Per- and Poly-fluoroalkyl Substances (PFAS): Policy Analysis
Toxics Use Reduction Institute
May 2021

This document analyzes the implications of adding a substance category, *Per- and Poly-Fluoroalkyl Substances Not Otherwise Listed (PFAS NOL)*, to the TURA list of Toxic or Hazardous Substances (TURA List). The category would be defined as follows:

> those PFAS that contain a perfluoroalkyl moiety with three or more carbons (e.g., $–C_nF_{2n}–$, $n \geq 3$; or $CF_3–C_nF_{2n}–$, $n \geq 2$) or a perfluoroalkylether moiety with two or more carbons (e.g., $–C_nF_{2n}OC_mF_{2m}–$ or $–C_nF_{2n}OC_mF_m–$, n and $m \geq 1$), that are not otherwise listed.

With this addition, businesses in TURA covered sectors with 10 or more full time employee equivalents (FTEs) would be subject to TURA program requirements if they manufacture or process 25,000 lb/year, or otherwise use 10,000 lb/year, of chemicals in this category. These businesses would be required to file annual toxics use reports, pay annual toxics use fees, and develop a toxics use reduction plan every two years.

This policy analysis explains the definition of the proposed category, summarizes key scientific information, reviews existing information about how the chemicals in this category are used, discusses opportunities for toxics use reduction, summarizes relevant regulatory information, and discusses the implications of this policy measure for the TURA program. The TURA Science Advisory Board (SAB) has recommended adding this category to the list. **Based on a thorough review of this information, the Toxics Use Reduction Institute recommends that this category be added to the TURA list.**

This document represents the culmination of over three years of work by the Science Advisory Board and the TURA Program to study the science of per- and poly- fluoroalkyl substances. In its work to review the science of PFAS, the SAB took account of scientific resources collected by the TURA program, as well as information provided by industry and environmental stakeholders. While working with the Board to define a category of PFAS, the Toxics Use Reduction Institute provided information regarding the potential for regrettable substitutions within this large class of chemicals. TURA Program staff also worked with staff from other state agencies and considered the preventative role TURA can play in reducing impacts from this class of chemicals.

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, making them useful in a variety of settings. They also share certain hazard characteristics, such as persistence and breakdown products of concern. PFAS have been detected in drinking water in many parts of Massachusetts, as discussed below.

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 research on the topic wherever possible.

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 covers 172 chemicals. The threshold for each chemical is 100 lb/year.

While these and other activities are on-going, PFAS continue to be used in industry and products, and released into workplaces and the environment. By adding PFAS to the Massachusetts Toxic or Hazardous Substances list, the TURA program has the opportunity to augment existing regulatory approaches – both by enhancing understanding of the use of these chemicals in industry, and by supporting and encouraging prevention-related activities. Toxics Use Reduction makes it possible to address PFAS contamination at its source, rather than only addressing PFAS after contamination has occurred. Listing PFAS under TURA would help manufacturers to understand how PFAS are being used and identify ways to reduce their use. In addition, the TURA approach makes it possible to address PFAS for which test methods and full toxicity information are not yet available.

Recommendation

The SAB reviewed the scientific evidence on 12 PFAS chemicals (PFNA, PFOA, PFHpA, PFHxA, PFBA, PFOS, PFHxS, PFBS, GenX, and PFPAs and PFPiAs) and their salts. 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 also reviewed the Organization for Economic Cooperation and Development (OECD) list of PFAAs and PFAA precursors, including information about known and potential breakdown pathways. OECD has created as comprehensive a list as possible of PFAS, including precursors. In addition, the SAB reviewed scientific information showing that the PFAA precursors break down into the PFAAs via a number of pathways.

Based on all of this information, the SAB voted to recommend listing PFAS as a category under TURA.[i] The SAB defined this category as "those PFAS that contain a perfluoroalkyl moiety with three or more carbons (e.g., $–C_nF_{2n}–$, $n \geq 3$; or $CF_3–C_nF_{2n}–$, $n\geq2$) or a perfluoroalkylether moiety with two or more carbons (e.g., $–C_nF_{2n}OC_mF_{2m}–$ or $–C_nF_{2n}OC_mF_m–$, n and $m \geq 1$)." This definition was crafted based on the SAB's review and recommendation to list individual PFAS chemicals, as well as the SAB's evaluation of the degradation/transformation of precursors to PFAAs.

TURI recommends listing PFAS as a substance category under TURA, consistent with the recommendation of the SAB. TURI recommends that the PFAS category be named "PFAS, not

[i] Vote taken 6/25/2020; 7 in favor, 1 opposed. Rationale for the 1 member who voted against the designation was a desire to review specific toxicity information for additional substances, especially polymers.

otherwise listed (NOL).” Thus, chemicals already listed individually due to listing under the Toxics Release Inventory (TRI) would not be covered by this category. If other substances that fit this definition are listed individually by EPA in the future, the expectation is that these would also not be covered by the category.

To understand the SAB’s approach to developing this recommendation, it is important to note that there are several thousand known PFAS chemicals. Thus, the SAB determined that it is not practical to review each chemical individually. In addition, although many of these chemicals are being discharged into the environment, many of them have not been studied with regard to health or environmental effects. Therefore, the SAB chose a range of PFAA’s for review, and reviewed degradation pathways for precursors to the substances they had reviewed.

Drinking Water Contamination in Massachusetts

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. 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.”[1]

Approach to PFAS in Massachusetts

A number of activities have been undertaken by the Commonwealth to address PFAS contamination and use in Massachusetts and thereby protect public health. These include the following.

- **Drinking water.** In 2020, MassDEP adopted an MCL of 20 parts per trillion (ppt) for six PFAS combined. MassDEP is also offering free PFAS sampling to all public water supplies (PWS), and is partnering with UMass Amherst to conduct sampling of private wells around the state.[2]
- **Waste Sites.** PFAS are considered to be "hazardous material" subject to the notification, assessment and cleanup requirements of the Massachusetts Waste Site Cleanup Program. In 2019, MassDEP adopted a standard of 20 ppt for six PFAS combined for groundwater cleanup in areas where groundwater is a current or potential drinking water supply. [3]
- **WWTP Sampling.** MassDEP has begun a sampling program at wastewater treatment facilities to test for the presence of PFAS and to further locate upstream sources.
- **AFFF Take-Back.** MassDEP established a take-back program for AFFF which collected over 17,000 gallons of legacy foams from public safety offices in Massachusetts.[4]
- **Assistance for affected communities.** MassDEP and MA Department of Public Health (DPH) are working with impacted communities to help residents understand their

