

PFAS in Drinking Water

by

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**Course 525
3 PDH (3 Hours)**

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PFAS in Drinking Water

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PFAS in Drinking Water

PFAS Overview

Per- and polyfluoroalkyl substances are known as PFAS or PFASs. They are a group of synthetic organofluorine chemical compounds that have multiple fluorine atoms attached to an alkyl chain. The arrangement makes them last an extremely long time (>1000 years) in a variety of environments. Hence, PFAS are known as persistent organic pollutants or “forever chemicals.”

PFAS also have superior water-resistant and heat-resistant properties. The combination of appealing properties makes PFAS a popular choice for materials, coatings, and a variety of consumer products. See Figure 1 for examples. Actually, I should say PFAS **was** a popular choice, until a couple decades ago when it was linked to serious health problems in humans and other animals. Since then, PFAS production has slowed.



Figure 1: Left) PFAS coated fabric. Right) PFA tubing.

Source: Left) commons.wikimedia.org/wiki/File:A_water_droplet_DWR-coated_surface2_edit1.jpg, Brocken Inaglory, CC-BY-SA-3.0
Right) commons.wikimedia.org/wiki/File:Pfa_tubing.jpeg, Bushytails, CC-BY-SA-3.0

PFAS also has a surfactant property, so was used in foam products for firefighting. The foam is sprayed on a surface which creates an aqueous film blanket with low surface tension. The PFAS foam efficiently covers the fuel surface, blocks oxygen supply, and suppresses fuel vapors. The fire stops and can't spread on the sprayed surface for a very long time.

PFAS in Drinking Water

PFAS in the Environment

PFAS has slowly accumulated in the environment and is now readily found in these places:

- Surface water
- Groundwater
- Ocean
- Sediment
- Soil
- Plants
- Animals on land and water (see Figure 2)
- Air (short-chain PFAS, settles within a few weeks)

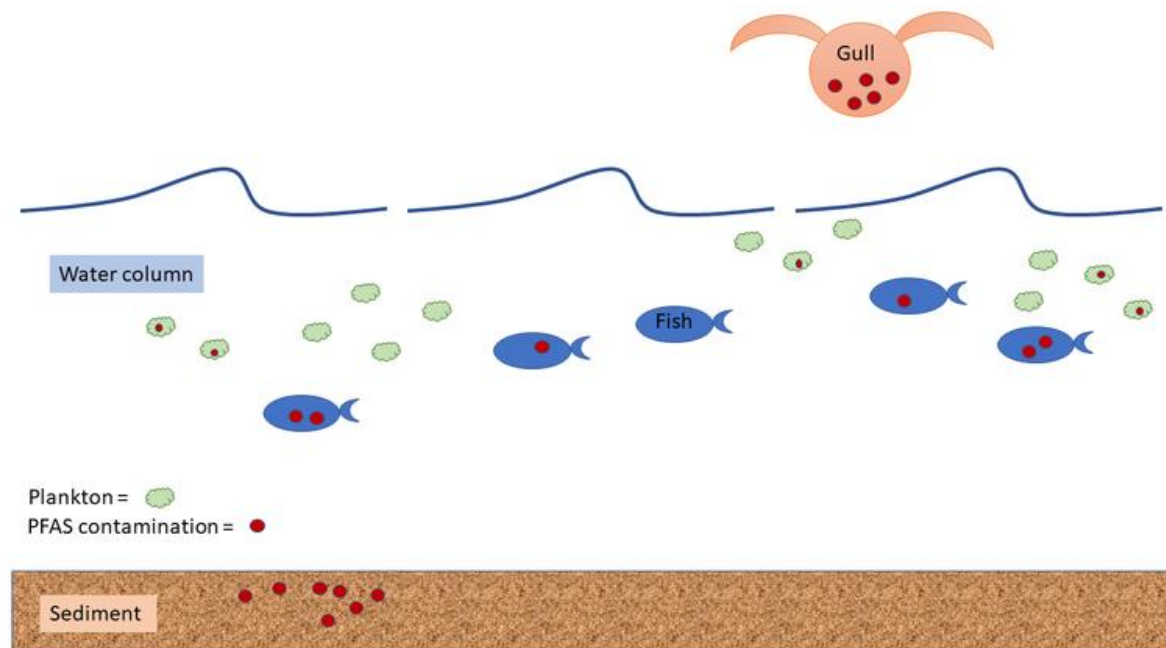


Figure 2: PFAS in sediments and water accumulating in marine organisms.

Animals higher on the food chain tend to accumulate more PFAS.

Source: commons.wikimedia.org/wiki/File:PFAS_Biomagnification.png, Yanishevsky, CC-BY-SA-4.0

PFAS concentrations tend to increase over time since they last hundreds or thousands of years. Fortunately, in the last 20 years, most companies have slowed or stopped producing PFAS and turned to alternatives.

PFAS in Drinking Water

Health Concerns

It is difficult to study the long-term health impacts of chemicals like PFAS. However, many medical studies, some going back to the 1970's, have shown direct links between many common types of PFAS chemicals and health problems. Figure 3 shows the main health impacts with high certainty items in bold.

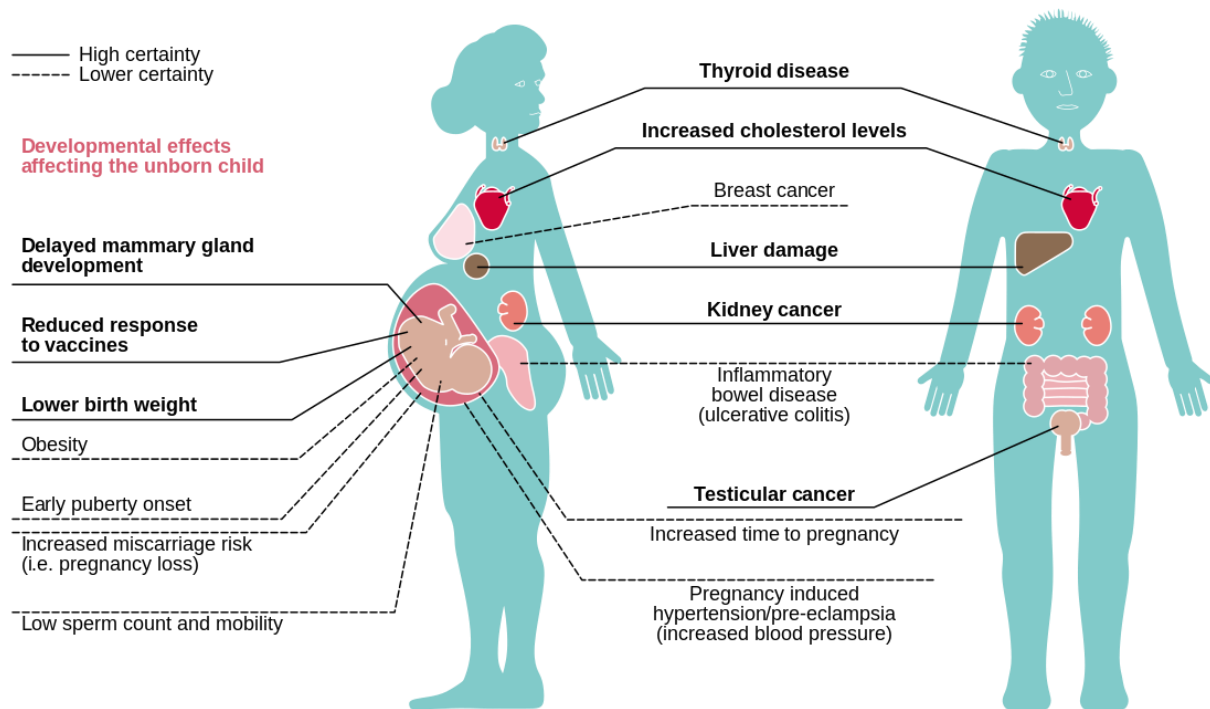


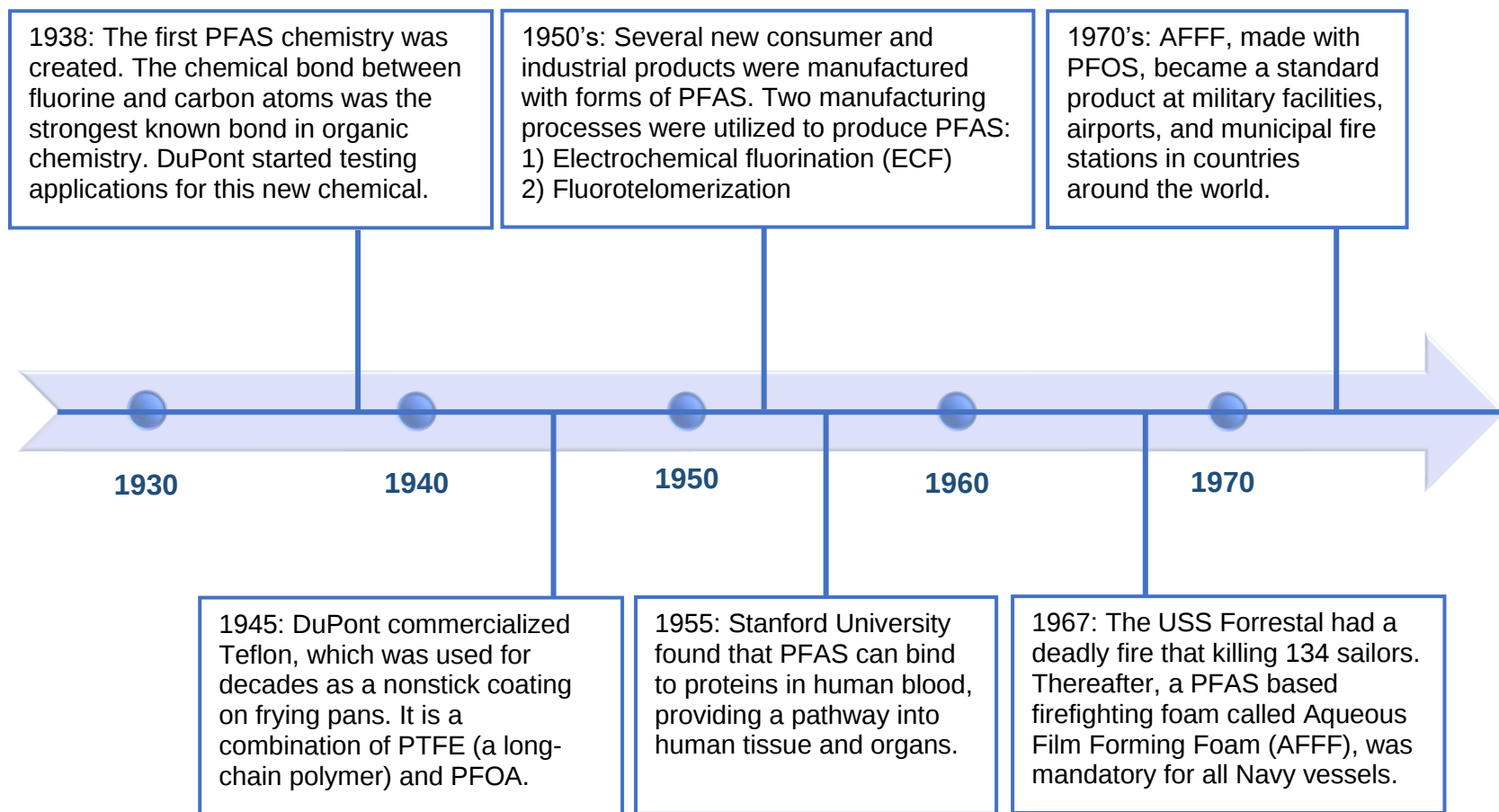
Figure 3: Health effects of exposure to PFAS in women, men, and fetuses.

