere to the solid's active sites.

PFAS adsorption rates may be affected by pH, organic co-contaminant nature and concentration, and the ionic strength of the solution. Because adsorption processes can remove a wide spectrum of organic contaminants, the presence of nontargeted contaminants can increase competition for sorption sites, thus reducing removal of PFAS (Gagliano et al., 2020). Pretreatment steps may be necessary to optimize the performance of media, including coagulation, precipitation, filtration, pH adjustment, or oxidant removal.

Adsorption technologies require further treatment or disposal of the spent adsorbent media. Once adsorptive media is exhausted and breakthrough (i.e., PFAS is observed at a specific concentration in the effluent) occurs, the adsorbent media is considered spent and must be replaced or reactivated using high temperatures or chemical regenerants to renew adsorptive capabilities. Reactivation can create concentrated PFAS separate wastestreams from regenerant concentrate or through incineration gas emissions. Once an adsorbent can no longer be reactivated, it must be disposed of as a solid waste.

The following sections outline different adsorbents that rely on physical adsorption of PFAS.

10.2.1 Activated Carbon

Activated carbon is a widely used adsorbent for contaminant treatment. Granular activated carbon (GAC) and powdered activated carbon (PAC) are carbonaceous media that can be used to adsorb natural and synthetic organic compounds. Activated carbon treatment is available, relatively inexpensive, and can be scaled to suit treatment requirements.

GAC and PAC differ in the diameters of the activated carbon particles (1.2 to 1.6 millimeters for GAC, approximately 0.1 millimeter for PAC). Because of the small particle size, PAC cannot be used in a flow through bed, but can be added directly to the water and then removed in the clarification stage (conventional water treatment or low-pressure membranes such as microfiltration or ultrafiltration). Used in this way, PAC is not as efficient or economical as GAC at removing PFAS.

The application of GAC as a treatment technology for PFAS removal has been practiced for more than a decade at industrial sites, military installations, and DWTPs. GAC media regeneration requires heating the spent material to temperatures greater than 1,000 °C and regenerated GAC may be less effective than virgin GAC (Watanabe et al., 2016).

GAC and PAC performance for PFAS treatment has been documented with bench, pilot, and full-scale studies reporting up to 99 percent removal of PFAS depending on the compound being treated (Zhao et al., 2011; Ross et al., 2018). Studies have shown that PFSAs are more readily adsorbed than PFCAs, and long-chain PFAS are more readily adsorbed than short-chain PFAS (Appleman et al., 2014; Ross et al., 2018; EPA, 2021f). Increased pH and organic matter content in the adsorbate can decrease PFAS adsorption rates.

10.2.2 Ion Exchange Resins

Ion exchange (IX) technology removes charged contaminant ions using exchange sites on synthetic, highly porous resins in batch or continuous flow reactors. The charged resin sites attract and bind to oppositely charged contaminant ions.

Most PFAAs are present in environmental matrices in their anionic form and may be removed from water by anion exchange resins. Sorption rates will vary based on the resin and porosity. Unlike activated carbon, IX resins can be specialized to selectively target specific PFAS, require less contact time, and remove higher PFAS loads than GAC or PAC.

While IX technology has been used for decades, the development and use of selective resins for PFAS removal is relatively new. IX resin options for removal of PFAS include single-use and regenerable resins. Single-use resins are used until breakthrough occurs at a preestablished threshed and are then removed from the treatment unit. Regenerable IX resins may be regenerated on site using regenerant solution once active sites have been occupied but may not offer the same removal efficiency as single-use resins and cannot be infinitely regenerated. Resin regeneration creates a concentrated PFAS liquid wastestream that must be further treated or disposed. Continuous flow studies of IX resins for PFAS removal report that breakthrough occurs for PFCAs before PFSAs and short-chain PFAS before long-chain PFAS (Boyer et al., 2021). Bench- and pilot-scale studies captured in EPA's DWTD report PFAS removals from 30 to 99 percent (EPA, 2021f).

10.2.3 Other Adsorbents for PFAS Removal

EPA identified several other adsorbents that have demonstrated an ability to remove PFAS, listed below. As with activated carbon and IX resins, the properties of the adsorbent and the wastestream impact the amount of PFAS that can be removed.

- **Polymer adsorbents.** Synthetic materials that can be designed with specific traits suitable for the targeted removal of specific PFAS. Polymer adsorbents may have high hydrophobicity or an electrostatically charged surface to increase PFAS removal. Some polymer adsorbents may be regenerated and studies show regeneration can occur under much lower temperatures compared to GAC, allowing for less damage to the adsorbent. Some polymer adsorbents, such as crosslinked cyclodextrin polymers and cationic hydrogels, demonstrate more than 90 percent removal of long-chain PFAS and more than 80 percent removal of short-chain PFAS (greater sorption of short-chain PFAS than GAC) (Xiao et al., 2019; Ateia et al., 2019; EPA, 2021f).
- **Modified mineral adsorbents.** Mineral sorbents that have been modified using organic additives to increase PFAS sorption, such as organically modified silica and organoclays (Stebel et al., 2019). Bench-scale studies have observed more than 90 percent removal of total PFAS, with higher PFSAs removal rates than PFCAs.
- **Biochar.** Carbonaceous material derived from biomass. Biochar requires less energy to generate than activated carbon but has slower adsorption kinetics and lower observed PFAS removal relative to GAC. Short-chain PFAS are not readily removed using biochar (Xiao et al., 2017; ITRC, 2020).