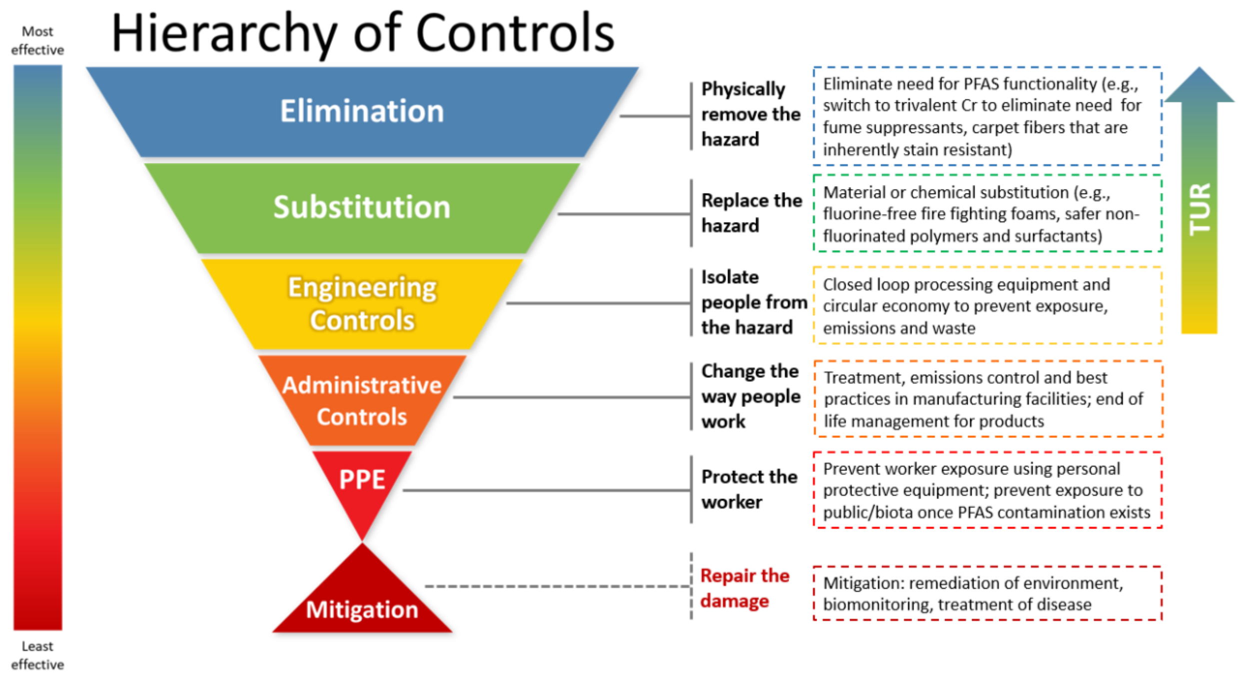
exposure to PFAS and potential health effects. MA DPH is also providing information to clinicians about medical care needs and answering questions from community members about their exposure and risk. MassDEP has also initiated a grant program to assist public water supplies as they address PFAS contamination.

As noted above, addressing PFAS under the TURA program would help manufacturers to understand how PFAS are being used and identify ways to reduce their use, waste generation and emissons, as well as employee exposure. These activities would complement and support the other efforts being made in the state to address these chemicals.

As shown in Figure 1, it may be helpful to think about responses to PFAS within the structure of the well-known Hierarchy of Controls diagram. The most protective options are to eliminate the hazard and/or adopt a safer substitute. Within the workplace, use of personal protective equipment is at the bottom of the inverted pyramid, representing the last option for protecting those working with a hazardous substance. Also shown below the prevention pyramid is the category of mitigation, which can be considered to include all the activities undertaken in response to contamination or exposure that has already occurred. This includes environmental cleanup as well as biomonitoring and disease surveillance and treatment.

Activities undertaken under TURA would fall into the category of elimination and substitution, the prevention-oriented activities; in addition, TURA planning would increase awareness of PFAS hazards and could lead to identification of priorities for engineering controls and administrative controls in some cases.

Figure 1: PFAS in the context of the Hierarchy of Controls



Background on PFAS

In its comprehensive 2018 study, *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 identified over 4,700 PFAS-related CAS numbers. 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, as shown in Figure 2. Additional detail is shown in Appendix A.

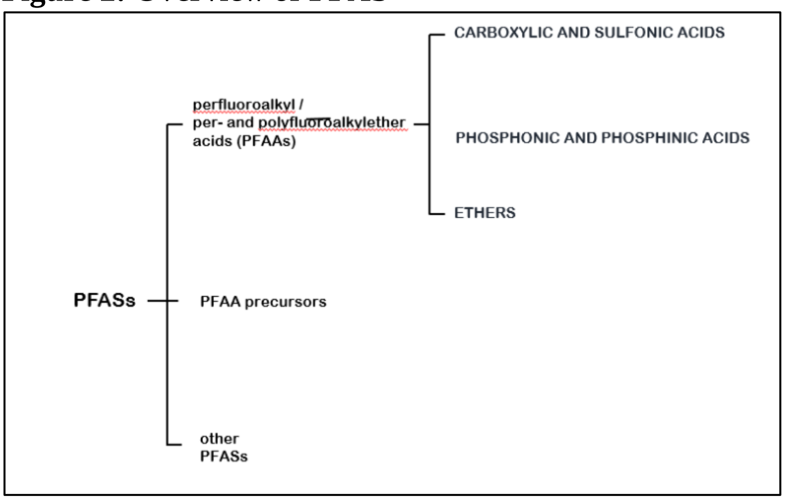
- **PFAAs.** The PFAAs are further separated into sub-groups:
  - **carboxylic and sulfonic acids** (perfluoroalkyl carboxylic acids [PFCAs], perfluoroalkane sulfonic acids [PFSAs]),
  - **phosphonic and phosphinic acids** (perfluoroalkyl phosphonic and phosphinic acids [PFPAs and PFPiAs], and
  - **ethers** (per- and polyfluoroether carboxylic and sulfonic acids [PFECAs and PFESAs]).
- **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 certain fluoropolymers and other compounds (see Appendix for more details). Note that the polymers may be solid resins or lower molecular weight polymer dispersons. Some polymers are included as PFAA

precursors. In our simplified diagram here, "Other PFAS" includes "other highly fluorinated substances that match the definition of PFASs, but have not yet been commonly regarded as PFASs" as shown in Appendix A.

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."[ii]

The SAB's review of individual chemicals encompassed representative chemicals within each of the broad subcategories of the PFAAs: the carboxylic and sulfonic acids, which have been widely identified as contaminants in the environment; the phosphonic/phosphinic acids; and the ethers (GenX and ADONA). The SAB then built upon this work by reviewing the breakdown of PFAA precursors into PFAAs. The SAB reviewed at least one precursor for each of the OECD subcategories of PFAAs. The SAB also considered a number of breakdown pathways, including hydrolysis, photolysis, biodegradation and thermal degradation. The SAB also reviewed PFAS definitions and class descriptions from other organizations in developing the PFAS category.

Figure 2: Overview of PFAS[iii]



[ii] 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 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."

[iii] "Other PFAS" includes "other highly fluorinated substances that match the definition of PFASs, but have not yet been commonly regarded as PFASs" as shown in Appendix A

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 began by examining eight substances of varying chain lengths: PFNA (C9); PFOS and PFOA (C8); PFHpA (C7); PFHxA and PFHxS (C6)[iv]; and PFBA and PFBS (C4).[v] 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.

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. The SAB also reviewed the OECD spreadsheet and methodology for identifying PFAA precursors and looked at several

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[iv] Note regarding the C6 molecules: EPA classifies PFHxS with the long-chain PFAS, and classifies PFHxA with the shorter-chain PFAS.

[v] Full names of these chemicals are as follows: Perfluorononanoic acid (PFNA [C9]); Perfluorooctanyl sulfonate (PFOS [C8]); Perfluorooctanoic acid (PFOA [C8]); Perfluoroheptanoic acid (PFHpA [C7]); Perfluorohexanoic acid (PFHxA [C6]); Perfluorohexane sulfonate (PFHxS [C6]); perfluorobutanoic acid (PFBA[C4]); Perfluorobutane sulfonate (PFBS[C4]).

representative precursors covering multiple breakdown pathways (See Appendix C for example pathways). **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.[5] 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." [6] 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[7] 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 effects, 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.[8,9]

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).[10] PFNA also is highly persistent in the environment and has a half-life of greater than 1.7 years.[11] 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.[vi]

[vi] 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-

The EPA Draft Toxicity Assessment for GenX[12] 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 an individual recommendation. The SAB noted an overall lack of publicly available studies, especially for cancer, immunotoxicity, neurotoxicity, thyroid and complete reproductive details.

