# Cleaning Up Forever Chemicals in Drinking Water

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November 13, 2023

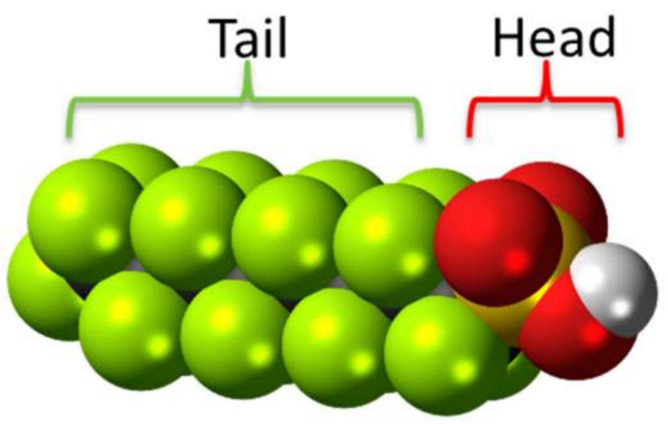
CDM Smith

# Agenda

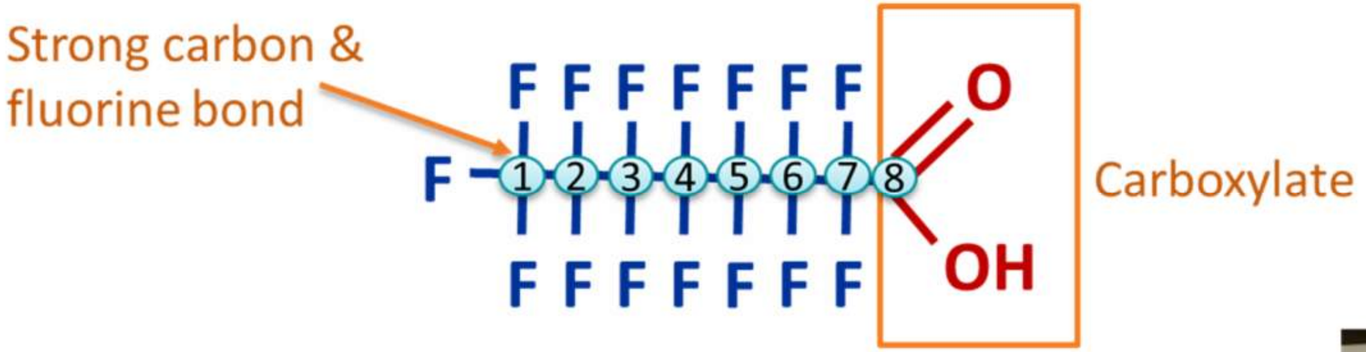
1. Background and Proposed PFAS Drinking Water MCLs
2. Impact to Water Treatment
3. Additional and Future Considerations

# Background and Proposed PFAS Drinking Water MCLs

# PFAS Overview

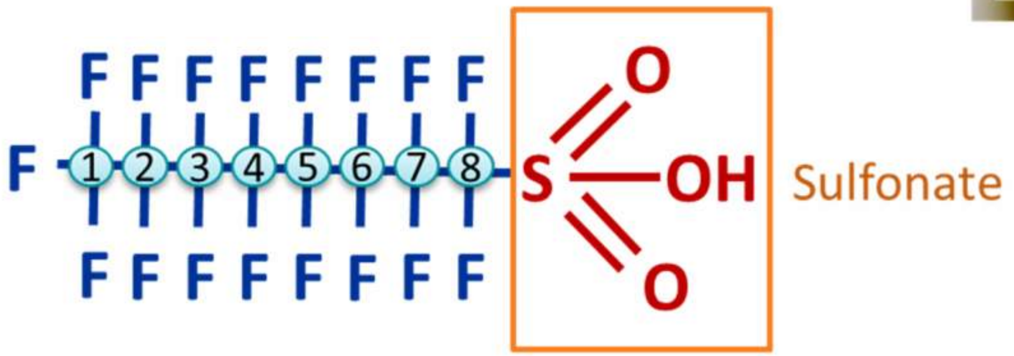



- *Per*- and *Poly*-FluoroAlkyl Substances (PFAS)
- PerFluoroOctanoic Acid (PFOA)

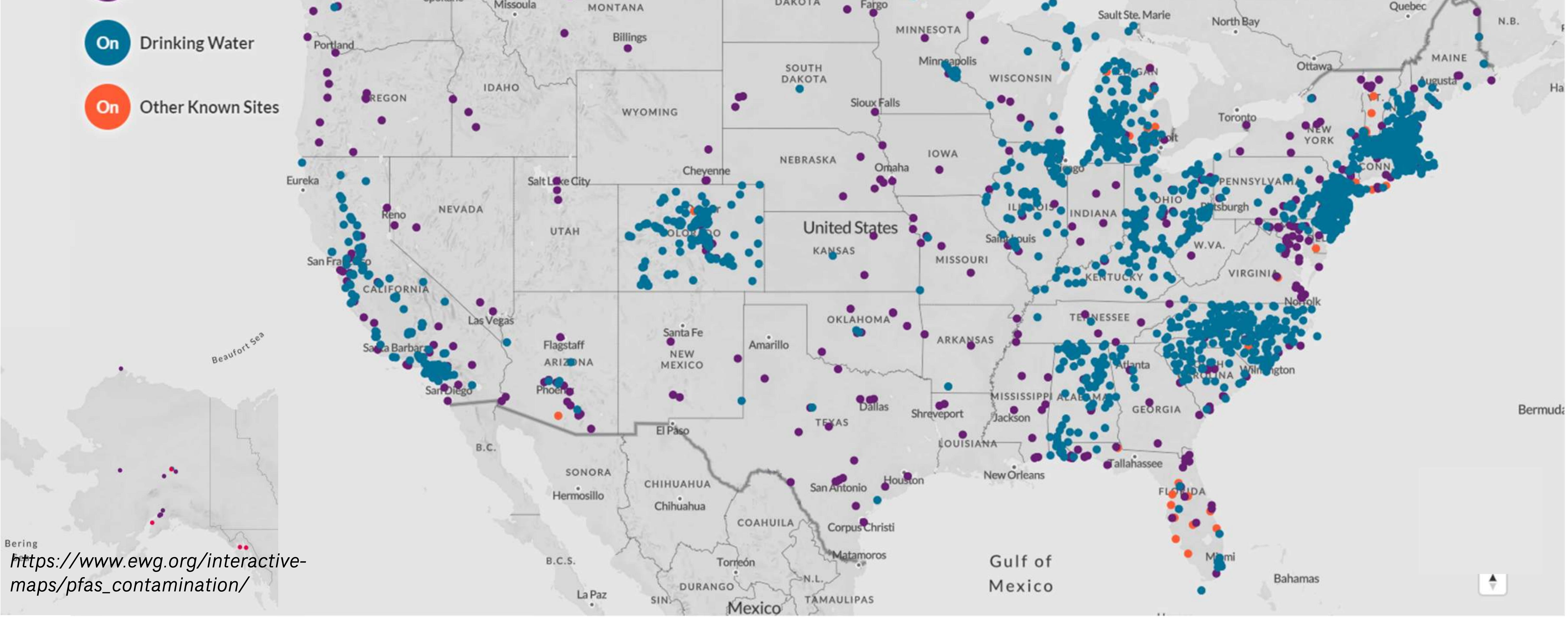


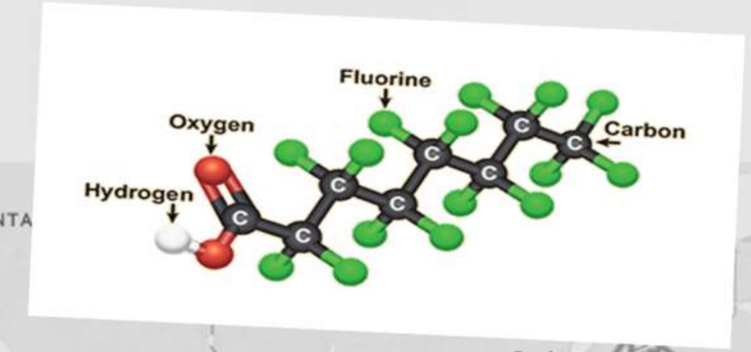


- PerFluoroOctaneSulfonic Acid (PFOS)