Source: en.wikipedia.org/wiki/File:Effects_of_exposure_to_PFASts_on_human_health.svg, European Env. Agency, CC-BY-SA-4.0

One of main ways PFAS can enter the human body is through consuming food or liquid with PFAS. The regular drinking of water with PFAS results in PFAS molecules being absorbed into the body and accumulates in human tissue, especially the liver and kidneys. Therefore, private and public drinking water is commonly tested for PFAS levels. Treatment techniques to remove PFAS from potable water supplies are becoming increasingly common.

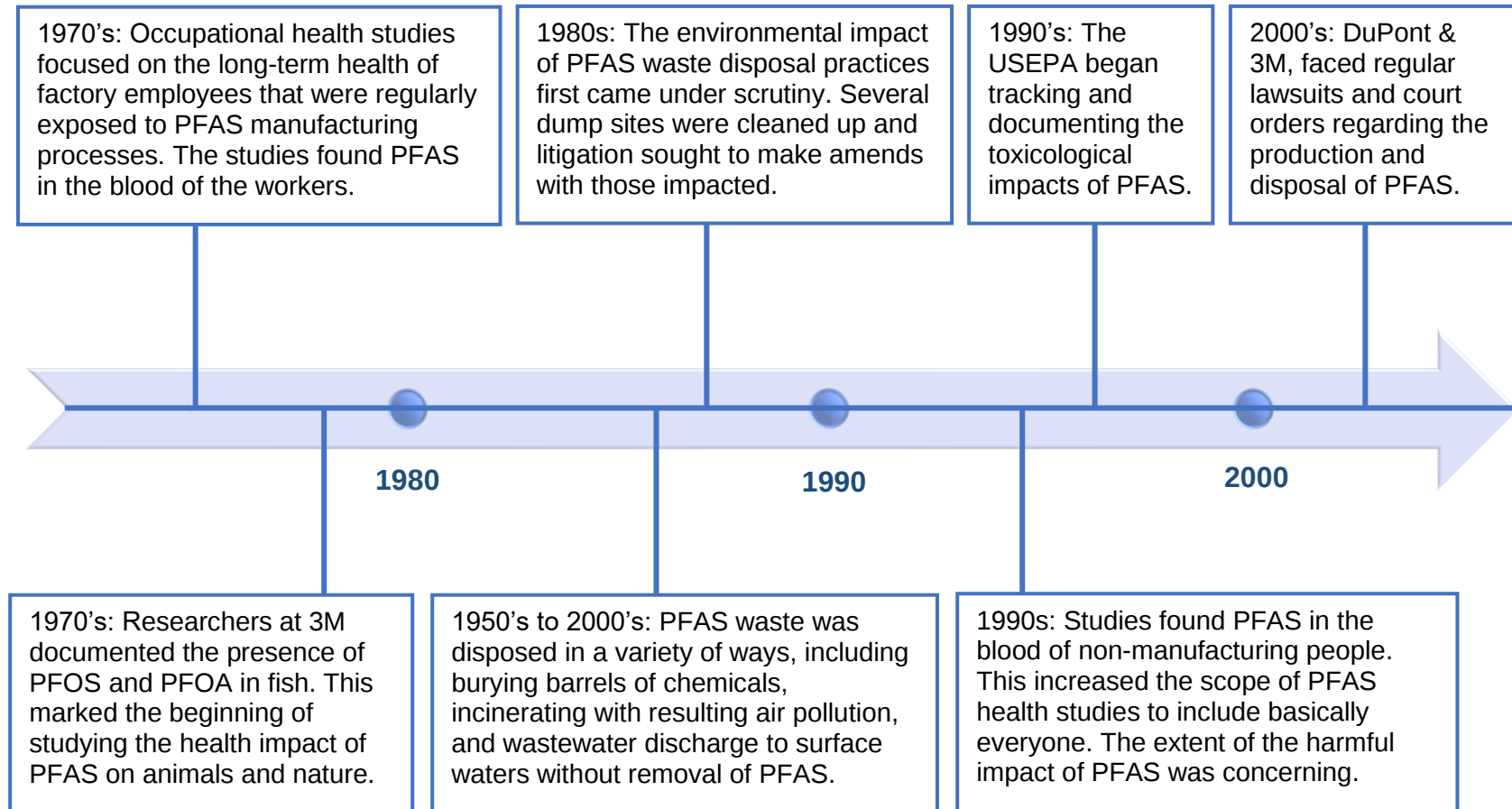
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History

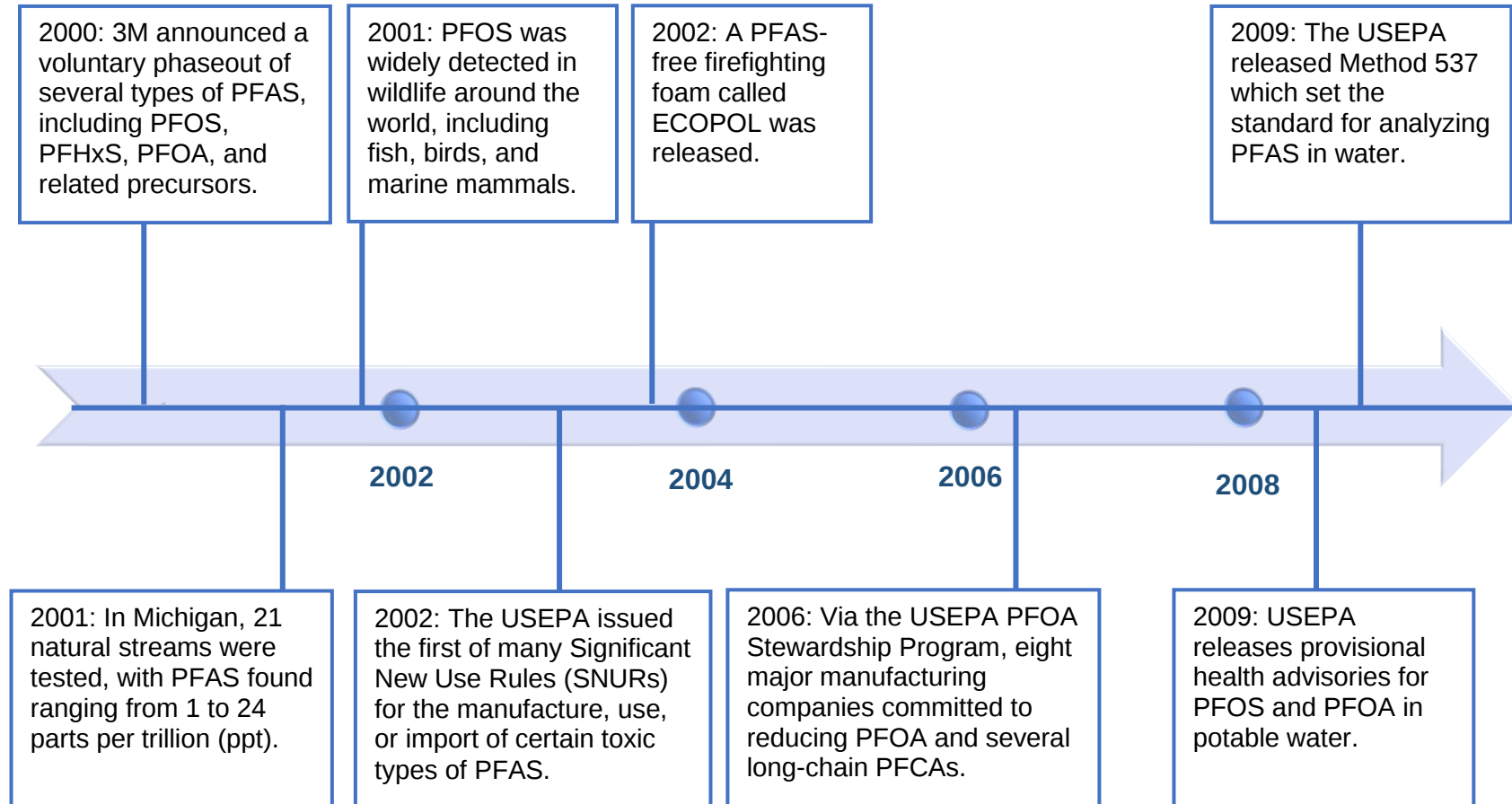


See the next section for an explanation of different types of PFAS.

