VEOLIA

PFAS - An Overview and End-to-End Treatment

WEF eShowcase - webinar
virtual || November 1, 2023

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Notice
DISCLAIMER

The information contained in this statement is based on the Veolia group's understanding and know-how of the scientific and technical fields discussed herein as of the time of publication. Statements that may be interpreted as predictive of future outcomes or performance should not be considered guarantees of such, but rather reasoned assessments of the possible evolution of the technologies described.

As this document is based on the state of the Veolia group's scientific, technical, and regulatory knowledge at the time of its publication, the completeness and accuracy of the information contained herein cannot be guaranteed.

Descriptions contained herein apply exclusively to those examples and/or to the general situations specifically referenced, and in no event should be considered to apply to specific scenarios without prior review and validation.

PFAS - AN OVERVIEW & END-to-END TREATMENT SOLUTIONS
AGENDA

PFAS Challenges in Water, Wastewater and Solids

KEY CHALLENGES

- **PFAS Drinking Water Regulations**
  Proposed regulation could require treatment of PFAS to very low concentrations
- **Wastewater PFAS Levels**:
  PFAS in wastewater from plant operations or events to meet current and/or future discharge regulatory requirements; can be complex waste stream for PFAS treatment technologies
- **PFAS Disposal**
  The options of on-site and off-site disposal of PFAS, treatment media and various solids are evolving rapidly and require present and future considerations when approaching PFAS treatment.

Regulations around PFAS in Waste and Wastewater
FREQUENTLY IN THE HEADLINES

- "Maine bans use of sewage sludge on farms to reduce risk of PFAS poisoning" The Guardian

- "EPA issues guidance on reducing PFAS through NPDES" Waterworld.

- EPA Finalizes Rule to Require Enhanced PFAS Reporting to the Toxics Release Inventory - TRI data (TRI-listed chemicals) is reported to EPA annually by facilities from industry sectors such as (source: epa.gov news release Oct 20, 2023):
  - Manufacturing
  - Metal mining
  - Electric power generation
  - Chemical manufacturing
  - Hazardous waste treatment
  - Federal facilities that manufacture, process, or otherwise use notable TRI quantities

Scope of the PFAS Problem

Scope

WHERE CAN WE FIND PFAS? EVERYWHERE

Focus on PFAS one of a family of
CONTAMINANTS OF EMERGING CONCERNS

Industrial organics

Pesticides

Pharmaceuticals and personal care products
(PPCPs)

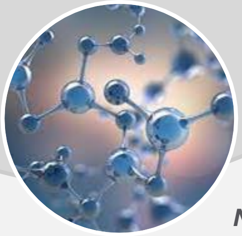
A continuously evolving number of contaminants of emerging concerns may be found in water, air and soil with potential harmful effects ⇒ **This is an issue to tackle** in order to protect human health and the environment

PFAS

Poly- and perfluoroalkyl substances are a large family of man-made chemicals strongly resistant to degradation, the most common being Perfluoro-octane sulfonate (PFOS) and Perfluorooctanoic acid (PFOA). Manufactured since the 1950's, they have been widely used in multiple products, for example fire fighting foams and various coatings.

Microplastics

Pathogens



Nanomaterials

What is PFAS?

Per- and polyfluoroalkyl substances (PFAS) - family of chemicals, used to make stain-resistant, water-resistant, and non-stick products. Common in consumer products as coatings, on food packaging, outdoor clothing, carpets, ski wax, etc.

Certain types of firefighting foam—historically used by the U.S. military, local fire departments, and airports to fight oil and gasoline fires—may contain PFAS.

Structure: C-F carbon fluorine bond; strongest known chemistry bond Due to very high ionization energy of C and; nicknamed the “Forever Chemical”

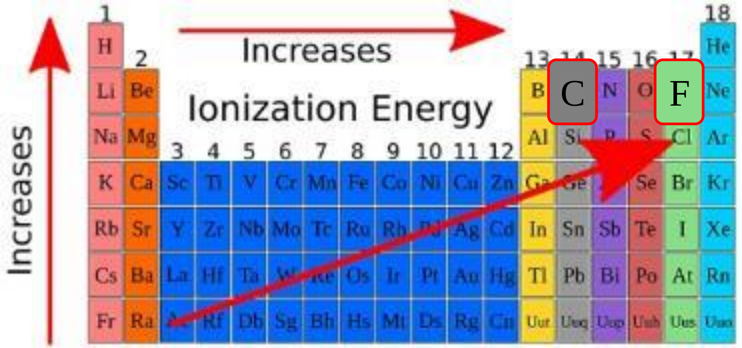
# of carbons – abbreviation – full name (molecular weight)

Sulfonic Acids/Sulfonates:

- 4 - PFBS – perfluoro butanesulfonic acid (300 MW)
- 6 - PFHxS – perfluorohexane sulfonic acid (400 MW)
- 8 - PFOS - perfluorooctane sulfonic acid (500 MW)

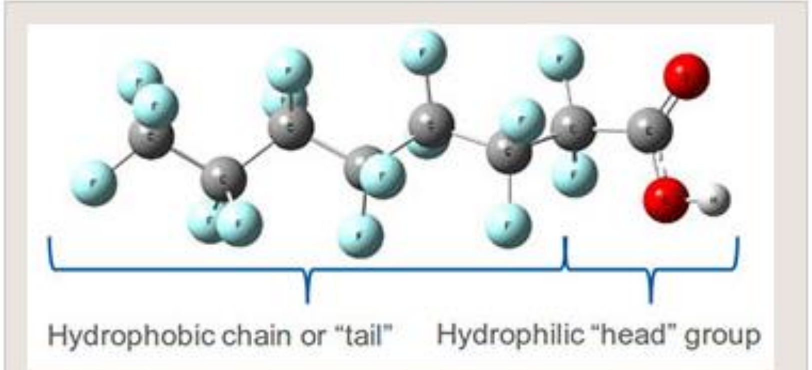
Carboxylic Acids:

- 4 - PFBA – perfluoro butanoic acid (212 MW)
- 6 - PFHxA - perfluorohexanoic acid (314 MW)
- 7 - PFHpA – perfluoro heptanoic acid (364 MW)
- 8 - PFOA – perfluorooctanoic acid (414 MW)
- 9 - PFNA - perfluorononanoic acid (464 MW)



