Per- and Poly-fluoroalkyl Substances (PFAS):
Policy Analysis
Toxics Use Reduction Institute
DRAFT
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Overview

The per- and poly-fluoroalkyl substances (PFAS) constitute a large category of chemicals. PFAS chemicals have unique properties, such as water and stain resistance, that can make them useful in a variety of settings. They all share certain characteristics, such as persistence and breakdown products of concern.

PFAS have been studied in detail by a number of authoritative bodies. For example, the Organisation for Economic Co-operation and Development (OECD) has done the most comprehensive work on PFAS as a class; the US EPA has done extensive research on two PFAS compounds; and certain states have researched individual PFAS chemicals in depth. Therefore, the TURA program has made use of existing documentation on the topic wherever possible.

PFAS have been detected in drinking water in many parts of Massachusetts. As described by the Massachusetts Department of Environmental Protection (MassDEP), "Between 2013 and 2015 in Massachusetts, 158 public water systems serving more than 10,000 people and 13 smaller systems were required to test for six PFAS chemicals as part of EPA's third round of the Unregulated Contaminant Monitoring Rule (UCMR3). PFAS was detected at nine Massachusetts drinking water sources above EPA's specified reporting limits." Several efforts are under way to address some aspects of PFAS contamination in Massachusetts, including an effort to set a maximum contaminant level (MCL) for six PFAS.[1] MassDEP has noted that "since 2013, the sum of the concentrations of the six PFAS compounds above 20 ppt [parts per trillion] have been detected at over 20 PWSs [public water systems] in Massachusetts."[2]

Due to national concerns about PFAS contamination, the 2019 National Defense Authorization Act (NDAA) has required EPA to add an initial group of PFAS to the list of chemicals subject to reporting under the Toxics Release Inventory (TRI). Based on EPA's analysis, this initial requirement will cover 160 chemicals.

While these and other activities are on-going, PFAS continue to be used in industry and products, and released into the environment. Addressing PFAS under the TURA program would help manufacturers to understand how PFAS are being used, identify ways to reduce their use, and limit their future liability.

Recommendation

There are several thousand PFAS chemicals, so it was not possible for the TURA Science Advisory Board (SAB) to review them all individually. In addition, research has not yet been conducted on health effects of many of these chemicals, although they are being discharged into the environment. Therefore, the SAB chose representative subcategories for review.

The SAB has reviewed the scientific evidence on 12 PFAS chemicals and their salts. The SAB has voted on a number of recommendations related to PFAS (see Appendix D), and is continuing to review information on the category. Across the entire category of perfluoroalkyl/per- and polyfluoroalkylether acids (PFAAs), the SAB found many similar hazards, as described in more detail below. The SAB is currently reviewing scientific information showing that the PFAA precursors break down into the PFAAs via a number of pathways. The SAB is currently reviewing the Organization for Economic Cooperation and Development (OECD) list of PFAAs and PFAA precursors, including information about known and potential breakdown pathways.

In considering a recommendation on listing of a PFAS category, TURI will take into account the SAB's findings on PFAS as a class, drawing upon their detailed review of individual chemicals within the class as well as their on-going review of breakdown pathways. TURI's approach to defining a proposed PFAS category will also take into account the list of PFAS that will be added to TRI.

OECD has created as comprehensive a list as possible of substances that they consider to be PFAS, including precursors. Once the SAB has completed its work, TURI will make a recommendation about how to define a PFAS category under TURA.

Category description

The following is a description of the broad chemical category of PFAS. This is an approach to organizing chemicals that have similar chemical characteristics, not a description of a proposed regulatory category.

An OECD study identified over 4,700 PFAS-related CAS numbers. In its 2018 document, *Toward a New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances (PFASs): Summary Report on Updating the OECD 2007 List of Per- and Polyfluoroalkyl Substances (PFASs),* OECD broadly divided PFAS into "commonly recognized per- and polyfluoroalkyl substances" and "other highly fluorinated substances that match the definition of PFASs, but have not yet been commonly regarded as PFASs." Within the first category of "commonly recognized" PFAS, OECD divides the substances into perfluoroalkyl/per- and polyfluoroalkylether acids (PFAAs), PFAA precursors, and other PFASs. For convenience and clarity within the present document, TURI uses the following broad terms for subcategories of PFAAs: "carboxylic and sulfonic acids," "phosphonic and phosphinic acids," and "ethers" (see Figure 1).

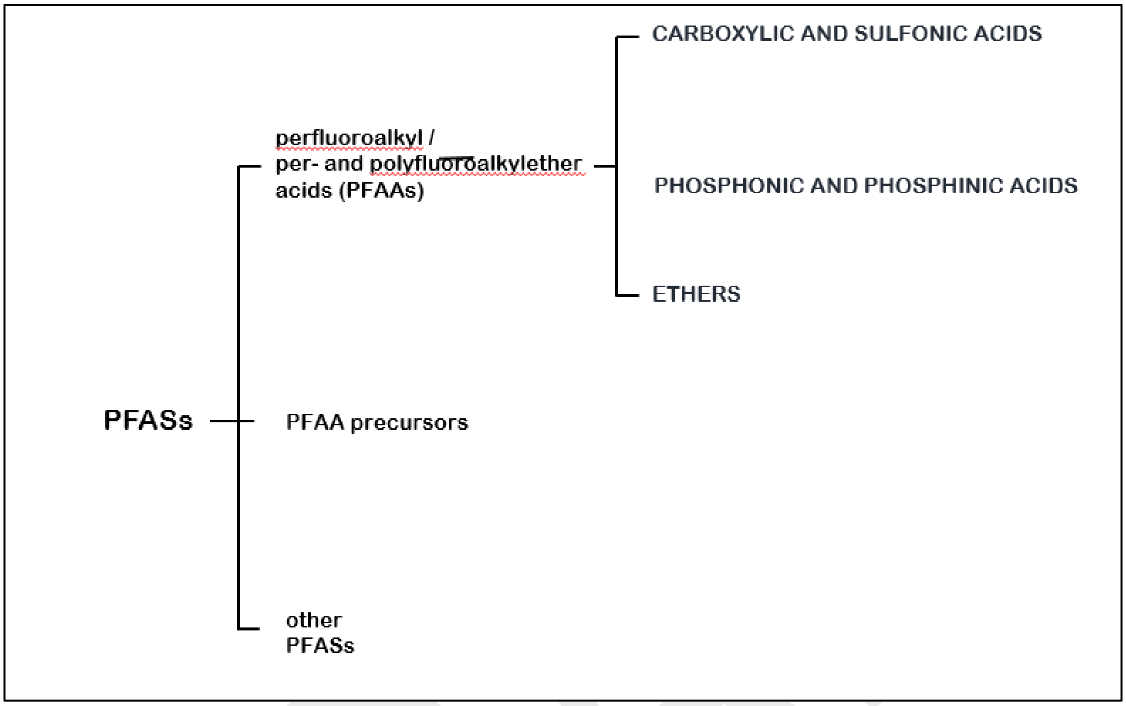

Figure 1: Overview of PFAS

- **PFAAs.** The PFAAs are further separated into sub-groups: the carboxylic and sulfonic acids (perfluoroalkyl carboxylic acids [PFCAs], perfluoroalkane sulfonic acids [PFSAs]), the phosphonic and phosphinic acids (perfluoroalkyl phosphonic acids [PFPAs], perfluoroalkyl phosphinic acids [PFPiAs]), and the ethers (per- and polyfluoroether carboxylic and sulfonic acids [PFECAs and PFESAs]). This grouping is shown in simplified form in Figure 1, and with additional detail in Appendix A.
- **PFAA Precursors.** The PFAA precursors are chemicals that break down into the PFAAs. An example of this process is shown in Appendix C.
- **Other PFAS.** The category of "other PFASs" includes fluoropolymers and other compounds (see Appendix for more details). Note that the polymers may be solid resins or lower molecular weight polymer dispersons.

Note: PFCAs, PFSAs, and their precursors are often identified by the length of the fluorinated carbon chain. For example, C8 refers to an 8-carbon alkyl chain. OECD and EPA have also developed an approach to categorizing PFAS into "long chain" and "short chain."[1]

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[1] OECD 2018 notes that "Based on the commonly accepted OECD definition, long-chain PFAAs refer to perfluoroalkyl carboxylic acids (PFCAs) with ≥ 7 perfluorinated carbons and perfluoroalkane sulfonic acids (PFSAs) with ≥ 6 perfluorinated carbons." OECD. 2018. *TOWARD A NEW COMPREHENSIVE GLOBAL DATABASE OF PER- AND POLYFLUOROALKYL SUBSTANCES (PFASs): SUMMARY REPORT ON UPDATING THE OECD 2007 LIST OF PER- AND POLYFLUOROALKYL SUBSTANCES (PFASs).* ENV/JM/MONO(2018)7. Series on Risk Management No. 39. Viewed at http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en, February 2019. For a helpful discussion of naming conventions, see ITRC. "Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS), available at https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_naming_conventions__3_16_18.pdf. As explained by ITRC, "Note that for carboxylates, the total number of carbons used for naming the compound includes the carbon in the carboxylic

The SAB's work to date has focused on the PFAAs. Within this category, the science described in this document refers to the carboxylic and sulfonic acids, which have been widely identified as contaminants in the environment, the phosphonic/phosphinic acids, and GenX and ADONA (as examples of ethers).