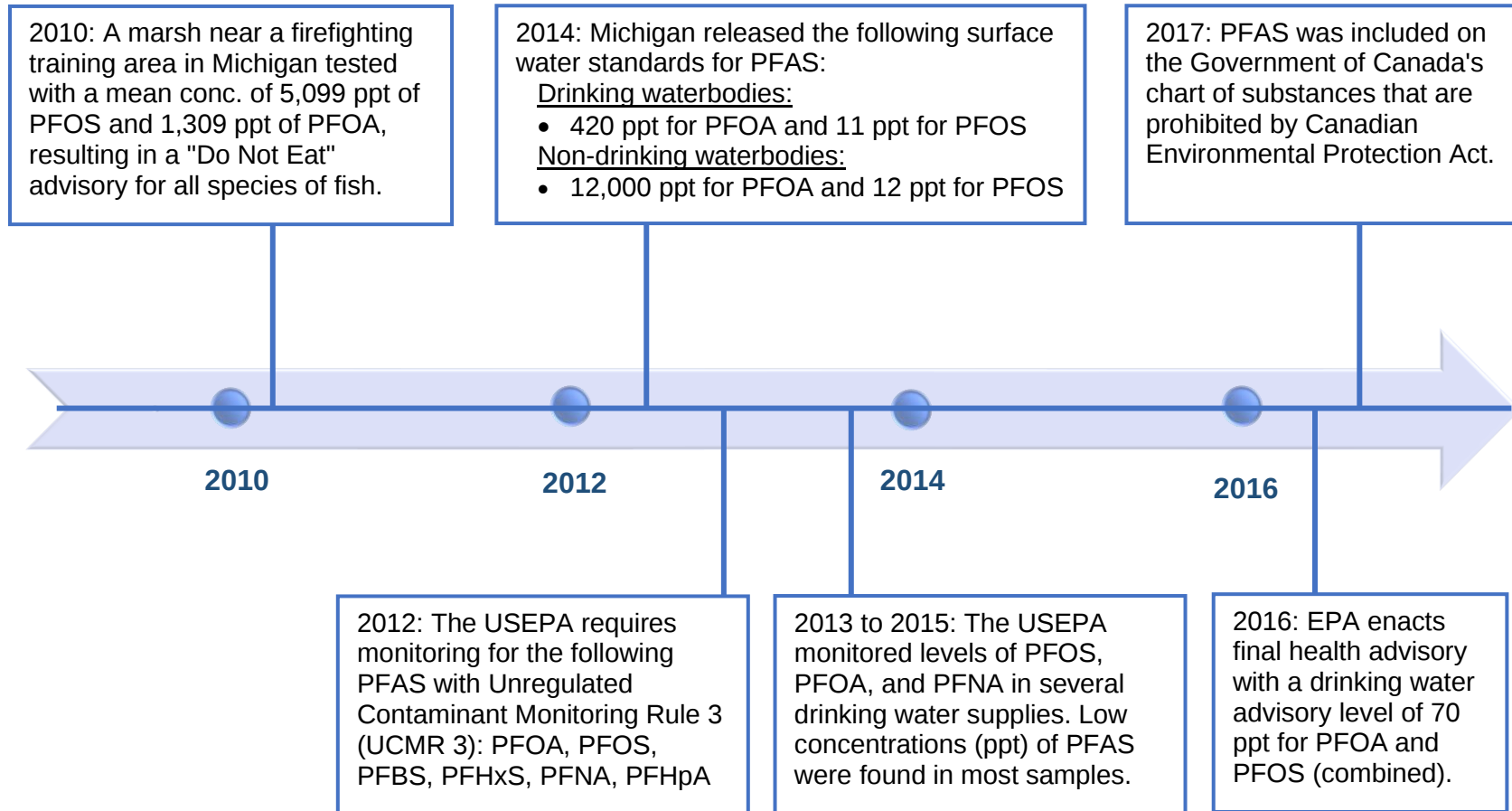
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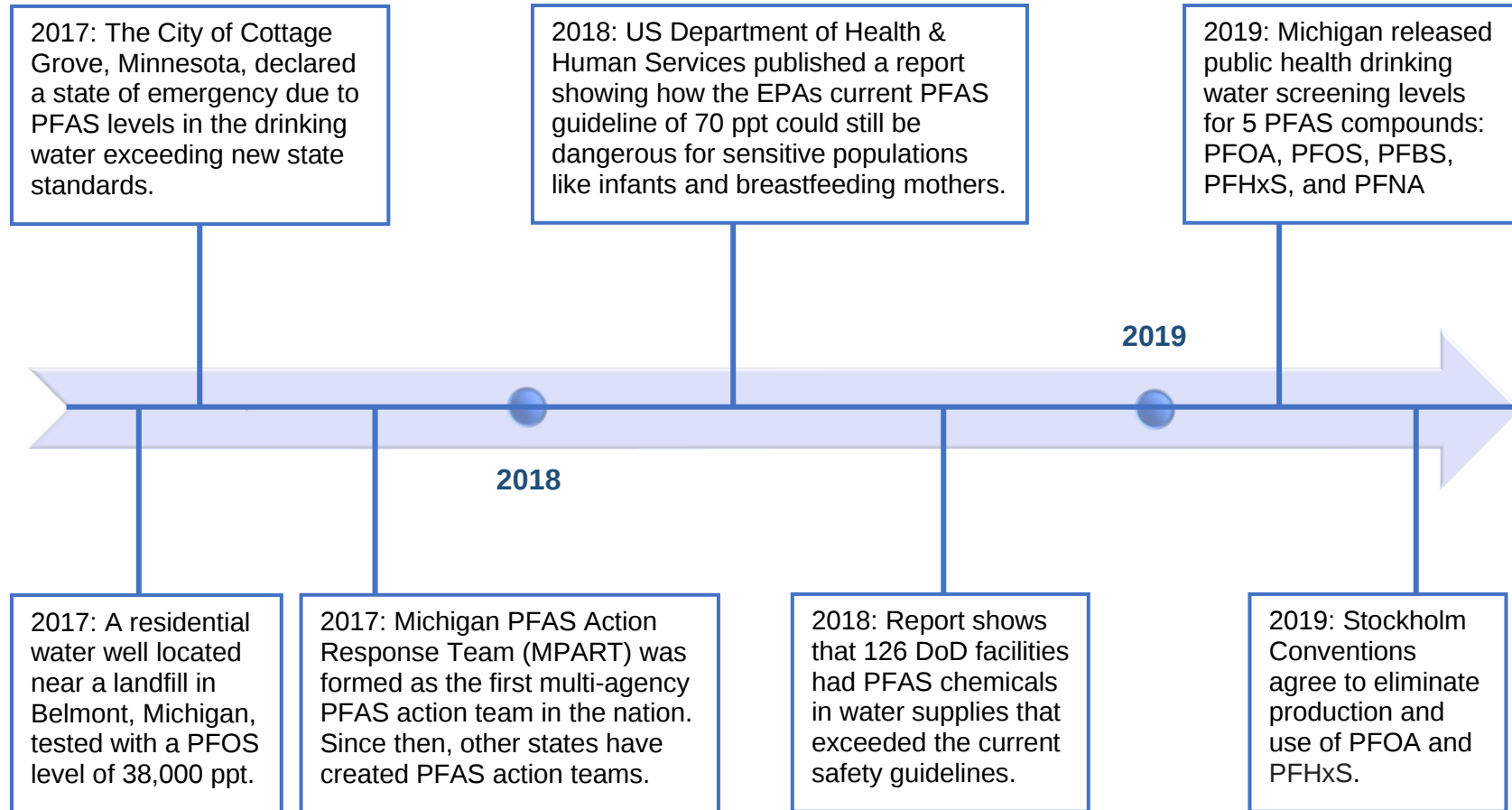
PFAS in Drinking Water



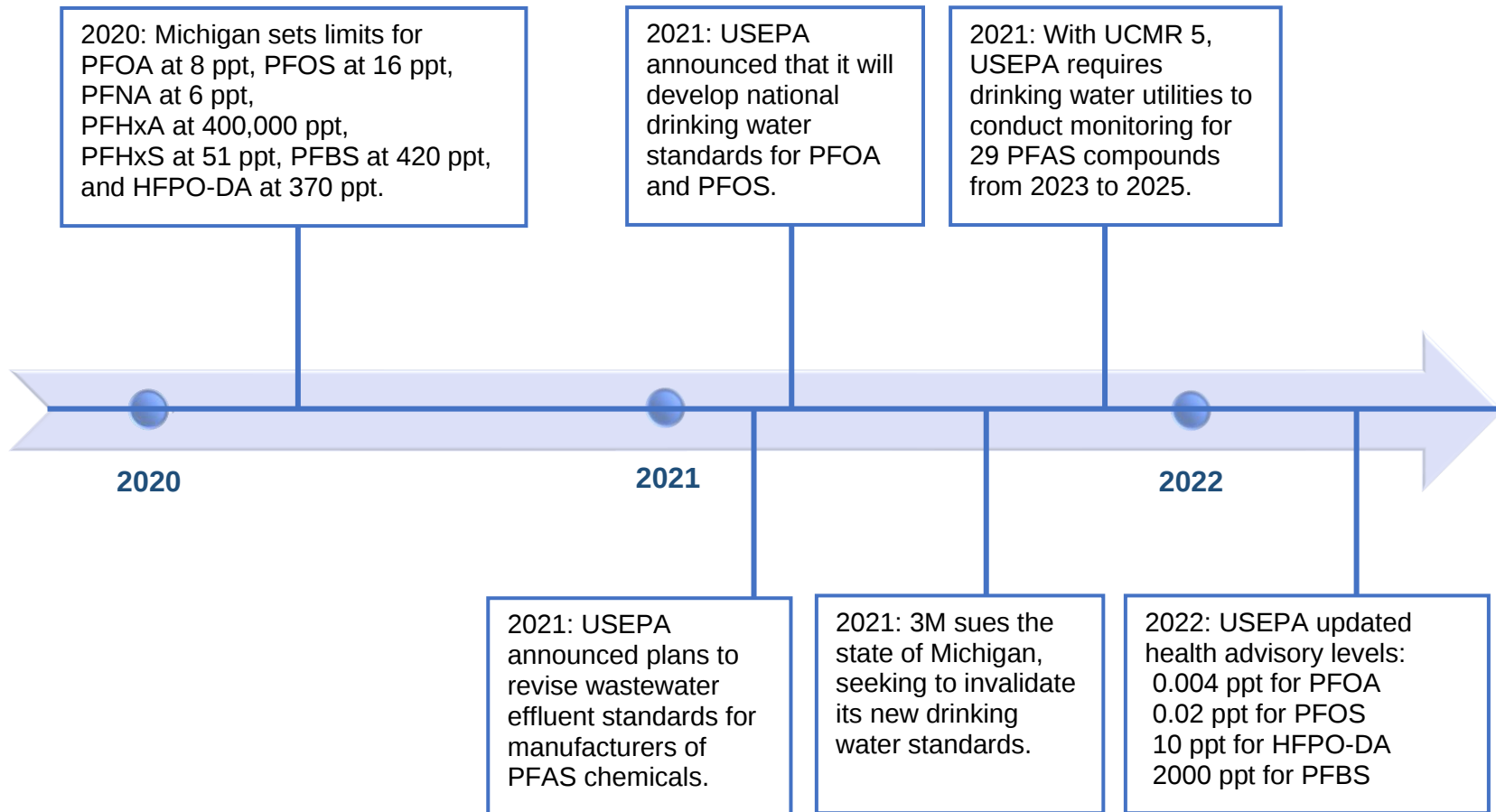
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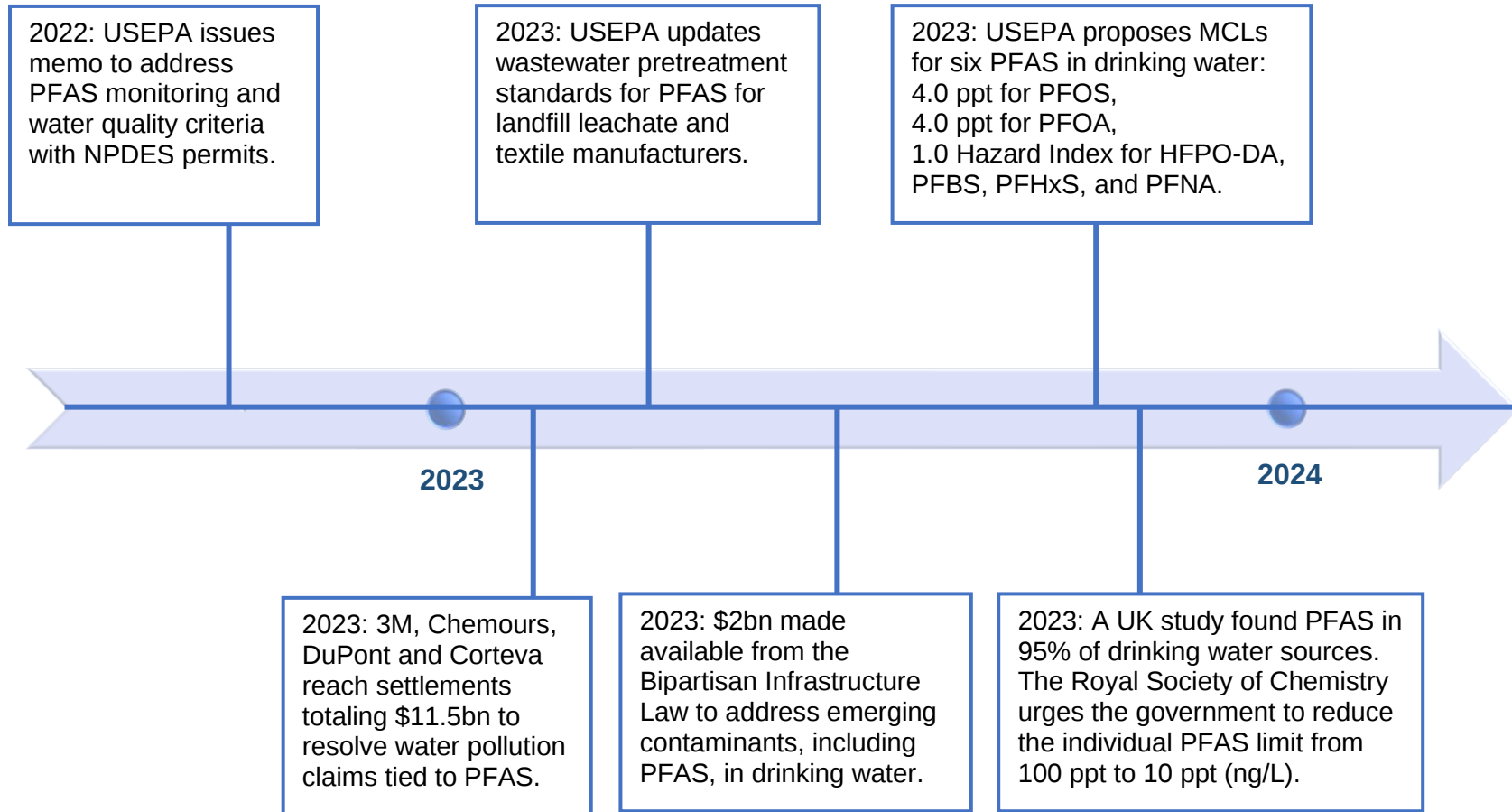
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PFAS in Drinking Water