Phosphonic and phosphinic acids: PFPAs and PFPiAs. PFPAs and PFPiAs are typically used in mixtures of a range of alkyl chain lengths, so they were evaluated as a group. 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,[13] 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.[14] 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).[15]

Polymers. The SAB discussed polymers, including representative structures, their manufacture and potential for degradation. Scientific evidence reviewed includes concerns with non-polymer residuals, mixtures, and thermal and mechanical degradation. Some concerns noted:

- Fluoropolymers are manufactured using PFAAs and there were concerns with residuals in polymers.
- Fluoropolymer coatings are provided as small polymer particles, either as dry powder or in dispersions which contain residual PFAAs. These are used by businesses and consumers to apply fluoropolymer coatings, and the PFAAs are released to air or water.
- Fluoropolymers begin to break down thermally at relatively low temperatures, which may be reached during plastics processing, curing, use and end-of-life incineration.
- Side-chain fluorinated polymers (with non-fluorinated carbon backbones) are subject to mechanical and thermal degradation, with side chains cleaving from the backbone.

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.

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
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, and are primarily the Board's review of the C8 Health Study. For PFOS, the only endpoint noted is from the Board's review of an NTP immunotoxicity study on PFOS and PFOA, although there is a significant body of evidence for many other chronic health effects.
* 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		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 and other 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 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).
- For PFPAs and PFPiAs, evidence of bioaccumulation was primarily for longer chain substances and mixtures

Information on toxicological and environmental impacts of PFAS is being published and disseminated at a rapid rate. For example, a group of scientists recently published a PFAS-Tox Database of more than 700 scientific studies for 29 PFAS with more being added. [16]

Use information

To understand PFAS use, it is possible to draw upon general information as well as information that is specific to Massachusetts. However, important gaps exist due to lack of use reporting.

General use information

Use of PFAS can be roughly divided into non-polymeric and polymeric uses. Non-polymeric PFAS may be as used as surfactants, wetting agents, emulsifiers and polymerization processing aids, mist suppressants, pesticide active ingredients, and film formers.[17] Polymeric PFAS may be used as lubricants, insulators, protective coatings, and raw materials for textiles, semiconductors, and automotive components.[18] 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.[19]

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.[20]

Massachusetts use information

Limited information is available on PFAS use in Massachusetts. Listing PFAS under TURA would lead to greater information availability.

To estimate how many facilities may be using PFAS in Massachusetts 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[vii], 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.[viii]

[vii] 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)

[viii] Buffered oxide etchants (BOE) are blends of hydrofluoric acid and ammoninum fluoride used to etch silicon wafers in electronics manufacturing. This facility is using a BOE with a fluorinated surfactant added to improve wetting of the substrate.

- *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 in the OECD New Comprehensive Global Database of PFASs.[21]

Table 3: 2017 Massachusetts Tier II Data

	OECD Structure Category Name (where relevant)[22]	**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
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,[23] the U.S. Environmental Protection Agency (EPA),[24] the Interstate Technology Regulatory Council (ITRC),[25] and the New York State Pollution Prevention Institute (NYSP2I).[26]

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.[ix] 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.

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.

Regarding fluoropolymers, very few facilities reported fluoropolymer use under Tier II, but it is not known whether that indicates absence of use, or simply reflects an understanding that they are not required to report these chemicals or uses under Tier II. Listing under TURA will facilitate obtaining this information.

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

[ix] 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).

reporting, around 20 to 40 additional facilities could be required to report PFAS use under TURA, assuming use of regular TURA thresholds (25,000 and 10,000 lb/year). 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.

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 this category is adopted. Five to ten potential filers are estimated from Tier II, and 20-40 facilities are estimated from the review of additional website research. 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. Program staff estimate that these users are likely to be existing TURA filers. This estimate is based on the knowledge that most PFAS uses in industry are likely to occur at facilities that use other reportable chemicals.

Opportunities for TUR

In considering opportunities to reduce PFAS use, some researchers have adopted a framework that distinguishes among uses. Cousins et al. have noted 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."[27]

The TURA program has briefly examined alternatives for several applications. In addition to adopting safer alternatives, facilities may be able to reduce their PFAS use through improved operations and maintenance and other techniques. In addition, elimination without substitution is possible in some applications.

Textile and Fabric Treatment

PFAS are used in a range of applications for textile and fabric treatment. Many of these simply provide functions related to consumer use, such as visual enhancement of furniture or clothing, including stain resistance. For applications that are primarily cosmetic, simply eliminating PFAS may be the most practical approach. In other cases, PFAS are used in protective applications, for example in treatment of firefighters' protective clothing or military gear. In these applications, it is necessary to conduct research on safer alternatives.

Multiple PFAS-free chemical alternatives are becoming available for applications related to repelling soils and staining agents . 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] Some companies, such as W.L. Gore have developed strategies for eliminating certain PFCs from specific product categories; for example, W.L. Gore has now eliminated certain PFCs from over 50% of their "general outdoor product portfolio."[32]

PTFE and other fluorinated coatings are also used on fabric tents, awnings, archtitectural roofing membranes and other industrial fabrics.[33, 34] Alternatives are under development and include siloxanes and urethanes.[35] Alternatives assessments will be key to avoiding regrettable substitutes given the concerns with these types of substances.

Fume suppressants and metal finishing

PFAS have historically been used as fume suppressants (or mist suppressants) in hexavalent chromium plating and chromic acid anodizing operations. PFAS are used in this setting to reduce toxic vapors escaping from the hexavalent chromium bath. They may also be used in chromic acid etch tanks.[36] Industry has moved away from PFOS-based fume suppressants in favor of C6-based PFAS, but the low surface tension and stability required are still a challenge for non-fluorinated products. There is a need for additional research and development of non-fluorinated alternatives for this application. Products are available that claim to be fluorine-free, although they may not be appropriate for all baths.[37] Other options include process modification to a larger closed process, increased ventilation and treatment of air emissions. The most practical and effective way to reduce or eliminate PFAS in this setting is to adopt safer alternatives to hexavalent chromium, an area in which the TURA program is actively engaged.

PFAS can also be used in some electroless nickel plating applications. For example, polytetrafluoroethylene (PTFE) can be used to add lubricity to the hardness of electroless nickel.[38]

Food packaging and food contact paper

PFAS are often used in food packaging to add grease resistance to paper and cardboard products, leading to concerns about PFAS in food as well as in compost. Substantial 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 that are available without PFAS.[39]
- 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.[40]
- The State of Washington is working on an Alternatives Assessment for PFAS in food packaging. Alternatives identified for consideration include uncoated paper; paper with alternative coatings (petroleum or bio-based wax, kaolin clay, silicone and plastic (e.g., PET, PE, PVA, PLA); and non-paper materials, such as aluminum foil.[41]

Other fluoropolymer coatings

Other fluoropolymer applications include coatings for medical devices and for cookware.[x] Fluoropolymer coatings reduce friction on the surface of medical devices such as catheters and guidewires, and can provide color coding autoclave resistant finishes. For example, PTFE coatings on metal substrates are often aqueous dispersions of fine particles of PTFE and PFAS surfactants, cured in a high temperature oven, releasing PFAS surfactants into the air. Other coating systems are fully cured fine powders which are added to binders and solvents, and cured by driving off the solvent.[42] One possible alternative under investigation is silica-based sol-gel coatings (siloxane-based, ceramic-like coatings).[43] For cookware, a wide range of safer alternatives are available. These include cast iron, enamel-coated cast iron, ceramic and stoneware, stainless steel, and carbon steel.[44]

As for other PFAS uses, there are also TUR techniques to reduce use, byproducts and worker and public exposure. In their TUR planning, facilities using these products in manufacturing can consider tighter process control, closed loop systems, lower temperature processing, and other techniques.