Summary of Scientific Information

Summary. In general, the chemicals that the SAB has reviewed are characterized by very high persistence in the environment; they do not break down under normal environmental conditions. In addition, all of these chemicals pose some degree of bioaccumulation concern, especially in air breathing organisms. The longer-chain chemicals are the most bioaccumulative, but the shorter-chain chemicals also bioaccumulate, at least in plants. Key health endpoints of concern include effects on the endocrine system, including liver and thyroid, as well as metabolic effects, developmental effects, neurotoxicity, and immunotoxicity. Some of these health endpoints have been documented for multiple chemicals that the SAB reviewed. Other health effects have been documented for only one or two chemicals, but are highlighted here because they have been found in a large number of studies.

SAB approach. In order to understand the characteristics of a range of PFAAs, the SAB examined eight substances of varying chain lengths: PFNA (C9); PFOS and PFOA (C8); PFHpA (C7); PFHxA and PFHxS (C6)[2]; and PFBA and PFBS (C4). The SAB then reviewed two ethers (GenX and ADONA), and phosphonic and phosphinic acids (PFPA and PFPiAs) of varying chain lengths.

For PFOS and PFOA, the SAB recommended listing based on PBT data from authoritative sources.

For the other chemicals, the SAB reviewed the literature on health and environmental effects as well.

The literature on health effects of PFOS and PFOA was also used for context in evaluating the other PFAS substances. This included examining the health and environmental effects of PFOS and PFOA, then examining the literature to determine whether information is available on these effects for the other chemicals in question.

In addition to considering primary research publications, the SAB was able to draw upon analyses conducted by many other government agencies, including other states such as Minnesota and New Jersey.

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acid functional group (COOH), and so although PFOA has seven carbons in its fluoroalkyl tail, all eight of the carbons in the molecule are used to name it, hence perfluorooctanoate. However, in terms of chemical behavior, PFOA would be more analogous to seven-carbon perfluoroheptane sulfonate, PFHpS, than to eight-carbon perfluorooctane sulfonate, PFOS."

[2] Note regarding the C6 molecules: EPA classifies PFHxS along with PFOS and PFOA as a long-chain PFAS, while PFHxA is classified with the shorter-chain PFAS.

PFAAs are highly persistent and do not break down under environmentally relevant conditions. Longer-chain substances (in particular the C8 substances, PFOS and PFOA) have been studied in greater depth than shorter-chain substances. The in-depth information on longer-chain substances includes the C8 Science Panel study of epidemiological data on more than 70,000 individuals resulting from widespread human exposure to C8 compounds in drinking water in Parkersburg, West Virginia, due to releases from a DuPont facility.

In addition to reviewing the hazard information presented below, the SAB reviewed a number of degradation/transformation pathways. These are the pathways through which a PFAS precursor breaks down into one of the end degradation products. All the chemicals for which hazard information is presented here are end degradation products in addition to being used intentionally.

PFOS and PFOA. In its examination of the C8 substances, the SAB found evidence of persistence, bioaccumulation, and acute toxicity. These findings were sufficient for the SAB to recommend listing these substances. In addition, the SAB was able to review the results of the C8 Health Project.[3] This project resulted from a settlement agreement related to PFOA contamination in two states. It documented a wide range of chronic human health endpoints associated with exposure to PFOA. Hazards that were documented within the C8 Health Project include carcinogenicity (probable links to kidney and testicular cancer), pregnancy-induced hypertension (PIH), ulcerative colitis, thyroid disease, and hematological effects including effects on blood cholesterol levels, among others. In addition, a report by the National Toxicology Program (NTP) notes that PFOS and PFOA are "presumed to be an immune hazard to humans." [4] This information added important additional context for understanding the range of health impacts of PFAS of other lengths as well. The SAB was able to use this information to identify health endpoints for literature review.

C7 and lower. For the PFAS substances with fewer than eight carbons, less information was available. They are all highly persistent in the environment and have a range of half-lives[5] in the human body (days to years). These substances also show some evidence of bioaccumulation and they are very mobile, creating the potential for global transport. They have been found in serum and breastmilk, and their presence in the environment creates the potential for on-going exposures. They are less acutely toxic than the C8 substances. However, the SAB's literature review found evidence of a range of chronic health effects, including immunotoxicity, thyroid, liver/metabolic effects, endocrine effects, hematological effects, neurodevelopmental effects, reproductive effects, asthma, and neurotoxicity. These substances are strong acids and are very corrosive in their concentrated form.

It is also worth noting that while the shorter-chain substances are not as bioaccumulative in air-breathing organisms as the longer-chain substances, they show greater bioaccumulation in plants.[6,7]

C9. The New Jersey Drinking Water Institute had recently published its Health-Based Maximum Contaminant Level Support Document for the C9 substance, perfluorononanoic acid (PFNA).[8] PFNA also is highly persistent in the environment and has a half-life of greater than 1.7 years.[9]

PFNA shows bioaccumulation concern and mobility in the environment. The SAB's literature review also found evidence of developmental/reproductive effects, immunotoxicity, effects on the liver, neurotoxicity and corrosivity.

Ethers: GenX and ADONA. GenX and ADONA are trade names for two PFAS "that have been developed for use as processing aids in the manufacturing of fluoropolymers" and that have been detected in the environment. Both are fluorinated ether carboxylates.[3]

The EPA Draft Toxicity Assessment for GenX was published shortly before the SAB review. The SAB noted persistence, mobility, corrosivity, and liver toxicity as the primary concerns for GenX.

For ADONA the SAB noted that it followed the patterns of the other PFAS that the SAB has reviewed, such as liver effects, persistence, differences in effects based on gender, corrosivity, and maternal toxicity. However, available data were not sufficient for a recommendation. The SAB noted an overall lack of publicly available studies, especially cancer, immunotoxicity, neurotoxicity, thyroid and complete reproductive details.

Phosphonic and phosphinic acids: PFPA and PFPiA. Concerns were identified for mobility, persistence, and corrosivity (pKa), as well as evidence of liver toxicity and acute toxicity for some of the compounds. Additional evidence shows these compounds are precursors to PFCAs such as PFOA.

Bioaccumulation – additional information. It is also helpful to understand that while bioaccumulation is often assessed through studies of fish, in the case of PFAS, this approach is less relevant. PFAS bind to proteins rather than to lipids,[10] so it is important to consider levels in blood serum, rather than in fatty tissue. In addition, gill-breathing organisms are more able to eliminate certain PFAS due to their water solubility, while air-breathing organisms are more vulnerable to bioaccumulation.[11] Although bioaccumulation in fish may be lower than in air-breathing organisms, bioaccumulation of certain PFAS is being detected in fish (for example, in fish livers).[12]

Table 1 shows the information reviewed by the SAB regarding chronic health effects. An "X" indicates that there was evidence for that effect in the literature. For additional information, see Appendix B.

Table 1: Chronic health effects

	PFNA	PFOA	PFOS	PFHpA	PFHxA	PFHxS	PFBA	PFBS	GenX	ADONA	PFPA/PFPiA
Cancer		Kidney, testicular							X		
Immunotoxicity	X	Ulcerative colitis	X					X	X		
Thyroid		X			X	X	X	X		X	X

[3] GenX is a "trade name for ammonium, 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate (CF3 CF2 CF2 OCF(CF3)COONH4 +, CAS No. 62037-80-3), a perfluoropolyether carboxylate surfactant." ADONA is a "trade name for ammonium 4,8-dioxa-3H-perfluorononanoate (CF3 OCF2 CF2 CF2 -OCHFCF2 COONH4 + (CAS No. 958445-44-8), a polyfluoropolyether carboxylate surfactant." For more information, see ITRC, "Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS)," available at https://pfas-1.itrcweb.org/wp-content/uploads/2017/10/pfas_fact_sheet_naming_conventions_11_13_17.pdf.

Endocrine (other than thyroid)					X	X	X	X			
Hematological		Cholesterol				X	X	X			
Liver/metabolic	X			X	X	X	X	X	X	X	X
Reproductive	X	PIH**							X	X	X
Developmental	X			X	X		X	X	X		
Neurodevelopmental						X					
Neurotoxicity	X				X	X		X			
Asthma						X		X			
Other	Mutagenicity				Kidney			Kidney	Kidney		Acute toxicity

Note: The SAB did not conduct a literature review for PFOS and PFOA due to the volume of information available through authoritative bodies and large scale epidemiological studies. Therefore, the endpoints shown for PFOA are not identical to those shown for the other chemicals. For PFOS, the SAB was able to use information from NTP so a literature review of additional studies was not necessary.
** Pregnancy Induced Hypertension

Table 2 shows the information reviewed by the SAB regarding the presence of PFAS in the environment, including presence in groundwater and surface water, as well as their potential for persistence and bioaccumulation.