Types of PFAS

There are thousands of different types (or compounds) of PFAS chemicals. The EPA toxicity database, DSSTox, lists 14,735 unique PFAS chemical compounds. Drinking water standards focus on a select few of the most common and most hazardous forms of PFAS. Figure 4 shows common PFAS chemicals in a triangle format, with carboxylate forms on the left and sulfonate forms on the right.

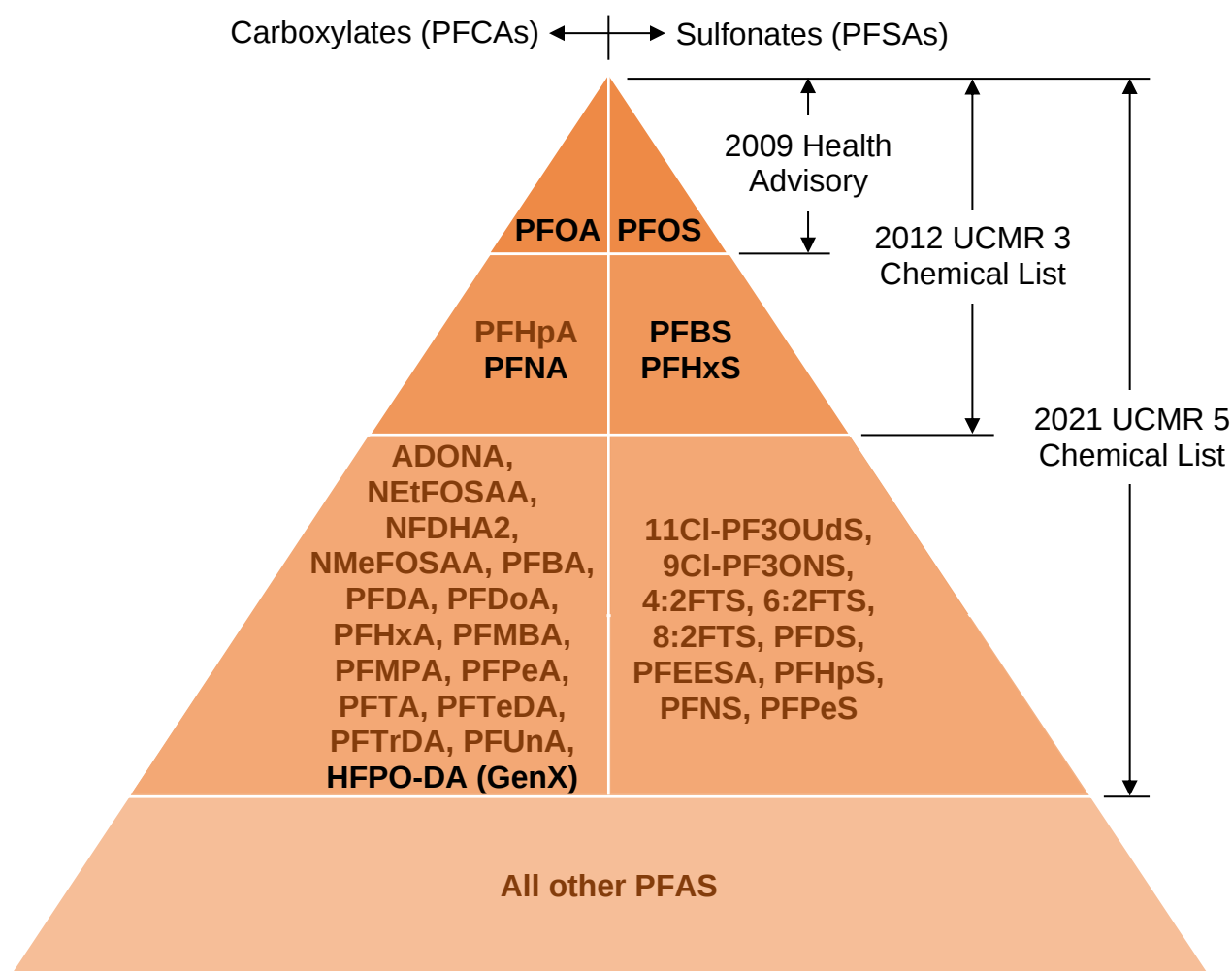


Figure 4: Triangle of PFAS forms with those given earlier attention on top. The PFAS in **black** are in the USEPA proposed MCLs in 2023.

Source: Author

All PFAS have a string of carbon atoms, each bonded with two fluorine atoms. It is these strong fluoride bonds that make the compounds last so long.

PFAS in Drinking Water

Head Difference

For perfluoroalkyl carboxylic acids (PFCAs), or carboxylates, the head is a -CO_2 ion.

For perfluoroalkyl sulfonic acids (PFSA), or sulfonates, the head is a -SO_3 ion.

See Figure 5 for the most common examples of each.

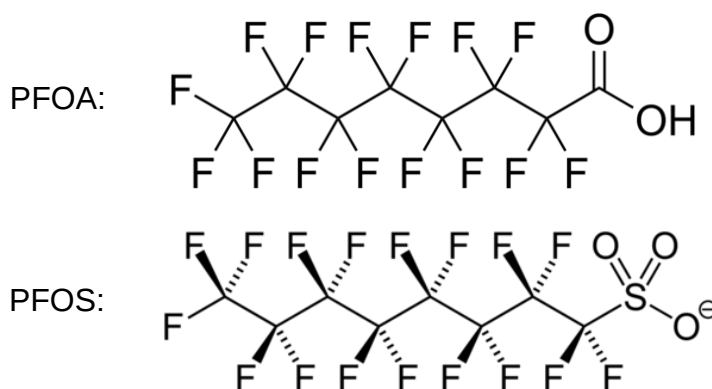


Figure 5: Top) Example carboxylate, PFOA, with a -CO_2 head on right.
 Bottom) Example sulfonate, PFOS, with a -SO_3 head on right.
 Note that the carbon atoms are at junctions without a letter, as is customary.
 Source: public domain

Per- and Poly-

PFAS chemicals can also be grouped into “per-” (fully) and “poly-” (partly) forms.

Perfluoroalkyl have carbon chains that are fully fluorinated (carbon-fluorine bonds only).

Polyfluoroalkyl have carbon chains that are not fully fluorinated (contains some carbon-hydrogen bonds or carbon-oxygen bonds). The “per-” forms tend to be stronger, more toxic, and more heavily regulated. See Figure 6 for examples.

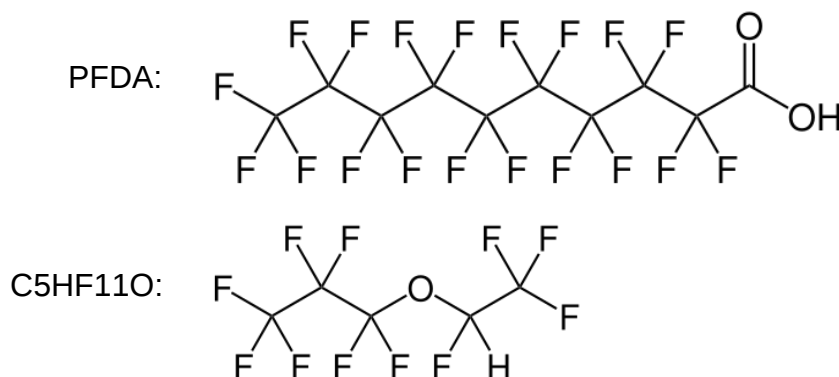


Figure 6: Top) Example “per-” form with fully fluorinated chain.
 Bottom) Example “poly-” form with an oxygen bond in an otherwise fluorinated chain.
 Source: public domain

PFAS in Drinking Water

Polymer PFAS

PFAS chemicals can also be grouped into polymers and non-polymers. Polymers have chains with ≥ 15 carbon atoms for carboxylates (PFCAs) and ≥ 14 carbon atoms for sulfonates (PFSAs). Examples include fluoropolymers (common for non-stick coatings) and side-chain fluorinated polymers (SCFPs, common for textile finishes). Often polymers are too long to absorb into the human body and thus are not regulated in drinking water. However, they can break down into non-polymer PFAS and thus are still a concern. See Figure 7 for example polymer PFAS.

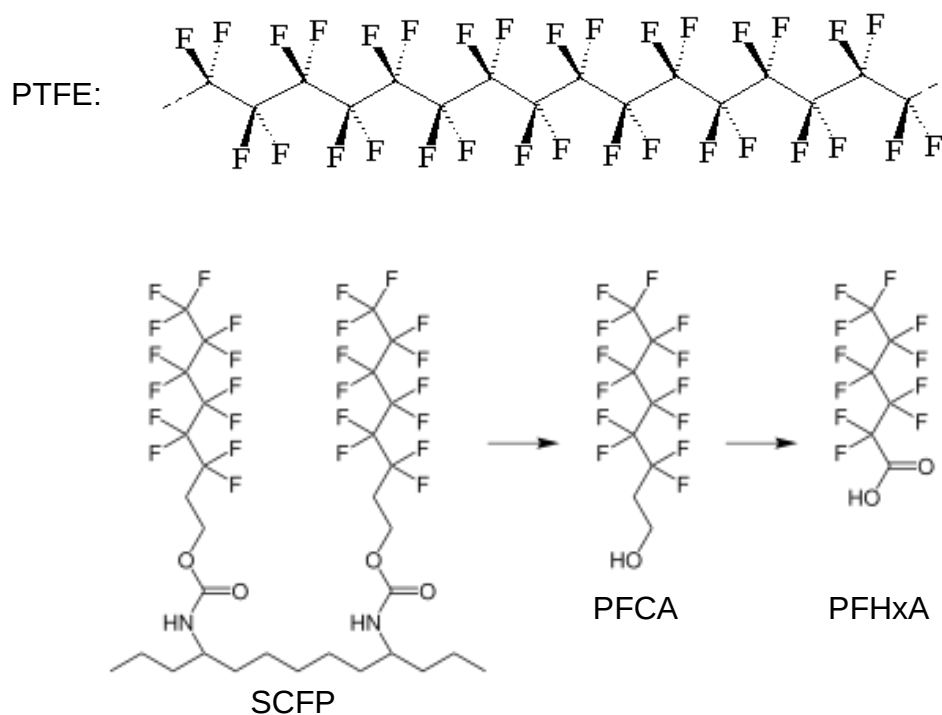


Figure 7: Top) Example fluoropolymer PTFE (Teflon).
Bottom) Example side-chain fluorinated polymer degrading into PFHxA.