10.3 Membrane Filtration

Membrane filtration is a physical separation process used for removal of both organic and inorganic compounds in water. A driving force is applied to the influent stream to push pressurized water through a semi-permeable membrane while rejecting larger, undesirable contaminants. Treated water (permeate) passes through the membrane and the rejected water (concentrate) is collected for treatment or disposal. All membrane processes generate a concentrated PFAS liquid wastestream that must be further treated or disposed. Membranes may also need to be replaced or disposed, generating a solid waste product. The following types of membranes are well-studied for PFAS removal:

- **Reverse Osmosis (RO).** RO is a form of membrane filtration in which pressure is applied to transport liquid through a membrane with a pore size of less than 1 nanometer. RO can be run as a continuous flow or batch process. EPA's DWTD reports that RO typically achieves at least 98 percent removal of PFAS regardless of chain length or functional group (EPA, 2021f). One full-scale treatment study has reported between 67 and 97 percent removal of total PFAS using RO (Glover et al., 2018).
- **Nanofiltration (NF).** NF is a membrane process that is lower in pressure than RO in which the membrane has pore sizes between 1 and 10 nanometers. Nanometer-sized membrane pores are used to remove compounds in a process similar to RO, but NF allows smaller PFAAs and salt ions to pass through which would otherwise be captured by the smaller pore sized used in an RO system. Lab-scale studies have shown nanofiltration removal of PFAS up to 90 percent (Boo et al., 2018).
- **Low Pressure Membrane Filters.** Ultrafiltration and microfiltration, two additional types of membrane filters with pore sizes larger than 10 nanometers, are less effective at capturing nonpolymer PFAS and are typically used for particulate removal. Sampling at full scale DWTPs using microfiltration or ultrafiltration has shown no or inconsistent removal (typically less than 50 percent) of PFCAs and PFSAs (EPA, 2021f), unless a powdered adsorbent is used within the system.

Wastestreams may need to go through a pretreatment step to reduce the risk of membrane damage or fouling (loss of production capacity) due to accumulation of material on the membrane surface.

10.4 Incineration/Thermal Treatment

Thermal treatment or incineration is using high temperatures to chemically break down PFAS. Incineration has been used to destroy other halogenated organic chemicals such as polychlorinated biphenyls (PCBs) and ozone-depleting substances, where sufficiently long exposures to sufficiently high temperatures break the carbon-halogen bond, after which the halogen can be scrubbed from the flue gas, typically as an alkali-halogen (EPA, 2019c). These treatments can be used for AFFF and solid wastes onto which PFAS has adsorbed, such as spent GAC or sludge, but may also be applied to PFAS-containing wastewater. However, PFAS are more difficult to break down than other halogenated organic chemicals due to fluorine's electronegativity and the chemical stability of fluorinated compounds.

Incinerators or combustors that are already in place for hazardous or municipal waste destruction may be used to destroy PFAS (Watanabe et al., 2016; EPA, 2020e). Incomplete destruction of PFAS during combustion can result in the formation of smaller PFAS or mixed halogenated organic byproducts, referred to as products of incomplete combustion (PICs) (EPA, 2019c, 2020f).

The effectiveness of incineration to destroy PFAS and the tendency for formation of PICs is not currently well understood. Few experiments have been conducted under oxidative and temperature conditions representative of field-scale incineration. Limited studies on the thermal destructibility of fluorotelomer-based polymers found no detectable levels of perfluorooctanoic acid after 2 second residence time at 1,000°C (Yamada et al., 2005; Taylor et al., 2014). Emission studies, particularly for PICs, have been incomplete due to lack of necessary measurement methods suitable for the comprehensive characterization of fluorinated and mixed halogenated organic compounds. EPA is actively researching the effective destruction temperatures and treatment times for PFAS, the potential to generate PICs, and the release and potential land deposition of PFAS-containing stack gases.

10.5 Advanced Oxidation and Reduction Processes

Advanced oxidation and reduction as methods for destruction of PFAS have been studied more in recent years. Through a series of oxidation and reduction reactions, PFAS molecules are defluorinated, decreasing the fluorinated carbon chain length until the PFAS molecules are degraded into base components such as CO_2, H_2O, and F^-. Full destruction is achieved when only the base components remain. Because PFAS are destroyed through these processes, PFAS are eliminated from wastewater rather than being captured via adsorption or membrane filtration. If PFAS molecules are not fully destroyed through these reactions, effluent concentrations of PFAAs and precursors can increase.

Most advanced oxidation and reduction processes do not generate a liquid or solid waste that would need to be managed.