Table 2: Persistence, presence in the environment, and bioaccumulation

	PFNA	PFOA	PFOS	PFHpA	PFHxA	PFHxS	PFBA	PFBS	GenX	ADONA	PFPA/ PFPiA
Persistence	X	X	X	X	X	X	X	X	X	X	X
Bioaccumulation	X	X	X	X	X	X	X	X	X		
Presence in the environment	X	X	X	X	X	X	X	X	X		
Presence in biota, including humans	X	X	X	X	X	X	X	X	X		X

Notes:
- Information on these chemical properties is drawn from peer reviewed studies and from US or EU government documents.
- PFOS and its salts and perfluorooctanyl sulfonyl fluoride as well as PFOA, its salts, and PFOA-related compounds are designated as Persistent Organic Pollutants under the Stockholm Convention. For up to date information as of December 2019, see: http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx.
- PFHxS, its salts and PFXxS-related compounds are currently under review for possible addition to the Stockholm Convention as well.
- PFHxS and its salts are listed as vPvB, and PFNA and its salts, APFO, and PFOA are listed as PBT by the European Chemicals Agency (ECHA, Candidate List of Substances of Very High Concern for Authorization, https://echa.europa.eu/candidate-list-table).

Use information

Non-polymeric PFAS may be as used as surfactants, wetting agents, emulsifiers and polymerization processing aids, mist suppressants, pesticide active ingredients, and film formers.[13] Polymeric PFAS may be used as lubricants, insulators, protective coatings, and raw materials for textiles, semiconductors, and automotive components.[14] Some PFAS may be coincidentally manufactured and released to the environment as a result of the use or manufacture of other PFAS chemicals. For example, it has been documented that PFHxA can be a byproduct of PFAS manufacturing.[15]

Many of the chemicals in this category may be used for multiple purposes. For example, perfluorobutane sulfonic acid (PFBS) based substances are used as surfactants, as flame retardants, and in metal plating.[16]

To estimate how many facilities may be using PFAS in MA and could be affected by listing of PFAS under TURA, TURA program staff analyzed EPCRA Tier II data and also conducted research using other resources, as described below.

EPCRA Tier II Reporting

EPCRA Tier II requires reporting of any chemical with a Safety Data Sheet if it is stored at 10,000 pounds or more at a facility (or at 500 pounds or more if the chemical is designated as an extremely hazardous substance). A review of the 2017 Tier II data shows 49 records for PFAS chemicals[4], although this may include some duplicates. These results are described below and summarized in Table 3.

- *PFAAs.* One manufacturing facility reported on perfluoroalkane sulfonyl compounds used for a buffered oxide etch with surfactant.
- *Precursors.* Three facilities submitted a combined total of 16 reports for semifluorinated PFAA precursors or related compounds. Two facilities reported on perfluorinated PFAA precursors; one was a fire protection equipment distributor and the other was a chemical distributor for the electronics sector. One military-related facility reported on a fluorotelomer related compound, also used as a surfactant.
- *Fluoropolymers.* Fifteen of the records are for fluoropolymers (17 total entries, but 2 appear to be duplicates).
- *AFFF.* Nine facilities reported storing AFFF. Three are military/aerospace sites and five are energy-related businesses. One is a solar energy facility.

Table 3 shows the number of 2017 Tier II chemical reports, organized where possible by chemical structure as described by the OECD New Comprehensive Global Database of PFASs.[17]

Table 3: 2017 Massachusetts Tier II Data

	OECD Structure Category Name (where relevant)[18]	**Number of Tier II Reports in 2017***
PFAA	Perfluoroalkane sulfonyl compounds	1
PFAA precursors	Fluorotelomer-related compounds	1
	Other PFAA precursors and related compounds – perfluorinated	2
	Other PFAA precursors or related compounds - semifluorinated	16
Other PFAS	Fluoropolymers	17 ***
Possibly PFAA	AFFF**	9

[4] Search terms: 2017 MA Tier II data searched for key words: “fluoro”, (yielded records); “AFFF”, (yielded records); “Teflon”, (yielded records); “PFOA”, (no records); “PFOS,” (no records); “PFBS,” (no records); “PFBA,” (no records); “PFHxA,” (no records); “PFHxS, (no records); “PFNA,” (no records); “PFHpA,” (no records); “PTFE” (yielded records); “Alkyl,” (yielded records); “Foam” (yielded records)

Unknown	Not specified/cannot categorize based on available information	3
	Total	49***
	* This table includes facilities listed in Tier II regardless of whether they would be expected to be subject to TURA reporting requirements. ** AFFF is not an OECD category name. These chemicals could possibly be perfluoroalkane sulfonyl compounds or perfluoroalkyl carbonyl compounds. See NYSP2I. December 2018. "Per- and polyfluorinated Substances in Firefighting Foam." Page 6. Viewed at http://theic2.org/article/download-pdf/file_name/2018-12_Per%20and%20Polyfluorinated%20Substances%20in%20Firefighting%20Foam.pdf *** Possibly 2 duplicates	

Tier II data do not necessarily provide a comprehensive overview of all PFAS use. For example, of six facilities interviewed by one TURA program staff member in 2019, two gave answers that did not correspond to their Tier II reporting. One facility stated it did not use PFAS, although it has reported PFAS use under Tier II. Another facility, which produces coated fabrics for the military, stated that it does use PFAS, but this facility had not reported under Tier II (possibly due to being under threshold).

Of the facilities that reported under Tier II in 2017, some would be likely to be required to report under TURA. Specifically, the manufacturing facilities and the chemical distributors would be likely to be subject to TURA, if their use of these chemicals exceeds the relevant threshold. TURA program staff estimate that of the Tier II reporters, five to ten would be expected to file under TURA. In addition, as we have observed, there are other facilities that may be using PFAS but not reporting under Tier II.

Additional research on Massachusetts use of PFAS

The TURA program also conducted a search with the intention of producing a broader, but by no means comprehensive, list of facilities that appear to manufacture in Massachusetts and are likely, but not confirmed, to use or manufacture per- and polyfluoroalkyl substances. This additional search was based upon the publicly available information on company products and processes that correspond with descriptions of PFAS use found in information produced by the OECD,[19] the U.S. Environmental Protection Agency (EPA),[20] the Interstate Technology Regulatory Council (ITRC),[21] and the New York State Pollution Prevention Institute (NYSP2I).[22]

Specifically, the TURA program took the following approach to identifying potential PFAS users in Massachusetts. First, program staff used three databases – Hoover Online, ReferenceUSA, and A to Z -- to search for businesses in Massachusetts operating under specific SIC or NAICS codes.[5] These SIC and NAICS codes were selected as a means to gather preliminary information, but are not expected to cover all the relevant industry sectors. Reporting requirements under TURA would provide more reliable information.

[5] The following SIC codes were included in the search: 2821 (Plastics Materials and Resins), 3479 (Metal Coating and Allied Services), and 3999 (Manufacturing Industries), SIC 2295 (Coated Fabrics, Not Rubberized) and SIC 5172 (Petroleum Products). The following NAICS codes were used in the search: 322220 (Paper Bag and Coated and Treated Paper Manufacturing), NAICS 334419 (Other Electronic Component Manufacturing), NAICS 335999 (All Other Miscellaneous Electrical Equipment and Component Manufacturing), and NAICS 335929 (Other Communication and Energy Wire Manufacturing).

TURA program interns then reviewed the web pages of the businesses identified from the database search, and noted which businesses had a high probability of using PFAS based on their product profile. For example, if a facility website noted that its process includes application of a water-resistant coating, this was noted as a potential PFAS user. This does not indicate that PFAS chemicals are actually being used at the facility, but simply that it is a possibility.

The sectors reviewed in this process included Coated Fabrics, Not Rubberized; Electronic Component Manufacturing, Electrical Equipment and Component Manufacturing; Manufacturing Industries; Metal Coating and Allied Services; Plastics Materials and Resins; Petroleum Products; and Paper Products. There are additional sectors that would also be of interest but were not included in this process; one example is textile and leather coating. Reviewing additional sectors would be likely to suggest additional possible users.

Based on this review of web pages, approximately 240 facilities were identified as possible users of PFAS in Massachusetts. Without contacting each individual facility, it is not possible to determine which of them are actually using PFAS. For lack of more precise information, TURA program staff are estimating that in addition to those facilities identified through Tier II reporting, around 20 to 40 additional facilities could be required to report PFAS use under TURA if a reporting category is defined to include all types of PFAS recognized by OECD. It is important to bear in mind that this is a very rough estimate because of the lack of reliable information on use of chemicals in this category. The actual number of facilities subject to reporting would depend on many factors, including how the category is defined and what reporting threshold is adopted.

Estimating total users

TURA program staff have developed a rough estimate of the number of facilities that could be subject to TURA program requirements if the PFAS recognized by OECD are added to the TURA list. Five to ten possible users are estimated from Tier II and 20-40 possible users are estimated from the review of websites. Putting these two information sources together, and in the absence of a more complete and reliable data source, program staff estimate a total of approximately 25-50 users of PFAS in TURA covered sectors. The actual number of filers would depend on many factors, including thresholds, categories vs. individual chemicals, and approach to fluoropolymers.