Source: public domain

PFAS in Drinking Water

Non-Polymer PFAS

Non-polymer “per-” PFAS are grouped into “short-chain” and “long-chain” based on the number of carbon atoms in the chain. Long-chains contain ≥ 7 carbons for carboxylates (PFCAs) and ≥ 6 carbons for sulfonates (PFSAAs). Carboxylates have an extra carbon in the $-\text{CO}_2$ head, so the transition to long-chain is one carbon atom higher. Table 1 lists common short-chain and long-chain PFAS based on the number of carbons in the chain. The two **red** PFAS are from the 2009 Health Advisory. The six **bold** PFAS are from the 2012 UCMR3. The six **orange** PFAS are often considered ultrashort-chain.

Table 1: Short and Long-Chain “Per-” PFAS				
No. of Carbons	Carboxylates (PFCAs)		Sulfonates (PFSAAs)	
1	Short-chain	-	Short-chain	TFMS
2		TFA		PFEtS
3		PFPrA		PFPrS
4		PFBA		PFBS
5		PFPeA		PFPeS
6		PFHxA		PFHxS
7	Long-chain	PFHpA	Long-chain	PFHpS
8		PFOA		PFOS
9		PFNA		PFNS
10		PFDA		PFDS
11		PFUnA		PFUnS
12		PFDoA		PFDoS
13		PFTTrDA		PFTTrDS
14		PFTeDA	Polymer	PFTeDS
15+	Polymer	Various		Various

Long-chain PFAS tend to strongly repel water (hydrophobicity) which makes them commercially attractive. Long-chain PFAS are more highly regulated than short-chain or polymer types of PFAS. Long-chain and polymer types of PFAS are easier to remove from drinking water by membrane filtration. Figure 8 depicts how ultrashort and short-chain PFAS are physically smaller than long-chain PFAS, and thus require smaller openings for membrane removal.

PFAS in Drinking Water

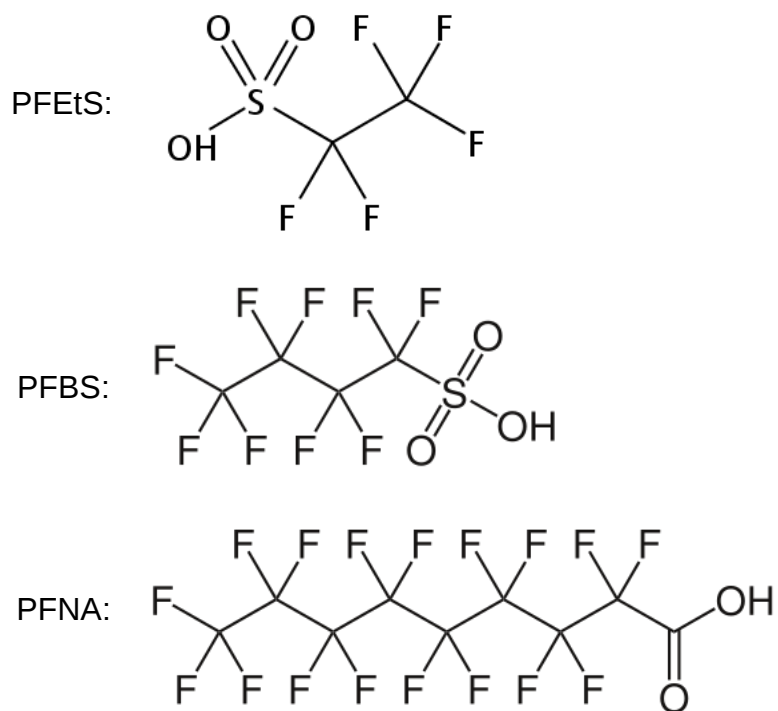


Figure 8: Top) Example ultrashort-chain PFAS (2 carbons).
Middle) Example short-chain PFAS (4 carbons).
Bottom) Example long-chain PFAS (9 carbons).

Source: public domain

PFAS in Drinking Water

PFAS Family Tree

A comprehensive family tree with types of PFAS is presented in Figure 8. The individual PFAAs boxed in red are listed previously in Table 1.

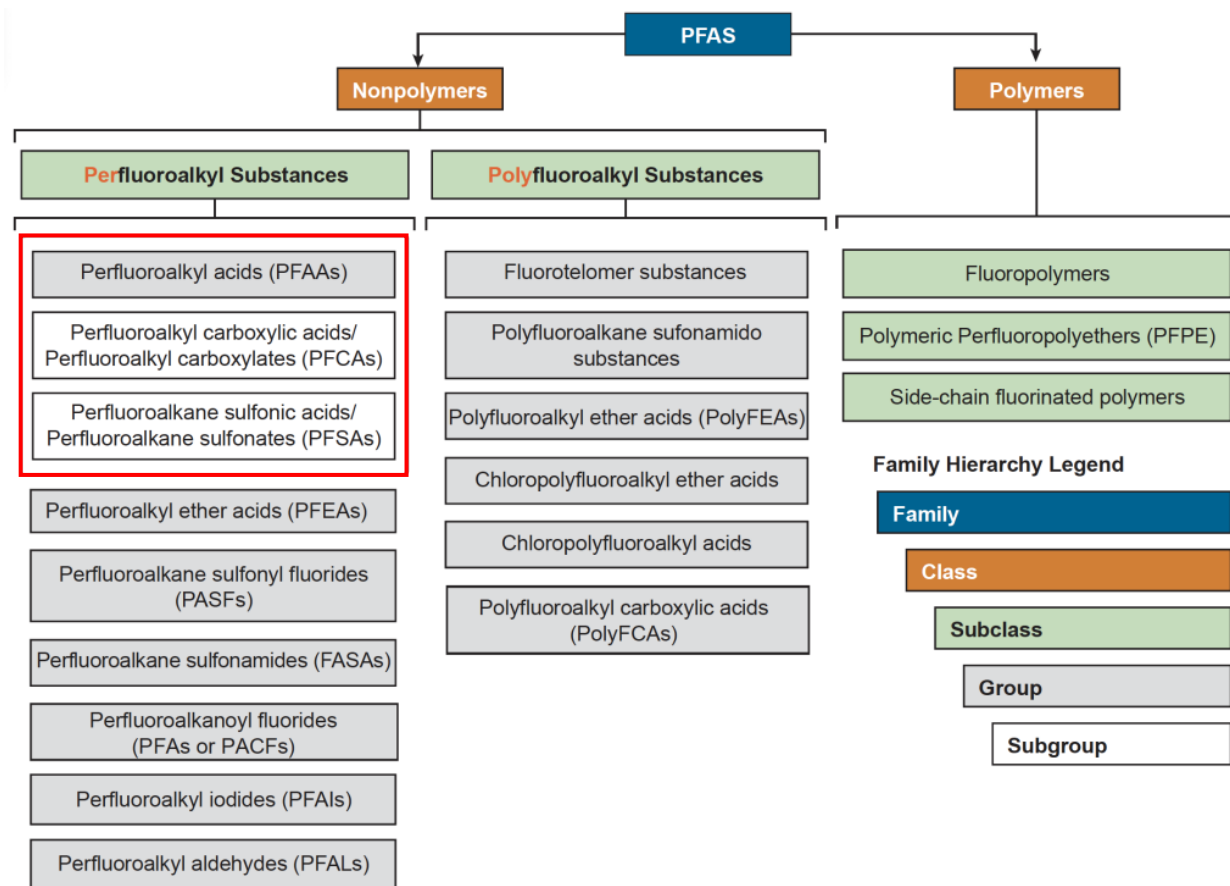


Figure 8: PFAS family tree with a red box around the group that is given the most focus in drinking water regulations.

Source: <https://pfas-1.itrcweb.org/2-2-chemistry-terminology-and-acronyms>, Interstate Technology and Regulatory Council

PFAS in Drinking Water

Drinking Water Limits

Currently there is no national enforceable limit on PFAS in drinking water in the United States. The 2021 USEPA UCMR 5 included requirements for monitoring for 29 types of PFAS, but with no enforceable limits. The 2022 USEPA Health Advisory (HA) included very low levels for PFOA, PFOS, HFPO-DA (GenX), and PFBS, but was issued as a warning only. In 2023, the USEPA proposed the following maximum contaminant levels (MCLs), which are yet to be enacted:

- 4.0 ppt for PFOS
- 4.0 ppt for PFOA
- 1.0 Hazard Index for HFPO-DA, PFBS, PFHxS, and PFNA

Once the proposed rule is finalized, water systems will have three years to comply with the MCLs. National and state grants and loans will likely be issued at that time to upgrade treatment facilities and utilize new water sources. Compliance is determined by calculating annual averages at each sampling point (each water source or entry point into the distribution system). Sampling frequency is either quarterly (every 3 months) or biannual (twice a year, minimum 90 days apart) as indicated in Table 2.

Table 2: Proposed PFAS Sampling Frequency		
Water Source	No. of Customers	Frequency (Months)
Groundwater	≥10,000	3
	<10,000	6*
Surface Water	N/A	3

Note: (*) Twice a year, min. 90 days apart

State Limits

In the absence of enforceable national standards, several states have set their own limits. See the states in red in Table 3. The states in black have PFAS limits that require notification to the public and other actions if the limit is exceeded. Note that several states are considering adding or changing their limits, so this table may not reflect the latest state requirements.