# PFAS Contamination in the US (2022)




*https://www.ewg.org/interactive-maps/pfas_contamination/*

# USEPA

**2009:** *EPA issues health advisory levels*
PFOS: 200 ppt and PFOA: 400 ppt

**2016:** *Revised health advisory levels*
PFOS: 70 ppt and PFOA: 70 ppt
PFOA+PFOS: 70 ppt

**2019:** *Feb 14, 2019 EPA published the PFAS Action Plan.*

**2019:** *EPA begins designation proposals of PFOS and PFOA as hazardous substances under CERCLA.*

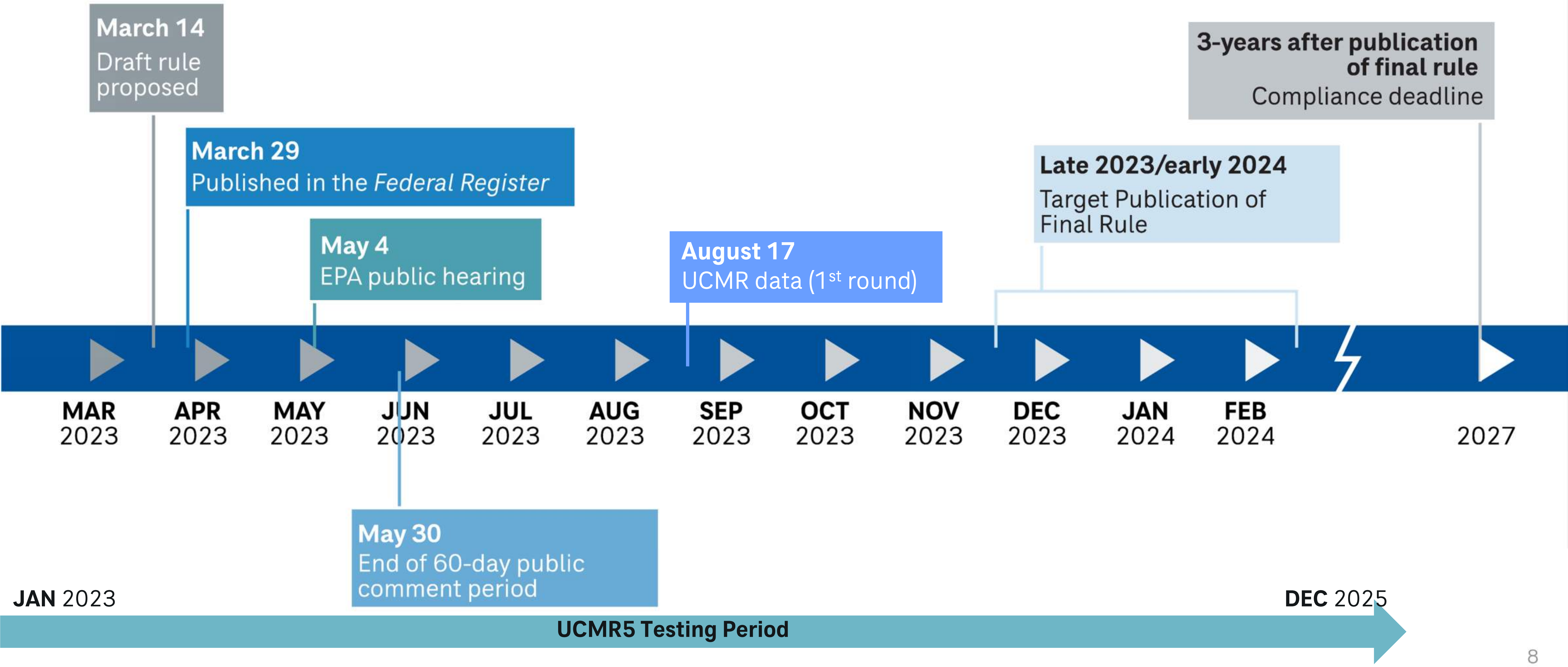
**2020:** *EPA announces the proposed decision to regulate PFOA and PFOS in drinking water.*

**2022:** *June 15, 2022, EPA revised Health Advisory Levels for PFOA = 0.004 ppt, PFOS = 0.002 ppt, Gen-X = 10 ppt, and PFBS = 2000 ppt.*

**2023:** *EPA includes 29 PFAS compound to its UCMR5, which requires testing in 2023 – 2025.*

**March 2023: EPA Publishes Draft Drinking Water MCLs**

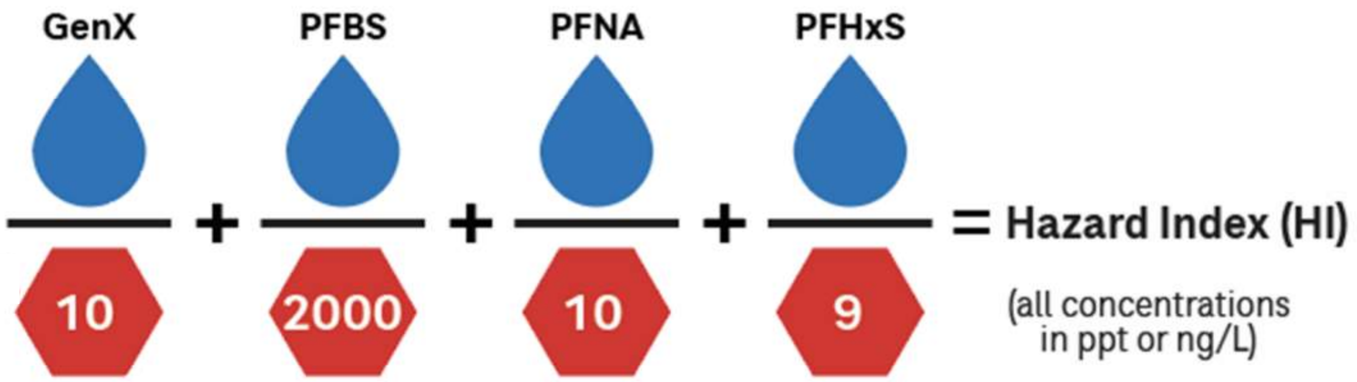
# USEPA PFAS Regulatory Timeline



# Proposed Primary Standards (MCLs)

## Numerical levels for compliance

- **4.0 ng/L** or ppt MCL **PFOA**
- **4.0 ng/L** or ppt MCL **PFOS**
- **1.0 (unitless, NOT 1 ppt)** Hazard Index (HI) for a mixture of **PFNA**, **PFHxS**, **PFBS**, and **GenX**