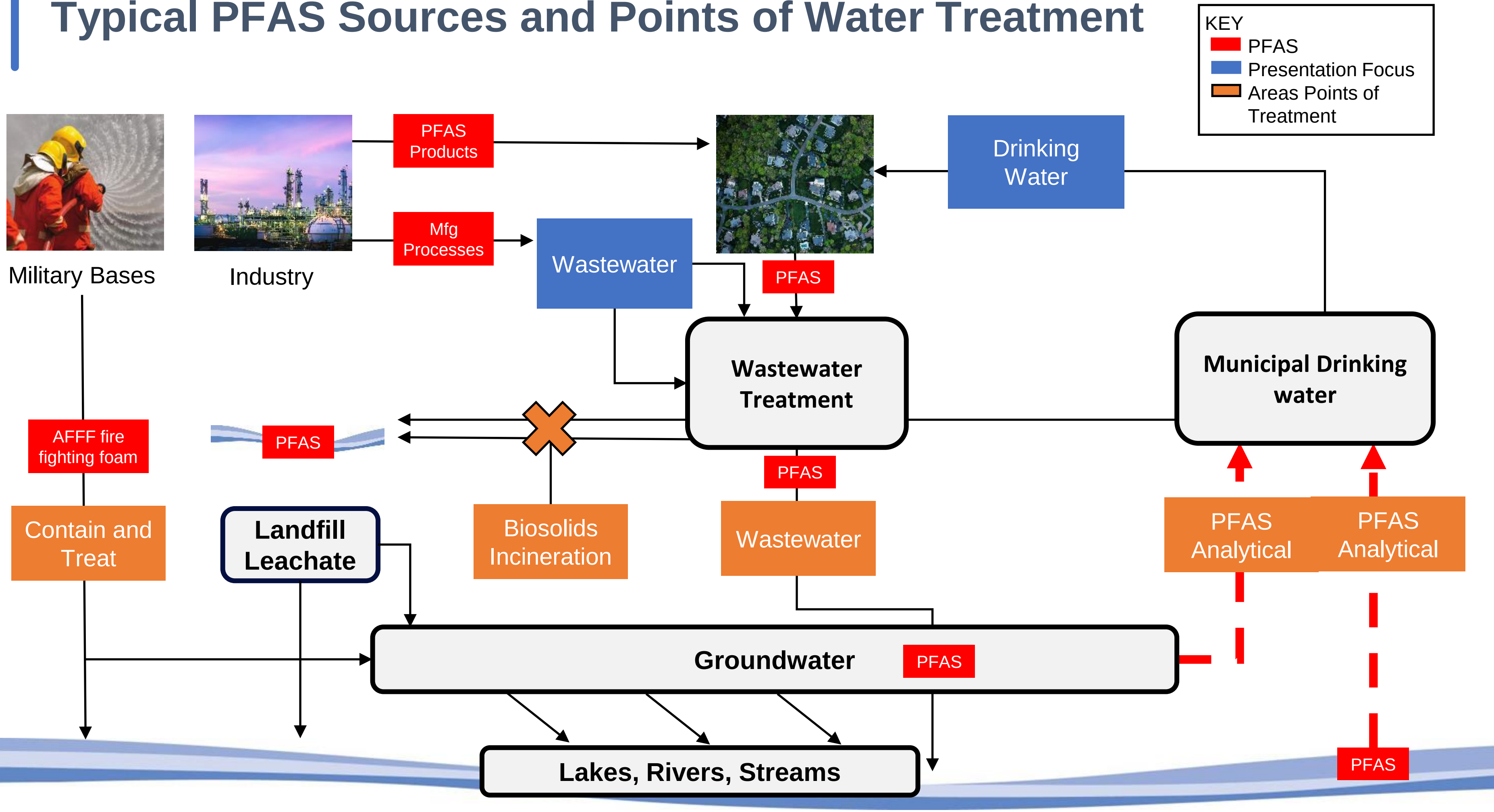
1. Small atomic number; electrons close to nucleus
2. Electrons closer to nucleus held stronger

For example; PFOA has 8 total carbons:



molecular structure of perfluorooctanoic acid, a ubiquitous PFAS

Typical PFAS Sources and Points of Water Treatment



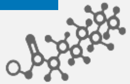
List of some common specific types of PFAS

	ANALYTE	SHORTHAND	CAS	CARBON	FLUORINES	MW
1	Perfluorobutanic acid	PFBA	375-22-4	4	7	214
2	Perfluoropentanoic acid	PFPeA	2706-90-3	5	9	264
3	Perfluorohexanoic acid	PFHxA	307-24-4	6	11	314
4	Perfluoroheptanoic acid	PFHpA	375-85-9	7	13	364
5	Perfluorooctanoic acid*	PFOA	335-67-1	8	15	414
6	Perfluorononanoic acid*	PFNA	375-95-1	9	17	464
7	Perfluorodecanoic acid	PFDA	335-76-2	10	19	514
8	Perfluoroundecanoic acid	PFUnA	2058-94-8	11	21	564
9	Perfluorododecanoic acid	PFDoDA	307-55-1	12	23	614
10	Perfluorobutanesulfonic acid*	PFBS	375-73-5	4	9	300
11	Hexafluoropropylene oxide dimeracid*	HFPO-DA	13252-13-6	6	11	330
12	4,8-dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4	7	12	378
13	Perfluorohexanesulfonic acid*	PFHxS	355-46-4	6	13	400
14	Perfluorooctanesulfonic acid*	PFOS	1763-23-1	8	17	500

*Included in EPA Proposed Drinking Water MCL

Scope
WHY IS PFAS A CONCERN?

Definition



Poly- and perfluoroalkyl substances (PFAS) are a large family of manufactured **fluorochemicals, resistant to heat, water and oil**

Impact on the Environment

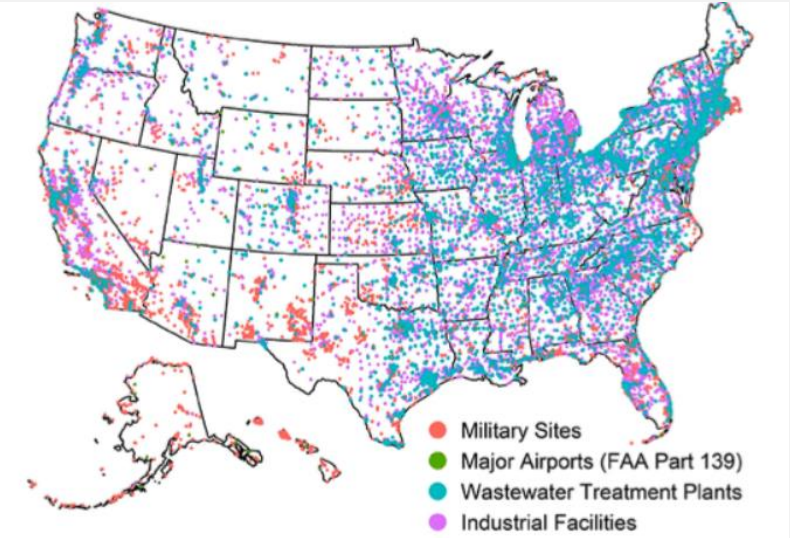
- Have the shortest and strongest carbon-fluorine bond, resistant to breaking down in the environment.
- Detected in drinking water supplies throughout the U.S.

Health Concerns

- Compounds are believed to accumulate in the human body.
- Certain PFAS have been linked to negative health impacts by the EPA.

Source: EPA.gov/PFAS

Sites with Known or Suspected PFAS Use



Map source: Environ. Sci. Technol. Lett. 2022, 9, 11, 983–990
Publication Date: October 12, 2022 https://doi.org/10.1021/acs.estlett.2c00502

Water | Soil & Biosolids | Waste

Scope

REGULATIONS ON WATER, SOIL, SOLIDS, AND WASTE

2002

USEPA restriction on long-chain PFAS

2006

EU REACH restriction PFOA & PFOS

2009

USEPA :
1st DW health advisory:
- PFOS: 200 ng/l
- PFOA: 400 ng/L

Northern Europe countries define limits for PFAS in DW

2015

Denmark, Norway and Sweden adopt limits for PFAS in DW, GW, soil & sludge

2016

USEPA DW advisory update:
- PFOS: 70 ng/L
- PFOA: 70 ng/L
- 70 ng/L combined PFOA and PFOS

Australia defines limits for DW & recreational water
Canada issues guidelines for DW

2017

US states start defining specific DW and GW standards.

Maine bans sludge landspreading due to PFAS concern

2019

USEPA issues guidances values for PFAS in GW as low as 10 ng/l for PFOS and PFOA

USEPA incineration of AFFF ban in NY and illinois, pending for Pennsylvania and Washington

2020

EU defines new directive on DW that restrict 20 PFAS <0,1 µg/l
And total PFAS <0,5 µg/l enforced in 2026

PFOA banned in the EU

2021

Canada, Netherlands: limits for some PFAS in soil and sludges
More stringent limits in **Denmark**

USEPA 4 PFAS added to the Toxics Release Inventory

2022

Germany and Belgium adopt limits for PFAS in soil and sludge

2023

USEPA proposal of DW regulatory limits to include GENX and other short-chain PFAS
- PFOS: 4,0 ng/L
- PFOA: 4,0 ng/L
- GenX, PFBS, PFNA, PFHxS : Hazard Index of 1

Canada issues more restrictive guidelines for DW at 30 ng/l for total PFAS

USEPA (2024) Final rule for CERCLA, RTK, TESC, TRI

USEPA Effluent Guidelines Program Plan 15 include PFAS discharges limits from multiple industrial categories

Global PFAS restriction proposal

PFAS is a global issue … driving regulation in many countries…important to understand which apply to your location.