10.5.1 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) treat water by activating an oxidizing agent to react with and degrade contaminants. Chemical oxidation uses chemical catalysts to initiate degradation reactions. Chemical catalysts that have been studied for PFAS destruction include ozone, zero valent iron, and persulfate (Mitchell et al., 2013; Dai et al., 2019; Lee et al., 2020). Electrochemical oxidation uses electrical currents generated by specialty electrodes to catalyze oxidation reactions. Boron doped diamond electrodes, metal-oxide electrodes, and porous electrode membranes have been studied for PFAS destruction and studies report PFAS mass reductions ranging from 71 to 99 percent (Gomez-Ruiz et al., 2017; Le et al., 2019; AECOM, 2020; EPA, 2021w).

EPA's PFAS Innovative Treatment Team (PITT) identified electrochemical oxidation and supercritical water oxidation (SWCO) as two noncombustion PFAS destruction treatments for further research and consideration (EPA, 2021w, 2021x). SWCO catalyzes rapid oxidation reactions by applying heat greater than 705 °C and pressure greater than 221.1 bar to an aqueous solution or solid. In the presence of an oxidizing agent, supercritical water dissolves and oxidizes PFAS. SWCO has demonstrated up to 99 percent destruction of targeted PFAS in diluted AFFF, membrane concentrate, and landfill leachate by three vendors (EPA, 2021x). PITT further reports that SWCO is a potential solution for treatment of spent GAC and IX resin.

AOPs are nonselective, oxidizing all available contaminants. Therefore, the presence of nonPFAS oxidizable compounds in the influent may increase competition and reduce PFAS removal efficiency (particularly with chemical oxidation). Removing nonPFAS oxidizable compounds prior to AOP reduces treatment time and the amount of oxidant needed to destroy PFAS, increasing treatment performance (Ross et al., 2018).

10.5.2 Advanced Reduction Processes

Advanced reduction processes (ARPs) use the same reaction mechanisms as AOPs but use positively charged radicals to initiate reduction reactions to degrade PFAS rather than oxidation reactions. Strong alkaline systems are required to initiate reduction reactions. Lab-scale studies have shown between 70 percent and 99.9 percent destruction of PFAS at pH9 to pH12 using ARPs (Qu et al., 2014; Bentel et al., 2020).

10.6 Emerging PFAS Treatment Technologies

Table 14 presents PFAS treatment technologies that are in earlier stages of research and development. Some of these technologies build on treatment mechanisms outlined in the previous sections. There are limited data available on applicability and scalability of these treatments.

Table 14. Emerging PFAS Destruction Technologies

Treatment	Treatment Description	State of Research	Reference
Aqueous Electrostatic Concentrator	Combined use of IX membrane and electrodes to separate PFAS from solution and initiate oxidation reactions.	Lab-scale study of the patented technology reports 99% removal of both PFOA and PFOS.	Jackson, 2019
Bismuth Oxyhydroxyphosphate (BOHP)	Photocatalytic process in which BOHP ($Bi_3O(OH)(PO_4)_2$) is activated by ultraviolet light to degrade PFAS through oxidation or reduction reactions.	A pilot-scale study from the DOD's Strategic Environmental Research and Development Program (SERDP) reports up to 95% destruction of PFCAs and 90% degradation of fluorotelomers.	Sahu et al., 2018 Cates, 2020
Boron Nitride Oxidation	Use of activated boron nitride and ultraviolet light to degrade compounds.	One lab-scale study reports 99% removal of PFOA and 20% removal of HFPO-DA.	Duan et al., 2020
Electron Beam (E-beam)	Use of an accelerator to generate a stream of highly energetic electrons that are bombarded onto contaminated water, initiating both reduction and oxidation reactions.	Reports from SERDP state E-beam technology reduced PFOA and PFOS concentrations by up to 99.99% in soil samples and up to 87.91% in groundwater samples.	Pillai, 2020
Enhanced Contact Plasma Reactors (ECPR)	Plasma-based water treatment uses electricity to convert water into a mixture of highly reactive species (i.e., plasma) that rapidly and nonselectively degrade PFAS.	Lab-scale studies report up to 99% removal of PFAS for lab-prepared solutions and landfill leachate samples.	Singh et al., 2019, 2021
Mechanochemical Degradation	Destruction method using a high-energy ball-milling device and co-milling reagents to produce localized high temperatures and radicals that break down contaminants.	One lab-scale study reports 99% destruction of target PFAS in AFFF-impacted soil. Identified by EPA's PITT as a potential noncombustion destruction method for PFAS that would not require high temperatures or solvents.	EPA, 2021y
Pyrolysis and Gasification	Thermal treatment that decomposes materials at moderately elevated temperatures in oxygen free or very low oxygen environments. Used to transform biosolids into biochar and hydrogen-rich synthetic gas.	Limited data available on PFAS destruction. Identified by EPA's PITT as a potential noncombustion destruction method for PFAS in biosolids.	EPA, 2021z
Sonochemical Oxidation/ Ultrasound	Use of sound waves to facilitate cavitation in water which in turn releases large amounts of thermal energy and hydroxyl radicals to initiate PFAS degradation reactions.	One lab-scale study reports 90% destruction of PFOS. Identified by EPA's PITT as a potential noncombustion destruction method for PFAS in biosolids.	Wood et al., 2020

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