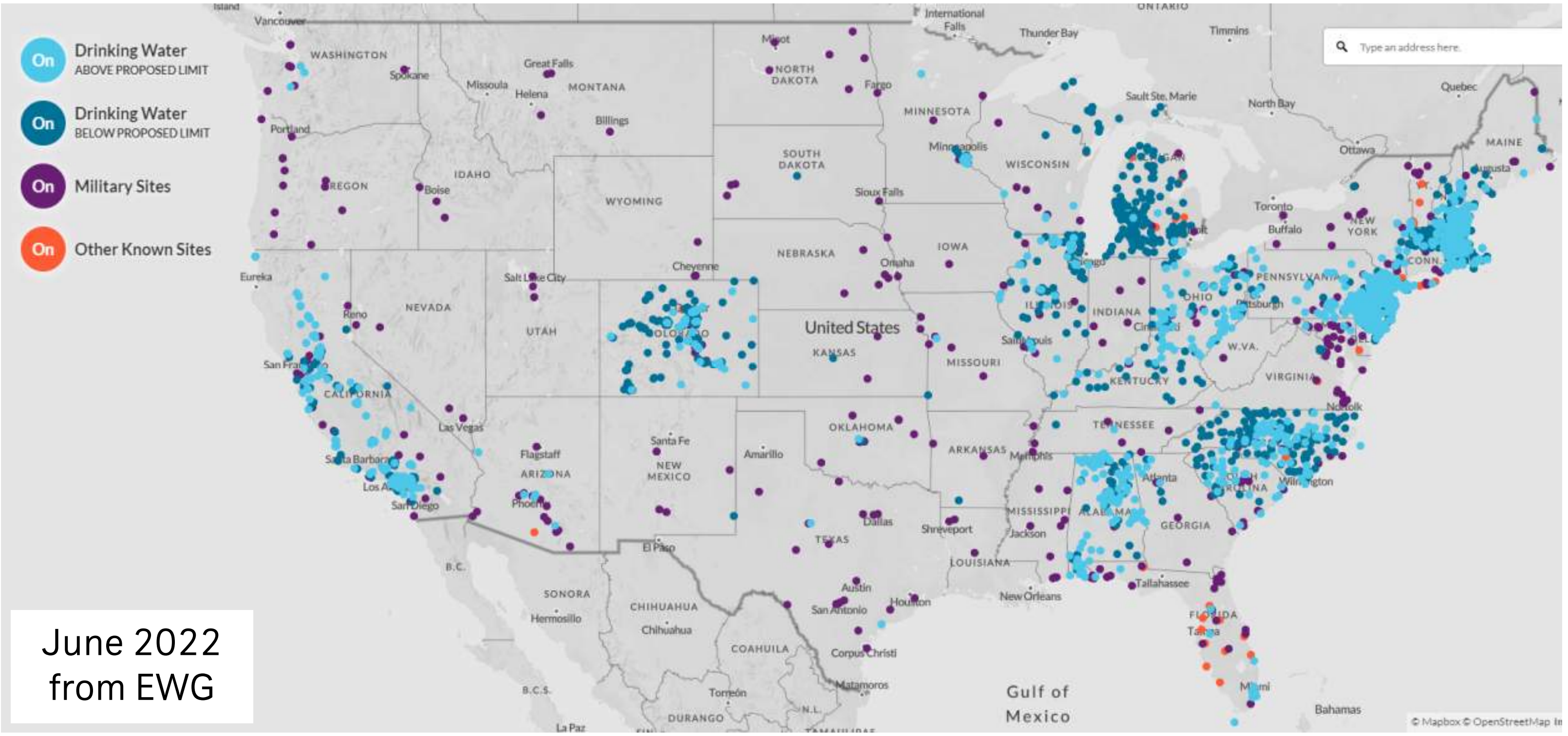



**"Under the HI approach, additional PFAS can be added over time once more information on health effects, analytics, exposure and/or treatment becomes available, and merits additional regulation as determined by EPA."**

# Impact to Water Treament

# PFAS in your water supply – *What's next?*

- Temporarily or permanently remove sources
- Change water supply sources
- Blend sources temporarily or permanently
- Treatment to remove PFAS




June 2022
from EWG

# Water quality is key to selecting treatment technology

**PFAS**

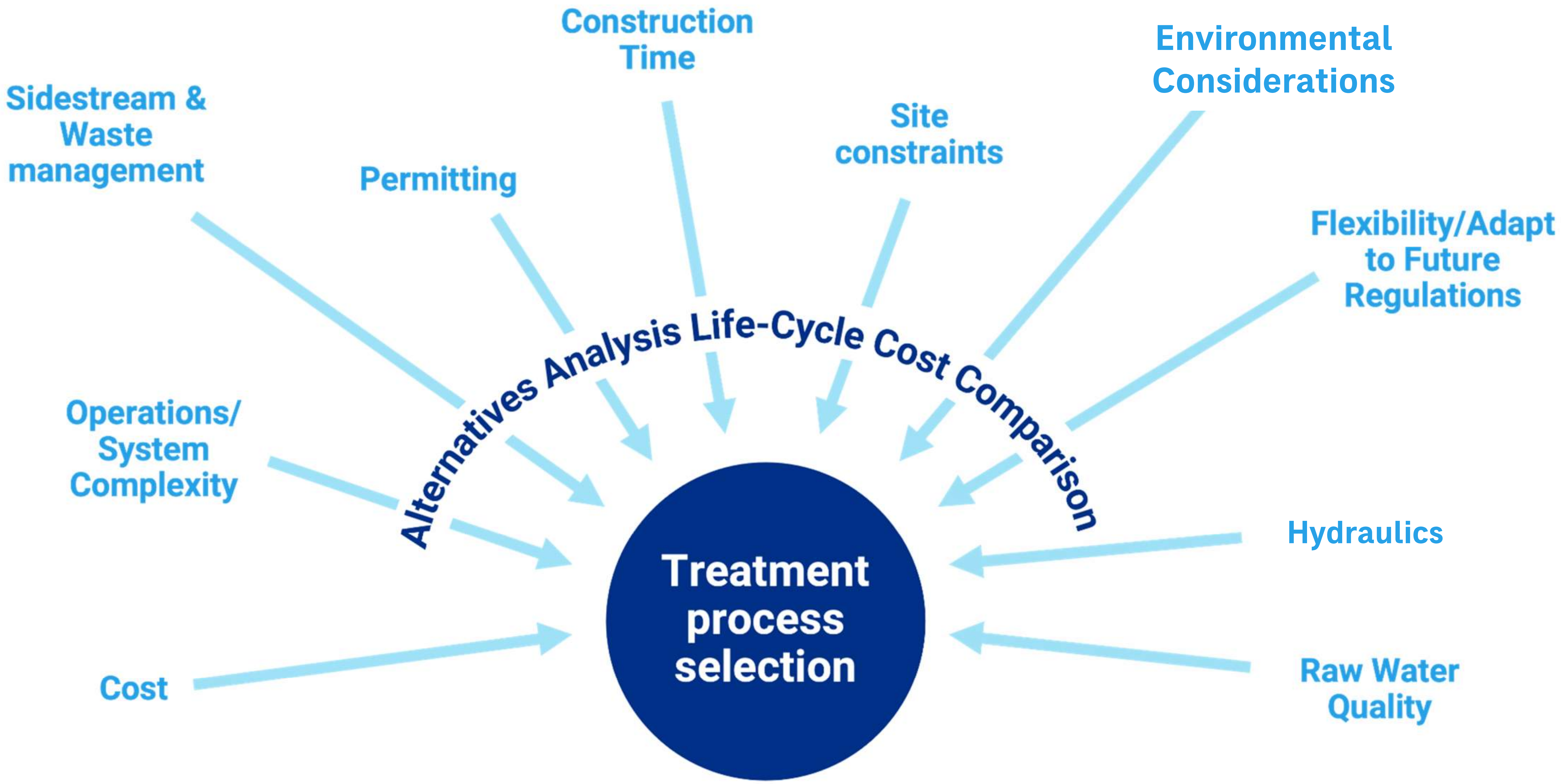
- Which compounds are you treating for?
- HALs or USEPA / state regulations
- Flexibility for future MCLs and/or more compounds regulated

**Treatment of Other Constituents**

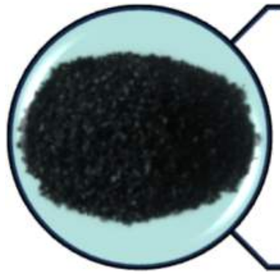
- Softening
- Iron/Manganese
- Nitrate
- VOCs
- Perchlorate
- Hexavalent chromium
- Emerging compounds – 1,4-dioxane
- Others?