Opportunities for TUR

In considering opportunities to reduce or eliminate PFAS use, some researchers have adopted a framework that distinguishes among uses. An article by Cousins et al. contends that many uses of PFAS can be phased out because they are not necessary or because "functional alternatives are currently available that can be substituted into these products or applications."[23] They refer to the Madrid Statement, which calls on the international community "to cooperate in limiting the production and use of PFASs and in developing safer nonfluorinated alternatives."[24]

Cousins et al. propose three categories to describe different levels of essentiality of PFAS use: "non-essential," "substitutable," and "essential." This approach draws upon the approach used in the Montreal Protocol to categorize and address ozone-depleting chlorofluorocarbons. They define "non-essential" uses as those that are are mainly driven by market opportunity. The authors describe use of PFAS in these cases as "nice to have," but note that PFAS use in these cases can be phased out. They define "substitutable" uses as those that perform important functions, but for which alternatives have been developed that have equivalent functionality and adequate performance. PFAS can be removed from these uses. Efforts may be needed to make alternatives to PFAS for these uses more well-known and available. Costs of alternatives should decrease as use increases. Finally, they use the term "essential" to refer to those applications that are important for health or safety or other important purposes and for which alternatives are not yet established.[25] These too may be eliminated over time, but innovative research may be needed to develop feasible alternatives. Market incentives and funding can help to stimulate such research.

The TURA program has briefly examined alternatives for several applications. This is an area of active research, and the program will gather additional information on these topics.

- *Aqueous Film-Forming Foam (AFFF):* An April 2019 report by the New York State Pollution Prevention Institute (P2I) reviewed available information on fluorine-free foams. The P2I researchers identified more than 90 fluorine-free options. "[26] They identified a number of challenges, including lack of independent testing data and lack of full information on ingredients in foams. They identified a number of future steps that will facilitate selection among this variety of fluorine-free products. The report's recommendations include further research on ingredients of fluorine-free alternatives, assistance to non-military users in changing to fluorine-free alternatives.[27] Other institutions, including the Department of Defense, are also working actively to research and facilitate the adoption of fluorine-free options.
- *Textile and Fabric Treatment:* Multiple PFAS-free chemical alternatives that prevent soils from adhering to and staining agents from penetrating the fiber surface are becoming available. The exact formulation of these products is largely unknown because manufacturers withhold the information as proprietary trade secrets.[28]According to a recent IPEN report, alternative fabric treatments are based on paraffins, silicones, dendrimers (hyper-branched polyurethane polymers), and polyurethane for water and dirt resistance for outdoor clothing.[29] A Danish report states that many non-fluorinated alternatives to PFAS-based finishing agents provide water repellency but may not provide as much repellency against oil, alcohol, and oil-based dirt. According to the report, alternatives based on polymer coatings, such as polyvinyl chloride (PVC) or polyurethane, may provide such repellency, although the fabrics may not be as breathable and have not been comprehensively assessed.[30] Other potential PFAS alternatives have been patented but may not yet be commercially available.[31]
- *Fume suppressants:* PFAS have historically been used as fume suppressants in hexavalent chromium plating operations. Additional information is needed on PFAS alternatives in this application.
- *Food packaging and food contact paper:* Efforts have been undertaken to gather and disseminate information on PFAS-free food packaging. Toxic-Free Future and Clean Production Action have developed a list of single-use disposable food packaging products is available without PFAS.[32] As Oregon's Department of Environmental Quality prepared to evaluate alternatives to food packaging containing PFAS, it published an

April 2019 "roadmap" to the process, prepared by Northwest Green Chemistry. The document recommends considering both existing and emerging options for PFAS-free food contact materials.[33]

Regulatory context

Due to the emerging nature of scientific knowledge about health and environmental impacts of PFAS, as well as revelations about water supply contamination in an increasing number of geographic areas, a variety of regulatory processes are on-going. A number of current regulatory actions are described here. This review is not comprehensive and regulatory actions are continually evolving In addition, there may be inconsistencies in state information in this document due to timing of updates of such activity on websites and in publications.

Approaches to grouping

A workshop held in Zürich, Switzerland in November 2017 brought together researchers and regulators from around the world to work towards better coordination to address PFASs. The group made a number of recommendations. One is that, given "the large number of substances in the PFAS family…actions need to address groups of PFASs rather than individual chemicals."[34] Such a grouping approach "requires a better mechanistic understanding of the physicochemical and toxicological properties of PFASs as well as additional data that can be used to support grouping approaches for PFASs."

The group supports regulation focused on high persistence in the environment, which "can lead to a continuous and nearly irreversible accumulation of PFASs in the environment and, in turn, increased exposure and risks to humans and wildlife…" Participants agreed on the importance of reducing, and eventually phasing out, nonessential uses of PFASs. As there is not a generally accepted definition of "essential uses," goals include defining this with regard to PFASs, and working to develop safe alternatives to PFASs that avoid regrettable substitutions.[35]

International

International agreements. PFOS as well as its salts and perfluorooctanyl sulfonyl fluoride are listed on Annex B of the Stockholm Convention on Persistent Organic Pollutants and are targeted for phaseout globally, with some exemptions.[36] In addition, PFOA, its salts, and PFOA-related compounds are listed on Annex A of the Convention. PFHxS (C6), its salts and PFHxS-related compounds are currently under review for possible addition to the Convention.[37] In September 2018, the UN Stockholm Convention on Persistent Organic Pollutants Review Committee (POPRC) recommended listing PFOA, its salts, and PFOA-related compounds in Annex A of the treaty, which calls for global elimination. The Committee also recommended removing exemptions for some applications of PFOS; and taking PFHxS, its salts and related compounds "to the next review stage, which requires a risk management evaluation…"[38] [39] [40]

A committee of the UN's Rotterdam Convention - which governs the prior informed consent of the importation and exportation of hazardous chemicals - also recommended the listing of PFOA, its salts, and PFOA-related compounds in September 2018.[41]

European Union. PFOA, PFHxS and its salts, PFNA and its salts, and ammonium pentadecafluorooctanoate (APFO, the ammonium salt of PFOA) are listed on the Candidate List of Substances of Very High Concern for Authorization under the EU's REACH regulation.[42] In addition, a number of other PFAS have been added to ECHA's Registry of Intentions for SVHC designation. These include nonadecafluorodecanoic acid (PFDA), henicosafluoroundecanoic acid (PFUnDA), tricosafluorododecanoic acid (PFDoDA) and several others.[43] PFOS is regulated in the EU as a persistent organic pollutant.

Canada. In October 2018, the Canadian government, through its health department and environment department, initiated development of amendments to its toxic substances regulations "to further restrict the manufacture, use, sale, offer for sale and import of…three oil and water repellents (PFOS, PFOA and LC-PFCA)."[44]

China. In 2011, China restricted the production of PFOS and PFOA and encouraged research and development on alternatives. In 2014, China's environmental protection ministry banned "production, transportation, application, imports and exports of PFOS, its salts, and perfluorooctane sulfonyl fluoride (PFOSF), except for specific exemptions and acceptable use."[45]

Federal

EPA – TRI. The National Defense Authorization Act[46] (NDAA) provides for the addition of a number of PFAS to the EPCRA 313 (TRI) list, effective January 1, 2020. Specifically, it provides for the addition of PFOA and its salts, PFOS and its salts, GenX and its ammonium salts, PFNA, PFHxS, and any PFAS substance that is in the TSCA inventory as of February 2019 and is currently subject to a significant new use rule (SNUR). The Act provides for a 100 lb reporting threshold and leaves open the question of designation of a class for SNUR chemicals. It also requires EPA to consider a number of other possible additions, including shorter chain and ether substances, to the TRI list within two years.

EPA has reviewed the criteria provided for in the NDAA and "found 158 chemicals that meet the requirements of this part of the NDAA. Twelve of these are among the 14 PFAS specifically listed in the NDAA; with the addition of the other two, there are a total of 160 PFAS subject to listing under the NDAA."[47]

EPA has also issued an Advance Notice of Proposed Rulemaking (ANPRM) on possible listing of additional PFAS.[48] In the notice, EPA notes that, " EPA is also considering establishing reporting thresholds for PFAS chemicals that are lower than the usual statutory thresholds due to concerns for their environmental persistence and bioaccumulation potential."[49]

EPA – SNURs. PFOS and PFOA are no longer manufactured within the US, although they are present in some products imported into the US. EPA has issued significant new use rules (SNUR) for these and certain other substances.

EPA – UCMR. EPA has collected data on selected PFAS under its Unregulated Contaminant Monitoring Rule 3 (UCMR 3) (77 FR 26072, 2012). UCMR allows EPA "to collect data for contaminants that are suspected to be present in drinking water and do not have health-based standards set under the Safe Drinking Water Act (SDWA)."[50] Under UCMR 3, EPA has required testing for PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFBS in all larger drinking water systems.[51]

EPA – health advisory for PFOS and PFOA. For PFOS and PFOA, EPA has developed a health advisory of 70 ppt (equivalent to ng/L) for lifetime exposure to the sum of PFOS and PFOA in public drinking water. "EPA's health advisories are non-enforceable and non-regulatory" and are designed to provide technical information to states and other public health officials.[52]

EPA – PFAS Action Plan. In February 2019, EPA released a "Per- and Polyfluoroalkyl Substances (PFAS) Action Plan." The main actions the EPA announced are initiating steps to:

- evaluate the need for a maximum contaminant level (MCL) for PFOA and PFOS;
- begin the necessary steps to propose designating PFOA and PFOS as "hazardous substances" through one of the available federal statutory mechanisms;
- develop groundwater cleanup recommendations for PFOA and PFOS at contaminated sites; and
- develop toxicity values or oral reference doses (RfDs) for GenX chemicals and perfluorobutane sulfonic acid (PFBS).[53]

EPA- Draft Toxicity Assessment for GenX and PFBS. In November 2018 the EPA released Draft Toxicity Assessments for PFBS and GenX. These documents provided comprehensive toxicity reviews as well as draft RfDs.