Fluoropolymer resins

Various fluoropolymer resins are used to manufacture products, particularly in extreme environments, or where heat, low coefficient of friction or chemical resistance are needed. Uses in Massachusetts include insulation and jacketing of wire and cable (e.g., PVDF, FEP, PTFE and ETFE). For wire and cable, depending on the application, other resins to consider include sulfone polymers, polyamides, TPEs (thermoplastic elastomers) and high-performance low smoke halogen-free resins.[45]

Aqueous Film-Forming Foam (AFFF)

AFFF is an important source of PFAS contamination in the environment. The majority of use is by airports, military, and fire departments. There are also Massachusetts manufacturing facilities that use AFFF, although they would not be expected to be subject to TURA reporting requirements unless AFFF is part of their product. Fluorine-free foams (F3) are commercially available, and widely in development. They are already being used for training purposes, and by airports in some countries.

According to an industry source, "Many airports globally have gained significant confidence in the fire extinguishment performance of F3 [fluorine-free] foams such they have transitioned away from AFFF containing PFASs over the last decades. For example, some major international airports using F3 foams include London Heathrow, Gatwick, Stansted and City,

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[x] One case of water contamination in Massachusetts resulted from use of a fluoropolymer for coating applications at a medical devices facility. PFAS were discharged into air, leading to groundwater contamination.

Manchester, Paris Charles De Gaulle, Paris Orly, Lyon, Helsinki, Lisbon, Dubai, Brussels, Copenhagen, Oslo, Stockholm, Stuttgart, Dortmund, Sydney, Melbourne and Brisbane."[46]

A recent report by the International POPs Elimination Network (IPEN) notes that "a significant number of foam manufacturers now offer both fluorine-containing AFFFs and high-performance fluorine-free F3 products in order to satisfy customer demand and the need for environmental and health protection," and lists more than ten manufacturers of these products. The report notes that the transition has moved forward successfully in European and Australian markets, and the alternatives are cost competitive.[47]

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."[48] The report's recommendations include further research on ingredients of fluorine-free alternatives, assistance to non-military users in changing to fluorine-free alternatives.[49] Other institutions, including the Department of Defense, are also working actively to research and facilitate the adoption of fluorine-free options.

In addition, MassDEP has been partnering with Connecticut Department of Energy and Environmental Protection (CT DEEP) to test the performance of several F3 foams, as well as testing them for presence of fluorinated chemicals. [50]

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; the regulatory information summarized below was last updated in late 2019.

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.[51] 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.[52] 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…"[53] [54] [55]

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.[56]

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.[57] 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.[58] PFOS is regulated in the EU as a persistent organic pollutant.

In addition, a restriction proposal for PFAS is being prepared under REACH. The proposal is being prepared by five member countries (Germany, the Netherlands, Norway, Sweden and Denmark). The regulation is expected to enter into force in 2025.[59]

The European Commission's *Chemicals Strategy for Sustainability* was published in October 2020.[60] This strategy document includes a focus on PFAS, identified as a particularly high priority area for action due to water contamination, health effects, and costs associated with contamination. The Commission "proposes a comprehensive set of actions to address the use of and contamination with PFAS," and provides a stated goal "that the use of PFAS is phased out in the EU, unless it is proven essential for society." The Commission states that it will:

- "ban all PFAS as a group in fire-fighting foams as well as in other uses, allowing their use only where they are essential for society;
- address PFAS with a group approach, under relevant legislation on water, sustainable products, food, industrial emissions, and waste;
- address PFAS concerns on a global scale through the relevant international fora and in bilateral policy dialogues with third countries;
- establish an EU-wide approach and provide financial support under research and innovation programmes to identify and develop innovative methodologies for remediating PFAS contamination in the environment and in products;
- provide research and innovation funding for safe innovations to substitute PFAS under Horizon Europe."

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)."[61]

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."[62]

Federal

EPA – TRI. The National Defense Authorization Act[63] (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 that are in the TSCA inventory as of February 2019 and is currently subject to a significant new use rule (SNUR). This includes precursors to the named PFAAs. 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 initially identified a list of 172 chemicals for listing under TRI based on these criteria.[64] As they review CBI chemicals, they will update that list; for example, 3 more chemicals were added for reporting year 2021.

EPA has also issued an Advance Notice of Proposed Rulemaking (ANPRM) on possible listing of additional PFAS.[65] 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."[66]

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. In addition, EPA recently modified their process for allowing low volume exemptions (LVEs) under TSCA, in an effort to prevent new PFAS from entering the market. [67]

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)."[68] Under UCMR 3, EPA has required testing for PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFBS in all larger drinking water systems.[69] As noted earlier in this document, testing conducted under UCMR 3 has led to the identification of multiple situations of drinking water contamination in Massachusetts.

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.[70]

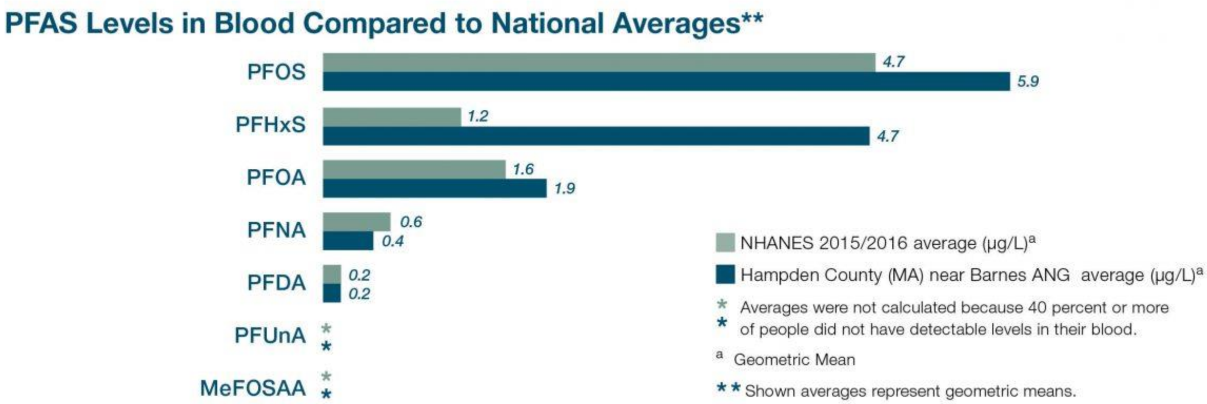
EPA – PFAS Action Plan. In February 2019, EPA released a "Per- and Polyfluoroalkyl Substances (PFAS) Action Plan." The main actions the EPA announced are initiating steps to: evaluate the need for a maximum contaminant level (MCL) for PFOA and PFOS; begin the necessary steps to propose designating PFOA 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).[71]

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 and 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 PFAS, and includes peer-reviewed profiles that summarize key literature on their toxicological properties.[72]

In addition to studying the health effects of PFAS, the ATSDR conducts exposure assessments, including Barnes Air Force Base in Westfield, MA, and communicates exposure information to affected communities. Results from the exposure assessment at Barnes Air Force Base show blood levels of certain PFAS above national average levels (see Figure 3).[73]

Figure 3: Results of CDC/ATSDR PFAS Exposure Assessment (Image from ATSDR fact sheet)[74]



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 purchases 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."[75]

States[xi]

A number of states have adopted, or are in the process of developing, regulations and programs to address PFAS. This includes approaches that:

- 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

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[xi] Note: This set of examples is not comprehensive. In addition, policies are updated frequently so some policies discussed here may have been updated since this summary was written.

- 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. Examples of monitoring activities include those in New Hampshire, Washington, California, and North Carolina.