**Potential Interferences with Treatment Technologies**

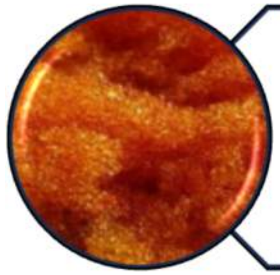
- Radionuclides
- Hardness
- Metals
- Sand/fine sediment
- Organics (including TOC/DOC)
- Entrained air (common in wells)


Construction Time
Environmental Considerations
Sidestream & Waste management
Permitting
Site constraints
Flexibility/Adapt to Future Regulations
Alternatives Analysis Life-Cycle Cost Comparison
Operations/ System Complexity
Treatment process selection
Hydraulics
Cost
Raw Water Quality

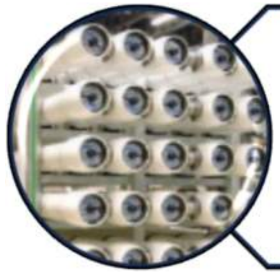
# BAT Treatment Technologies for PFAS Removal



Granular Activated Carbon (GAC)



Anion Exchange (AIX)



NF and RO Membranes

Table 2-1. Summary of PFAS removals for various treatment processes.

| Compound | Molecular Weight (g/mol) | Aeration | Coagulation/Dissolved Air Flotation | Coagulation/Flocculation/ Sedimentation/Granular Filtration or Microfiltration | Anion Exchange | Granular Activated Carbon Filtration | Nanofiltration | Reverse Osmosis | Permanganate/Ozone/ Hypochlorous/Hypochlorite/ Chloramination/UV photolysis |
|---|---|---|---|---|---|---|---|---|---|
| PFBA | 214 | ● (assumed) | ● (assumed) | ● | ● | ● | ■ | ■ | ● |
| PFPeA | 264 | ● | ● | ● | ● | ▼ | ■ | ■ | ● |
| PFHxA | 314 | ● | ● | ● | ● | ▼ | ■ | ■ | ● |
| PFHpA | 364 | ● | ● | ● | ▼ | ■ | ■ | ■ | ● |
| PFOA | 414 | ● | ● | ● | ▼ | ■ | ■ | ■ | ● |
| PFNA | 464 | ● | Unknown | ● | ■ (assumed) | ■ (assumed) | ■ | ■ | ● |
| PFDA | 514 | ● | Unknown | ● | ■ (assumed) | ■ (assumed) | ■ | ■ | ● |
| PFBS | 300 | ● | ● | ● | ▼ | ■ | ■ | ■ | ● |
| PFHxS | 400 | ● | ● | ● | ■ | ■ | ■ | ■ | ● |
| PFOS | 500 | ● | ▼ | ● | ■ | ■ | ■ | ■ | ● |
| FOSA | 499 | Unknown | Unknown | ● | Unknown | ■ (assumed) | Unknown | ■ (assumed) | Unknown |
| N-MeFOSAA | 571 | ● (assumed) | Unknown | ● | ■ (assumed) | ■ (assumed) | ■ (assumed) | ■ | Unknown |
| N-EtFOSAA | 585 | ● | Unknown | ● | ■ (assumed) | ■ (assumed) | ■ (assumed) | ■ | Unknown |

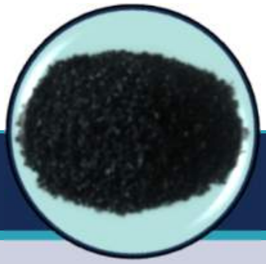
*From Dickerson & Higgins, 2016 (WRF, #4322)*

● ɿoval <10% ▼ Removal 10-90% ■ Removal >90% ☐ Unknown ☐ Assumed

THE Water Research FOUNDATION

WRF 4322: Treatment Mitigation Strategies for PFCs

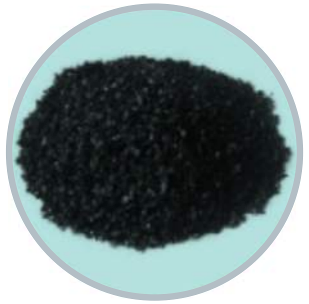
# GAC vs. AIX



| GAC | Single Use AIX |
|---|---|
| **7 – 20-minute EBCT** | **2 – 3-minute EBCT** |
| Larger infrastructure footprint | Smaller infrastructure footprint |
| Typical bed life: 50,000 – 120,000 bed volumes | Typical bed life: 250,000 – 300,000 bed volumes |
| GAC media is less expensive | IX-R media is more expensive |
| Less effective for short chain PFAS | Effective for a wider range of PFAS, but less effective for PPCPs |
| Well established technology | Not as extensively practiced as GAC |
| Backwash is available | Backwash not recommended |

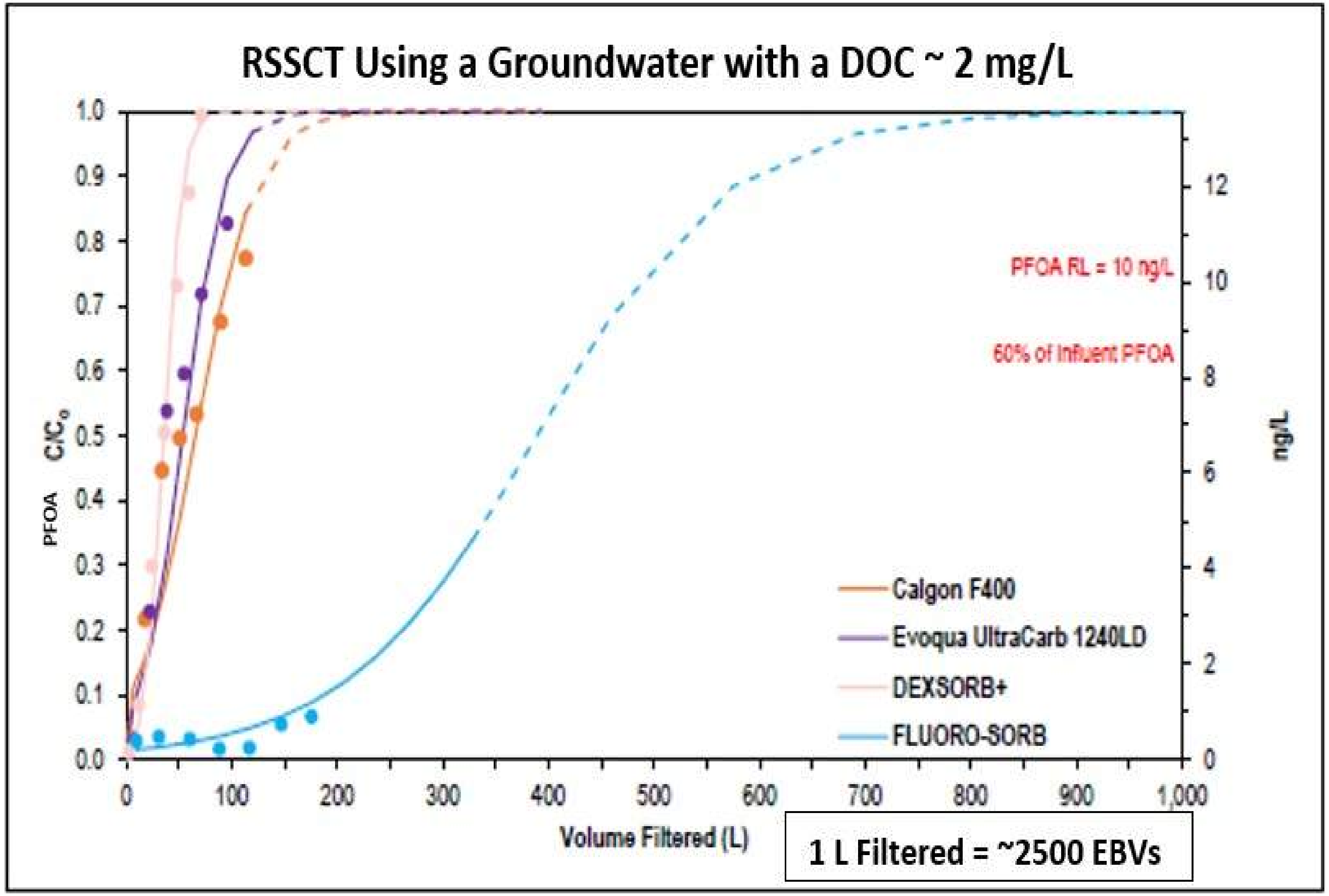
- Life cycle costs for GAC and IX-R are often similar
- Both generate spent media requiring off-site reactivation (GAC) or incineration (IX-R)
- Pretreatment may be needed for both technologies to increase media life span