ATSDR. The Agency for Toxic Substances & Disease Registry (ATSDR) published "Toxicological Profile for Perfluoroalkyls: Draft for Public Comment" in June 2018; the public comment period closed on August 20, 2018. The toxicological profile characterizes the toxicology and adverse health effects information for perfluoroalkyls. It includes peer-reviewed profiles that review key literature about their toxicological properties.[54]

Department of Defense. The Department of Defense (DoD) held its first PFAS Task Force meeting in August 2019. DoD has found that numerous water systems for which it is the purveyor or from which it buys water have PFOS and PFOA levels higher than health advisory recommendations. DoD has "stopped land-based use of AFFF in training, testing and maintenance" per a 2016 policy. When it must use AFFF in emergencies, "releases are treated as a spill."[55]

State[6]

A number of states are in the process of developing new regulations and programs to address PFAS. This includes developing regulations and programs to:

[6] Note: This summary is current as of November 23, 2019; Massachusetts information is current as of December 2019.

- monitor and study PFAS
- label or disclose products containing PFAS
- limit or ban the use of PFAS
- specify that certain product types must be free of PFAS; and
- regulate PFAS levels in groundwater or drinking water.

This section summarizes these areas of activity at the state level. Examples are also shown in the tables in Appendices E and F.

Monitoring. The North Carolina legislature funded the monitoring and treatment of PFAS, particularly "GenX" substances.[56] [57] GenX is the trade name for a fluoroether-based processing aid technology. According to the U.S. EPA, in 2008, the agency received new chemical notices under the Toxic Substance Control Act from the manufacturer "for two chemical substances that are part of the GenX process (Hexafluoropropylene oxide (HFPO) dimer acid and the ammonium salt of HFPO dimer acid)."[58] These chemicals are generally referred to as GenX.

New Hampshire's Department of Environmental Services is investigating a number of sites in the state for the presence of PFAS in groundwater. These include landfills, industrial sites, fire departments and training facilities, and a wastewater treatment facility.[59]

The Washington Department of Health "plans to test several hundred water systems in the state for trace contamination of more than a dozen chemicals found in some firefighting foams."[60]

PFAS chemicals are included in the California Environmental Contaminant Biomonitoring Program, also known as Biomonitoring California.[61] A scientific guidance panel makes recommendations about priority chemicals for biomonitoring.[62]

Labeling and disclosure. While many regulatory actions focus on PFAS in water and in products, others focus on labeling of products containing PFAS, or address PFAS as part of chemical action plans and through designation as a hazardous waste. For example, in November 2017, PFOS and PFOA were listed as known to the state to cause reproductive toxicity under California's Proposition 65 law.[63] The State of Washington requires the reporting of PFOA and related substances, and PFOS and its salts, in children's products. [64] As part of the State of Washington's actions on PFAS-containing firefighting foam, as of July 1, 2018, manufacturers and sellers of PFAS-containing firefighting Personal Protective Equipment (PPE) "must notify purchasers in writing if the equipment contains PFAS and the reasons for using the chemicals."[65]

Environmentally Preferable Purchasing (EPP) policies. The Minnesota Pollution Control Agency works with the state's administrative department to develop specifications that aim to reduce environmental impacts of products and service contracts (often referred to as Environmentally Preferable Purchasing policies). In Minnesota, many state contracts are used by public entities in the state, as well as some non-profits. Specifications include that compostable food ware products "must not contain perfluoroalkyl and polyfluoroalkyl (PFAS)."[66] The State of Washington law that addresses PFAS in firefighting foam and PPE also directs the state's Department of Ecology and Department of Enterprise Services to develop preferred purchasing guidance. The guidance is meant to assist additional public sector partners to avoid purchasing firefighting foams and firefighting PPE that contain PFAS.[67]

Listing under safer products program. In 2018, the California Department of Toxic Substances Control proposed listing PFAS in carpets and rugs as a priority product under its Safer Consumer Products program.[68] In November 2019, it also proposed listing PFAS for use on converted textiles or leathers such as carpets, upholstery, clothing and shoes as a priority product.[69]

Firefighting foam. The State of Washington banned the use of PFAS-containing Class B firefighting foam (designed for flammable liquid fires) for training effective July 1, 2018. A ban on the manufacture, sale, and distribution of PFAS-containing Class B firefighting foam, with certain exemptions, takes effect on July 1, 2020.[70] In Minnesota, the use of Class B firefighting foam with intentionally added PFAS will be prohibited for use in testing and training effective July 1, 2020, unless otherwise required by law and with provisions for appropriate controls, among other requirements related to firefighting foam.[71]

Food packaging. In 2018, the State of Washington passed a law prohibiting all PFAS in paper food packaging. The law will take effect in 2022, after the state identifies safer alternatives and considers feedback from an external review process.[72] A bill in the New York State Senate would prohibit "the manufacture, sale, or distribution of food packages in which PFAS chemicals are present in any amount."[73] A bill in Vermont, also introduced, like New York's, in February 2019, requires the health department to analyze whether there are safer alternatives to food packaging to which PFAS have been added, and if so, would prohibit their manufacture and sale.[74] A bill introduced in the New Jersey legislature in February 2019 directs the state environmental agency "to study and, if necessary, regulate perfluoroalkyl and polyfluoroalkyl substances in food packaging."[75] In Massachusetts, a bill was introduced in 2019, H.3839, which would ban the sale and distribution of food packaging to which PFAS have been intentionally added.[76] Bills and laws on this topic frequently specify that a ban is contingent on identifying safer alternatives.

Drinking water action levels, Maximum Contaminant Levels (MCLs), and groundwater cleanup standards. Because PFAS have been found as widespread contaminants in many public water supplies, many state level regulatory authorities are working to develop MCLs or other regulatory standards. Most or all of these regulatory efforts address chemicals in the carboxylic and sulfonic acids category. Some states have relied primarily on EPA's health advisory, while others have worked to develop more protective standards and/or have undertaken to address a larger number of PFAS. Some states regulate specific PFAS chemicals individually. Others are regulating some PFAS chemicals as a group.

The Connecticut Department of Public Health has developed a Drinking Water Action Level of 70 ppt for the sum of five PFAS chemicals (PFOA and PFOS, plus PFNA, PFHxS, and PFHpA).[77]

Michigan has made substantial progress in identifying PFAS contamination and is working to identify upstream users and past users of PFAS. Michigan's "Rule 57 Water Quality Values" includes procedures for calculating water quality values to protect humans, wildlife, and aquatic life. Values that are determined include Human Noncancer Value (HNV).[78] The state developed these values for drinking and non-drinking water for PFOA and PFOS in surface waters in 2011 and 2014 respectively. Under the state's Industrial Pretreatment Program PFAS Initiative, publicly owned treatment works are required to survey industrial users with potential sources of PFAS and conduct follow-up sampling of probable sources.[79]

Vermont has adopted a law providing for testing of public community water systems for five PFAS chemicals. If the sum of these chemicals exceeds 20 ppt, "the water system will issue a 'do not drink' announcement and implement treatment to reduce contamination levels below state standards." In addition, MCLs will be issued by February 2020.[80,81] The health department advises that if PFAS exceeds the state standard in one's public drinking water, "To minimize your exposure, do not use your water for drinking, food preparation, cooking, brushing teeth, preparing baby formula, washing fruits and vegetables, or any other manner of ingestion…Do not use water containing the five PFAS over 20 ppt to water your garden. The PFAS could be taken up by the vegetables."[82]

New Jersey has take a number of actions on PFAS. In 2018, NJ adopted a statewide drinking water standard for PFNA with an MCL of 13 ppt.[83] Water systems were required to start testing in the first quarter of 2019. A ground water quality standard for PFNA of 0.01 µg/L (equivalent to 10 ng/L or 0.01 ppb) was adopted under amendments to NJ's Ground Water Quality Standards Rules in January 2018. Also in 2018, PFNA was added to New Jersey's List of Hazardous Substances.[84] In 2017, New Jersey established a drinking water guidance value for PFOA of 14 ppt. In 2017, the New Jersey Drinking Water Quality Institute published a draft health-based recommendation of 13 ppt for PFOS, and in 2018 the New Jersey Department of Environmental Protection accepted the recommended PFOS MCL.[85] In April 2019, New Jersey's Department of Environmental Protection proposed drinking water MCLs of 14 ppt for PFOA and 13 ppt for PFOS. The same levels are also proposed as groundwater quality standards for site remediation activities.[86] A public comment process is under way.