PFAS in Drinking Water

Table 3: PFAS Levels by State (as of Jan 2024)							
Red are MCLs (required); Black are non-mandatory; Units in (ppt, ng/L) u.n.o.							
States	PFOA	PFOS	PFNA	PFHxS	HFPO-DA (GenX)	PFBS	Other
All, USEPA HA '22	0.004	0.02	-	-	10	2,000	-
All, USEPA Prop. MCLs '23	4	4	1.0 Hazard Index (see next section)				-
Alaska	70 (total)		-	-	-	-	-
California	5.1	6.5	-	3	-	500	-
Colorado	70 (total)			700	-	400,000	-
Connecticut	16	10	12	49	19	760	6 others
Delaware	70 (total)		-	-	-	-	-
Hawaii	12	7.7	12	1,900	12	1,700	12 others
Illinois	2	14	21	140	-	2,100	3,500
Maine	20 (total of PFOA, PFOS, PFHxS, PFNA, PFHpA, and PFDA)						
Maryland	-	-	-	140	-	-	-
Massachusetts	20 (total of PFOA, PFOS, PFHxS, PFNA, PFHpA, and PFDA)						
Michigan	8	16	6	51	370	420	400,000 PFHxA
Minnesota	35	15	-	47	-	100	200 PFHxA 7,000 PFBA
Nevada	667 (total)		-	-	-	667,000	
New Hampshire	12	15	11	18	-	-	-
New Jersey	14	13 (total)		-	-	-	-
New Mexico	70 (total)		-	-	-	-	-
New York	10	10	-	-	-	-	-
North Carolina	-		-	-	140	-	-
Ohio	70 (total)		21	140	25	140,000	
Oregon	30 (total)				-	-	-
Pennsylvania	14	18					
Rhode Island	20 (Total of PFOA, PFOS, PFHxS, PFNA, PFHpA, and PFDA)						
Vermont	20 (Total of PFOA, PFOS, PFHxS, PFNA, and PFHpA)						
Washington	10	15	9	65	-	345	-
Wisconsin	70 (Total)		-	-	-	-	-

PFAS in Drinking Water

Group Limits

In 2020 Massachusetts set a standard in the northeast when it established an MCL of 20 parts per trillion for the total of six toxic PFAS compounds known as the “MA 6”, consisting of PFOS, PFOA, PFDA, PFHpA, PFHxS, & PFNA. This requires testing for each PFAS chemical and then summing the values. Maine, Rhode Island, and Vermont followed with similar group limits.

Group limits bring the focus on decreasing the total PFAS rather than individual types. For example, compare these two cities:

- 1) City A only has PFOS at 16 ppt and no other PFAS present (16 ppt total PFAS).
- 2) City B has PFOS, PFOA, PFDA, & PFHxS at 15 ppt each (60 ppt total PFAS).

City B has drinking water with a greater potential for health impact from PFAS. However, with only individual MCLs at 15 ppt for each type of PFAS, City B would pass while City A would fail. The group PFAS approach at 40 ppt total would force City B to address the elevated levels.

The USEPA acknowledged the benefit of the group approach, but also recognized that some PFAS are worse for human health than others. Thus, the USEPA developed the “Health Hazard” approach whereby the sum of the PFAS concentrations takes into account the relative health impact of each type of PFAS (see the next section).

PFAS in Drinking Water

Hazard Index

The Hazard Index (HI) is a USEPA approach that quantifies the combined effect of multiple chemicals. As applied to PFAS, the HI considers PFNA, PFHxS, PFBS, and HFPO-DA (GenX). Each of these has a different health-based value, which is the concentration determined not to have significant health effects. The health-based values are as follows:

- PFHxS = 9 ppt (most toxic)
- PFNA = 10 ppt
- GenX = 10 ppt
- PFBS = 2,000 ppt (least toxic)

The HI is the sum of the measured concentration divided by the health-based value for each of four PFAS. A value greater than 1.0 is considered over the proposed MCL. The USEPA HI formula is as follows:

$$\text{Hazard Index} = \left(\frac{[\text{GenX}_{\text{water}}]}{[10 \text{ ppt}]} \right) + \left(\frac{[\text{PFBS}_{\text{water}}]}{[2000 \text{ ppt}]} \right) + \left(\frac{[\text{PFNA}_{\text{water}}]}{[10 \text{ ppt}]} \right) + \left(\frac{[\text{PFHxS}_{\text{water}}]}{[9.0 \text{ ppt}]} \right)$$

The annual HI value is calculated based on averaging the quarterly or biannual sampling at each sampling point over a 1-year period. Values below the practical quantitation level (PQL) are considered to be zero, so that analytical errors don't result in a false overage. PQLs are provided in Table 4.

Table 4: USEPA PFAS PQLs	
Compound	PQL
PFOS	4.0
PFOA	4.0
PFHxS	3.0
GenX (HFPO-DA)	5.0
PFNA	4.0
PFBS	3.0

PFAS in Drinking Water

Example Problem 1

The City of Fetna compliance point is sampled quarterly for PFOS with the following results: 3.0, 5.5, 2.0, and 6.5 ppt. What is the PFOS value to report and is it in compliance with the USEPA proposed MCL of 4.0 ppt?

Solution:

The PFOS value to report is the average of the quarterly PFOS values, which is calculated by summing and dividing by 4. However, the values in the first and third quarters (3.0 and 2.0) are below the PQL of 4.0 and thus not included:

$$\text{PFOS value} = (0 + 5.5 + 0 + 6.5) / 4 = 12 / 4 = 3.0 \text{ ppt}$$

In this case the PFOS value to report is less than the MCL of 4.0 ppt, and thus in compliance.

PFAS in Drinking Water

Example Problem 2

The City of Fetna also has a surface water compliance point that is sampled twice a year for PFAS, with the results in Table 5. What is the HI value to report and is it in compliance with the USEPA proposed MCL?

Table 5: PFAS Test Results for Problem 2 (ppt)						
Test No.	PFOA	PFOS	PFNA	PFHxS	HFPO-DA (GenX)	PFBS
1	3.0	2.6	5.2	9.8	12.2	2,300
2	4.0	1.1	7.8	10.6	10.5	1,200

Solution:

The Hazard Index (HI) value to report is the average of the two HI values, one for each test. The HI values are calculated with the four HI PFAS values (the four last columns), which does not include PFOA & PFOS). None of the values are below the PQLs in Table 4, so none need to change to zero.

The calculations are as follows:

Test 1:

$$HI = \frac{\text{GenX}}{10} + \frac{\text{PFBS}}{2000} + \frac{\text{PFNA}}{10} + \frac{\text{PFHxS}}{9} = \frac{2.5}{10} + \frac{350}{2000} + \frac{4.0}{10} + \frac{1.0}{9} = 0.94$$

Test 2:

$$HI = \frac{4.5}{10} + \frac{300}{2000} + \frac{5.0}{10} + \frac{1.0}{9} = 1.21$$

Average:

$$HI = \frac{0.94 + 1.21}{2} = 1.07$$

The HI value to report is greater than the proposed HI MCL of 1.0, and thus is not in compliance.

PFAS in Drinking Water

Lab Test Methods

For official monitoring and reporting of PFAS, a certified laboratory should be utilized for water quality testing. Field testing or test strips are not available for PFAS. USEPA approved methods are listed in Table 6 with example lab prices as of Jan 2024.

Table 6: USEPA Approved Methods for Testing PFAS						
Type of Water	EPA Method	Analytical Technique	No. of Compounds	Cost (2024)	Time (min.)	Notes
Potable	537.1	SPE and LC/MS/MS	18	\$185	40	Replaces 537 (fast but inconsistent) Low detection limit
	533	Isotope Dilution Anion Exchange, SPE and LC/MS/MS	25	\$215	35	Targets short-chain
	TOF Assay	Combustion Ion Chromatography (CIC)	1 (Total Organic Fluorine)	\$75	~120	Estimate total PFAS, Modified Method 1621
Non-Potable	8327, SW-846	External Standard Calibration and MRM LC/MS/MS	24	\$185	21	Equal to ASTM D8421 (44 compounds)
	1633	SPE and LC/MS/MS	40	\$125	20	Recommended for NPDES and pretreatment permits
	TOP Assay	Oxidize all polyfluorinated compounds into PFAAs	1 (Total Organic Precursors)	\$1,000	>60	Measures current and potential PFAAs, see EOF & AOF assays
	1621	Combustion Ion Chromatography (CIC)	1 (AOF = Adsorbable Organic Fluorine)	\$55	~120	Determines presence of organofluorines, EPA wastewater standard
Notes: SPE = Solid phase extraction LC/MS/MS = Liquid chromatography with tandem mass spectrometry MRM = Multiple reaction monitoring						

PFAS in Drinking Water

Removal Techniques

The following tables provide details on common treatment methods for PFAS removal.

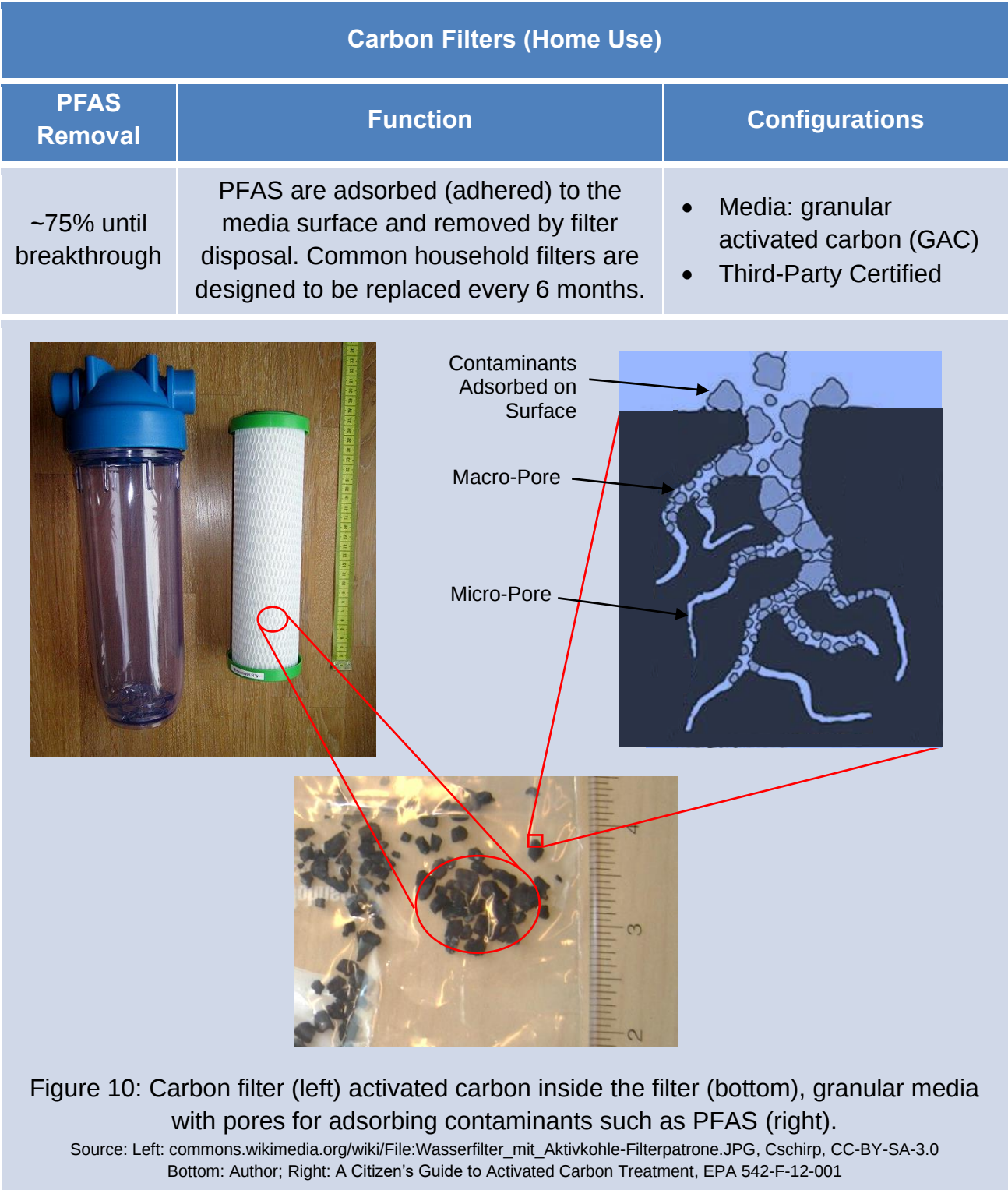
Adsorption		
PFAS Removal	Function	Configurations
>99% until breakthrough	PFAS are adsorbed (adhered) to the media surface and removed by backwash, regeneration, or disposal. Breakthrough of short-chain PFAS, such as PFBA & PFBS, occur prior to long-chain breakthrough.	• Fixed-bed • Fluid-bed / Fluidized Bed Reactor (FBR) • Media: granular activated carbon (GAC), activated alumina, modified clay



Figure 9: Activated carbon adsorption system for water treatment, with six vessels. Each vessel can be isolated to replace the media inside.