# Advancements in Novel Adsorbents Show Promise



**Granular Activated Carbon**

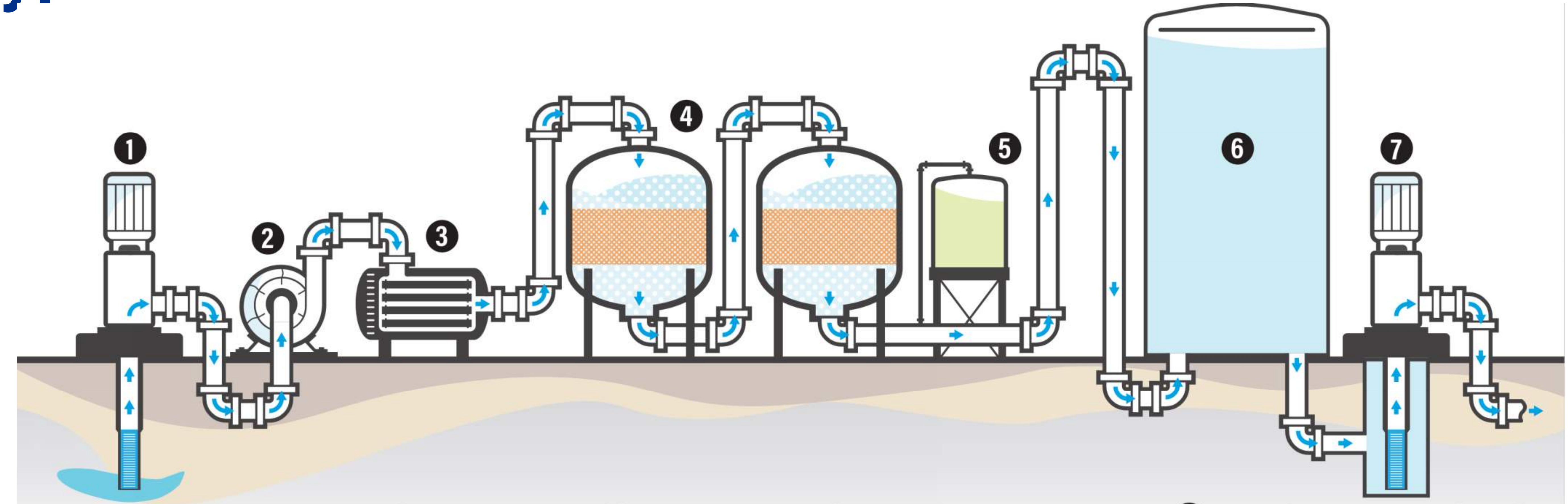
**Novel Adsorbents**
- Carbon (biochar)
- Clay (bentonite)
- Mixed minerals (aluminum oxide, iron oxide, silicates)




*Treatment of Low-TOC and Low-PFAS Groundwater Using Conventional (Calgon F400 GAC and Ultracarb 1240LD GAC) and Novel (DexSorb+ and FLUORO-SORB®) Sorbents.*
*Data courtesy of Colorado School of Mines (Chris Bellona)*

# Process Validation and Optimization Testing


# Typical Treatment Process




**1 Groundwater Wells**

Water is sourced through groundwater wells. Each well is paired with a pump that provides the necessary power to draw out water from underlying aquifers.

**2 Feed Pumps**

Feed pumps provide the energy needed to push water through the treatment system.

**3 Cartridge Filters**

Cartridge filters provide essential pretreatment of source water to remove particulates prior to ion exchange treatment.

**4 Ion Exchange Vessels**

Ion exchange vessels are filled with tiny, positively charged resin beads that attract and remove the negatively charged PFAS contaminants.

**5 Disinfection**

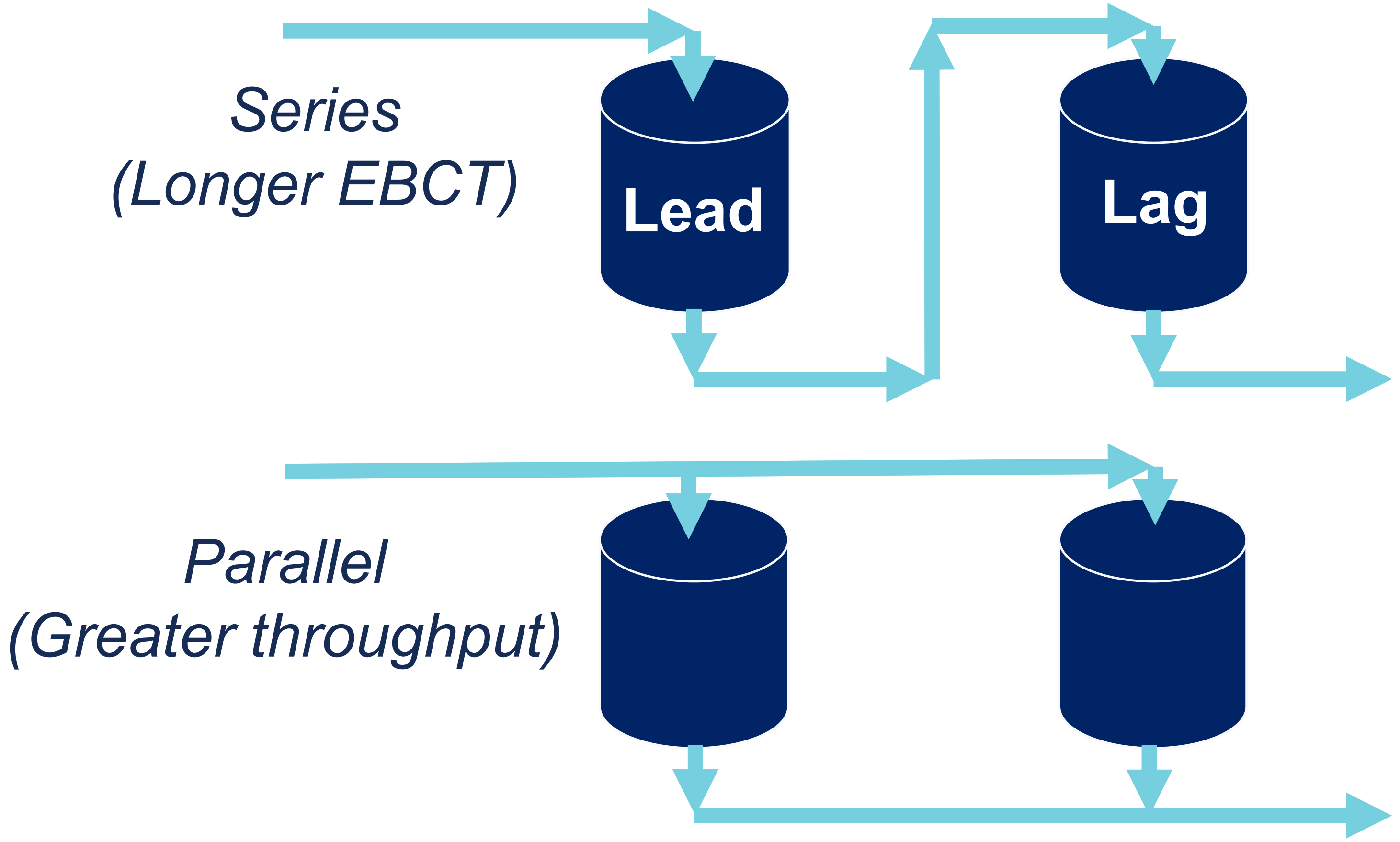
Sodium hypochlorite is injected to ion exchange effluent for disinfection.