In July 2019, the New York State Department of Health recommended drinking water standards (MCLs) of 10 ppt for both PFOA and PFOS.[87] In 2016, New York regulated PFOA and PFOS as hazardous substances. The final rule became effective in 2017.[88]

In July 2019, the New Hampshire legislature's administrative rules committee approved new drinking water standards/MCLs for PFOA (12 ppt), PFOS (15 ppt), PFHxS (18 ppt), and PFNA (11 ppt). Beginning in October 2019, water systems were required to sample for PFAS quarterly.[89]

The Washington State Board of Health is currently engaged in rulemaking for standards for certain PFAS in drinking water.[90]

Massachusetts: Drinking water and groundwater

Drinking water. In 2018, MassDEP's Office of Research and Standards published recommendations that EPA's Health Advisories and Reference Doses for PFOS and PFOA also be applied to PFNA, PFHxS, and PFHpA, and that an additive toxicity approach be used. For PFBS, it recommended an interim approach of using the Minnesota standard.[91] In December 2019, MassDEP issued a proposed regulation establishing a Total PFAS Contaminant Level (maximum contaminant level – MCL) of 20 ppt for the sum of the concentrations of six PFAS: PFOS, PFOA, PFHxS, PFNA, PFHpA, and perfluorodecanoic acid (PFDA).[92]

Groundwater cleanup standards. Massachusetts DEP has adopted changes to its Waste Site Cleanup regulations to include new standards for PFAS. The groundwater cleanup standard for current or potential drinking water sources is set at 20 ppt for the six PFAS noted above. The standards became effective on December 27, 2019.[93]

As context for the drinking water and groundwater standards, MassDEP noted that "since 2013, the sum of the concentrations of the six PFAS compounds above 20 ppt have been detected at over 20 PWSs [public water systems] in Massachusetts."[94]

Health Risk Limit and guidance values for drinking water and groundwater.

In April 2019, the Minnesota Department of Health (MDH) issued new health-based values for PFOS (15 ppt, replacing the previous value of 27 ppt) and PFHxS (47 ppt, replacing the 27 ppt PFOS health-based value which had been adopted as a surrogate for PFHxS due to a lack of available data specific to PFHxS).[95] The state also has drinking water guidance values for PFBS (2 ppb), PFBA (7 ppb), and PFOA (35 ppt).[96]

The Texas Risk Reduction Program (TRRP) "has derived risk-based inhalation exposure limits (RBELs) for select PFAS. These RBELs are applicable to PFAS that may volatilize from soil to air at remediation sites managed under the TRRP rule (Texas Commission on Environmental Quality [TCEQ], 2017)," according to the Interstate Technology Regulatory Council.[97]

Statewide plans and multi-agency task forces. Some states have established statewide plans or multi-agency PFAS task forces.

- Washington's Department of Health and Department of Ecology jointly developed a draft statewide Chemical Action Plan for PFAS. Draft recommendations include expanded testing of drinking water, further reduction of PFAS in products, and further assessment of PFAS in waste streams.[98]
- In Maine, an executive order created the Governor's Task Force on the Threats of PFAS Contamination to Public Health and the Environment. The purpose of the Task Force is to identify the extent of PFAS exposure in Maine, examine the risks of PFAS to Maine residents and the environment, and recommend approaches to most effectively address this risk.[99] The Task Force's 11 members include representatives of several state agencies, the state public health association, and additional organizations.[100]
- In Michigan, the PFAS Action Response Team was created in 2017 as a temporary body. In 2019, the governor signed an executive order establishing the team as an advisory body within the state's environmental agency. It includes representatives of seven state agencies, and is charged with providing recommendations and coordinating efforts in this area.[101]
- The Connecticut Interagency PFAS Task Force has recommended a set of actions to address PFAS; the plan was officially released by the Governor in November 2019.[102]

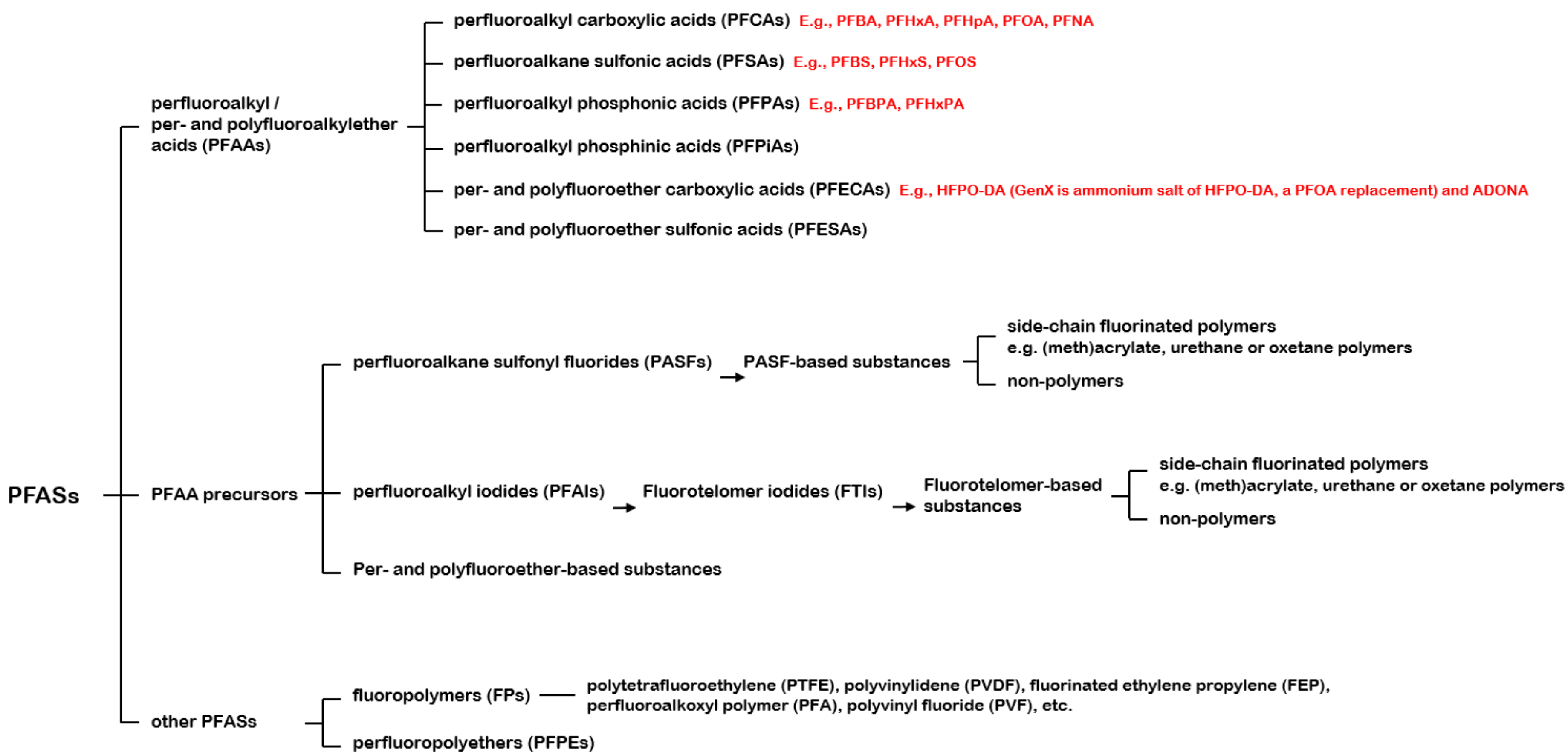
City and County Examples

San Francisco's "Plastic, Litter, Toxics Reduction" law aims to "phase out the use of toxic and persistent fluorinated chemicals in single-use foodware."[103] It requires that as of January 1, 2020, BPI (Biodegradable Products Institute)-certified, compostable foodware (one of three acceptable types of foodware) must not contain added fluorinated chemicals.[104]

Appendix A

This flow chart is simplified and adapted from a flow chart published by OECD.[105] TURI has added the example notations in red font.

Commonly recognized per- and polyfluoroalkyl substances (PFAS)



Other Highly Fluorinated Substances that match the definition of PFAS, but have not yet been commonly regarded as PFAS

OECD has identified a number of other highly fluorinated substances that match the definition of PFAS, but have not yet been commonly regarded as PFAS. These include the perfluorinated alkanes, perfluorinated alkenes and their derivatives, perfluoroalkyl alcohols, perfluoroalkyl ketones, semi-fluorinated ketones, side-chain fluorinated aromatics, as well as some hydrofluorocarbons (HFCs), hydrofluoroethers (HFEs), and hydrofluoroolefins (HFOs) that have a perfluoroalkyl chain of a certain length.

Appendix B

The table below shows key studies that were reviewed by the SAB and on which the SAB has relied in establishing a basis for concern about the health endpoint in question. The SAB's review included many additional studies beyond those noted here, including studies that show effects as well as studies that show no effect. The full set of references consulted by the SAB is shown in the SAB's bibliography.

