

Starting Soon

Sorption-based Technologies for Separation and Concentration of PFAS from Water

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<https://www.clu-in.org/conf/itrc/PFAS-sorption-techs/>

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Sorption-based Technologies for Separation and Concentration of PFAS from Water

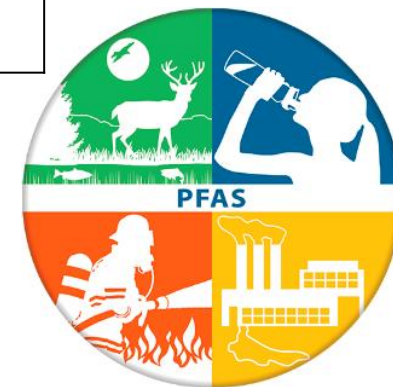


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Sorption-Based Technologies for Separation and Concentration of PFAS from Water

Section Number	Topic
18.1	<u>Introduction</u>
18.2	<u>Treatment Objectives and Considerations</u>
18.3	<u>Fixed-Bed Adsorbers</u>
18.4	<u>Foam Fractionation</u>
18.5	<u>Resources for Decision-Making</u>
18.6	<u>Barriers, Challenges, and Outlook</u>



ITRC PFAS Technical and Regulatory Guidance: <https://pfas-1.itrcweb.org/>

Training Purpose and Scope

“With so many sorption-based treatment systems to pick from, how do I pick the best one for my PFAS problem?”

Technologies Covered

- Fixed-Bed Adsorbers (18.3)
 - Granular Activated Carbon
 - Ion Exchange Resin
- Foam Fractionation (18.4)

Applications Considered

- Ex-situ treatment
- Water
 - Drinking water
 - Wastewater
 - Groundwater remediation
- Etc.

Learning Objectives

Review operating principles of sorption-based technologies

Understand how site conditions and treatment objectives influence technology selection

Become familiar with testing methods used to verify treatment effectiveness, optimize performance, and compare technologies

Identify water quality parameters that may adversely affect sorption-based technologies and the available pretreatment methods to address them

Learn how test data can be combined with cost and sustainability information to select a specific technology or system configuration

Treatment Objectives, Site-specific



- PFAS treatment is needed.
What's next?
 - Determine treatment objectives
 - Evaluate pretreatment needs
 - Identify pretreatment options
 - Consider site-specific factors

Two Critical Items to Acknowledge

Source reduction or elimination often more cost effective than PFAS treatment.



The objective of sorption-based PFAS treatment is to remove PFAS from the water or liquid waste stream such that the treated water is made suitable for some consumptive use or discharge.



Questions to Ask:

Why am I treating PFAS?

What are my treatment objectives?

Which PFAS am I treating?

What else am I treating?

Will anything interfere with the PFAS treatment method(s)?

Do I need pretreatment?

Where am I treating?

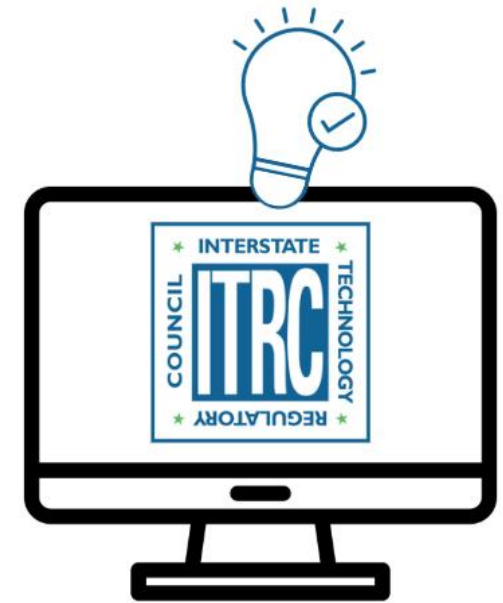
How much space do I have?

Knowledge Check

Check
In!

True or False?

Source reduction or elimination are often more cost effective than treatment.




Consumptive Use Objectives

Treatment objectives

- Public health concerns for drinking water suppliers
- Resident and worker health concerns for private potable wells

Target concentration basis

- Primary standards
- Interim values
- Advisory levels
- Treatment technique
- Go beyond minimum regulatory requirements



Why am I treating PFAS?

What are my treatment objectives?

Which PFAS am I treating?


Discharge Objectives

Treatment objectives

- Reduce concentration and/or mass loading
- Restore and maintain integrity of receiving waters

Target concentration basis

- Achieving a certain water quality
- Applied treatment technology capability
- Publicly owned treatment works (POTW) criteria
- Industry specific guidelines
- Highest attainable conditions under standard variances
- Corporate or governmental stewardship program goals

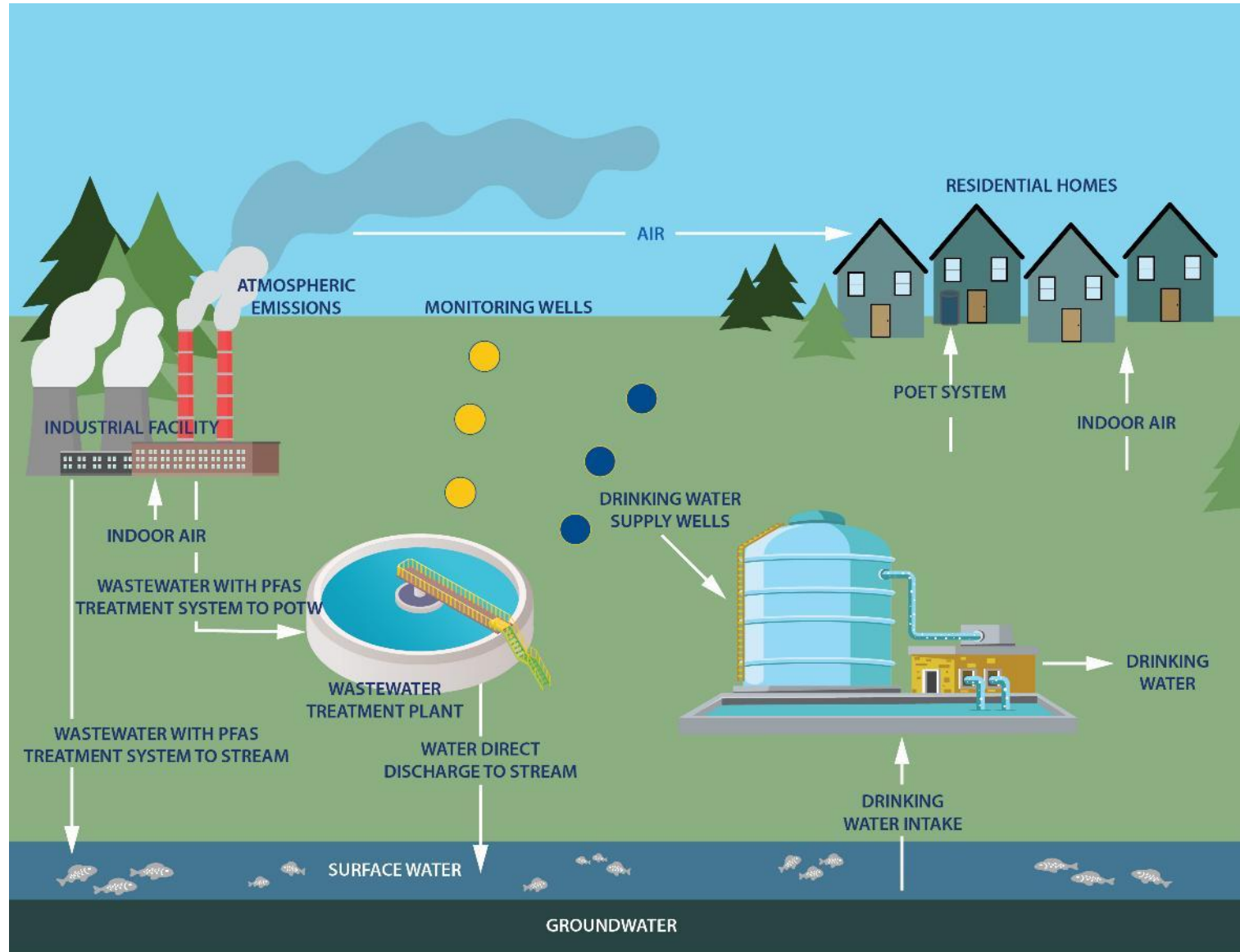


Why am I treating PFAS?

What are my treatment objectives?

Which PFAS am I treating?

Where You Need to Meet the Treatment Objective



Where am I treating?

Figure Source: V. Passaro, GES. Used with permission.