**6 Treated Water Reservoir and 7 Booster Pump Station**

Treated water is stored in a 4 million gallon capacity reservoir. Two booster pump stations pump treated water to the 400-ft and 555-ft pressure zones of the distribution system to provide drinking water to the public.

# Series (Lead-Lag) Operation for GAC and AIX

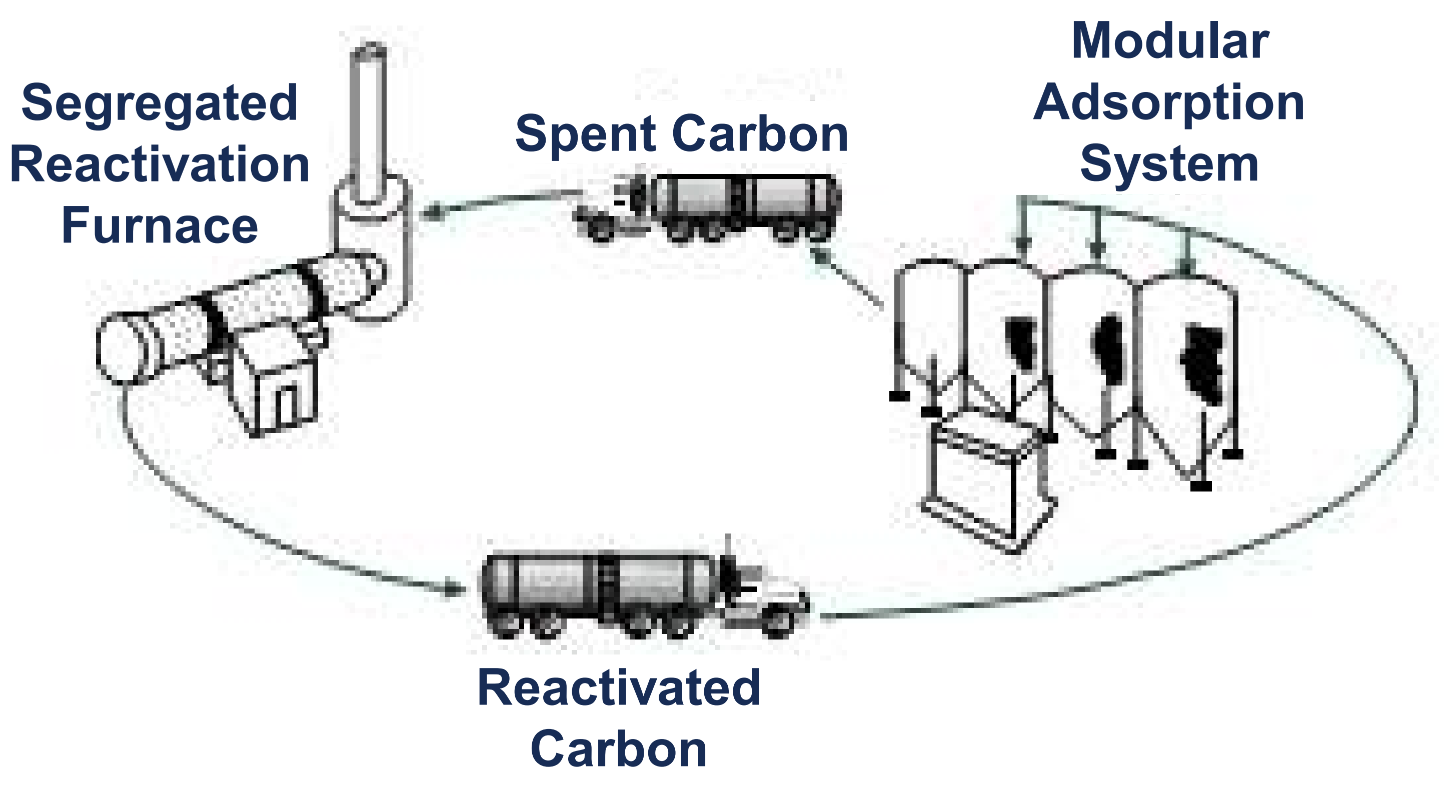
## *Provides More Safety/Redundancy than Parallel Treatment*




# Options to Dispose of Spent Media

## Granular Activated Carbon

- Landfill
- Incineration
- Reactivation / Reuse of Carbon




## Single Use Anion Exchange Resin

- Landfill
- Incineration
- No re-use of Anion Exchange Resin

# Case Study 1 – *Owen District Road GAC Facility, Westfield, MA (4 MGD)*

- Site is next to airfield, source water PFAS is 100s of ppt
- GAC adsorbers with 20-minute EBCT (lead-lag)
- Project Duration – approximately 30 months
- $5.5 Million construction cost (2018)
- Operating since June 2020
  - *To date, non-detect for the six PFAS compounds regulated in MA*

# Case Study 2 – *Grove Pond AIX Facility, Ayer, MA (2 MGD)*

- AIX with 3-min EBCT after existing greensand Fe/Mn removal plant
- AIX outperformed GAC in bench-scale testing
- $3.1 million construction (2019)
- Operating since October 2020
  - *To date, non-detect for the six PFAS compounds regulated in MA*

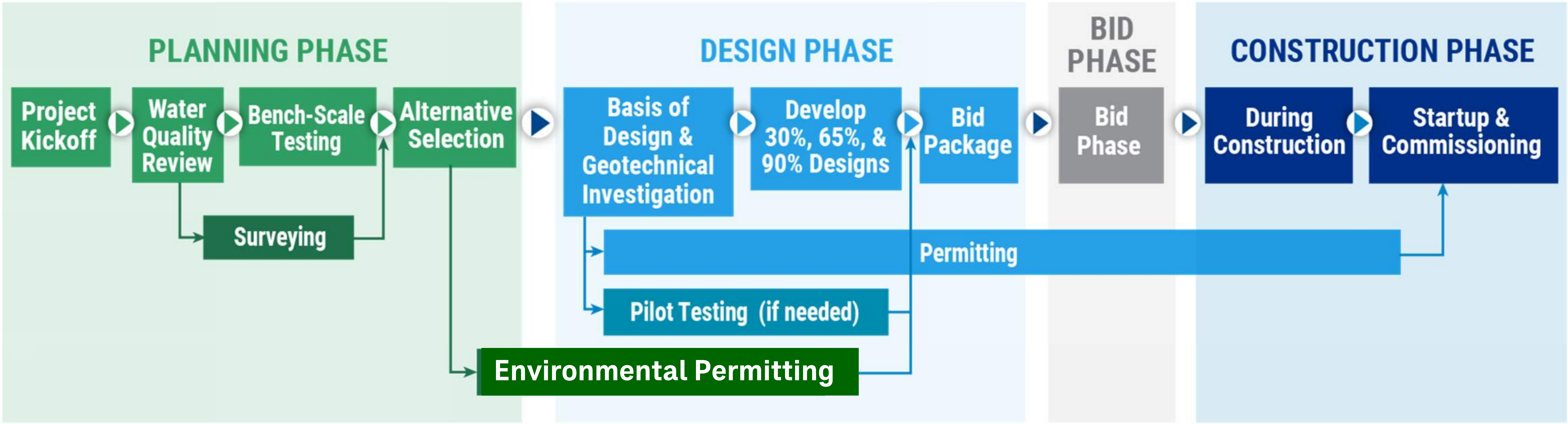
# Case Study 3 – *Northwest WTP LPRO Facility, Brunswick County, NC (41 MGD)*