	PFNA	PFOA	PFHpA	PFHxA	PFHxS	PFBA	PFBS	GenX	Adona	PFPA/PFPiA
Cancer		C8 Health Study						Rae 2015		
Immunotoxicity		C8 Health Study					Corsini 2012	Rushing 2017		
Thyroid		C8 Health Study		Ren 2016	Jain 2013 Weiss 2009	Bjork and Wallace '09 Butenhoff 2012	Feng 2017			Liu '19
Endocrine (other than thyroid)				Wolf 2008 Rosenmai 2016	Das 2017, Rosenmai 2017	Foreman 2009	Gorrochategui 2014			
Hematological		C8 Health Study				Butenhoff 2012 Van Otterdijk 2007				
Liver/metabolic	Das 2017		Wolf 2012, ATSDR 2018	Loveless 2009	Butenhoff 2009	Foreman 2009 Bjork and Wallace 2009 Wolf 2008 Rosenmai 2016		Sheng 2018, Wang 2017, DuPont 2008	Gordon 2011, Cheng 2018	Das '11
Reproductive		C8 Health Study						DuPont 2010, Conley 2019	Gordon 2011	Tatum '12
Developmental	Das 2015		Kim 2015	Loveless 2009 Iwai 2014		Das 2008	Feng 2017 Lieder 2009			
Neurodevelopmental					Maisonet 2012 Joensen 2009 Viberg 2013 Lee and Viberg 2013 Yang 2016					
Neurotoxicity	Oulhote 2016			Loveless 2009 Klaunig 2015	Zhang 2016 Lee and Yang 2014 Viberg 2013		Slotkin 2008			
Asthma					Dong 2013		Dong 2013			
Other	Mutagenicity: Yahia 2016			Kidney: Leider 2009			Kidney: NICNAS 2017			Wang '16

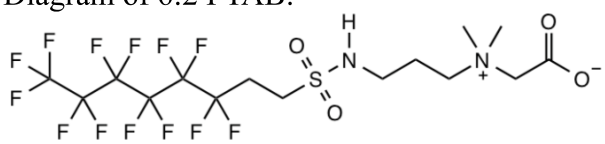
Appendix C: Example of breakdown into precursors: Chemical commonly used in AFFF

As an example of the degradation/transformation process, the following diagram shows the breakdown of 6:2 FTAB (a fluorotelomer commonly used in AFFF) into a number of PFCAs. It contains six fully fluorinated carbons and two unsubstituted carbons. As shown here, 6:2 FTAB can be a precursor to (i.e. can break down into) a number of chemicals with the same number of carbons or fewer, including PFPeA, PFHxA, or PFHpA. The process includes multiple steps, and depends on the degradation mechanism.

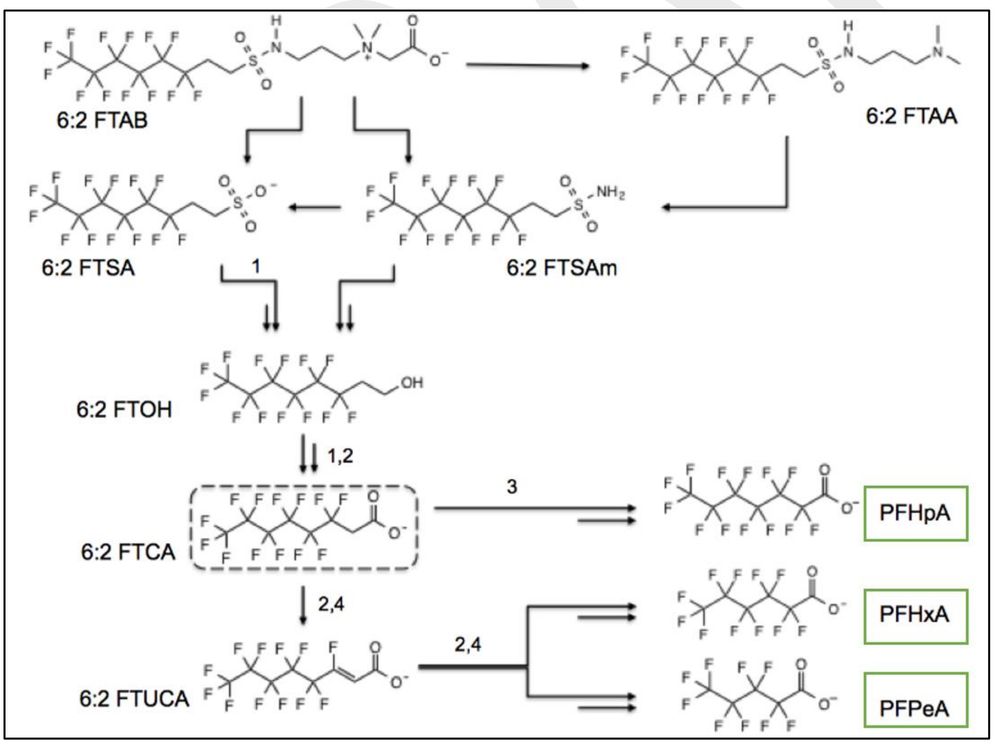
Full chemical name: 6:2 fluorotelomer sulfonamide alkylbetaine (6:2 FTAB) (34455-29-3)

Breakdown mechanism: Aqueous photoloysis

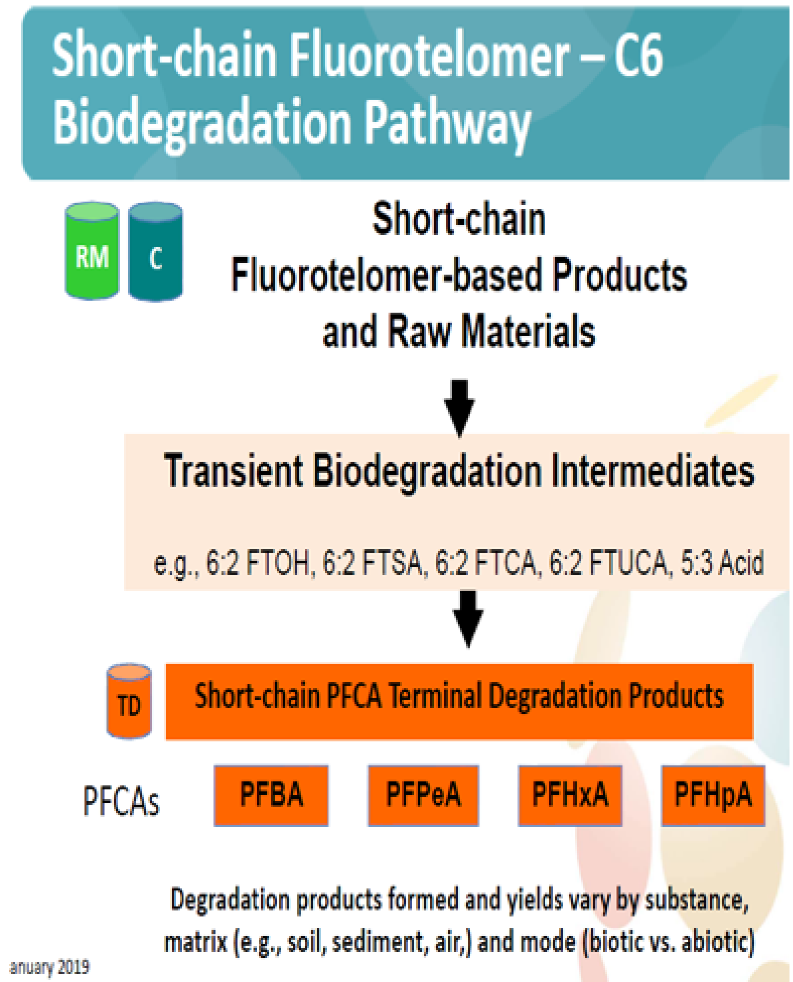
Diagram of 6:2 FTAB:



Sample breakdown pathways (double arrows indicate that a reaction occurs in multiple steps) (source: L.J. Trouborst, 2016. *Aqueous photolysis of 6:2 fluorotelomer sulfonamide alkylbetaine)*:



Summary of these breakdown pathways provided by Korzeniowski and Buck (Fluorocouncil/ACC), 2019:



Korzeniowski & Buck; "The PFAS Universe: Uses, Classification & Degradation" Webinar for IC2 & MA TURI. 30 January 2019. slide 59

Appendix D: Summary of SAB Recommendations on PFAS

This summary was updated in November 2019 and will be updated further as needed to reflect additional work by the SAB.

Date	Chemical Name	SAB Recommendation
January 11, 2017	Perfluorooctane Sulfonic Acid (PFOS) and its salts (C8)	**Recommended listing** PFOS and its salts based on persistence, bioaccumulation, ecotoxicity, and animal acute toxicity.
January 11, 2017	Perfluorooctanoic Acid (PFOA) and its salts (C8)	**Recommended listing** PFOA and its salts based on persistence, bioaccumulation, ecotoxicity, and animal acute toxicity.
April 11, 2018	Perfluorohexanesulphonic acid (PFHxS) (C6)	**Recommended listing** PFHxS due to persistence, bioaccumulation, mobility, corrosivity and mammalian toxicity: thyroid, liver/metabolic, and endocrine effects.
April 11, 2018	Perfluorohexanoic Acid (PFHxA) and its salts (C6)	**Recommended listing** PFHxA and its salts due to strong evidence on persistence, mobility, corrosivity, and mammalian toxicity: thyroid and liver, with concerns for kidney and developmental effects.
April 11, 2018	Perfluorobutanesulfonic acid (PFBS) and its salts (C4)	**Recommended listing** PFBS and its salts due to persistence, mobility, corrosivity and mammalian toxicity: thyroid and developmental toxicity, with additional concerns for reproductive toxicity, neurotoxicity and immunotoxicity.
April 11, 2018	Pentafluorobenzoic acid (PFBA) and its salts (C6)	**Recommended listing** PFBA and its salts due to persistence, mobility, corrosivity and mammalian toxicity: liver/endocrine with additional concerns for thyroid, developmental toxicity, hematological effects, and phytoaccumulation.
October 25, 2018	Perfluoroheptanoic Acid (PFHpA) and its salts (C7)	**Recommended listing** PFHpA and its salts due to persistence and liver effects, with concerns for corrosivity, mobility and bioaccumulation.
October 25, 2018	Perfluorononanoic Acid (PFNA) and its salts (C9)	**Recommended listing** PFNA and its salts due to persistence, bioaccumulation, developmental/ reproductive effects, immunotoxicity, and effects on liver, with additional concerns for mobility in the environment, neurotoxicity and corrosivity.
March 27, 2019	Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (GenX) (C6)	**Recommended listing** HFPO-DA and its ammonium salt due to persistence, mobility, corrosivity, and liver toxicity.
September 18, 2019	Hexafluoropropylene Oxide (HFPO) Dimer Acid and its Acyl Halides (C6)	**Recommended listing** the salts of HFPO-DA and its acyl halides which are precursors to HFPO-DA.
September 18, 2019	ADONA - Ammonium 4,8-dioxa-3H-perfluorononanoate or 3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid] (C8)	Board agreed that ADONA followed the patterns of the other PFAS that the SAB has reviewed, such as liver effects, persistence, gender differences, corrosivity, and maternal toxicity. However, available data were not sufficient for a listing recommendation. The SAB noted an over-all lack of studies, especially for cancer, immunotoxicity, neurotoxicity, thyroid and more complete reproductive details.
November 14, 2019	Perfluoroalkyl Phosphonic and Phosphinic Acids (C4-C12)	**Recommended listing** Perfluoroalkyl Phosphonic and Phosphinic Acids based on mobility, persistence, corrosivity (pKa). Additional evidence shows compounds are precursors to PFCAs (e.g. PFOA, previously recommended for listing). Additional concerns based on evidence of liver toxicity and acute toxicity for some of the compounds.