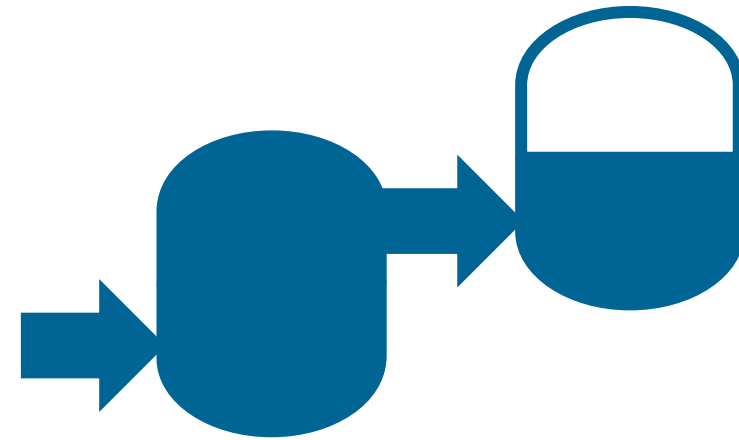
Additional Objective Information

Frequency

- Daily, weekly, monthly, quarterly monitoring
- Concentration basis (e.g., average, monthly maximum)

Other

- Empty bed contact time (EBCT)
- Hydraulic residence time (HRT)
- Redundancy
- Future regulatory changes



Questions to Ask:

Will anything interfere with the PFAS treatment method(s)?

Do I need pretreatment?

What else am I treating?

Overview of Co-Occurring Constituents

Co-occurring Constituent	GAC	IX Resin	Foam Fractionation
Suspended solids	X	X	X
TOC, TDS, DOC	X	X	
Fe, Mn	X	X	X (if oxidized)
VOCs	X		X
Fats, oils, greases	X	X	X
Bacteria/algae	X	X	
Disinfectants/oxidants	X	X	
Major anions (nitrate, sulfate, chloride, phosphate)		X	
Alkalinity and pH	X	X	
Hardness	X	X	X
Total and dissolved silica	X	X	X

Pretreatment Methods

Pretreatment Methods Considered in Guidance Document

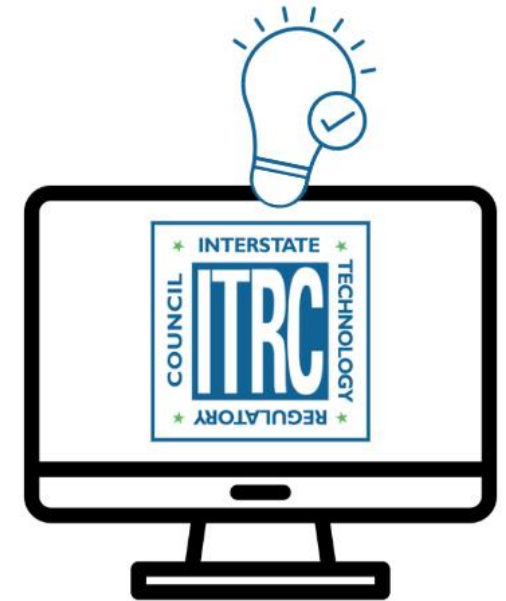
Suspended solids removal (e.g., bag/cartridge filters, sand filters)	Oil/water separation (e.g., oil/water separators, organoclay)	Settling/clarification tank (with or without coagulant or polymer addition)
Air stripping	Membrane processes (e.g., nanofiltration)	GAC (sacrificial)
Iron and manganese removal (e.g., greensand, aeration, oxidation)	Chemical addition (anti-scaling agents, pH control, sodium bisulfate)	Disinfection (e.g., UV, chlorine, ozone, biocides)
Ion exchange (e.g., water softening, demineralization, organic scavenger resins)		

Knowledge Check

Check
In!

True or False?


Regulated values are the only concentrations considered when determining treatment objectives.



Questions to Ask:



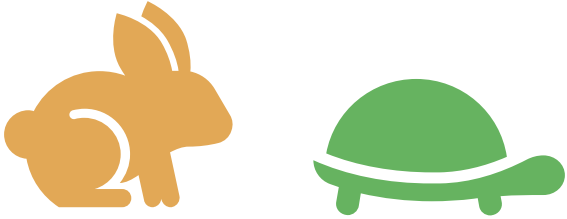
Do I need pretreatment?



How much space do I have?