- Surface water treatment system – Cape Fear River
- Three-stage LPRO to remove PFAS, 1,4-Dioxane, and other CECs
- Project Duration – approximately 48 months
- $70 million construction for LPRO system
  - *Lowest life-cycle cost alternative to treat multiple CECs*

# Case Study 3 – *Pilot Test Results*

| Parameter | Filtered Water Concentration | RO Treated Water | Calculated Removal % |
|---|---|---|---|
| Sum (45) of PFAS Tested | 423 – 892 ng/L | ND – 11 ng/L | -- |
| 1,4-Dioxane (industrial chemical) | 3.2 µg/L | 0.2 µg/L | 94% |
| Carbamazepine (seizure medicine) | 13 ng/L | ND | -- |
| Atrazine (herbicide) | 58 ng/L | ND | -- |
| Cotinine (metabolite of nicotine) | 15 ng/L | ND | -- |
| DEET (insect repellant) | 44 ng/L | ND | -- |
| Simazine (herbicide) | 57 ng/L | ND | -- |
| Tris (1,3 dichloro-2-propyl) phosphate (pesticide, flame retardant) | 120 ng/L | ND | -- |

# Planning for PFAS Treatment



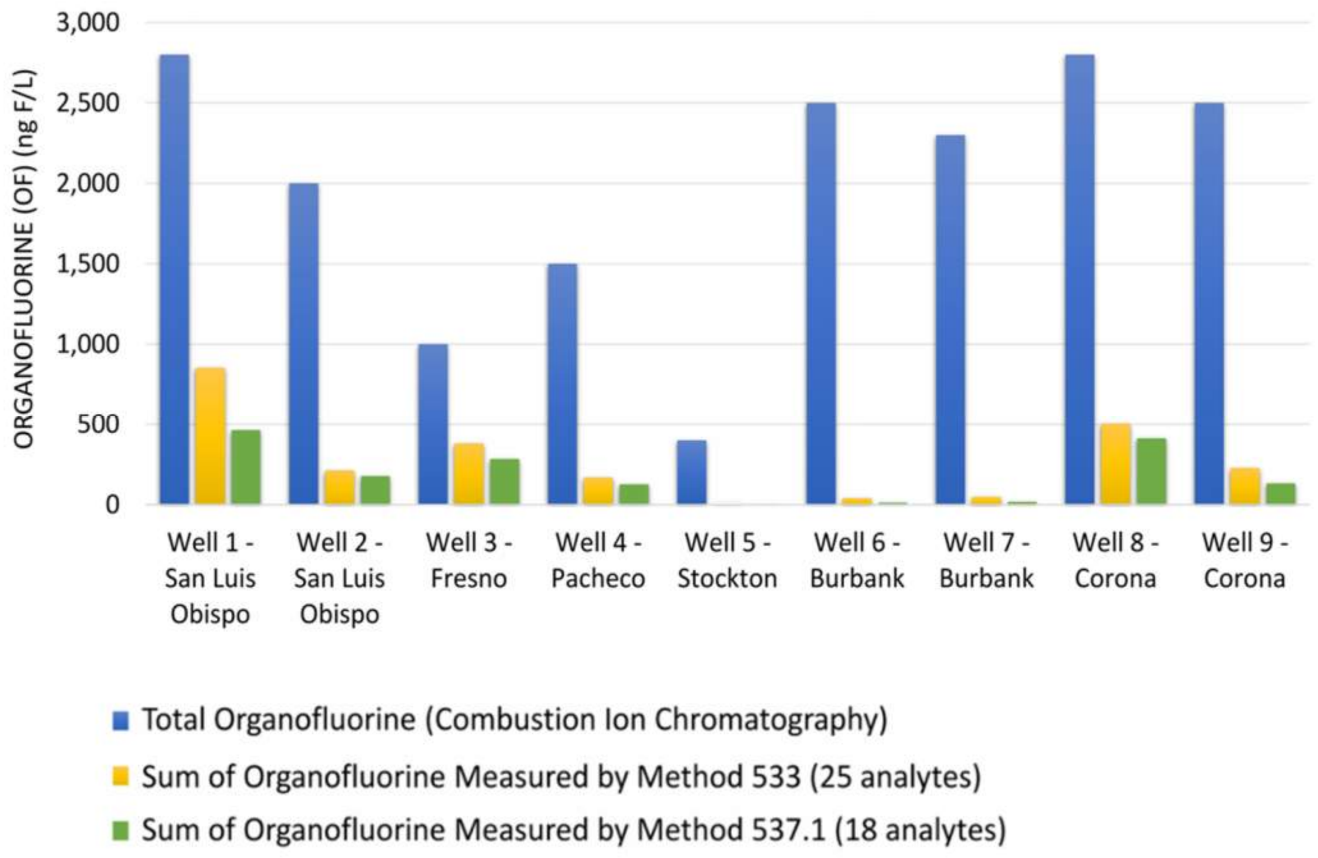
# Market Conditions Continue to Impact Implementation

- Expect ongoing market price volatility and delays in material procurement:
  - *Pressure vessels and media – in high demand*
  - *Electrical gear (MCCs, breakers)*
  - *VFDs*
- Pre-purchase of equipment can reduce construction duration by several months:
  - *Contractor can proceed without having to wait for shop drawings approval*
  - *Owner would own risk of potential equipment delays*
- Consider alternative delivery for implementation

# Additional and Future Considerations

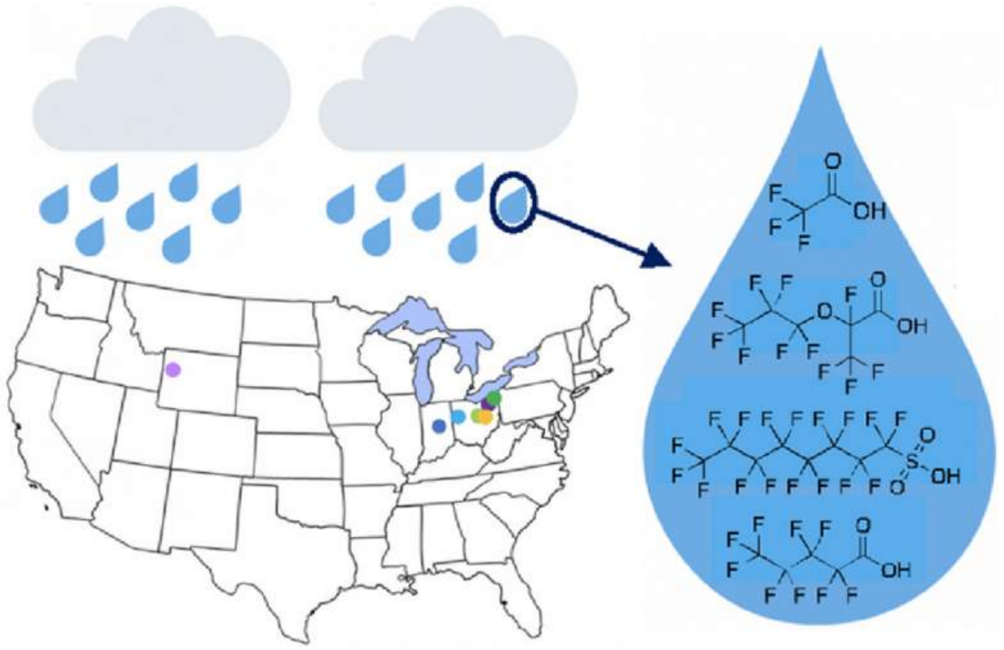
# Focus on Additional PFAS

- California addressing the entire class of PFAS
- European Chemicals Agency Proposed ban PFAS as a class of chemicals
- Focus on ultra-short PFAS