Scope
REGULATORY UPDATE

Drinking Water

<table>
<tr><th>Compound</th><th>Proposed MCLG*</th><th>Proposed MCL** (enforceable levels)</th></tr>
<tr><td>PFOA</td><td>Zero</td><td>4.0 ppt</td></tr>
<tr><td>PFOS</td><td>Zero</td><td>4.0 ppt</td></tr>
<tr><td>PFNA</td><td rowspan="4">1.0 (unitless) Hazard Index</td><td rowspan="4">1.0 (unitless) Hazard Index</td></tr>
<tr><td>PFHxS</td></tr>
<tr><td>PFBS</td></tr>
<tr><td>HFPO-DA (commonly referred to as GenX Chemicals)</td></tr>
</table>

*Maximum Contaminant Level Goals (MCLGs)
** Maximum Contaminant Levels (MCLs)

Final Rule anticipated by early 2024

Proposed rule requires compliance 3 years after promulgation

Wastewater

There is no specific federal regulation in place today for PFAS in wastewater

EPA chasing PFAS at the source has led to proactive initiatives by industry

EPA Certification of analysis method 1633 expected 2023; for analysis of non-potable water and solids

Waste

EPA proposed in August 2022 to designate two of the most widely used PFAS, PFOA and PFOS, as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as “Superfund.” EPA is currently reviewing public comments received for this proposal.

In April 2023, EPA issued an Advance Notice of Proposed Rulemaking (ANPRM) asking the public for input regarding potential future hazardous substance designations for additional PFAS under CERCLA.

Source: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca

Scope

REGULATORY UPDATE - U.S. Federal Level

Drinking Water

Compound	Proposed MCLG*	Proposed MCL** (enforceable levels)
PFOA	Zero	4.0 ppt
PFOS	Zero	4.0 ppt
PFNA	1.0 (unitless) Hazard Index	1.0 (unitless) Hazard Index
PFHxS		
PFBS		
HFPO-DA (commonly referred to as GenX Chemicals)		

*Maximum Contaminant Level Goals (MCLGs)
** Maximum Contaminant Levels (MCLs)

How is the Hazard Index calculated?

The Hazard Index (HI) is made up of a sum of fractions. Each fraction compares the level of each PFAS measured in the water to the highest level determined not to have risk of health effects.

Step 1. Divide the measured concentration of Gen X by the health-based value of 10 ppt
Step 2. Divide the measured concentration of PFBS by the health- based value of 2000 ppt
Step 3. Divide the measured concentration of PFNA by the health-based value of 10 ppt
Step 4. Divide the measured concentration of PFHxS by the health-based value of 9 ppt
Step 5. Add the ratios from steps 1, 2, 3 and 4 together

Equation

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

Step 6. To determine HI compliance, repeat steps 1-5 for each sample collected in the past year and calculate the average HI for all the samples taken in the past year.
Step 7. If the running annual average HI greater than 1.0, it is a violation of the proposed HI MCL.

https://www.epa.gov/system/files/documents/2023-03/How%20do%20I%20calculate%20the%20Hazard%20Index._3.14.23.pdf

Scope
REGULATORY UPDATE - U.S. State Level

Drinking Water

***MCLs, Notification, and Guidance and Action Levels, etc. are all in ng/L.**

Oregon	
PFOS+ PFOA+ PFHxS+ PFNA	30

Minnesota	
PFOA	35
PFOS	15
PFHxS	47
PFBA	7,000
PFBS	100
PFHxA	200

Michigan	
PFNA	6
PFOA	8
PFOS	16
PFHxS	51
HFPO-DA	370
PFBS	420
PFHxA	400,000

California	
PFOA	5.1
PFOS	6.5
PFHxS	3.0

Washington	
PFNA	9

Alaska, Colorado, Delaware, New Mexico, Ohio, Wisconsin	
various	70

New York	
PFDA	10
PFNA	10
PFHxS	10
PFHxA	10
PFOA+PFOS+ PFDA + PFNA + PFHxS + PFHxA	30

Vermont	
PFOA+ PFOS+ PFHpA+ PFHxA+ PFNA	20

Massachusetts, Rhode Island	
PFOA+ PFOS+ PFHxS+ PFHpA+ PFNA+ PFDA	20

New Hampshire	
PFOA	12
PFNA	11
PFHxS	18
PFNA	11

Pennsylvania	
PFOA	14
PFOS	18

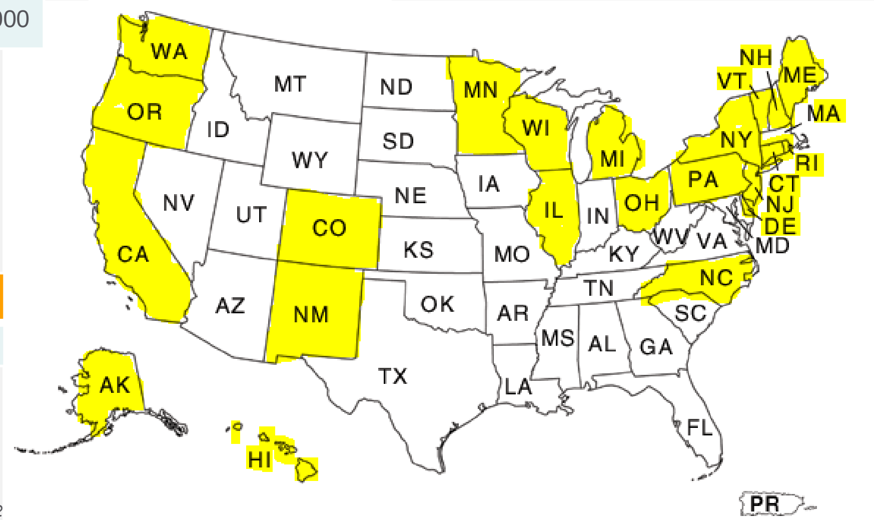
New Jersey	
PFOA	14
PFOS	13
PFNA	13

Illinois	
PFOS	14
PFNA	21
PFOA	2

Connecticut	
6:2 FTS , 9Cl-PF3ONS	2
8:2 FTS, 11Cl-PF3OUdS	5
PFOS	10
PFNA	12
PFOA	10
HFPO-DA	19
PFHxS	49

North Carolina	
HFPO-DA	140

Ohio	
PFOS+ PFOA	70
PFNA	21
PFHxS	140
HFPO-DA	21
PFBS	2,100



ct. 17, 202

Scope
REGULATORY UPDATE - Canada

Drinking Water

Compound	Objective	MAC* (enforceable levels)
PFOA	The sum of PFOA and PFOS divided by their MACs should be <1	200
PFOS		600
Total PFAS	<30 ppt	N/A

Federal Level:
See table.