System Size

- Rate of flow



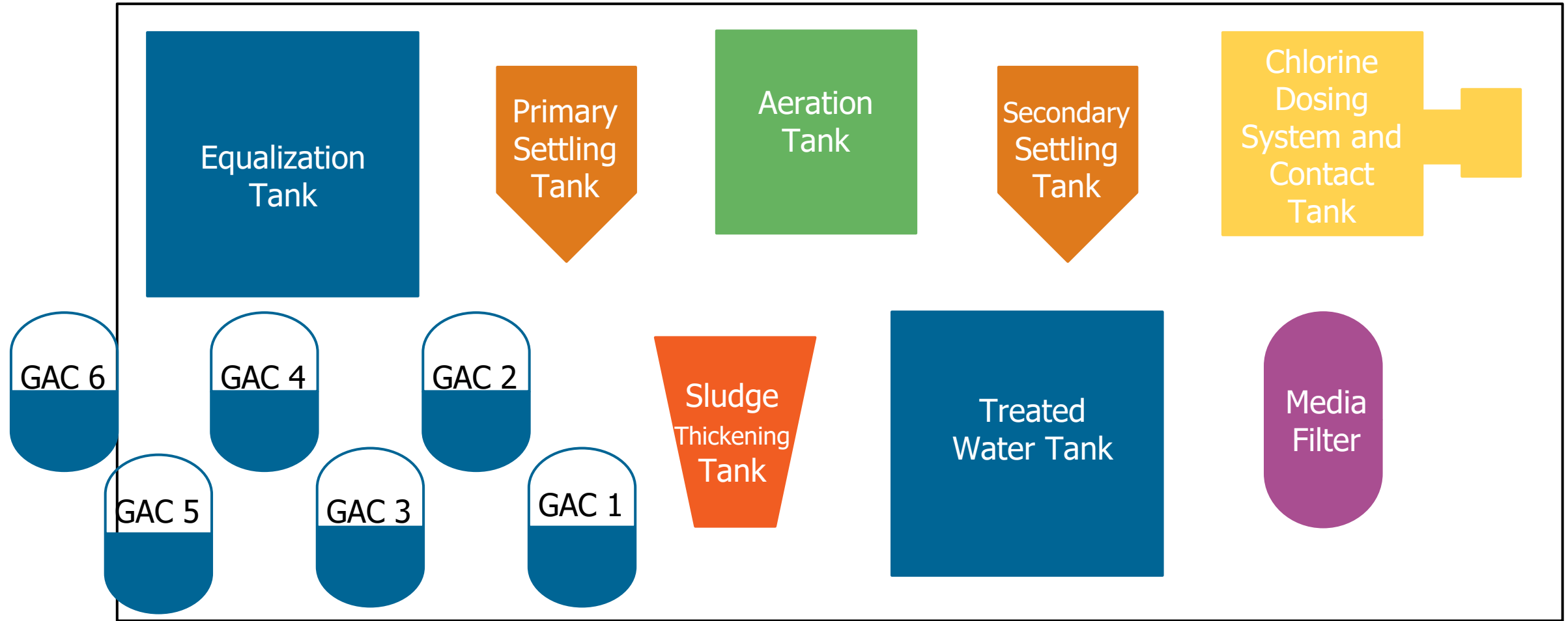
- Variability of flow



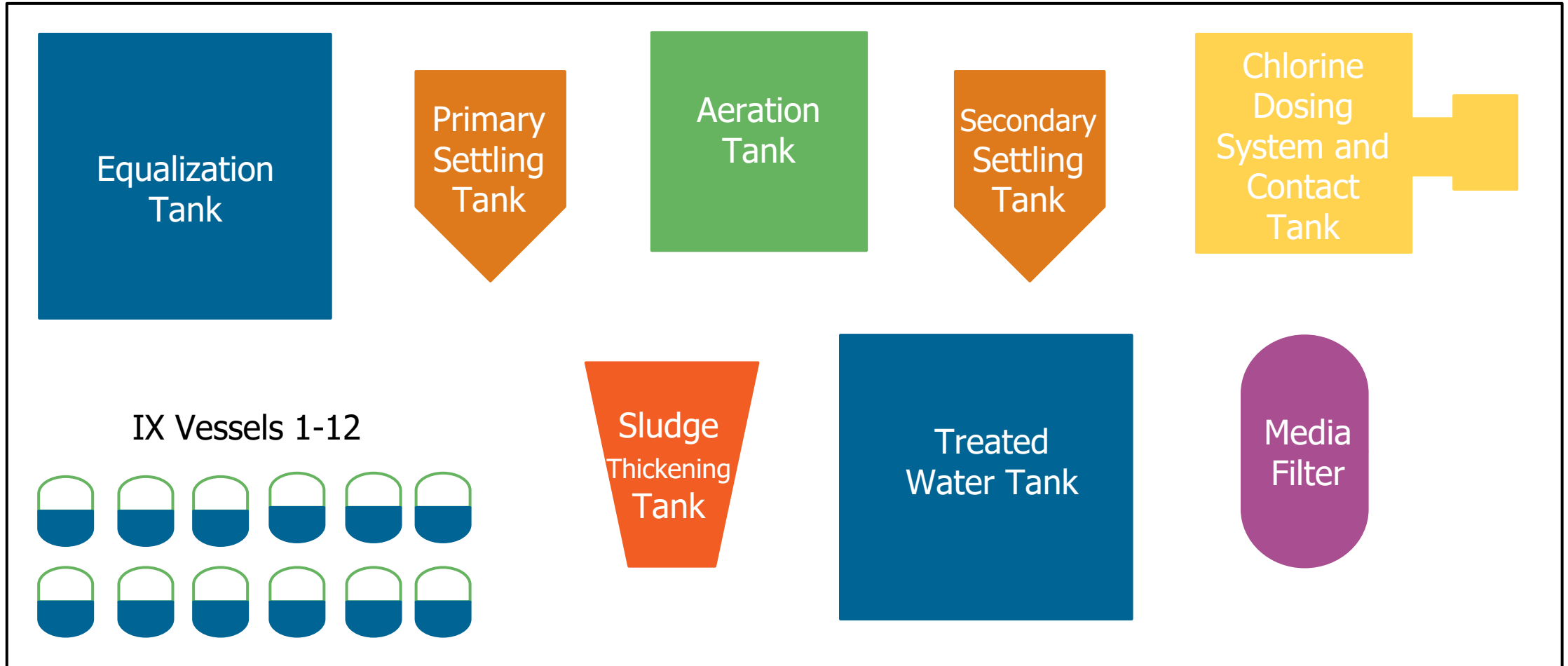
- Expandability of sorption treatment



System Size & Hypothetical Wastewater Treatment Plant



System Size & Hypothetical Wastewater Treatment Plant



PFAS-1 Section 18.2.5

- Additional Site-Specific and Operational Considerations
 - Installation at sites or facilities with existing treatment
 - Treatment space considerations
 - Site location utilities
 - Separated PFAS destruction and disposal
 - Community concerns
 - Operations oversight
 - Sample collection and analytical support
 - Sustainability
 - Centralized vs. distributed treatment

Questions We Asked and Answered:

Why am I treating PFAS?

What are my treatment objectives?

Which PFAS am I treating?

What else am I treating?

Will anything interfere with the PFAS treatment method(s)?

Do I need pretreatment?

Where am I treating?

How much space do I have?

Questions We Asked and Answered:



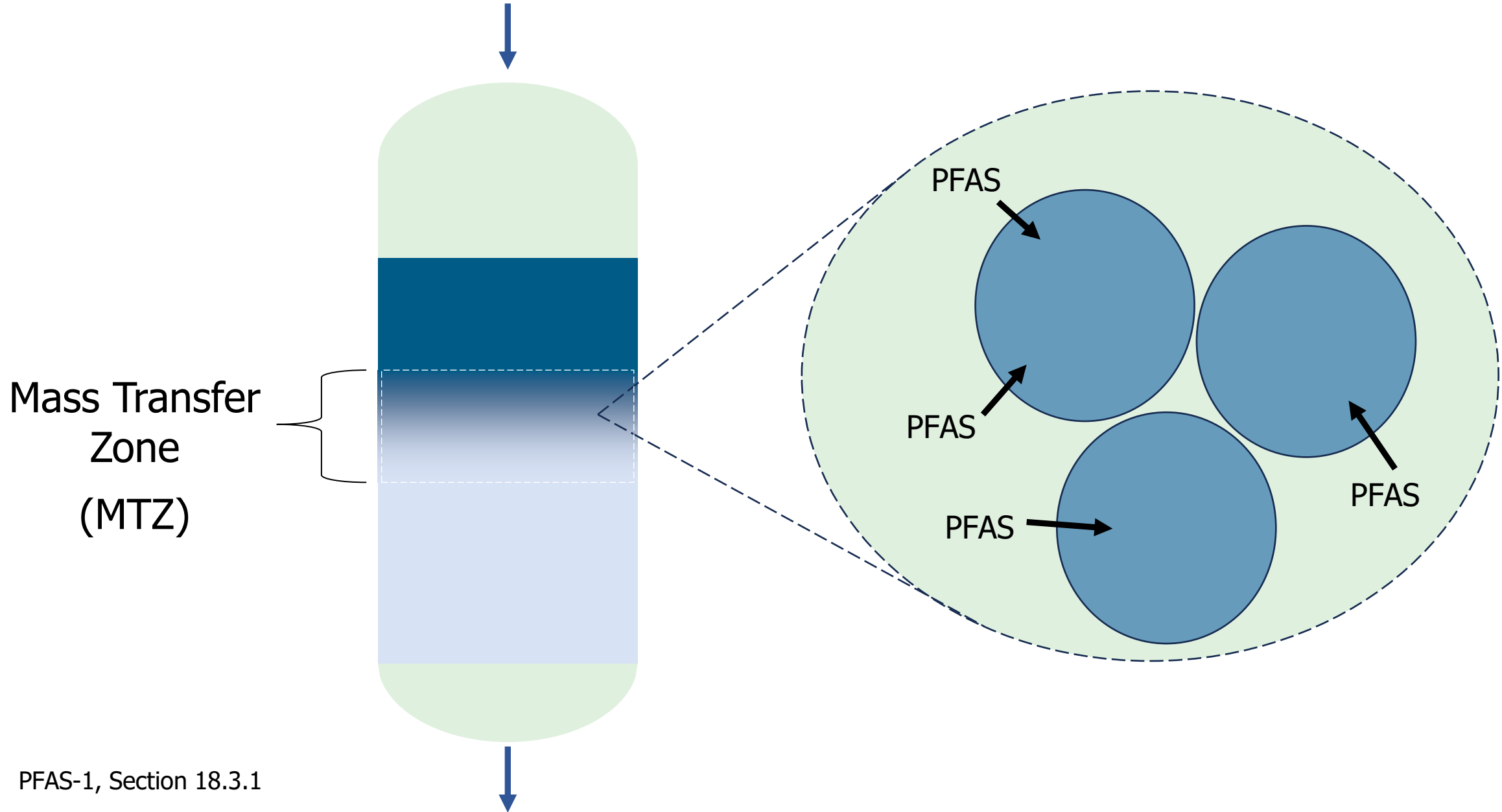
Fixed-Bed Adsorbers

Technical Overview

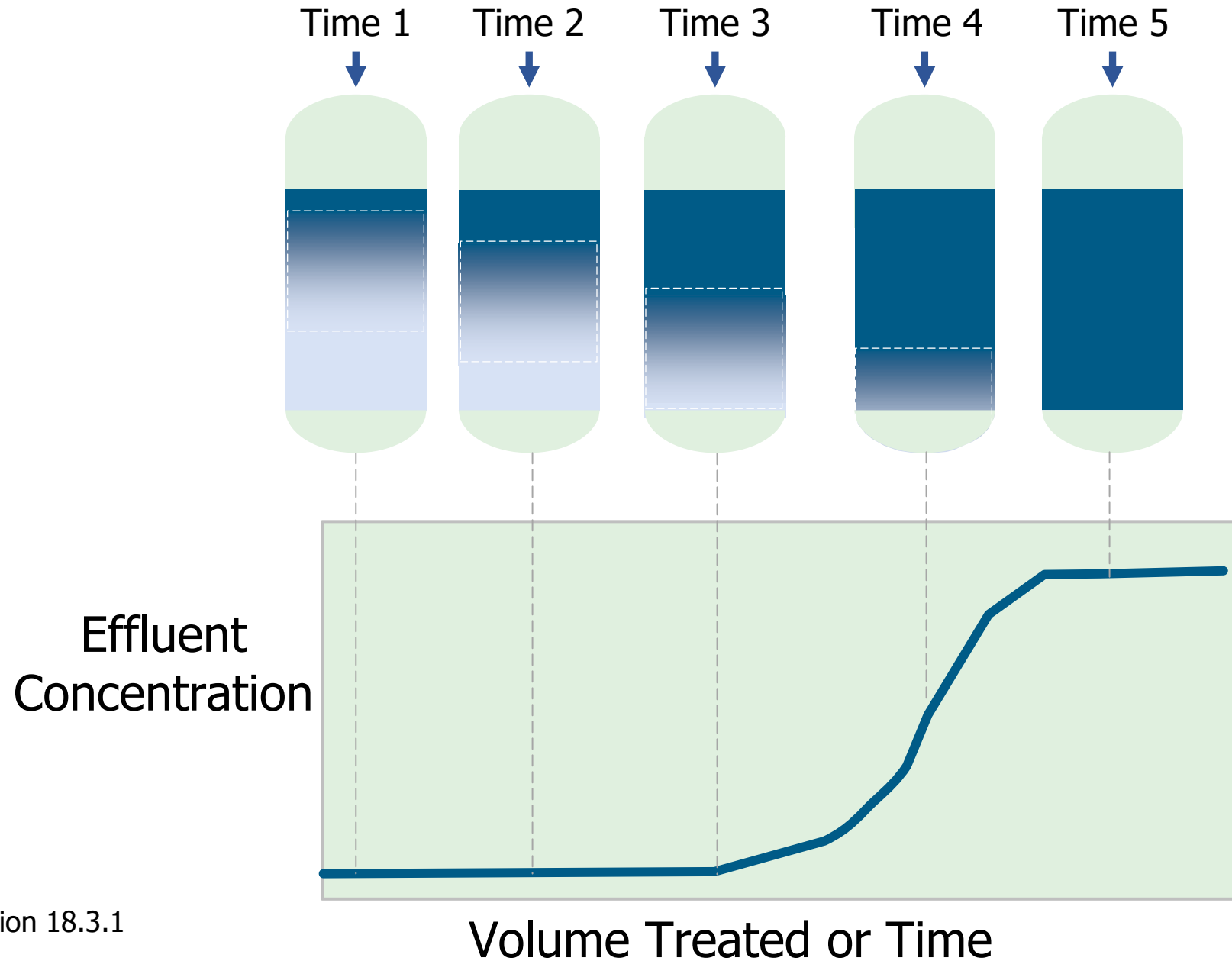
**Performance
Evaluation**

Fate of Spent Media

Fixed-Bed Concept

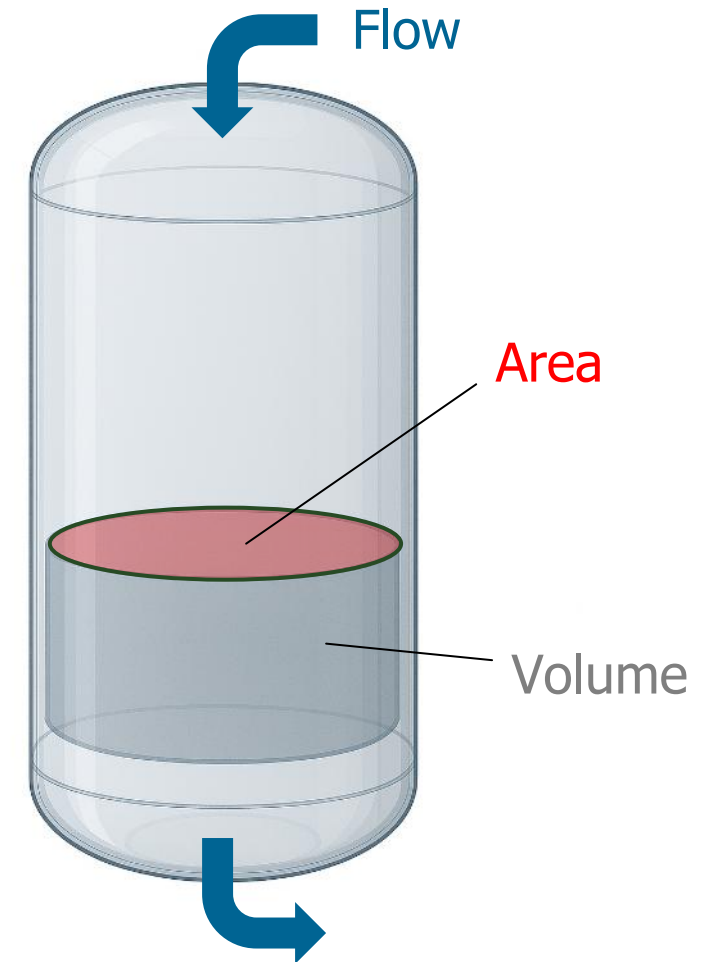


Progression of MTZ and Breakthrough



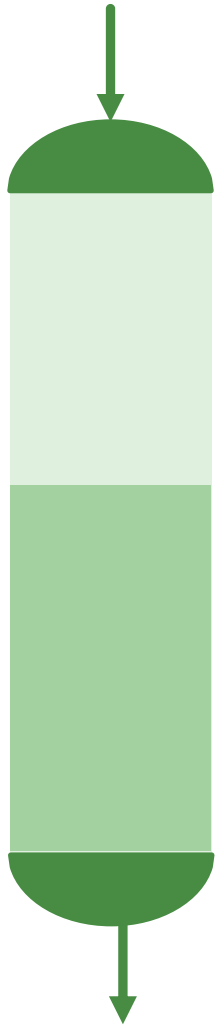
Fixed Bed Parameters

- **Empty Bed Contact Time (EBCT):** Time (min) for the flow rate to fill up the volume of the bed – without the media being present.
- **Hydraulic Loading Rate (HLR):** Flow rate per cross sectional area of the bed (gpm/ft² or m/hr)
- Maintaining design HLR is important
 - Flow too low: Channeling and early leakage
 - Flow too high: Backpressure and media fracture



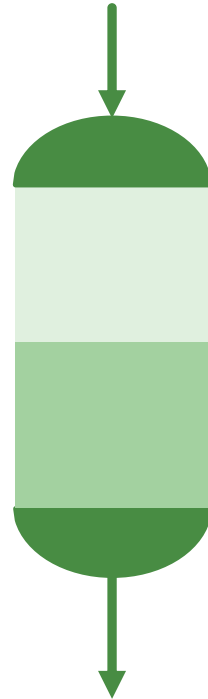
Source: Calgon Carbon Corporation. Used with Permission.

Fixed Bed Parameters



Granular Activated Carbon

- EBCT: 10 to 20 minutes per vessel
- HLR: 2 to 10 gpm/ft² (5 to 25 m/h)