- New Hampshire's Department of Environmental Services has investigated, or is investigating, a number of sites for the presence of PFAS in groundwater. These include landfills, industrial sites, fire departments and training facilities, and a wastewater treatment facility.[76]
- The Washington Department of Health has worked to "test several hundred water systems in the state for trace contamination of more than a dozen chemicals found in some firefighting foams."[77]
- PFAS chemicals are included in the California Environmental Contaminant Biomonitoring Program, also known as Biomonitoring California.[78] A scientific guidance panel makes recommendations about priority chemicals for biomonitoring.[79]
- The North Carolina legislature funded the monitoring and treatment of PFAS, particularly "GenX" substances.[80] [81] 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)."[82] These chemicals are generally referred to as GenX.

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 2017, PFOS and PFOA were added to California's Proposition 65 list based on reproductive toxicity.[83] In 2021, the state published a notice of intent to list PFOA as known to cause cancer; announced a review of the carcinogenicity of PFOS; and announced a review of the reproductive toxicity of PFDA, PFHxS, PFNA and PFUnDA.[84]
- The State of Washington requires the reporting of PFOA and related substances, and PFOS and its salts, in children's products. [85] 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."[86]
- A bill in the Vermont Legislature would include PFAS on the list of Chemicals of High Concern to Children.[87]

Environmentally Preferable Purchasing (EPP) policies. Examples of EPP approaches include Minnesota and Washington.

- 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)."[88] Also, under its Toxics Reduction and Pollution Prevention program, Minnesota is working to reduce PFAS "in firefighting foam, chrome plating, and food packaging, with related efforts in state and local government purchasing."[89]
- The 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.[90]

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.[91] 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.[92]

Restrictions, bans, and assessments of alternatives. Examples of these approaches are found in Washington, Minnesota, and other states, with a focus on fire fighting foams and food packaging materials.

- 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.[93]
- In Minnesota, the use of Class B firefighting foam with intentionally added PFAS are 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.[94] In addition, any use of PFAS-containing class B foam on a fire must be reported to the State Fire Reporting System.
- In 2018, Washington adopted 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.[95] They completed an alternatives assessment in February 2021 that identified safer alternatives for four food packaging applications.[96]
- New York banned PFAS in food packaging in 2020.[97]
- As of the most recent updates to the present document, several bills were also under consideration. A bill currently in the Vermont Legislature,would restrict the use, manufacture, sale, and distribution of class B firefighting foam containing PFAS; food packaging to which PFAS (or phthalates or bisphenols) have been added; residential rugs, carpets, and aftermarket stain and water resistance treatments to which PFAS have been added; and ski wax with PFAS.[98] 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."[99] In Massachusetts, H.2348 would ban the sale and distribution of food packaging to which PFAS have been

intentionally added.[100] Bills 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. As of late 2019, such levels and standards included the following:

- 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).[101]
- 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).[102] 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.[103] In July 2020, the state established MCLs for for PFOA, PFOS, PFNA, PFHxA, PFHxS, PFBS, and HFPO-DA (Gen-X).[104]
- 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.[105,106] 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."[107]
- New Jersey has taken a number of actions on PFAS. In 2018, NJ adopted a statewide drinking water standard for PFNA with an MCL of 13 ppt.[108] 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.[109] 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.[110] 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.[111] 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.[112] In 2016, New York regulated PFOA and PFOS as hazardous substances. The final rule became effective in 2017.[113]
- 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.[114]
- As of the last update to this Policy Analysis, the Washington Department of Health was engaged in rulemaking for standards for certain PFAS in drinking water.[115]

Drinking water and groundwater: Massachusetts

As noted above, several efforts have been undertaken to address some aspects of PFAS contamination in Massachusetts.

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.[116] In October 2020, MassDEP promulgated a 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).[117]

Groundwater cleanup standards. MassDEP 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.[118]

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."[119]

Health Risk Limit and guidance values for drinking water and groundwater. Examples in this area include Minnesota and Texas.

- In 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).[120] The state also has drinking water guidance values for PFBS (2 ppb), PFBA (7 ppb), and PFOA (35 ppt).[121]
- 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.[122]

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.[123]
- 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.[124] The Task Force's 11 members include representatives of several state agencies, the state public health association, and additional organizations.[125]
- 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.[126]
- 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.[127]

Air Emissions

- In January 2021, the New York State Department of Environmental Conservation proposed a limit on air emissions of PFOA.[128]
- Michigan has regulated air emissions of PFOA and PFOS.[129]

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," and requires that compostable foodware not contain added fluorinated chemicals.[130]

Other Considerations

A workshop held in Zürich, Switzerland in November 2017 brought together an international group of researchers and regulators to work toward 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." 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."[131] The group expressed its support for 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…"

More recently, Kwiatowski et al. (2020) researched approaches to PFAS regulation and concluded " the high persistence, accumulation potential, and/or hazards (known and potential) of PFAS studied to date warrant treating all PFAS as a single class."[132] Balan et al. (2021) present the rationale of the California Department of Toxic Substances Control (DTSC) in regulating PFAS as a chemical class in its implementation of California's Safer Consumer Product Regulation. Balan et al. note that "Regulating only a subset of PFAS has led to their replacement with other members of the class with similar hazards, that is, regrettable substitutions. Regulations that focus solely on perfluoroalkyl acids (PFAAs) are ineffective, given that nearly all other PFAS can generate PFAAs in the environment." DTSC has taken a "P-sufficient" approach, taking account of the fact that "all PFAS show high persistence (P) or degrade to other class members that are highly persistent."[133]

Many states have developed drinking water and other regulations for small groups of PFAS substances, as discussed above. The National Defense Authorization Act applies to a larger group of PFAS substances, covering both longer-chain PFAS and their precursors. Several organizations are working on reports or white papers regarding PFAS groupings and the rationales for a variety of possible groupings; these include the Society for Environmental Toxicology and Chemistry (SETAC) and OECD.

Implications for the TURA program

This section presents the expected implications for the TURA program of adding a PFAS category to the TURA list. This includes implications of category designation; implications for compliance and reporting; implications for and applicability of TURA program services; and implications for fees and costs.

Implications of category designation

Chemical categories are used in the TURA list in a number of cases. The TURA program's approach to categories has generally been based on the approach used under the federal Emergency Planning and Community Right-to-Know Act (EPCRA). The most recent case in which the TURA program created a category designation was for the C1-C4 NOL category. In this case, as in some others, the category is defined using a chemical structure and text description, with a non-exhaustive list of CAS numbers provided as guidance to assist the regulated community.

Defining a chemical category is appropriate in a number of circumstances, and can provide several advantages compared with listing chemicals individually. Advantages to use of categories include avoiding adverse substitutions; providing clear information to users in the absence of a defined list of CAS numbers; and addressing a set of chemicals with similar health or environmental effects together.

- Adverse substitutions: One important reason to create a chemical category is to address concerns related to adverse, or "regrettable," substitutions. If a large group of chemicals that are structurally similar may potentially be used as substitutes for one another, regulating them one at a time can create unintended consequences, in which a more-regulated chemical may be replaced by an equally hazardous, less-regulated chemical. Creating a category provides clear guidance to chemical users, and helps to avoid such adverse substitutions.

- Incomplete set of CAS numbers: A chemical category is also helpful when specific CAS numbers do not adequately capture the chemicals of concern. For example, if there are a number of theoretical compounds in a category, and many of them do not yet have CAS numbers, then a category defined through chemical structure and descriptive text is more informative than a list of specific chemicals.
- Similar hazards across a group: A category is also useful when a number of structurally similar chemicals have, or are reasonably anticipated to have, similar health or environmental impacts. This makes it possible to address these hazards proactively by addressing the group of chemicals together.
- Confidential Business Information (CBI): A category approach is useful when the specific identity of many chemicals in the category are claimed by the manufacturers as CBI. Reporting under TURA would not require a user to obtain and report that specific chemical identity.