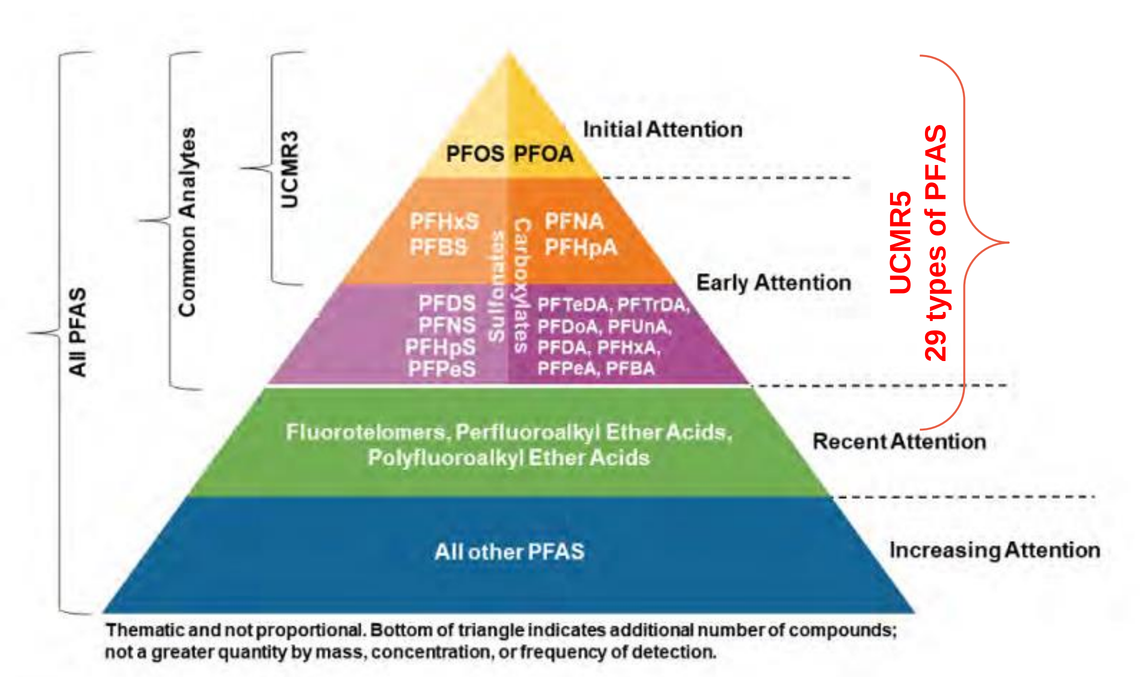
"Total PFAS" objective is vague but language suggests this could be applied to the PFAS in EPA Methods 533 and/or 537.1.

Provinces, Territories:
Ontario is developing new guidelines for PFAS as a group.

* Maximum Acceptable Concentration (MACs)
https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/water-talk-per-polyfluoroalkyl-substances-drinking-water.html

Scope

EVOLVING REGULATIONS



Source: ITRC - J. Hale, Kleinfelder

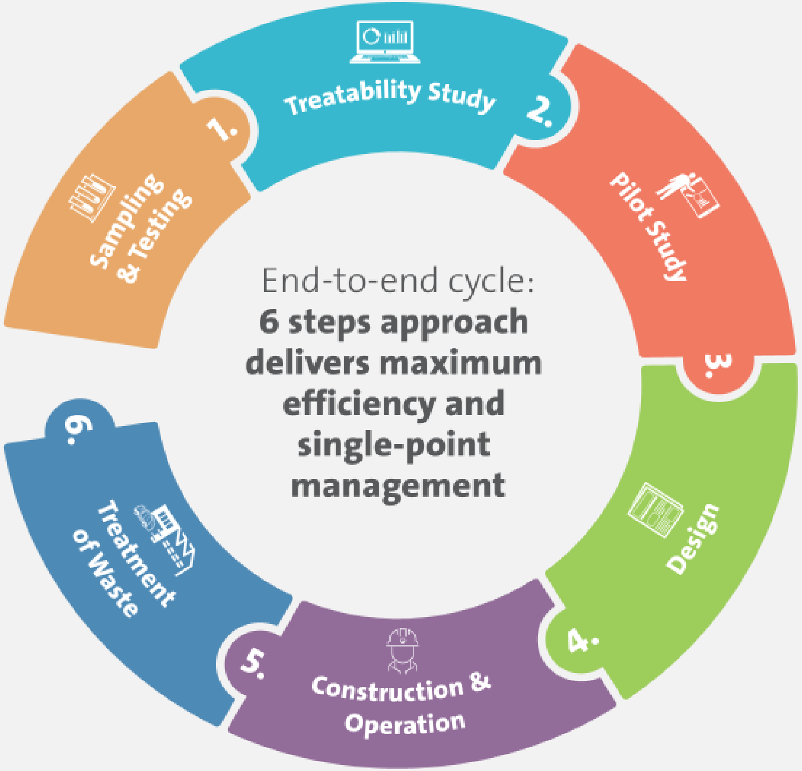
UCMR5: Fifth Unregulated Contaminant Monitoring Rule requires sample collection for 30 chemical contaminants *between 2023 and 2025* using analytical methods developed by EPA and consensus organizations. This action provides EPA and other interested parties with scientifically valid data on the national occurrence of these contaminants in drinking water.

Source:www.epa.gov

SOLUTIONS & EXPERIENCE

Solutions & Experience

PFAS – SIX STEPS OF THE END-TO-END TREATMENT SOLUTION



Solutions & Experience
SAMPLING & TESTING CAPABILITIES

Laboratory capabilities in North America

VWTS, Tomball Technology Center, TX US:
EPA Method 533, 25 types of PFAS, Average of ~60 samples / month, VWTS provides customized PFAS sampling kit

Solutions & Experience
US EPA PFAS Testing Methods

Method	Date	# of PFAS Types	Comments
537.0	2009	14	Drinking Water
537.1	2018	18	Drinking Water; added 4 PFAS Types
537 Modified	2018	18-34	Drinking Water; lab dependent
533	2019	25	DW; added 11 PFAS Types, shorter Chains
3512	2021	24	Non-potable water samples, Screening Only
1633	2021	40	DRAFT method Non-potable water, surface water, ground water, soil, solids, biosolids, sediment, landfill leachate and fish tissue. Single lab study, still going thru process -- Expected 2024

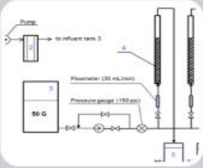
PFAS Analytical Testing
VEOLIA’S FACILITY - Tomball, TX

Quick Facts – EPA 533 Method for PFAS

- Performance and Quality: 25 PFAS Compounds, 1ppt LOD
- Convenience: Veolia’s Tomball Lab Supply provides customized PFAS sampling kit
- Throughput: State of the art automated sample extraction unit
- Flexible: Ability to customize methods to meet customer needs

New, High-end Hardware for PFAS Analysis

Customer Application Areas



Treatability Studies
- Derisk process design in Lab
- RSSCT Column & Membrane testing

Pilot & Commission
- Start up support (non-certified)
- Troubleshooting

Operating Systems
- Water Quality Testing
- Operational Monitoring
- Troubleshooting

New Solutions
- New solutions
- Technology
- Flowsheets

PFAS Sample Kit available

Tomball Lab provides comprehensive, non-certified Analytical Testing to meet customer PFAS detection needs

Solutions & Experience
TREATABILITY STUDY

All water matrices are different with a **diversity of PFAS** and presence of **co-contaminants** and **organic matters** which can **compete** with PFAS for treatment affinity. That's why it is necessary to implement some treatability study to determine the best value treatment, to assess its performance and to predict operating parameters.

Solution: Laboratory & bench testing capabilities

Rapid small-scale column tests (RSSCTs) are used in laboratory testing to determine contaminant treatment effectiveness for granular activated carbons (GACs) and ion exchange resins (IX) in a short time-frame compared to pilot testing.

RSSCTs are performed on our laboratories by reducing the GAC or resin particle size via grinding, allowing for increased mass transfer and water throughput.

Solutions & Experience
PILOT STUDY

Pilot testing - evaluate multiple flowsheets on-site in real-world conditions for several weeks or months to determine the optimal combination of treatment technologies.

- Compare different configurations of a separation step— such as RO—followed downstream by GAC, IX, and a novel adsorbent

Pilot tests help quantify technical issues that were not determined in lab tests, and can be **used for performance monitoring**, verifying **regulatory requirements**, and **creating economic models** of each alternative.