Source: commons.wikimedia.org/wiki/File:Fischer-Deponie_Aktivkohle-Filter_033w.jpg, Peter Haas, CC BY-SA 3.0

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Ion Exchange		
PFAS Removal	Function	Configurations
>99%	Special resin exchanges its ions for PFAS molecules and other anions (e.g., nitrates, sulfates, silica). Requires upstream filtration to protect expensive resin from fouling.	• Anion resin (media) • Fixed bed • Moving bed/ suspended • Magnetic (MIEX) • One stage or two-stage • Mixed system

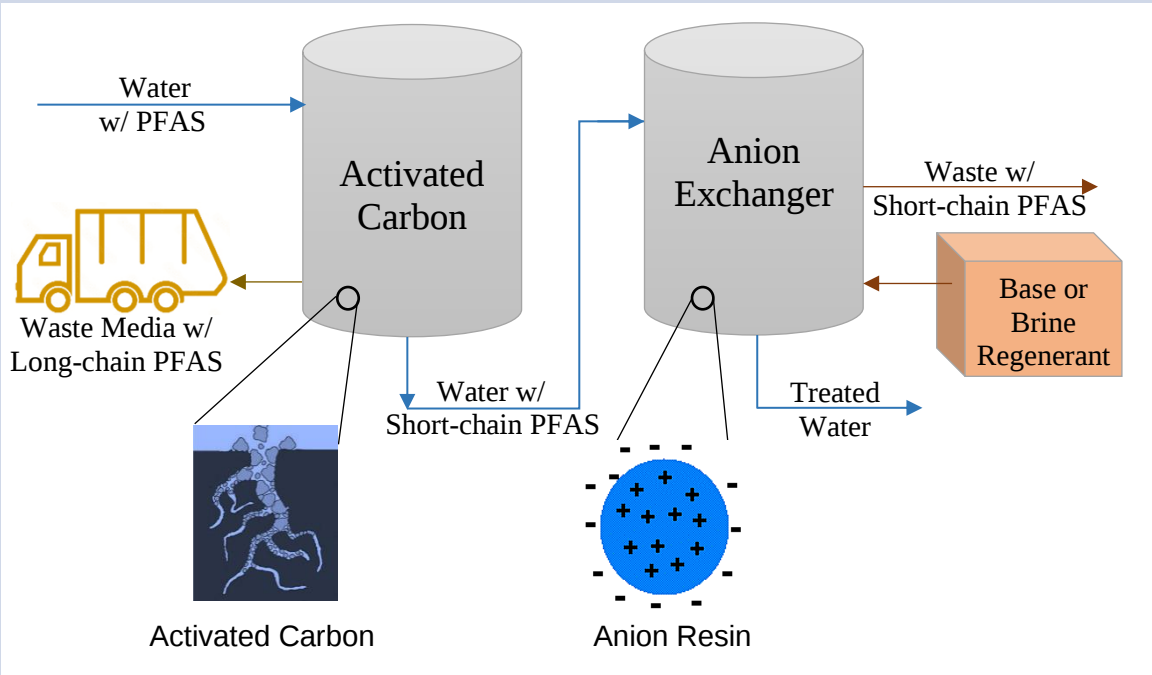


Figure 11: A mixed GAC and ion exchange system, starting with fixed-bed activated carbon (GAC) followed by ion exchange. The GAC focuses on long-chain PFAS while the anion resin polishes any remaining short-chain PFAS. Used GAC is wasted while anion resin is regenerated onsite by soaking media in a strong base or brine regenerant.

Source: Author

PFAS in Drinking Water

Nanofiltration (NF)		
PFAS Removal	Function	Configurations
>90%	Blocks a variety of contaminants, including PFAS, from passing through small openings (1 to 10 nm), and sends them into a concentrate stream. The permeate is very clear water.	• Nano-filtration (NF) • Tubular (shell and tube) • Spiral-wound • Hollow fiber • One or Two Stage • Recirculation



Figure 12: Two skids with ultrafiltration membranes (green tubes) and high-pressure feed pumps (blue).

Source: commons.wikimedia.org/wiki/File:Wastewater_UF_membrane_system,_Aquabio.jpg, Aquabio Ltd., CC-BY-SA-3.0

PFAS in Drinking Water

Reverse Osmosis (RO)		
PFAS Removal	Function	Configurations
>95%	Blocks salts, metal ions, carbonates, and a variety of contaminants, including PFAS, from passing through very small openings (0.1 to 1 nm), and sends them into a concentrate stream. The permeate is very clear water.	• Thin Film Composite (TFC or TFM) membrane • Cellulose Triacetate (CTA) membrane • Polymeric • Ceramic • One or Two Stage • Recirculation



Figure 13: Large water plant with four RO skids, each with (81) blue RO tubes. Two upstream cartridge filters are seen in the bottom.

Source: commons.wikimedia.org/wiki/File:Northcapecoral-RO.jpg, Twhair, CC-BY-SA-4.0

PFAS in Drinking Water

Reverse Osmosis Filtration System (Home Use)		
PFAS Removal	Function	Configurations
>99% until breakthrough	Under-sink treatment system with prefilters and RO filter. Blocks contaminants, including PFAS, from passing through very small openings (0.1 to 1 nm), RO concentrate goes to drain. The permeate (clean water) usually routes to a sink drain.	- GAC prefilter 3 to 7 Stages - UV post-disinfection - Carbon post-filter - Holding Tank - Valves and tubing - Pressure pump



Figure 14: 4-Stage 100 gpd RO Water System with (3) prefilters (carbon and sand) at the bottom, a booster pump (silver) and a RO De-Ionizing Filter (white).

Source: commons.wikimedia.org/wiki/File:Rodi.jpg, Kingfish101, CC-BY-SA-3.0

PFAS in Drinking Water

Comparison of Technologies

Table 7 lists the typical advantages and disadvantages of each of the common PFAS removal techniques for a mid-size water treatment facility (10,000 to 100,000 customers). The table assumes that membrane concentrate cannot be discharged to drain but requires adsorption treatment. For each application, bench-scale or pilot testing is required to confirm PFAS removal, media lifespan, system sizing, and other critical factors.

Table 7: Comparison of PFAS Removal Technologies for a Water Treatment Facility				
Technique	System Assumptions	PFAS Removal	Advantages	Disadvantages
GAC Adsorption	Upstream filtration, three media vessels, offsite regeneration	>99%	• Lowest capital cost • Option for onsite regeneration • Media type can be changed or mixed	• Frequent media change • Frequent media monitoring • Potential for breakthrough • Upstream filtration • Large footprint
Ion Exchange	Upstream filtration, three media vessels, media disposal offsite	>99%	• Reliable • Low maintenance • Option for onsite regeneration	• Expensive media • High lifecycle cost • Potential for breakthrough • Upstream filtration
Nano-Filtration	Two membrane skids, GAC for concentrate	>90%	• Pathogen removal credit • Small footprint • Softens water	• Concentrate management • Membrane fouling
Reverse Osmosis	Two membrane skids, GAC for concentrate	>95%	• Pathogen removal credit • Removes most contaminants • Small footprint • Softens water	• Highest capital cost • Energy intensive • Concentrate management • Membrane fouling

PFAS in Drinking Water

Lifecycle Costs

When comparing costs of PFAS treatment alternatives, it is important to consider the annual operations and maintenance costs since those can be considerable. With adsorption, the media needs to be replaced often, perhaps annually. With ion exchange, the media is very expensive to replace, so an onsite regeneration is often installed which increases capital costs. Membrane filtration is energy intensive which increases the electricity bill.

Lifecycle cost refers to the total cost of ownership over the life of an asset. This whole-life costing approach includes costs incurred after an asset has been constructed or acquired, such as maintenance, energy usage, operation, and disposal. When comparing alternatives, a time period is selected to apply to all alternatives, such as 20 years. If the system still has value after the time period, that amount, called the salvage value, is subtracted.

The lifecycle cost can be calculated using the present worth approach for annual costs. Present worth accounts for money today being worth more in the future due to interest. The formula is as follows:

$$\text{Lifecycle Cost} = \text{Capital Cost} + \text{Annual O\&M} * \text{PWF} - \text{Salvage Value}$$

where:
$$\text{PWF} = \text{Present Worth Factor} = \frac{(1+i)^T - 1}{i * (1+i)^T}$$

$i = \text{interest rate (adjusted for inflation)}$

$T = \text{number of years}$

$$\text{O\&M} = \text{Ongoing Operations and Maintenance Costs}$$

PFAS in Drinking Water

Example Project

The Cape Fear Public Utility Authority (CFPUA) in North Carolina produces drinking water through the Sweeney Water Treatment Plant (WTP). There are 200,000 customers with an average daily flow of 44 million gallons per day (MGD). Raw water comes from the Cape Fear River. About 100 miles upstream on the river was a Chemours and DuPont chemical plant that manufactured PFAS chemicals for decades, resulting in fluctuating PFAS levels in the river.

CFPUA decided to upgrade the existing Sweeney WTP for PFAS removal. Pilot studies were done to test reverse osmosis, ion exchange, and granular activated carbon (GAC) filters. A GAC system was selected, designed, and constructed, with startup in October 2022. The filters contain almost 3 million pounds of GAC in rectangular concrete tanks. Test results are provided on the next page, showing how the finished drinking water is far below the USEPA proposed MCLs.

Example Problem 3

For the PFAS removal improvements at Sweeney WTP, capital costs totaled \$43 million and annual operations and maintenance costs are \$5 million (mostly for replacing the GAC media). Calculate the 20-year lifecycle cost, rounded to the nearest million. The interest rate is 5%. Salvage value is estimated to be \$10 million after 20 years.