The proposed PFAS NOL category meets all the criteria described above. A number of the chemicals may be reasonably anticipated to be used as substitutes for one another; for example, shorter-chain PFAS and GenX were developed as substitutes for longer chain PFAS. A number of possible compounds exist for which CAS numbers have not been generated. For example, an unlimited number of different functional groups could be added to a fluorinated carbon chain, each time creating a new unique chemical CAS number. Across the group of chemicals, specific health and environmental impacts (e.g. persistence) appear frequently. Regarding CBI, preliminary data from EPA under the TSCA Inventory Notification Rule noted that nearly one third of PFAS substances reported as active in commerce were claimed as CBI (148 CBI and 330 non-CBI).[134]

By defining and listing a PFAS NOL category, the TURA program can efficiently address this group of chemicals. The TURA program can provide clear, proactive guidance to businesses to assist them in addressing all chemicals in the category.

Compliance and reporting

Tracking use of PFAS in an industrial facility can pose special challenges due to the lack of clear nomenclature and the lack of testing standards for most PFAS. In addition, PFAS often are not listed on Safety Data Sheets (SDSs). This may be because they account for a small percentage of the product, or because they are classified as confidential business information (CBI). This lack of information increases the difficulty for facilities in identifying what is in the formulations they purchase. Compared with a list of specific PFAS, the proposed category will facilitate compliance, because facilities will not need to determine what specific PFAS they are using.

Industrial facilities have two principal options for determining the presence of any chemical, including PFAS, in chemicals ordered from a supplier. The first is to require that the supplier disclose the presence of the chemical of interest in any solutions provided to the facility. The second is to conduct testing. A variety of tests are available that allow determination of the presence of PFAS as a category. These include the total oxidizable precursors (TOP) assay, among others. TURA filers' obligation would be to use their best engineering estimate, not to conduct additional monitoring.[xii]

The TRI listing required by NDAA will provide some experience with supplier disclosure through the supply chain. In order to comply with the TRI requirements, manufacturers and distributors will be required to provide the relevant information to covered facilities. The TURA program has provided training and tools, for businesses on this topic as they prepare to comply with this new requirement. For example, OTA has provided a sample supplier notification letter for companies to use as they query their suppliers.

Thresholds

It is important to note that not all PFAS listed under TURA will have the same reporting thresholds. The TRI-listed substances will have a 100 lb/year threshold for each individual chemical. Those listed in the PFAS NOL category will have a 10,000 lb/year or 25,000 lb/year threshold for the category as a whole, unless there is a Higher Hazard Substance designation for some or all of the chemicals.

TURA program services

Both the Office of Technical Assistance (OTA) and TURI are available as a resource for new filers entering the program.

TURI has an academic research grant program that can target seed funding to researchers who are developing safer alternatives to toxic chemicals for specific applications. When specific industry needs are identified, along with companies willing to share performance criteria, materials and/or other forms of expertise, TURI can identify university researchers interested in focusing their R&D efforts for solutions. If a specific application of the use of chemicals in the PFAS NOL category presents an ongoing challenge for companies with respect to shifting to safer alternatives, TURI could support R&D to find feasible solutions. An example could be additional research on alternative fume suppressant options.

TURI's incentive grants for businesses can support businesses as they test and implement innovative safer technologies. TURI's demonstration site grants can help businesses that have already made a change to showcase their innovations to other businesses in related sectors. Both of these categories of grants can be used as a resource in helping Massachusetts businesses and communities adopt safer alternatives to chemicals in the PFAS NOL category.

[xii] Some information from the Plastics Industry Association may be useful to businesses in determining thermal degradation products and temperatures. (https://www.turi.org/Our_Work/Policy/Toxics_Use_Reduction_Act/Councils_and_Committees/TURA_Science_Advisory_Board/PFAS_information_reviewed_by_the_Science_Advisory_Board/The_PFAS_Universe_Webinar/Guide_to_the_Safe_Handling_of_Fluoropolymer_Resins) In some cases, businesses may be able to determine the presence of fluorine compounds if the SDS notes that HF is a byproduct of combustion.

In addition to the TURA program's ongoing trainings for businesses, OTA is working with MassDEP and US EPA to offer OTA services to potential PFAS users upstream from selected wastewater treatment facilities in sensitive drinking water protection areas. MassDEP is introducing OTA to selected wastewater treatment facilities (WWTF) who are referring companies directly to OTA while encouraging companies within their jurisdiction to take advantage of their free and confidential technical assistance services. OTA has also been participating in interstate biosolids meetings hosted by NH Dept of Environmental Services to create region-wide and replicable outreach and educational materials to prevent PFAS from entering biosolids. In addition, TURI is currently assisting on a study of AFFF alternatives for the US Department of Defense's Strategic Environmental Research and Development Program. The goal of this project is to improve the ability of the Department of Defense (DoD) to make informed, efficient choices on alternatives to aqueous film forming fluorinated fire-fighting foams (AFFF) by strengthening and building consistency in the approaches used to identify, compare, and adopt alternatives.

Fees and planning-related costs

There would be some additional cost to companies that would begin reporting PFAS NOL, including preparing annual toxics use reports and biennial toxics use reduction plans, and paying toxics use fees. All facilities currently reporting PFAS under Tier II are already filing under TURA for other chemicals, so these facilities would not incur a base fee due to this listing. If they are not already paying the maximum fee, they would begin to pay an additional per-chemical fee of $1,100.

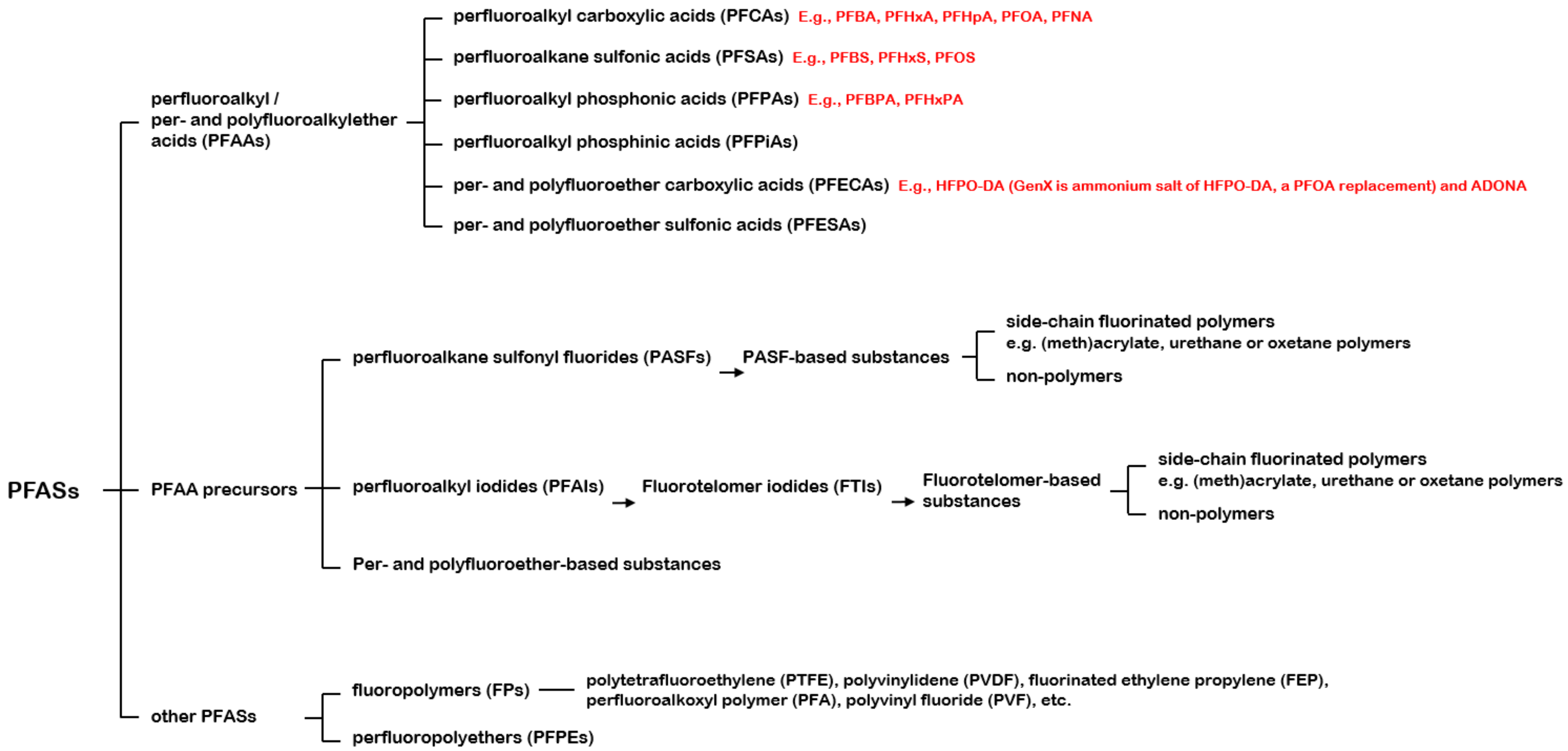
All potential filers are estimated to be current TURA filers, so additional planning costs would be modest. For companies that only need to report the PFAS NOL category, the cost of hiring a planner will likely be in the range of $1,000 - $3,000. Companies that want to have their own in-house TUR planner can qualify either by relying on past work experience in toxics use reduction or by having a staff member take the TUR Planners' training course. Those facilities with experienced staff can become certified for as little as $100. For those that want staff to take a course, the cost will be between $650- $2000 depending on whether the company has previously filed a TURA report. Companies with in-house toxics use reduction planners are likely to reap ancillary benefits from having an employee on staff who is knowledgeable about methods for reducing the costs and liabilities of toxics use. Additionally, through the process of planning and reducing or eliminating use of chemicals in the category, facilities may be able to expand their markets, better comply with other regulations and reduce their overall regulatory burden.