Can be expensive propositions if a structure needs to be built complete with equipment, components, pipes, instrumentation, and electrical supply.

- Operators can minimize these costs by employing **mobile equipment to test multiple configurations** on-site to determine the best flowsheet for each application. A mobile trailer is driven to the job location to treat and test site water, greatly simplifying the logistics of the pilot test.

VWTS PFAS whitepaper

Solutions & Experience

DESIGN - TECHNOLOGIES OVERVIEW

Separation technologies	*Degradation technologies*
Sorption technologies Activated Carbon (AC) Ion Exchange (IEX) Novel sorbents	**Advanced Oxidation Process (AOP)** Electrochemical oxidation Supercritical water oxidation Chemical oxidation Combined & Other
Membrane Filtration Reverse Osmosis Nanofiltration Ultrafiltration	**Plasma**
Foam fractionation	**Thermal treatment** Incineration Pyrolysis Gasification Other
Thermal desorption	**Combined solutions** (Membrane + AOP, AC + AOP, AOP + fungus degradation…)
Phytoremediation	**Other solutions**
Combined solutions (Membrane + adsorption, AC + IEX…)	
Other solutions	

Our system design is based on a **holistic approach.**

We consider a broad range of technologies and suppliers: from pretreatment to GAC, IX to Membranes and final concentration including **proprietary solutions**.

We are also conducting a **mapping of other innovative solutions** on the market to be able to offer to our clients the best available solution.

Solutions & Experience
DESIGN – ADSORPTION

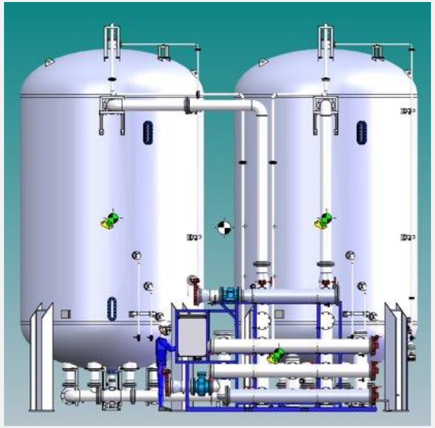
PFAS adsorption various medias:

- Activated Carbon
- Ion exchange resins

Considerations:

- Types of PFAS - long vs short chain, affinity for media
- Activity level - empty bed contact time (EBCT) - amount of media
- Overall capacity - volume treated before media replacement

LEAPfas™: proprietary designed vessels achieving Ultra-Low levels of PFAS in effluent on a consistent & reliable basis.



Solutions & Experience
DESIGN - ION EXCHANGE RESIN

Our solutions for adsorption using Ion exchange resins

1. No proprietary technology, standard units from external suppliers
2. Ionsoft® standard product
3. LEAPfas™: proprietary designed vessels achieving Ultra-Low levels of PFAS in effluent on a consistent & reliable basis.

Highlands, NJ

Solutions & Experience
DESIGN – MEMBRANE & FILTRATION SEPARATIONS

Our solutions for Membrane filtration

1. ZeeWeed UF hollow membrane
2. PROFlex NF and RO can be used for industrial, beverage, municipal and reuse applications
3. Sirion ®Reverse Osmosis standard product

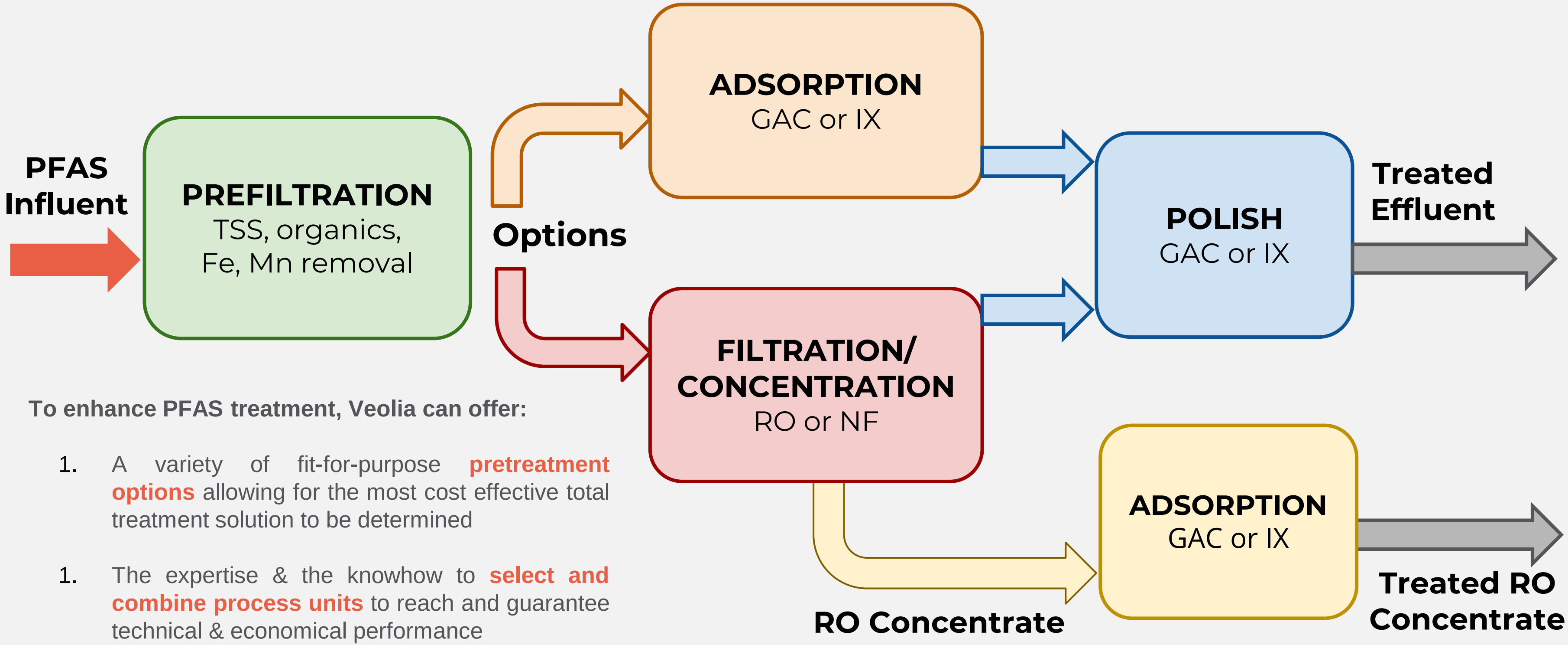
Solutions & Experience

WATER TREATMENT TECHNOLOGIES SOLUTIONS FOR PFAS

Technology	Pros	Cons
Granular Activated Carbon	Treats multiple water quality concerns Universally accepted Effective on long-chain PFAS	Availability/demand Competition from other contaminants Efficacy varies by type Less effective on short-chain PFAS Disposal/regeneration of spent media
Ion Exchange	Smaller footprint than GAC Designed specifically for PFAS, effective for more types Accepted by many	Single purpose Corrosion control impacts Disposal/regeneration of spent media
Reverse Osmosis/Nanofiltration	Effective for wide range of PFAS as well as other water quality concerns	High CAPEX & OPEX Treatment/disposal of concentrated waste stream
Alternative Treatment (novel adsorbents, water oxidation, foam fractionation, plasma, UV)	Potential for complete destruction of PFAS, more efficient treatment	Scalability Process safety Environmental impacts Regulator acceptance More study needed

Solutions & Experience

WATER TREATMENT TECH FOR A MULTISTEP APPROACH



To enhance PFAS treatment, Veolia can offer:

1. A variety of fit-for-purpose **pretreatment options** allowing for the most cost effective total treatment solution to be determined

1. The expertise & the knowhow to **select and combine process units** to reach and guarantee technical & economical performance