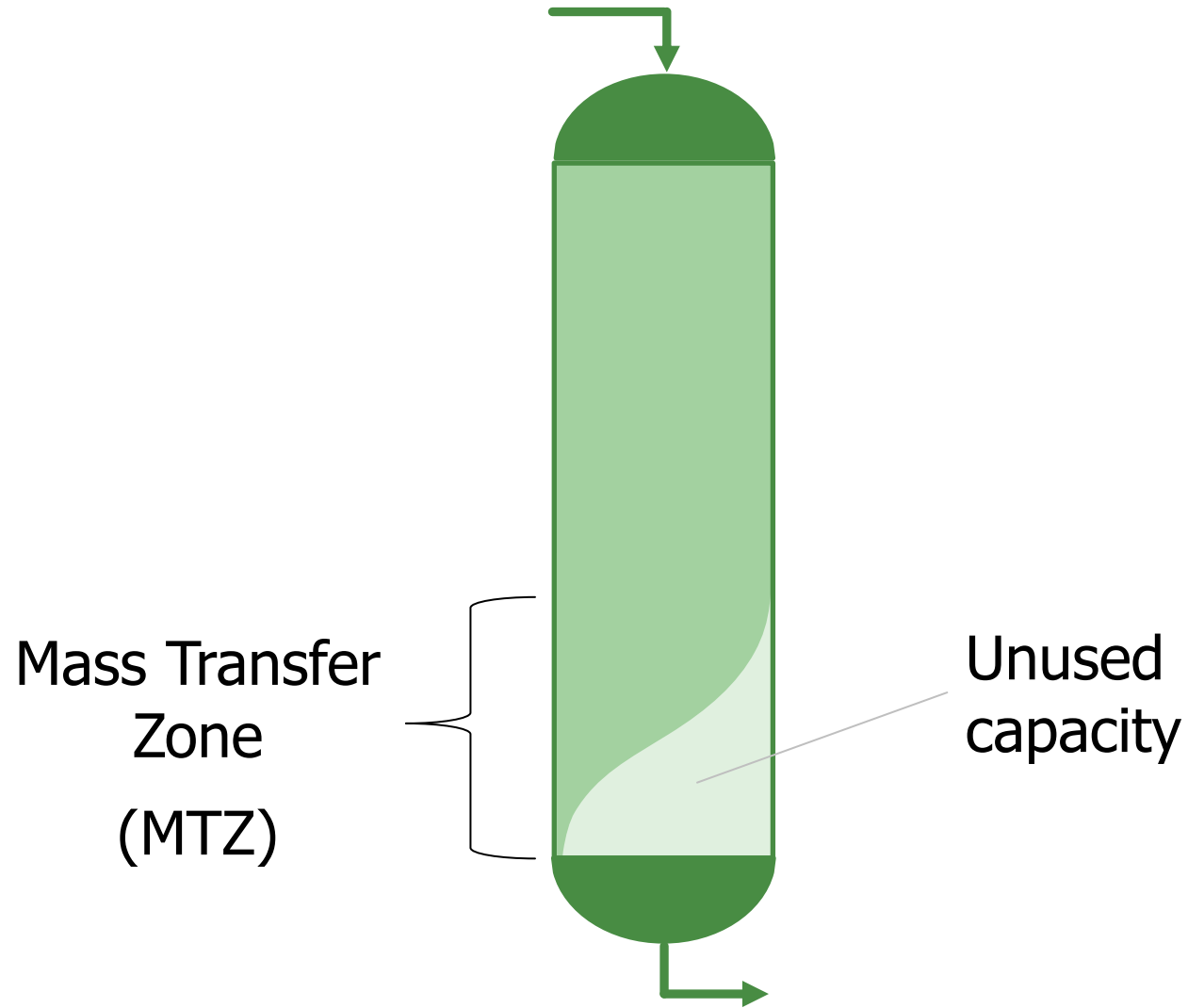


Ion Exchange

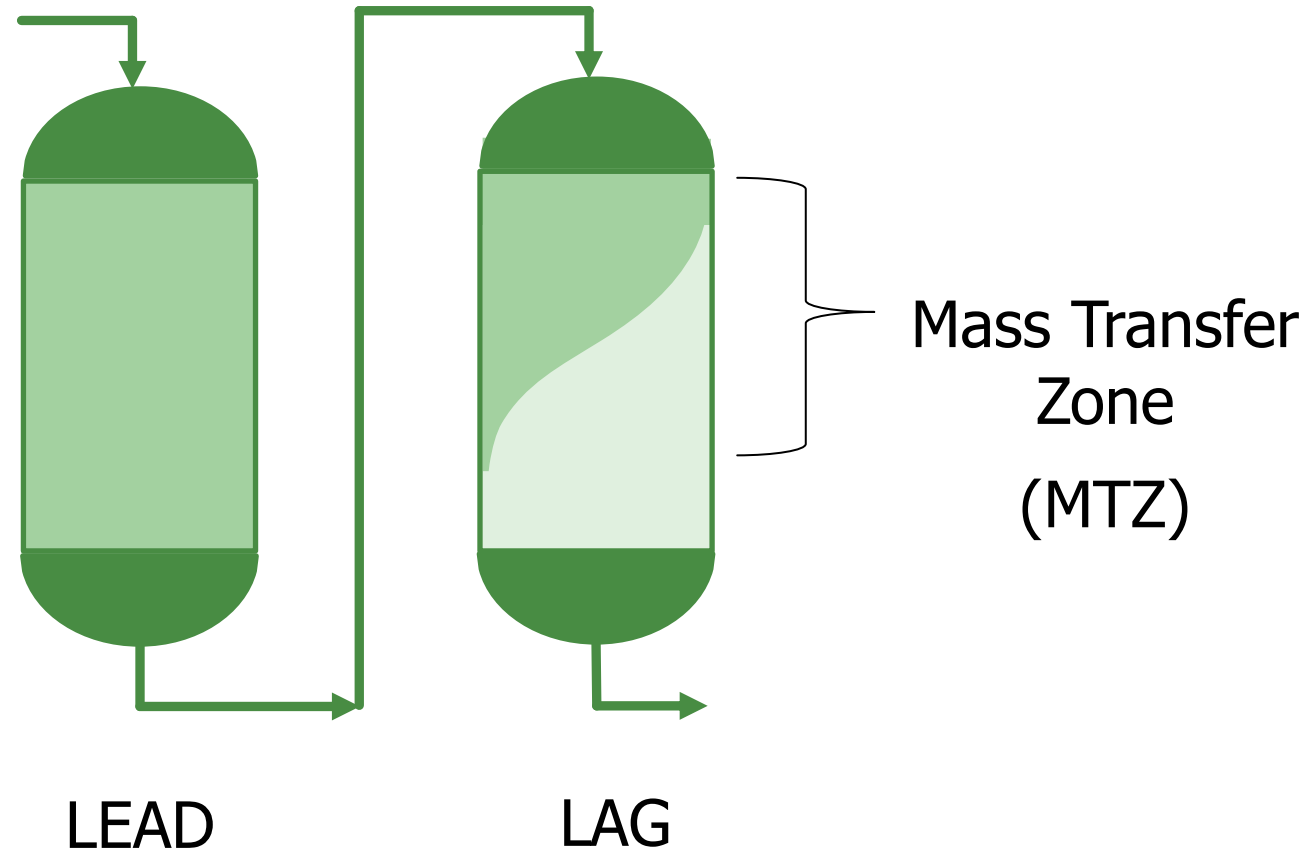
- EBCT: 1.5 to 3 minutes per vessel
- HLR: 6 to 18 gpm/ft² (15 to 45 m/h)

(These are typical ranges. Deviations may exist based on test results or vendor recommendations for specific applications.)

System Configurations – Single Column is Less Efficient

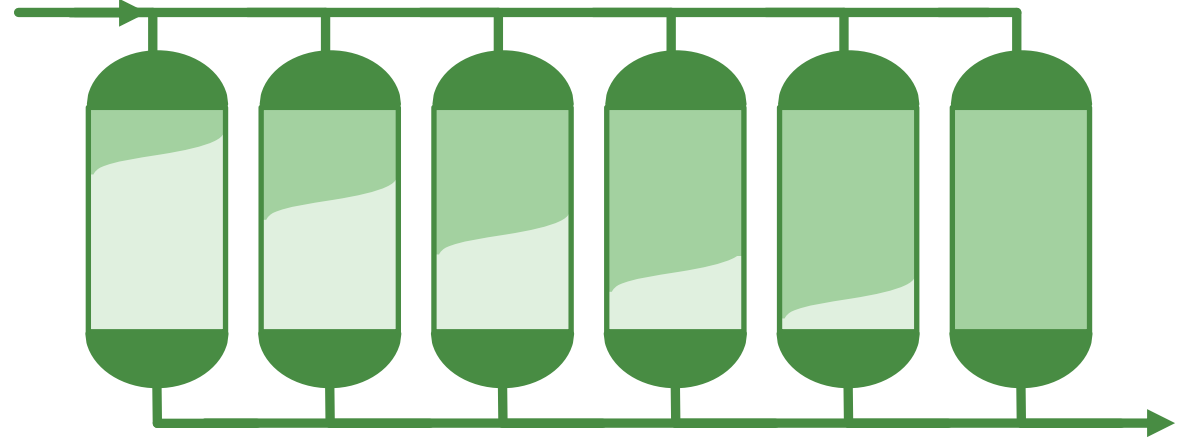
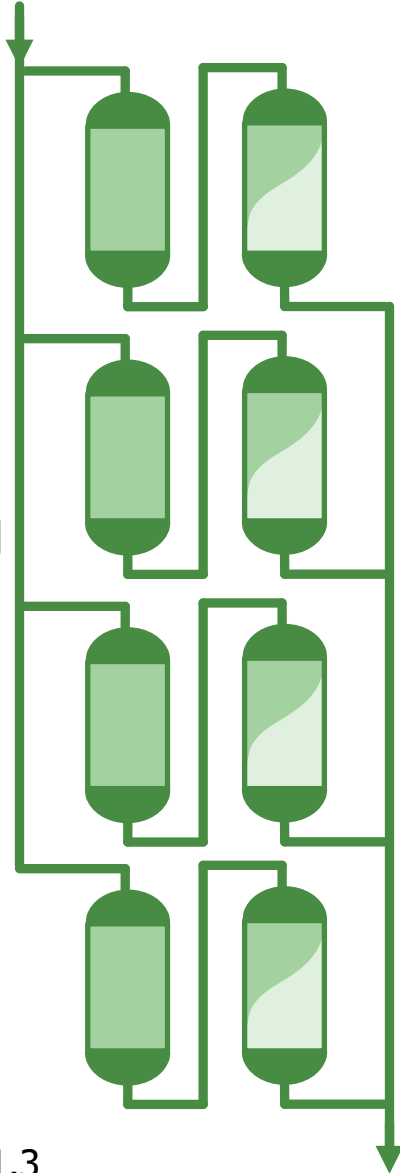


System Configurations – Lead / Lag Columns



System Configurations – Parallel Columns

Multiple Lead/Lag Trains



Staggered Changeouts

Water Quality Impacts and Pretreatment Needs

Water Quality	Issue	Pretreatment Examples
Total Suspended Solids (TSS)	Physical fouling	5- or 10-micron filters
Iron and Manganese	Physical fouling	Aeration, oxidants*, greensand*
Oxidants	Resin damage	Sodium bisulfite, GAC
Organic Carbon	Fouling, Competition	IX resins, coagulation, BAC

* Uses oxidants or other chemicals that damage or reduce effectiveness of IX resins.

BAC: Biological Activated Carbon

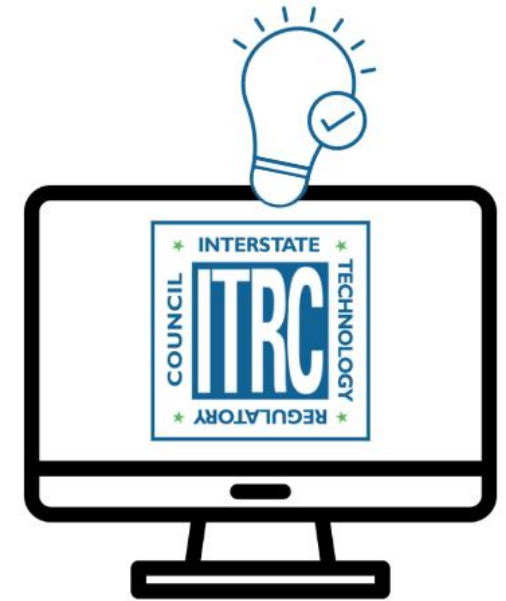
Refer to Tables 18-1 and 18-2 in Section 18.2.3 of PFAS-1 for more extensive pretreatment information.

Knowledge Poll

Check
In!

Which type of GAC generally has a higher adsorption capacity for PFAS?

- a) Bituminous
- b) Coconut
- c) Doesn't matter. All carbons are about the same.



GAC Information

■ Types

- Coconut and Wood
- Coal
 - Bituminous (reagglomerated, generally outperforms the others for PFAS removal)
 - Sub-bituminous
 - Lignite

■ Pore sizes: range from <2 to 50 nm

■ Particle size

- 12x40 (diam. 1.04 mm) – common mesh fraction for PFAS removal
- 8x30 (diam. 1.48 mm) – organic carbon removal and other applications



Source: Calgon Carbon Corporation. Used with Permission.