The total additional cost in fees to filers (and revenue to the program) could be $27,500 to $55,000 in per-chemical fees (25-50 filers for PFAS NOL). No new base fees are estimated at this time.

Appendix A

This flow chart is simplified and adapted from a flow chart published by OECD.[135] 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

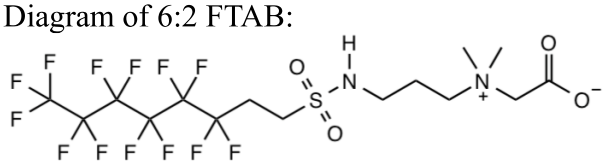
Appendix C: Example of breakdown into precursors: Chemical commonly used in AFFF

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.

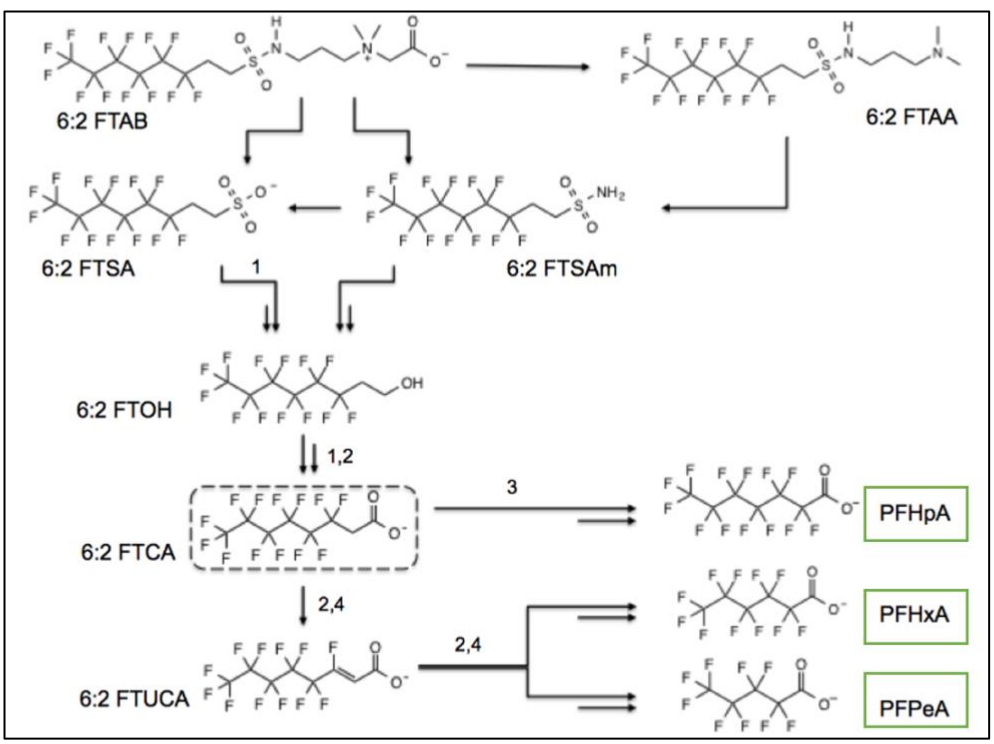
Full chemical name: 6:2 fluorotelomer sulfonamide alkylbetaine (6:2 FTAB) (34455-29-3)

Breakdown mechanism: Aqueous photoloysis

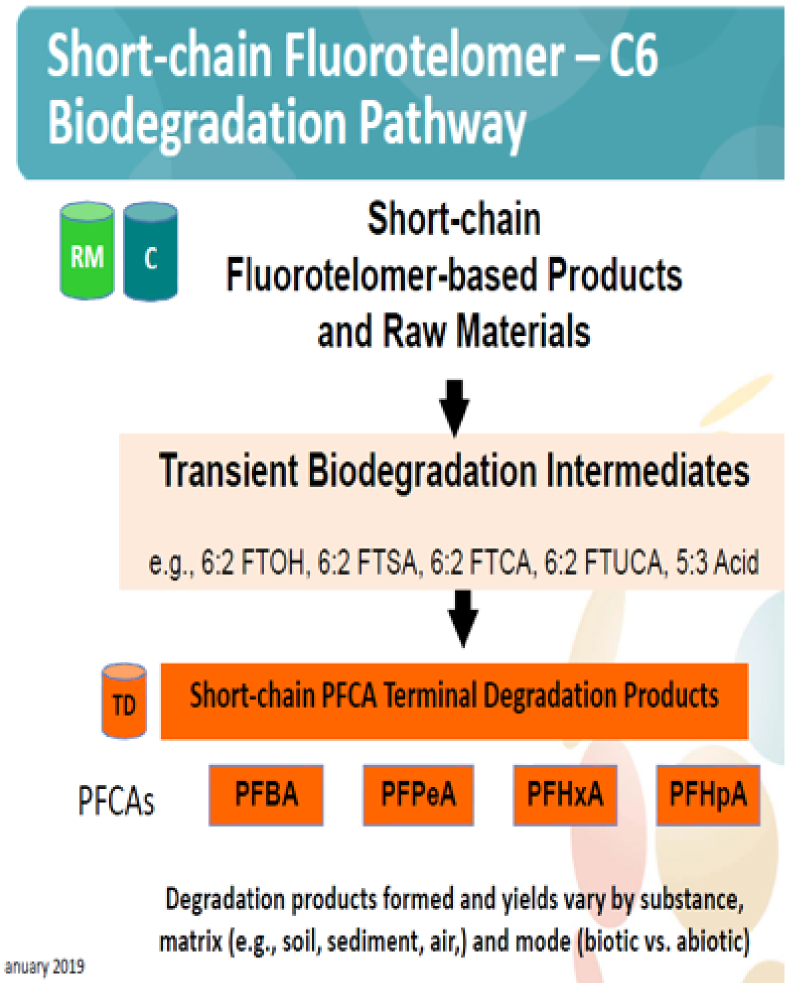
Diagram of 6:2 FTAB:



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)*:

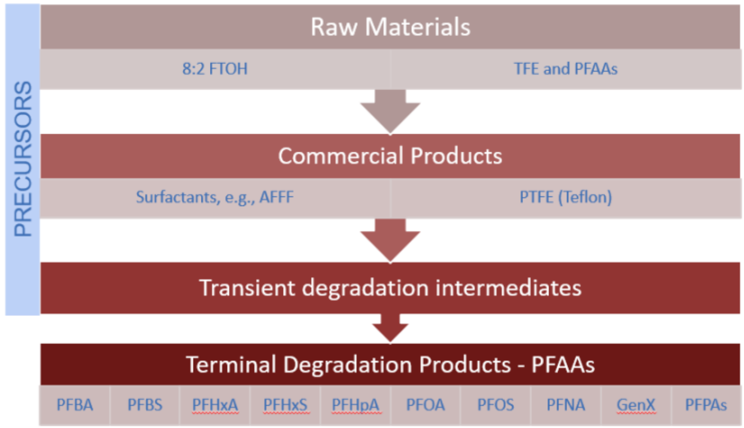


Summary of these breakdown pathways provided by Korzeniowski and Buck (Fluorocouncil/ACC), 2019:



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

The following diagram shows the role of precursors in the PFAS life cycle.



Appendix D: Summary of SAB Recommendations on PFAS

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.
June 25, 2020	PFAS Category	**Recommended listing** a category of chemicals defined as "those PFAS that contain a perfluoroalkyl moiety with three or more carbons (e.g $–C_nF_{2n}–$, $n \geq 3$; or $CF_3\text{-}C_nF_{2n}–$, $n\geq2$) or a perfluoroalkylether moiety with two or more carbons (e.g $–C_nF_{2n}OC_mF_{2m}–$ or $–C_nF_{2n}OC_mF_m–$, n and $m \geq 1$)"

Appendix E: State Actions to Address PFAS: Examples

Note: This table provides examples and is not comprehensive. In addition, some of the policies shown in this table are still under development, so there may be additional updates not reflected here.

One useful resource for up-to-date regulatory actions on drinking water is the website of the Association of State Drinking Water Administrators, at https://www.asdwa.org/pfas/. In addition, a useful listing of policy developments can be found on the website of the Green Science Policy Institute, at https://pfascentral.org/policy/.

State	Actions
California	• **Biomonitoring:** PFAS is included as a class in the Biomonitoring California Priority Chemicals list.[136,137] • **Labelling and disclosure:** In 2017, PFOS and PFOA were listed as known to the state to cause reproductive toxicity under Proposition 65. In 2021, the California EPA's Office of Environmental Health Hazard Assessment published a notice of intent to list PFOA as known to cause cancer; announced a review of the carcinogenicity of PFOS; and announced a review of the reproductive toxicity of PFDA, PFHxS, PFNA and PFUnDA.[138] • **California Safer Consumer Products Program:** In February 2020, the California Department of Toxic Substances Control (DTSC) proposed to adopt regulations listing carpets and rugs containing PFAS as a Priority Product under the Safer Consumer Products Regulation.[139] In 2019, DTSC presented initial findings from its evaluation of food packaging with PFAS, and proposed listing PFAS for use on converted textiles or leathers such as carpets, upholstery, clothing and shoes.[140,141] • **Drinking water**: In August 2019, California's Water Board established notification levels of 6.5 ppt for PFOS and 5.1 ppt for PFOA. In February 2020, it established response levels of 10 ppt for PFOA and 40 ppt for PFOS based on a running four quarter average. In March 2021, the Division of Drinking Water issued a drinking water notification level and response level of 0.5 parts ppb and 5 ppb, respectively for PFBS.[142]
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.[143] • **Action Plan:** In November 2019, the governor released a PFAS Action Plan that recommends a comprehensive series of actions to address PFAS.[144] • **Take-back of AFFF:** The state is planning take-back and safe disposal of AFFF from state and municipal fire departments.[145]

Massachusetts	• **Drinking water:**
	  ○ 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.[146]
	  ○ 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). These regulations were promulgated in October 2020.

	• **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.[147] • **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."[148]
Michigan	• **Drinking water:** In July 2020, the state established the MCLs for PFOA, PFOS, PFNA, PFHxA, PFHxS, PFBS, and HFPO-DA (Gen-X).[149] • **Groundwater standards**: The state also updated its groundwater standards to 8 ppt for PFOA and 16 ppt for PFOS.[150] • **Air emissions:** The state's air quality agency **"**derived health-based screening levels for PFOA and PFOS. Both screening levels are 0.07 micrograms per cubic meter (µg/m³) with a 24-hour averaging time. If both PFOA and PFOS are present in the air emissions, the combined concentration of these substances must be below 0.07 µg/m³, with a 24-hour averaging time."[151]
Minnesota	• **Environmentally Preferable Purchasing.** State contract specifications require that compostable food ware products not contain PFAS.[152] • **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.)[153] The state also has drinking water guidance values for PFBS (2 ppb), PFBA (7 ppb), and PFOA (35 ppt).[154] • **Bans and restrictions.** The use of Class B firefighting foam with intentionally added PFAS is 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.[155] In addition, any use of PFAS-containing class B foam on a fire must be reported to the State Fire Reporting System. • **Wastewater.** The Minnesota Pollution Control Agency (MPCA) requested $1.4 million from the Legislative-Citizen Commission on Minnesota Resources to analyze elevated levels of PFAS in waste streams.[156] • **Toxics Reduction and Pollution Prevention program.** MPCA is working to reduce PFAS "in firefighting foam, chrome plating, and food packaging, with related efforts in state and local government purchasing."[157]
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.[158]

New Jersey	• **Drinking water:**
	  o 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.[159]
	  o 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.
	  o In 2018, PFNA was added to New Jersey's List of Hazardous Substances.
	  o 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 June 2020, New Jersey's Department of Environmental Protection adopted drinking water MCLs of 14 ppt for PFOA and 13 ppt for PFOS.[160] The state also adopted the same levels as groundwater quality standards for site remediation activities; added certain PFAS to the NJ Community Right to Know Environmental Hazardous Substance list; and will require private well testing for PFAS during real estate transactions.[161]
New York	• **Cleanup:** In 2016, New York regulated PFOA and PFOS as hazardous substances. The final rule became effective in 2017.[162] • **Drinking water:** In August2020, the New York State Department of Health adopteddrinking water standards (MCLs) of 10 ppt for both PFOA and PFOS.[163] • **Air emissions.** In January 2021, the New York State Department of Environmental Conservation proposed a limit on air emissions of PFOA.[164] • **Food packaging.** In December 2020, New York banned PFAS in food packaging.[165]
North Carolina	• **Monitoring and treatment.** The state legislature funded the monitoring and treatment of PFAS, particularly GenX. • **Drinking water:** The state established a health advisory level of 140 ppt for GenX.[166]
Texas	• **Health Risk Limit values:** The Texas Risk Reduction Program (TRRP) has adopted standards for certain PFAS.[167]
Vermont	• **Drinking water**: The state's standard is 20 ppt for the sum of five PFAS (PFOA, PFOS, PFNA, PFHxS, PFHpA) in drinking water.[168] • **Bans and restrictions.** A bill in the Vermont Legislature would restrict PFAS in firefighting foam, food packaging, rugs, carpets, stain and water resistance treatments, and ski wax, and include PFAS on the list of Chemicals of High Concern to Children.[169]
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.[170] • **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***.[171] - 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 (Full table current as of: November 23, 2019; Massachusetts has been updated more recently.)

	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	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.

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