PFAS Pretreatment –
LOW PRESSURE (MF/UF) MEMBRANES

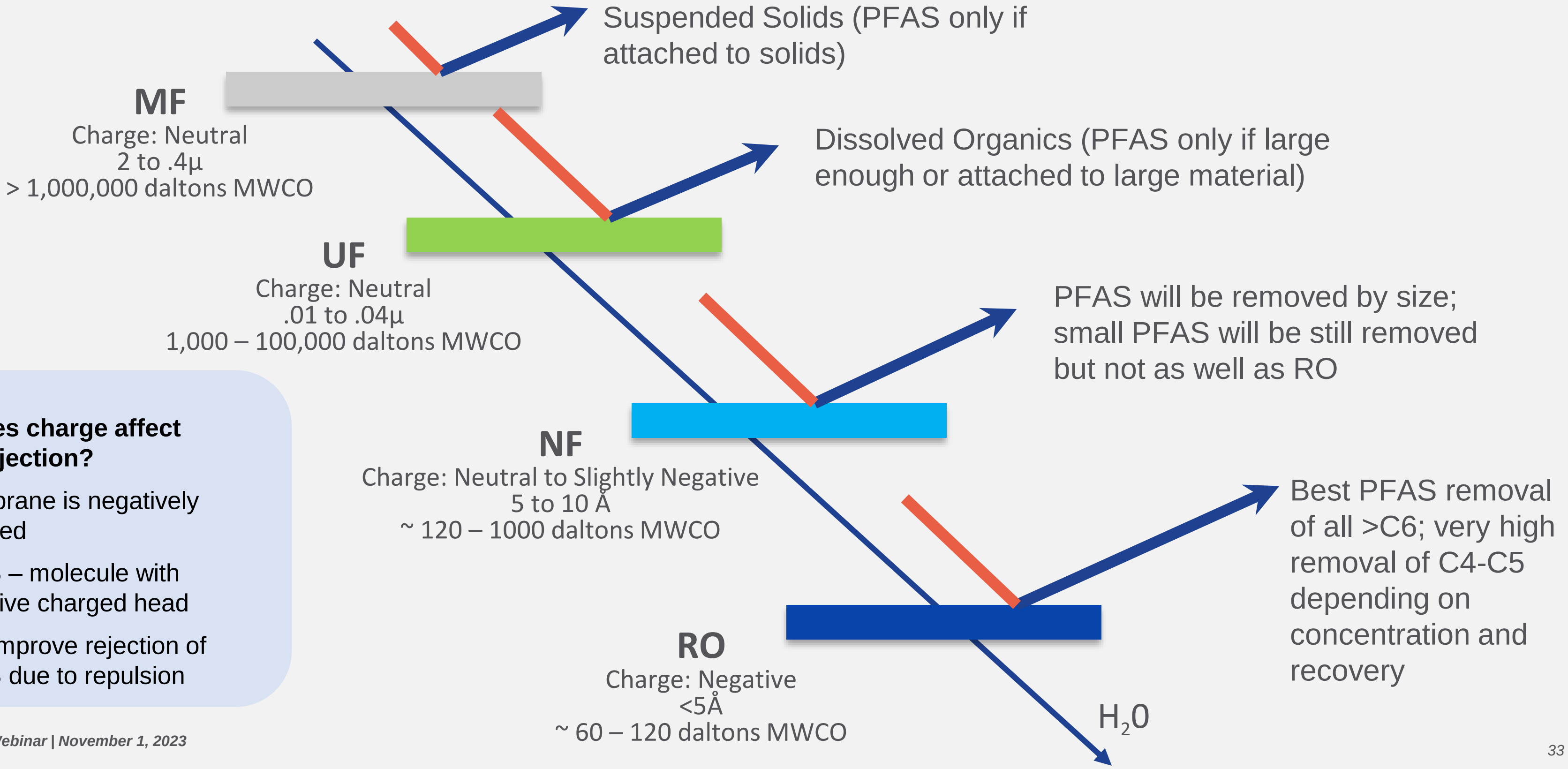
Immersed

- Hollow fiber
- Low pressure, vacuum-driven operation results in low energy
- High density result in less footprint and installed cost for large plants and less lifecycle for medium-to-large plants
- Simpler scale-up for larger systems

Pressurized

- Hollow fiber
- Higher pressures result in less membrane and less capital for small-to-medium plants
- Quick installation with skidded valve racks and less civil works (no membrane tanks).
- Inability to see fiber condition and detect a problem

Solution & Experience
MEMBRANE TREATMENT SEPARATION



How does charge affect PFAS rejection?

- Membrane is negatively charged
- PFAS – molecule with negative charged head
- Can improve rejection of PFAS due to repulsion

PFAS Membrane
HIGH PRESSURE (NF/RO LAB TESTING

- Source – well water containing PFAS (no spike)
- Test – in lab on 2540 spiral elements (2.5-inch dia x 40-inch long)
- 3 Membrane types – brackish water, low energy and nanofiltration
- Single element, single pass
- Composite permeate @ 90% recovery (10x concentration)
- % Removal PFAS =
  $(1 - (\text{Concentration}_{\text{Permeate}} \div \text{Concentration}_{\text{Feed}})) * 100\%$

Lab Data on Next Slide

PFAS Membrane Performance –
SOURCE: WELL WATER CONTAINING PFAS, NON-SPIKED

			Feed	Permeate			Concentrate			% Removal		
PFAS	g/mol	# C's		BW	LE	NF	BW	LE	NF	BW	LE	NF
PFBA	214	4	7.1	<1.0	<1.0	4.8	80	70	58	BDL	BDL	32.4%
PFPeA	264	5	28.3	<1.0	<1.0	4.1	290	250	220	BDL	BDL	85.5%
PFHxA	314	6	25.6	<1.0	<1.0	3.4	250	210	190	BDL	BDL	86.7%
PFHpA	364	7	13.2	<1.0	<1.0	1.6	140	120	98	BDL	BDL	87.9%
PFOA	414	8	18.6	<1.0	<1.0	1.8	160	150	120	BDL	BDL	90.3%
PFNA	464	9	9.5	<1.0	<1.0	<1.0	70	65	49	BDL	BDL	BDL
PFDA	514	10	1.2	<1.0	<1.0	<1.0	7.1	5.3	4.2	BDL	BDL	BDL
PFUnA	564	11	3.0	<1.0	<1.0	<1.0	16	12	7.9	BDL	BDL	BDL
PFBS	300	4	3.8	<1.0	<1.0	1.4	38	33	25	BDL	BDL	62.8%
PFPeS	350	5	5.2	<1.0	<1.0	1.7	53	49	42	BDL	BDL	67.0%
PFHxS	400	6	73.0	<1.0	1.8	13	740	670	530	BDL	97.5%	82.2%
PFHpS	450	7	3.4	<1.0	<1.0	<1.0	29	29	22	BDL	BDL	BDL
PFOS	500	8	200.0	<1.0	2	13	1300	1200	780	BDL	99.0%	93.5%
6:2 FTSA	428	8	14.0	<1.0	<1.0	1.5	120	100	87	BDL	BDL	89.3%
8:2 FTSA	528	10	4.3	<1.0	<1.0	<1.0	21	24	16	BDL	BDL	BDL
TOTAL			410.1	<1.0	3.8	46.3	3,314.1	2,987.3	2,249.1	BDL	99.1%	88.7%