Appendix E: State Actions to Address PFAS: Examples

Note: Full table is current as of November 23, 2019; Massachusetts information is current as of December 2019.

State	Actions
California	• **Biomonitoring:** PFASs are included in the state's biomonitoring program.[106] • **Labelling and disclosure:** In 2017, PFOS and PFOA were listed as known to the state to cause reproductive toxicity under Proposition 65. • **California Safer Consumer Products Program:** In 2018, the California Department of Toxic Substances Control proposed listing PFAS in carpets and rugs as a priority product under its Safer Consumer Products program, [107] and in November 2019, it proposed listing PFAS for use on converted textiles or leathers such as carpets, upholstery, clothing and shoes.[108]
Connecticut	• **Drinking water:** The state's public health department developed a Drinking Water Action Level for drinking water in the state in which the sum of five PFAS chemicals (PFOA, PFOS, PFNA, PFHxS and PFHpA) should not exceed the limit of 70 ppt.[109]

Massachusetts	• **Drinking water:**
	    o In June 2018, MassDEP's Office of Research and Standards published recommendations that EPA's Health Advisories and Reference Doses for PFOS and PFOA also be applied to PFNA, PFHxS, and PFHpA, and that an additive toxicity approach be used. For PFBS, it recommended an interim approach of using the Minnesota standard.[110]
	    o In December 2019, Massachusetts Department of Environmental Protection (MassDEP) issued a proposed regulation establishing a Total PFAS Contaminant Level (maximum contaminant level – MCL) of 20 ppt for the sum of the concentrations of six PFAS: PFOS, PFOA, PFHxS, PFNA, PFHpA, and perfluorodecanoic acid (PFDA).
	• **Groundwater cleanup standards:** Massachusetts DEP proposed and adopted changes to its Waste Site Cleanup regulations to include new standards for PFAS. The groundwater cleanup standard for current or potential drinking water sources is set at 20 ppt for the six PFAS noted above. The standards became effective on December 27, 2019.[111]
	• **Context for groundwater and drinking water standards:** MassDEP noted that "since 2013, the sum of the concentrations of the six PFAS compounds above 20 ppt have been detected at over 20 PWSs [public water systems] in Massachusetts."[112]

Minnesota	• **Environmentally Preferable Purchasing.** State contract specifications require that compostable food ware products not contain PFAS.[113] • **Health Risk Limit and guidance values for drinking water and groundwater.** In April 2019, the Minnesota Department of Health (MDH) issued health-based values for PFOS (15 ppt, replacing the previous value of 27 ppt) and PFHxS (47 ppt, replacing the 27 ppt PFOS health-based value as a "surrogate" for PFHxS due to a lack of available data specific to PFHxS.)[114] The state also has drinking water guidance values for PFBS (2 ppb), PFBA (7 ppb), and PFOA (35 ppt).[115]
New Hampshire	• **Drinking water**. In July 2019, the New Hampshire legislature's administrative rules committee approved new drinking water standards/MCLs for PFOA (12 ppt), PFOS (15 ppt), PFHxS (18 ppt), and PFNA (11 ppt). Beginning in October 2019, water systems were required to sample for PFAS quarterly.[116]
New Jersey	• **Drinking water:**

	○ In 2018, New Jersey adopted a statewide drinking water standard for PFNA with an MCL of 13 ppt. Water systems in New Jersey were required to start testing in the first quarter of 2019.[117] ○ A ground water quality standard for PFNA of 0.01 µg/L (equivalent to 10 ng/L or 0.01 ppb) was adopted under amendments to New Jersey's Ground Water Quality Standards Rules in 2018. ○ In 2018, PFNA was added to New Jersey's List of Hazardous Substances. ○ In 2017, New Jersey established a drinking water guidance value for PFOA of 14 ppt. ○ In 2017, the NJ Drinking Water Quality Institute published draft recommendations for a health-based MCL for PFOS of 13 ng/L. In June 2018, the state accepted the recommended MCL. ○ In April 2019, New Jersey's Department of Environmental proposed drinking water MCLs of 14 ppt for PFOA and 13 ppt for PFOS. The same levels are also proposed as groundwater quality standards for site remediation activities.[118] A public comment process is underway.
New York	• **Cleanup:** In 2016, New York regulated PFOA and PFOS as hazardous substances. The final rule became effective in 2017.[119] • **Drinking water:** In July 2019, the New York State Department of Health recommended drinking water standards (MCLs) of 10 ppt for both PFOA and PFOS.[120]
North Carolina	• **Monitoring and treatment.** The state legislature funded the monitoring and treatment of PFAS, particularly GenX.
Texas	• **Health Risk Limit values:** The Texas Risk Reduction Program (TRRP) has adopted standards for certain PFAS.[121]
Vermont	• **Drinking water**: The state's standard is 20 ppt for the sum of five PFAS (PFOA, PFOS, PFNA, PFHxS, PFHpA) in drinking water.[122]
Washington	• **Statewide Chemical Action Plan for PFAS**. The Department of Health and the Department of Ecology jointly developed a draft statewide Chemical Action Plan for PFAS. Draft recommendations include expanded testing of drinking water, further reduction of PFAS in products, and further assessment of PFAS in waste streams.[123] • **Drinking water:** In 2017, the Washington State Board of Health began rulemaking for standards for PFAS in drinking water (PFOA, PFOS, PFNA, PFHxS, and PFBS). • **Testing:** The Washington Department of Health plans to test several hundred water systems in the state for trace contamination of chemicals found in some firefighting foams. • **Bans and restrictions:** ○ The state banned the use of PFAS-containing Class B ***firefighting foam*** (designed for flammable liquid fires) for training effective July 1, 2018. ○ A ban on the manufacture, sale, and distribution of PFAS-containing Class B ***firefighting foam*** takes effect on July 1, 2020. ○ In 2018, the state passed a law prohibiting all PFAS in ***paper food packaging***. The law will take effect in 2022, after the state identifies safer alternatives and considers feedback from an external review process. • **Environmentally Preferable Purchasing.** The law addressing PFAS in firefighting foam and PPE directs two state agencies to develop guidance to assist public sector agencies to avoid purchasing these products containing PFAS. • **Labeling and disclosure:** ○ The state requires the reporting of PFOA and related substances, and PFOS and its salts, in ***children's products***.[124]

	○ As of July 1, 2018, manufacturers and sellers of PFAS-containing ***firefighting Personal Protective Equipment*** must notify purchasers in writing if the equipment contains PFAS and the reasons for using the chemicals.

Appendix F : State Actions Addressing Drinking Water Levels or Limits for PFAS: Examples (Current as of: November 23, 2019; Massachusetts is up to date as of December 2019)

	PFDA (C10)	PFNA (C9)	PFOA (C8)	PFOS (C8)	PFHpA (C7)	PFHxA (C6)	PFHxS (C6)	PFBA (C4)	PFBS (C4)	Additive values	Action and year
STATE											
CT		A	A	A	A		A			70 ppt	Drinking water action level (2016)
MA	A	A	A	A	A		A			20 ppt for the sum of all six PFAS	Proposed MCL (2019)
MN			35 ppt	15 ppt			47 ppt	7 ppb	2 ppb		Drinking water guidance (2017, 2019)
NH		11 ppt	12 ppt	15 ppt			18 ppt				Drinking water standards (2019)
NJ		13 ppt*	14 ppt**	13***							*Drinking water standard/MCL (2018) **Drinking water guidance value (2017) ***Health-based MCL (2018)
NY			10 ppt	10 ppt							Recommended MCL (2018)
VT		A	A	A	A		A			20 ppt for the five PFAS added together	Health advisory level (2018)

"A" indicates additive values.

[1] https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas accessed 2/3/20.
[2] *https://www.mass.gov/doc/310-cmr-2200-summary-of-proposed-regulations-and-note-to-reviewers/download*

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