■ Relative PFAS affinity

- Increases with PFAS chain length
- Sulfonic acids generally higher than carboxylic acids

IX Information

- **Types**

- Anion vs cation specific
- Weak vs strong
- Gel-type vs macroporous (macroporous more rugged, can withstand Cl_2)
- Backbone material / crosslinker
- Functional groups

- **For PFAS:** usually Cl^- form, strong-base anion exchange resin, polystyrene/divinylbenzene backbones (similar to resins for perchlorate or nitrate removal)

- **Pore sizes:** range from 1-2 nm (gel) to >20 nm (macroporous)

- **Particle size:** 0.3 – 1.2 mm



- **Relative PFAS affinity**

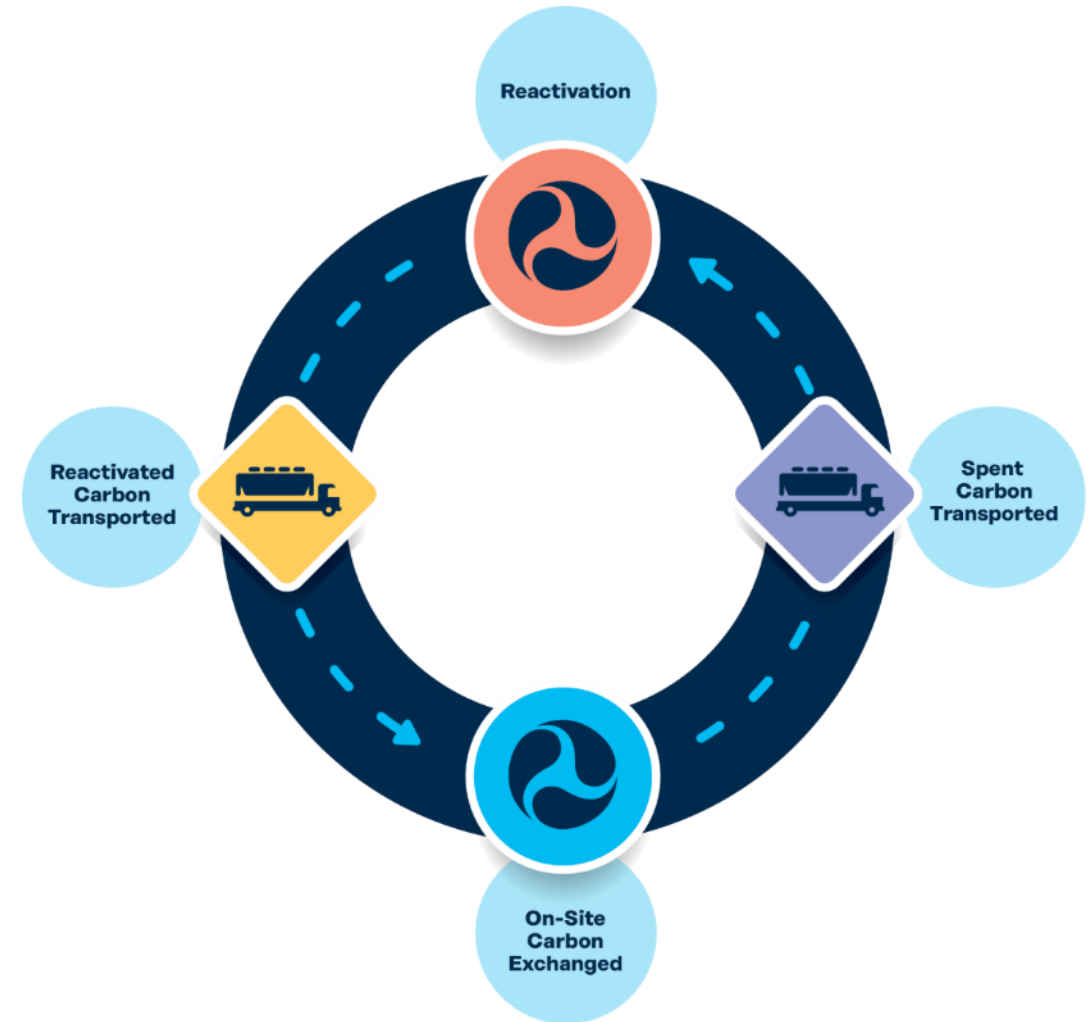
- Increases with PFAS chain length
- Sulfonic acids **much** higher than carboxylic acids

GAC vs IX

	GAC	IX
Can Achieve Goals	Yes	Yes
Footprint (amount of media)	Larger	Smaller
Pretreatment Needed	Typically	Typically
Oxidant Sensitivity	None	Gel-type is sensitive
Backwashing	Yes	No
Compounds Removed	All organics	Only ionic species
Relative PFAS Affinity	Long chain > short chain PFSA's > PFCAs	Long chain > short chain PFSA's >> PFCAs
Reactivation / Regeneration	Reactivation	Specialty IX regenerable

GAC Reactivation

- Thermal process, returns carbon to near virgin state
- Peer reviewed studies confirm >99.9% destruction of targeted PFAS
- Up to 80% reduction in global warming potential vs virgin activated carbon
- 15% - 30% virgin makeup due to losses
- Commercially available for many years (~17 facilities in US)
- Dedicated vs pool reactivation (pool reactivation not for potable use)



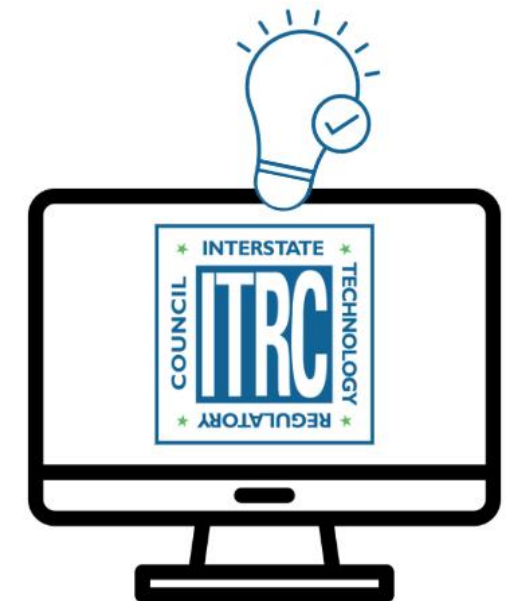
Source: Calgon Carbon Corporation. Used with Permission.

Knowledge Check

Check
In!

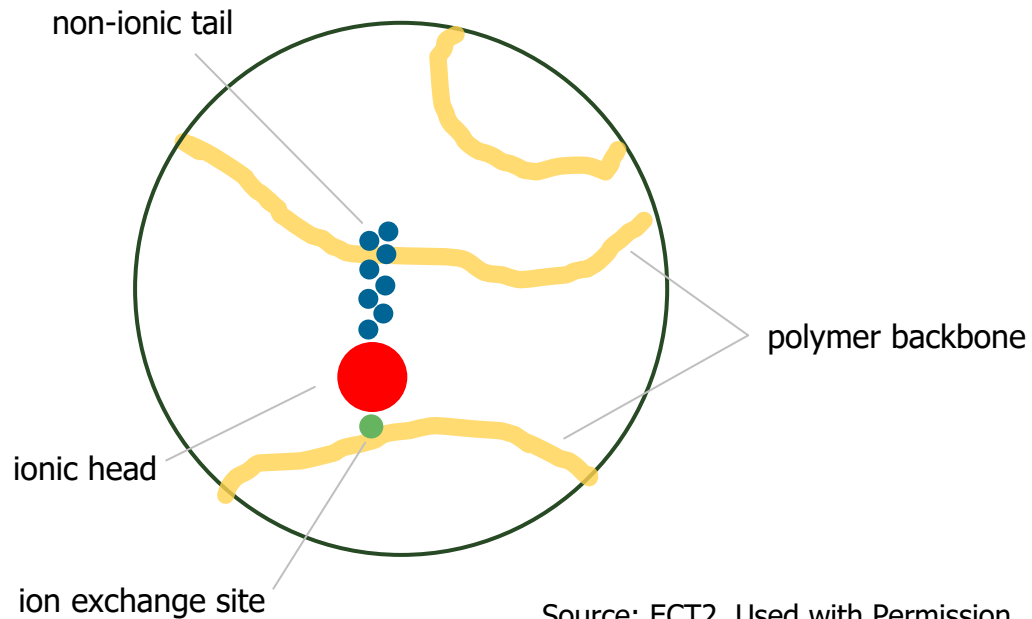
True or False?

Exhausted PFAS-selective anion exchange resin can be regenerated with brine, just like with nitrate treatment.



IX Regeneration

- Regenerant: mixture of water, alcohol, and salt to disrupt both the hydrophobic affinity and anionic attraction of the PFAS to the resin
- Commercially implemented since 2018



Source: ECT2. Used with Permission.



PFAS-1. Figure 15-14. Resin regeneration system.
Source: Steve Woodard, ECT2, and Nathan Hagelin, Wood Group, PLC (WSP). Used with permission

IX Regeneration

- Following regeneration, the resin is rinsed with water to remove residual regenerant
- The spent regenerant is often distilled to recover the alcohol for future regeneration cycles
- Resulting concentrate is called "still bottoms" and is highly concentrated in PFAS (e.g., >100 mg/L)
- No states currently approve solvent-regenerated IX resin for drinking water

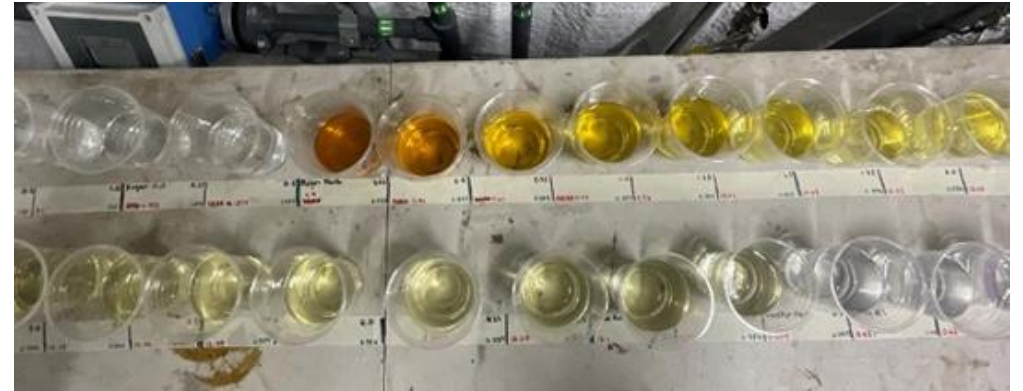


Image of spent regenerant solutions and rinse water incrementally produced during an IX regeneration process
Source: ECT2. Used with Permission.