Solution:

First, calculate the present worth factor, PWF:

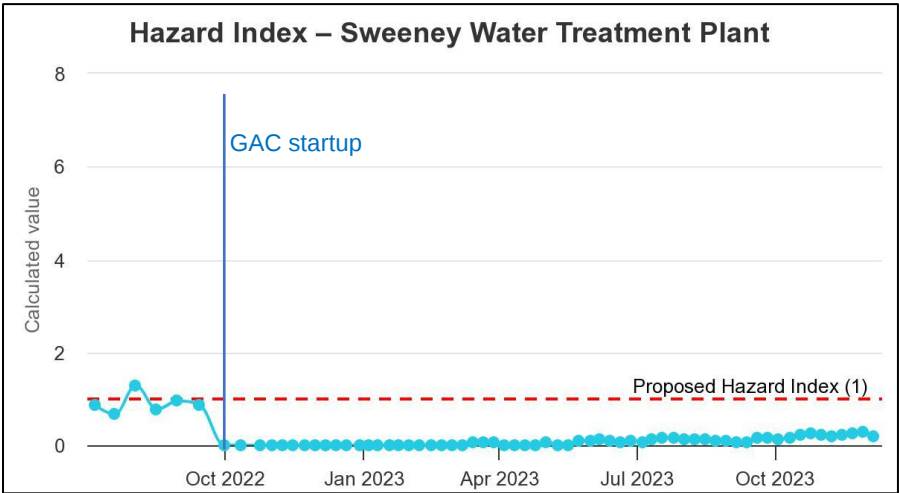
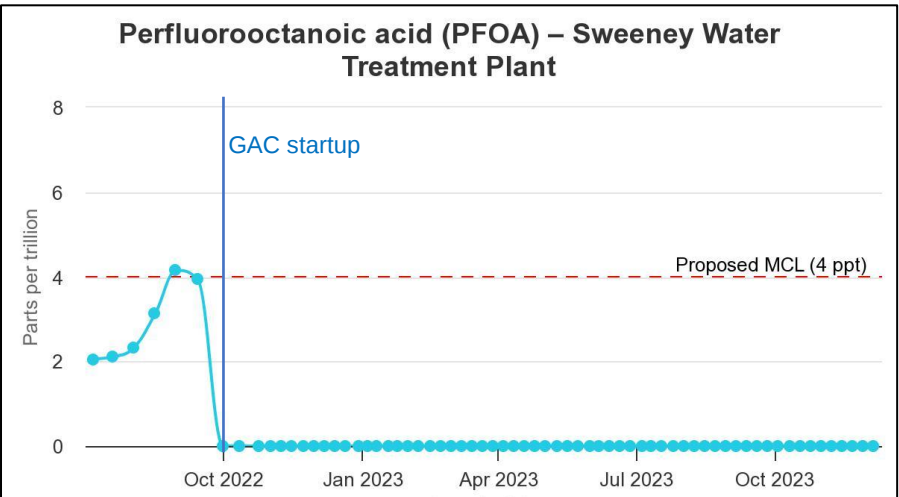
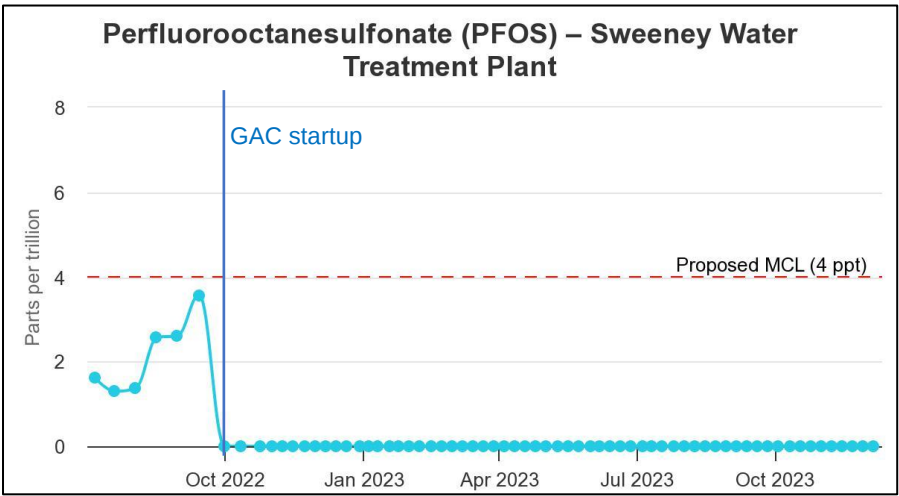
$$PWF = \frac{(1 + 0.05)^{20} - 1}{0.05 * (1 + 0.05)^{20}} = \frac{1.65}{0.13} = 12.46$$

Then use the lifecycle cost formula:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ O\&M * PWF - Salvage\ Value$$

$$Lifecycle\ Cost = \$43M + \$5M * 12.46 - \$10M = \$95M \text{ (rounded)}$$

PFAS in Drinking Water



PFAS in Drinking Water

Destruction Techniques

PFAS removed from a water system does not disappear. PFAS lasts hundreds or thousands of years, so if not destroyed, it can continue to negatively impact the environment or human health in the future. Disposal methods such as deep well injection and landfill storage provide long-term protection but do not destroy PFAS.

However, several PFAS destruction technologies do exist and have been implemented at small and large scales. PFAS destruction typically occurs at a dedicated waste management facility which receives PFAS containing solid and liquid waste from a variety of sources such as water treatment plants, wastewater treatment plants, landfills, industrial factories, chemical manufacturing facilities, and environmental cleanup sites.

PFAS destruction technologies include the following:

- Incineration of spent media or dried sludge; can combine with landfill solid waste
- Hydrothermal alkaline treatment
- Photolysis
- High-energy electron beam / radiolytic PFAS
- Electrochemical oxidation
- Advanced oxidation followed by advanced reduction processes (AOP/ARP)
- UV-hydrated electron
- Sonochemical processing / ultrasound sonolysis (see Figure 15)
- Non-thermal plasma (NTP) / electrical discharge plasma (see Figure 16)
- Supercritical water oxidation (SCWO) (see Figure 17)

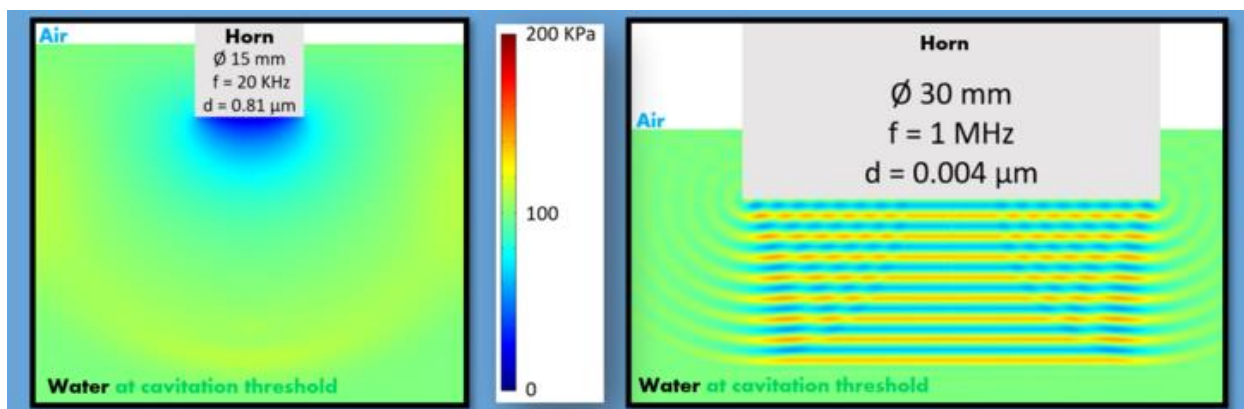


Figure 15: Modeling of ultrasonic horn sonication with better results on the right.

Source: commons.wikimedia.org/wiki/File:Ultrasonic_horn_cavitation_threshold_dimensionless_number_Garcia-Atance_sonochemistry_acoustic_bubbles_non_hydrodynamic_1309px.png, Gongafa, CC-BY-SA-4.0

PFAS in Drinking Water

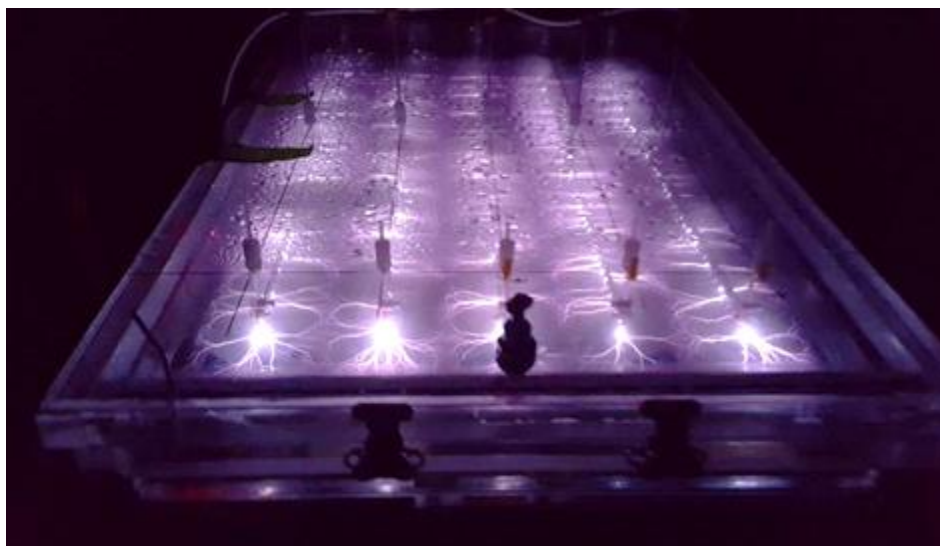


Figure 16: Electrical discharge plasma treatment system with a continuous flow of water through a tank with visible electrical arcs forming plasma.

Source: <https://www.enviro.wiki/index.php?title=File:Plasma4PFASFig2.png>, Plasma Research Laboratory, Clarkson University

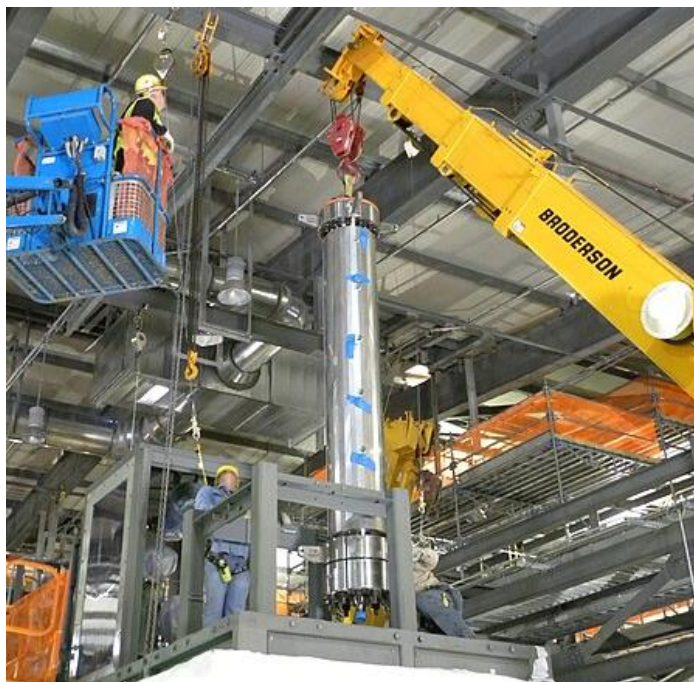


Figure 17: Supercritical water oxidation (SCWO) reactor being lowered into place.

Source: [commons.wikimedia.org/wiki/File:Blue_Grass_Chemical_Agent-Destruction_Pilot_Plant_Supercritical_Water_Oxidation_Processing_Building_\(12816257943\).jpg](https://commons.wikimedia.org/wiki/File:Blue_Grass_Chemical_Agent-Destruction_Pilot_Plant_Supercritical_Water_Oxidation_Processing_Building_(12816257943).jpg), CC-BY-2.0

PFAS in Drinking Water

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