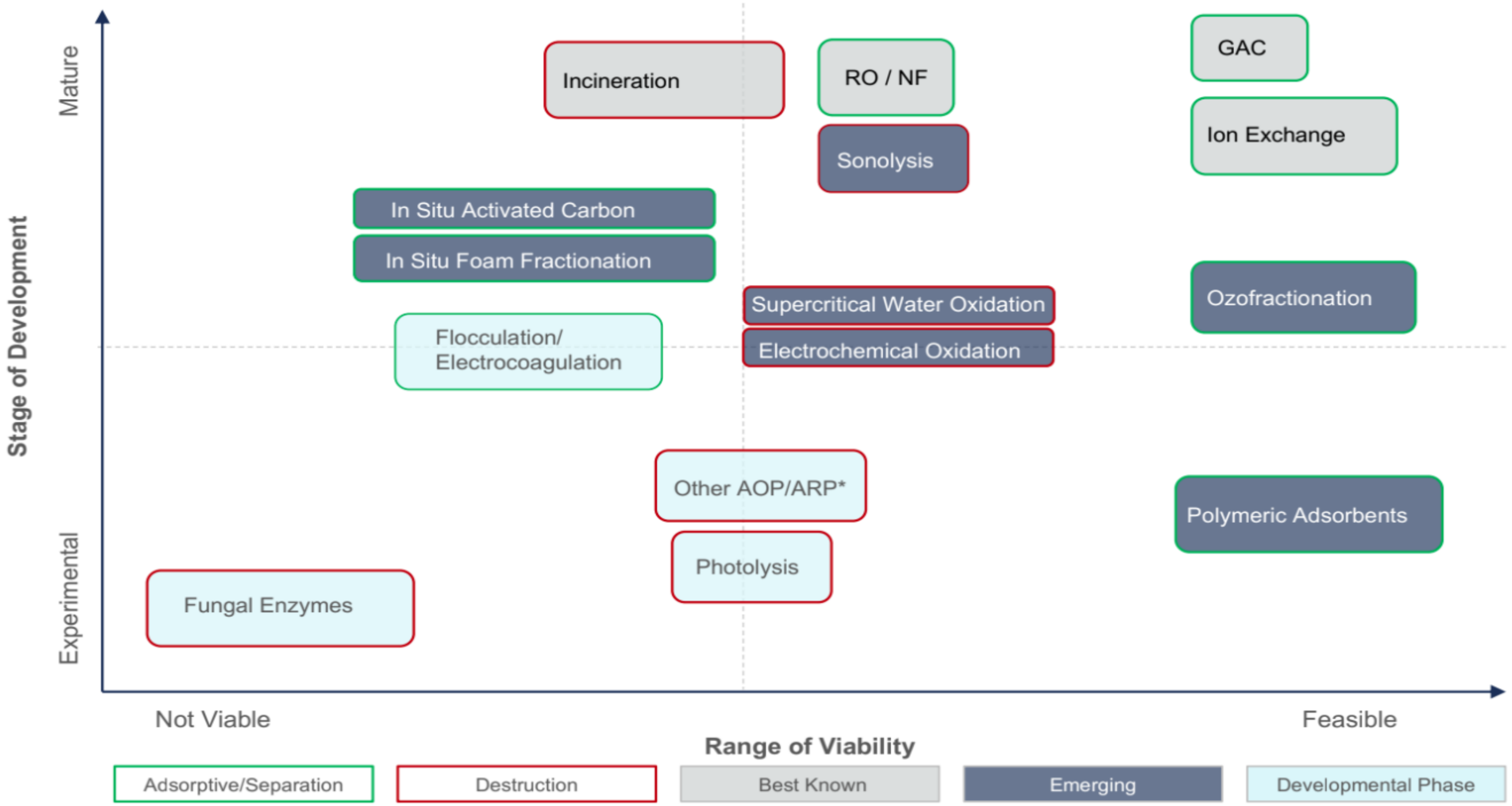
* All values are in ppt

Permeate results BDL (below detection)

PFAS Hybrid Systems
ADVANTAGES OF COMBINING MEMBRANES WITH ADSORPTION

- Membranes: less sensitive to chain length due to low molecular weight cut-off. Maximizes removal of short chain PFAS.
- Membranes: superior removal/rejection of PFAS (>99%) plus a “barrier” between the feed stream and the treated water - important for drinking water.
- Membranes: PFAS removal independent of the presence of competing contaminants, feed variability, or high TDS.
- “future proofing” of plant for other contaminants or changing PFAS regulations
- 3-4 times more PFAS removal per lb of media by pre-concentration with membranes than treating with IX/GAC alone, significantly reducing cost and footprint

PFAS Treatment Technology Landscape

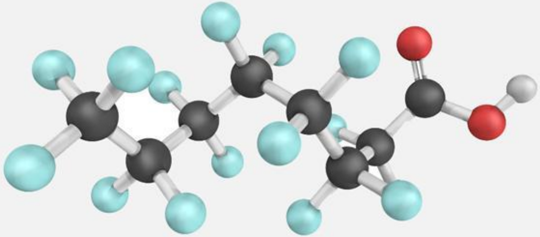


Note: *Advanced oxidation processes/Advanced reduction processes
Source: Dr. Tanju Karanfil, Clemson University, Evoqua, Calgon Carbon, Bluefield Research

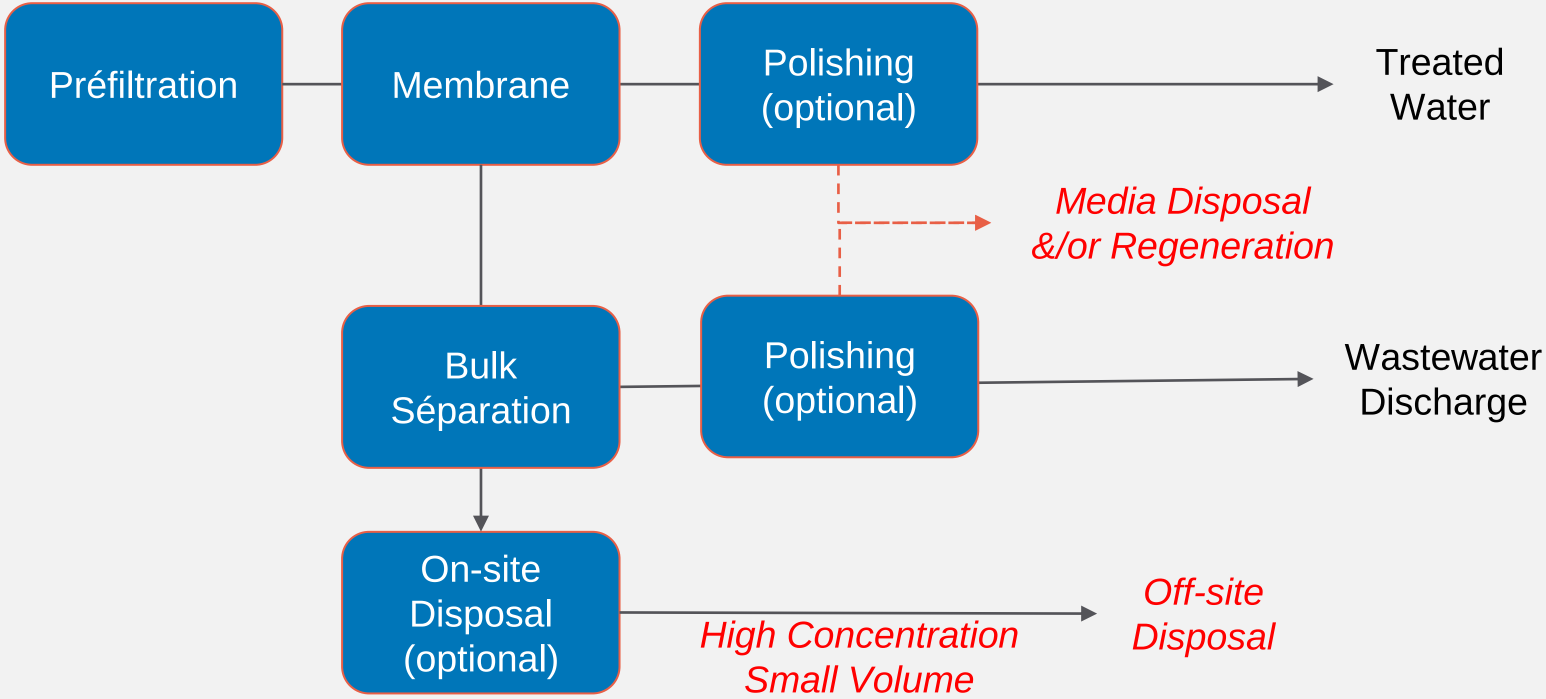
Solutions & Experience
VEOLIA'S EPA APPROVED FACILITY IN PORT ARTHUR, TX

PFAS contaminants, which have been isolated and removed, can ultimately be handled through disposal at specialized waste management facilities.