Fixed-Bed Adsorbers

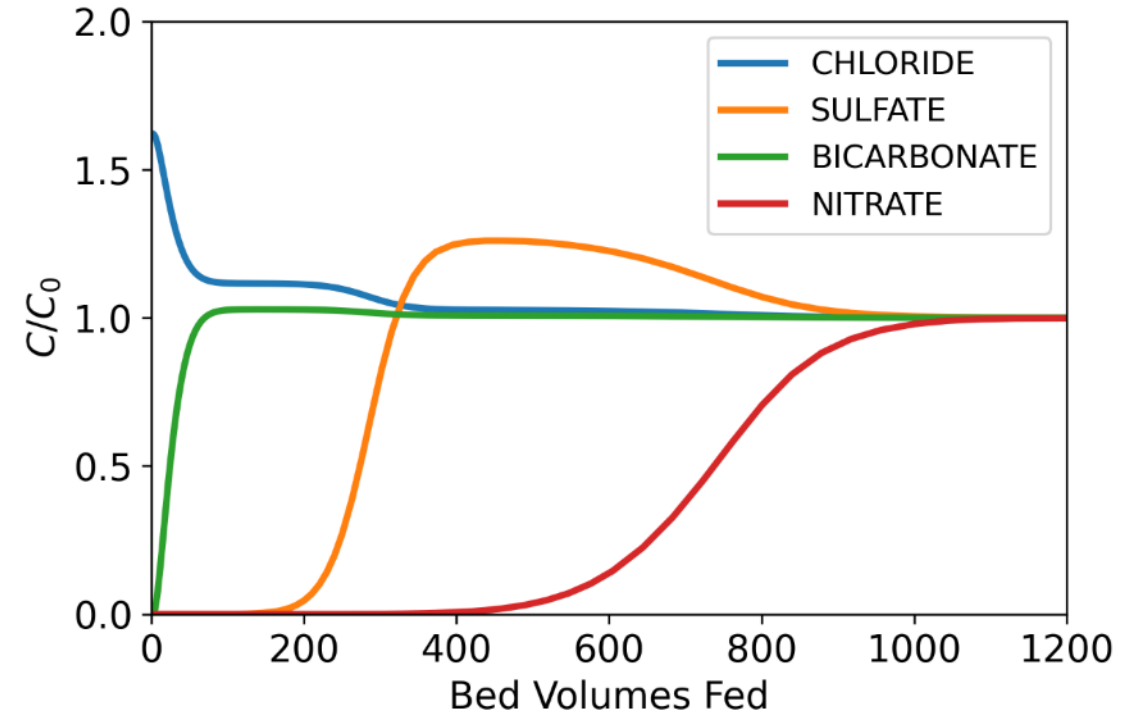
Technical Overview

Performance
Evaluation

Fate of Spent Media

Fixed-Bed Performance Modeling

- Various mechanistic and empirical models exist
- Several vendors and consultants have proprietary models
- US EPA offers free and open-source models for GAC and IX
- Parameters for detailed models are scarce
- Pure prediction (without calibration) typically not reliable
- Can be used to help design pilot systems and interpret results



PFAS-1. Figure 18-3. Example IX output of USEPA's IX model.

[https://github.com/USEPA/Water Treatment Models](https://github.com/USEPA/Water_Treatment_Models)

<https://github.com/USEPA/AdDesignS>

Summary of Performance Test Options

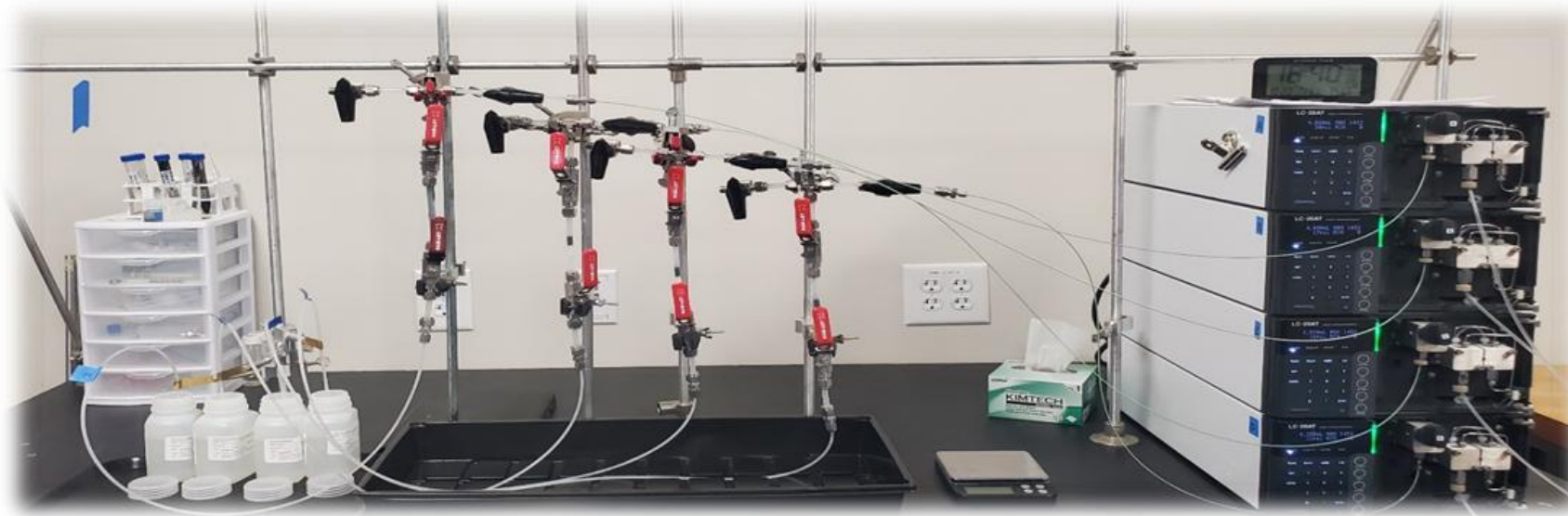
Test Type	Time	Cost	Ability to Compare Media?	Prediction of Full-Scale
Isotherm	Shortest	Least	Yes	Poor
Rapid Small-Scale Column Test	Moderate – Low	Moderate – Low	Yes	Moderate
Pilot	Moderate – High	Moderate – High	Yes	High
Full-Scale Demonstration	Longest	Highest	No	Best

Isotherm



- Sorbents added to bottles of contaminated water
- Sorption of contaminants measured
- Some methods:
 - Spike contaminant concentrations
 - Run multiple sorbent doses
- Useful for:
 - Evaluating if a contaminant is strongly or weakly adsorbed
 - Crude comparison of different sorbents
 - Informing modeling or piloting efforts

Rapid Small-scale Column Testing (RSSCT)



- Uses reduced size media for rapid tests
- Done primarily with GAC
- Uses site-specific water
- Prediction of full-scale performance is a topic of ongoing research
- Useful for:
 - Determining if sorbents will work
 - Comparing different sorbents
 - Comparing pretreatment options
 - Designing pilot studies

Pilot Tests

- On-site test at a low flow rate
- Most accurate prediction of media lifetimes
- Accounts for fluctuating influent conditions
- Can be used to evaluate pretreatment needs
- Sometimes incorporates multi-media
- Use full-scale parameters (e.g., HLR and/or EBCT) to size pilot columns



Source: U.S. EPA

Fixed-Bed Adsorbers




Technical Overview

Performance
Evaluation

Fate of Spent Media

Fate of Spent IX and GAC Media

Commercially-Available Options

	Landfill 	High Temperature Incineration 	Reactivation (recycling) 
IX	X	X	
GAC	X	X	X

Developing options

- PFAS destruction processes (e.g, SCWO, piezoelectric ball milling)

IX Regenerant Still Bottoms: Fate of Residuals

- Current commercial systems typically load the still bottoms over many regeneration cycles onto adsorptive media in a process called Superloading
 - Increases the overall waste reduction of the system
 - Converts the waste to a solid
 - Treated still bottoms can be fed back to system influent
- PFAS in still bottoms can also be destroyed using a variety of PFAS destruction technologies
 - Still bottoms contain high concentrations of PFAS (\sim mg/L to g/L) and salt (2 to 5%)
 - Demonstrations of still bottoms treatment with hydrothermal alkaline treatment (HALT), plasma and electrochemical oxidation are published
 - Demonstrations of still bottoms treatment with HALT and SCWO are currently underway through Defense Innovation Unit funded projects

Questions



Foam Fractionation

Foam Fractionation seems appropriate for your site/application but there are so many options and so much variable terminology.