# PFAS in Rainwater

- More water systems expected to become impacted by the PFAS regulations



## PFAS in Rainwater

**US Urban Locations**

| | PFOA (ppt) | PFOS (ppt) |
|---|---|---|
| Mean | 2.1 | 4.9 |
| Min | 0.03 | 0.07 |
| Max | 30 | 12 |

**US Rural Locations**

| | PFOA (ppt) | PFOS (ppt) |
|---|---|---|
| Mean | 1 | 5.4 |
| Min | 0.2 | 0.2 |
| Max | 3 | 50 |

*https://pubs.acs.org/doi/pdf/10.1021/acs.est.2c02765*

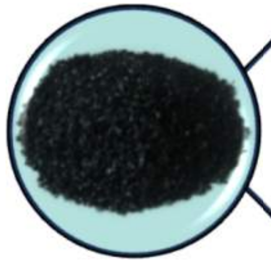
# Limitations of "Conventional" PFAS Treatment

1 High volume of spent media/waste stream requiring waste management

2 Significant pretreatment often required to remove competing solutes

3 High concentrations of PFAS can lead to inefficient target compound removal

4 Overall high costs for removing small mass of contamination (down to trace ppt levels)



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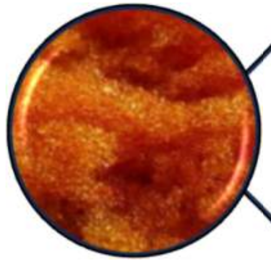
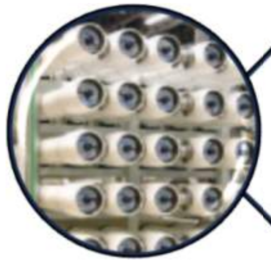


Anion Exchange (AIX)



NF and RO Membranes

# PFAS Destruct Technologies being Evaluated

where $P$ is the power (kW), $t$ is the treatment time (h), $V$ is the water volume ($m^3$), and $C_0$ and $C_t$ are the initial and final concentrations, respectively.

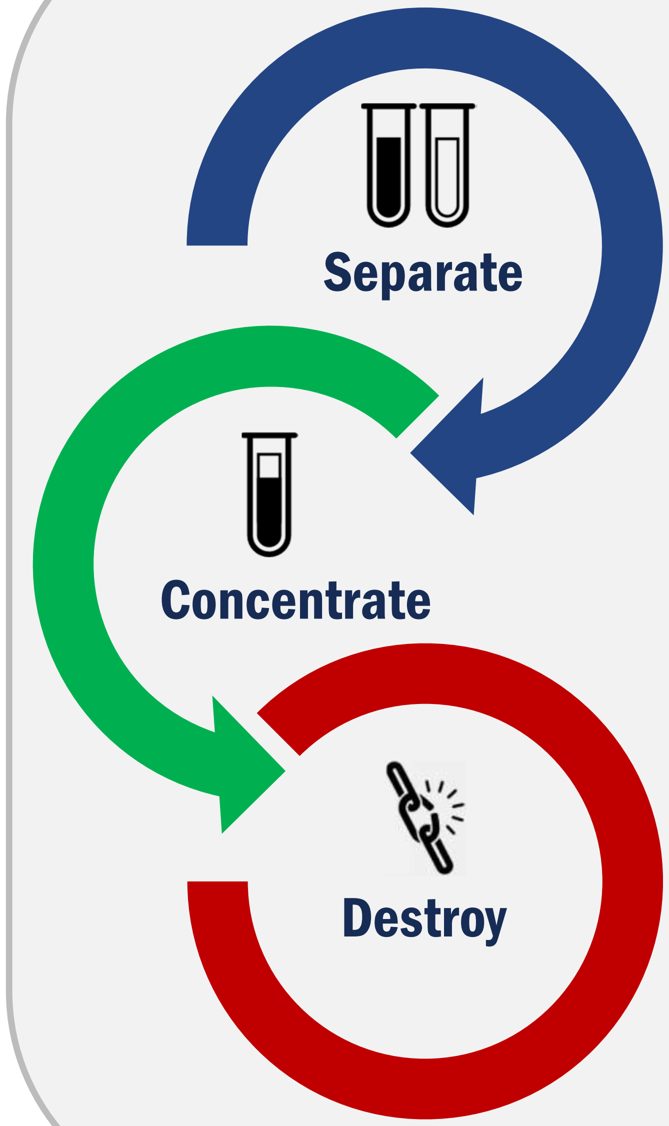
$$E_{EO}\left(\frac{kWh}{m^3}\right) = \frac{P\,t}{V\,\log\left(\frac{C_0}{C_t}\right)}$$

| System | PFAS | Volume (L) | OOM | Time (hr) | $E_{EO}$ (W-h/L) | Defluorination (%) | Source |
|---|---|---|---|---|---|---|---|
| **Electrochemical Oxidation** | PFOS, PFOA, dilute AFFF, RO | 20 | 3-5 | 8 | 46-140 | 86-99.9% | Chaplin, 2020, Schaefer, 2017, 2019,2020 |
| **Plasma** | | | | 1 | 9-84 | ~33-133% | Singh et al. 2019 |
| **UV-Sulfite** | | | | | 15-50 | 90% | Jassby, 2020, Rao, 2020, Su 2019 |
| **Hydrothermal Alkaline** | | | | | 127 | 70-99% | Strathman, 2020 |
| **Sonochemical** | | | | | 250-1500 | 90-99% | Kulkarni, 2022 |

**Separation Technologies:**
**Reverse Osmosis – 0.4 W-h/L**
**Ion Exchange – 0.01 W-h/L**

**MGD = 160 kL/h**
**If $E_{EO}$ is 10 W-h/L, that's 1.6 MW of power per MGD**

# Present and Future of PFAS Treatment




## Focused Technologies

- **Media separation:**
  GAC, AIX, and novel adsorbents
- **Liquid-liquid separation:**
  Membrane filtration or foam fractionation

- Foam fractionation → PFAS foam concentrate
- PerfluorAd® → flocculate and filter out anionic PFAS

- Electrochemical oxidation (ECO), UV reductive treatment, and others → complete destruction

# Take Aways

- Final PFAS rule expected in the next several months.  MCLs set near ambient concentration levels
- Regulations addressing more target PFAS likely, some focus on PFAS as a class
- Affected systems will need to move quickly to meet 3-year compliance window
- Selection of optimal PFAS treatment is site specific. Bench testing can quickly help evaluate technologies.
- Innovative treatment approaches evolving fast to concentrate and destroy multiple PFAS on site

# Questions?

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