These solutions are just beginning to be available at various locations in the U.S., and technology is rapidly advancing.

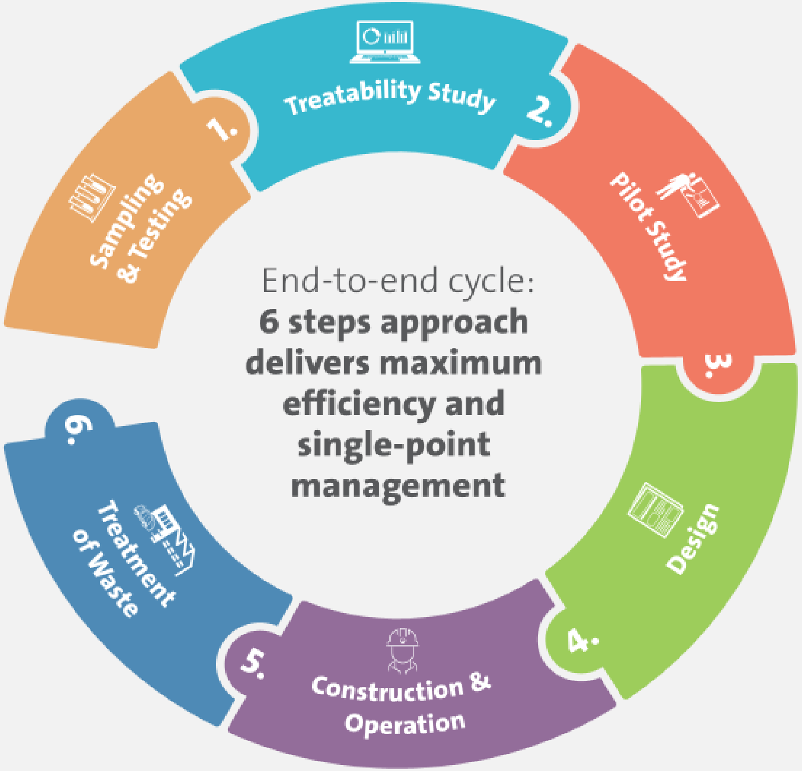


Solutions & Experience
FLOWSHEET OPTIONS



Solutions & Experience

PFAS – SIX STEPS OF THE END-TO-END TREATMENT SOLUTION



Conclusion
FOUR KEY TAKEAWAYS

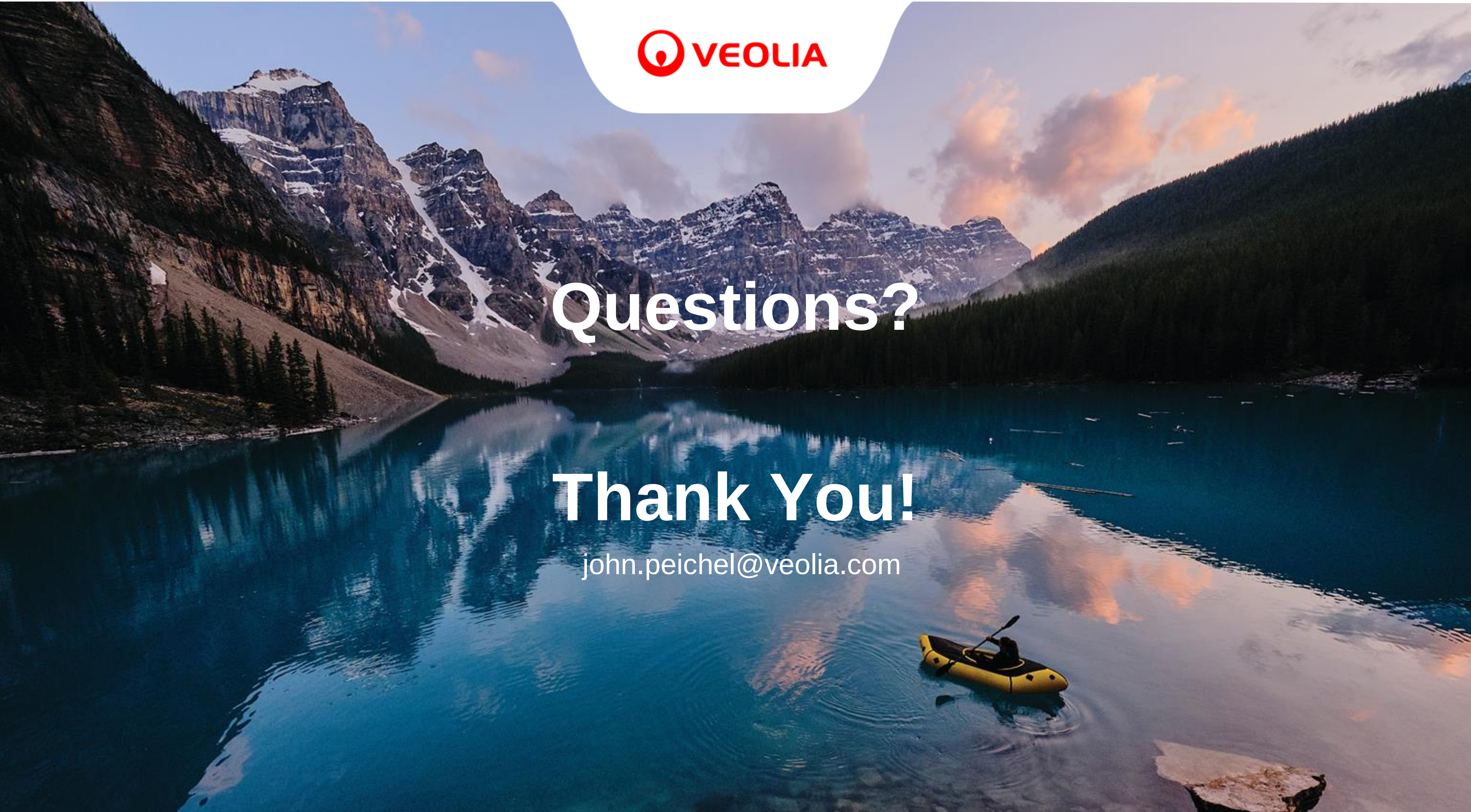
PFAS environment continues to evolve rapidly
Expect drinking water regulations to drive wastewater discharge requirements. Proactively consider current waste treatment, its impact on PFAS and plan for future requirements.

PFAS Regulation varies by States
A plant's drinking water and wastewater may not require PFAS treatment today. Future EPA drinking water MCLs and wastewater permit requirements are expected.

Evaluation of Risk
A facilities PFAS risk in source water can be evaluated prior to testing by researching your water source and neighboring activities (industry, landfills, chemical processing, airports, military, fire events, etc.)

GAC, IX and RO are effective in treating PFAS
Existing operations should identify and plan for future needs in terms of treatment, GAC/IX media replacement, PFAS accumulation/breakthrough, vessel design, RO concentrate PFAS levels, etc.

Know your **risks** - Collect **data** - Understand **alternatives** - Be **prepared** - Be **proactive**



Questions?

Thank You!

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