How do you understand which options are appropriate and select the best one?

Principles of Foam Fractionation and Operating Modes

Foaming Additives, Source Waters, and Pretreatment Considerations

Emissions Considerations and Air Testing Methodologies

Advantages & Disadvantages

Performance Evaluations

Foamate Management

Helpful Definitions

Foam Fractionation: any adsorptive bubble technique in which amphiphilic substances are adsorbed onto a gas-water interface for separation (with or without stable foam)

Bubble Fractionation: foam fractionation without stable foam where the upper aqueous layer or watery spillover is collected

Aerosol fractionation: bursting bubbles create aerosols containing PFAS that are collected

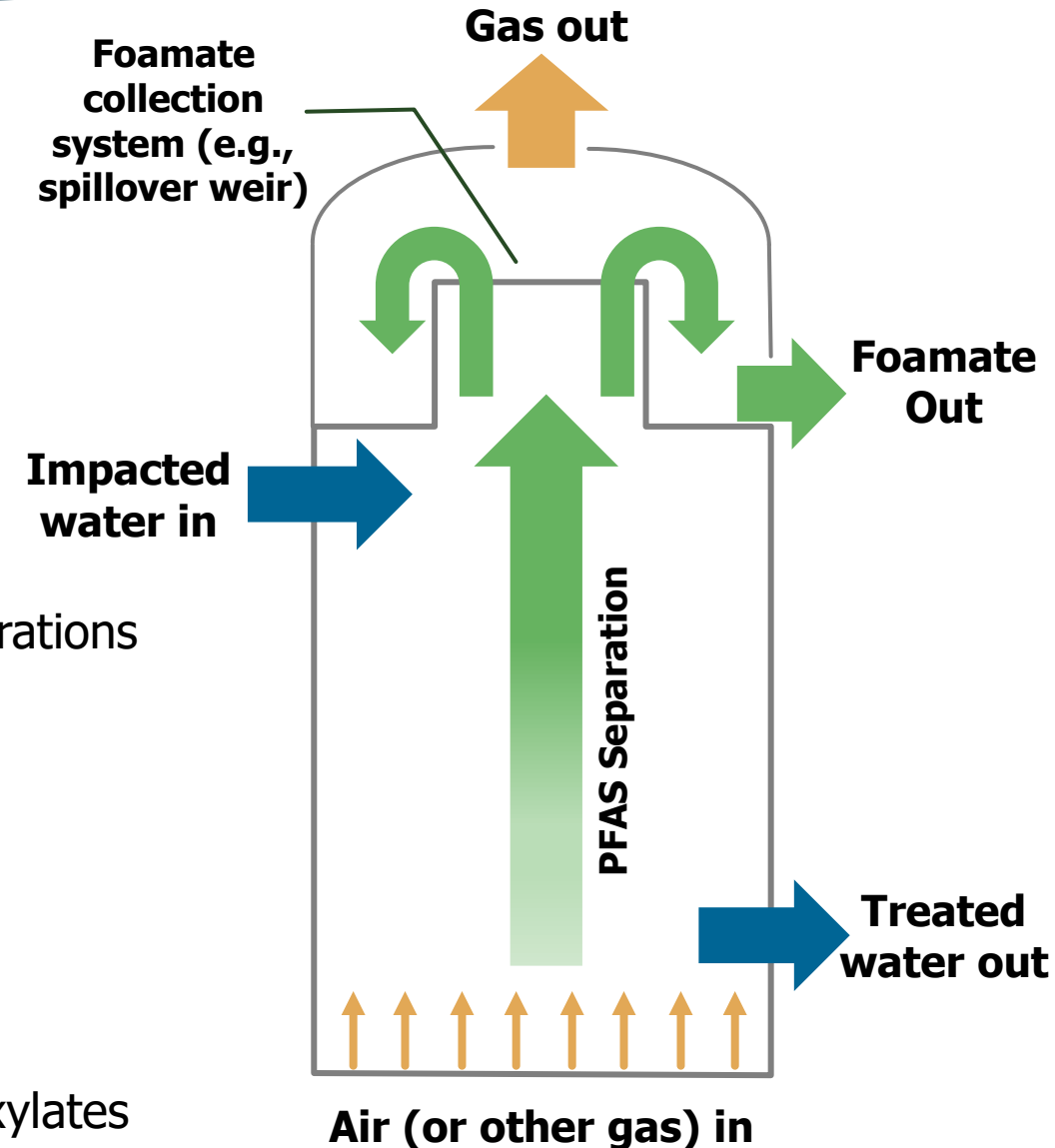
Foam: a stable mixture of gas and liquid
Wet foam contains a large proportion of water

Dry foam contains a lower proportion of water

Stable foam does not readily collapse into a liquid

Technology Overview

- At the top of the vessel, PFAS-enriched matrix (foamate) can be collected through:
 - Spill-over weir
 - Real-time vacuum
 - Clean water displacement
- Resultant products:
 - Treated liquid effluent
 - Foamate: collapsed into a liquid with elevated PFAS concentrations
 - Gas for discharge
- Removal depends on the affinity of individual PFAS to air-water interfaces (adsorption coefficients)
 - Long chain PFAS readily removed
 - Short chain PFAS less readily removed
 - Sulfonates more readily removed than corresponding carboxylates



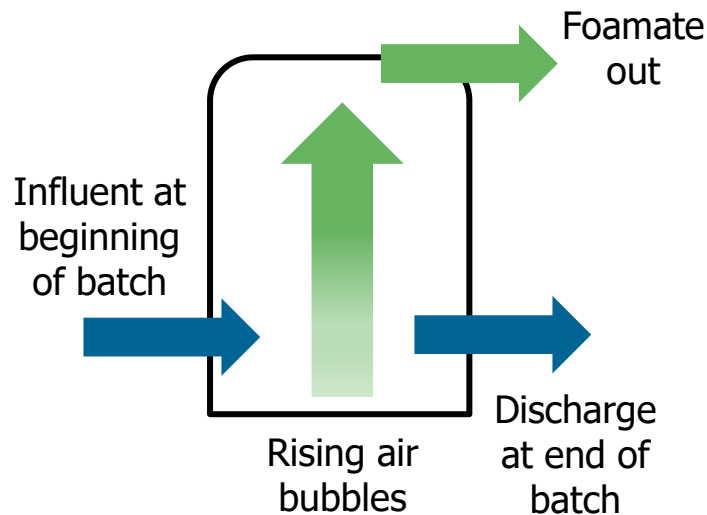
Source: Allonnia. Used with Permission

Operating Modes

Batch Process

- Fill vessel, run fractionation cycle, discharge treated water.
- More control over operating parameters
- Lower/irregular throughput

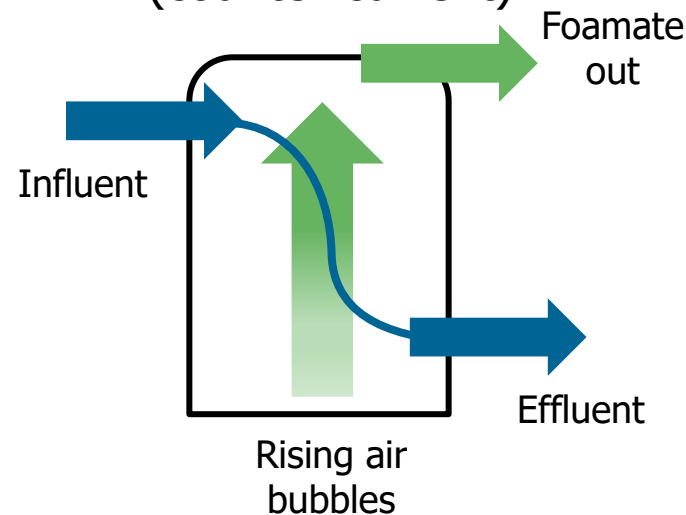
Batch Process



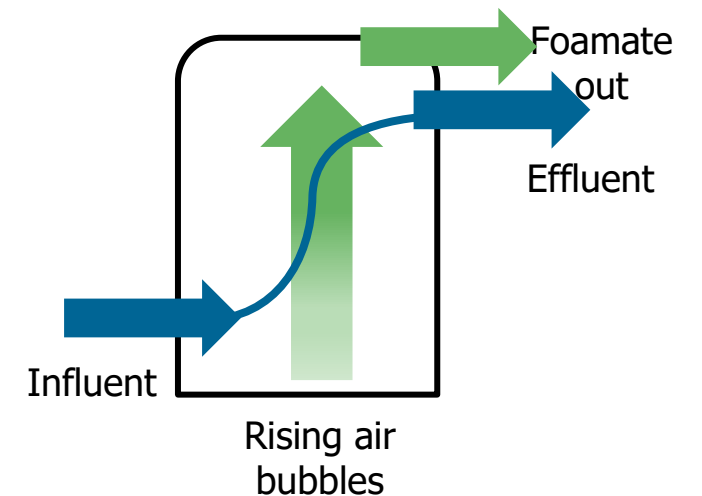
Continuous Process

- Continuous influent and effluent
- Can be counter-current or co-current
- Higher and continuous throughput

Continuous Process
(counter-current)



Continuous Process
(co-current)



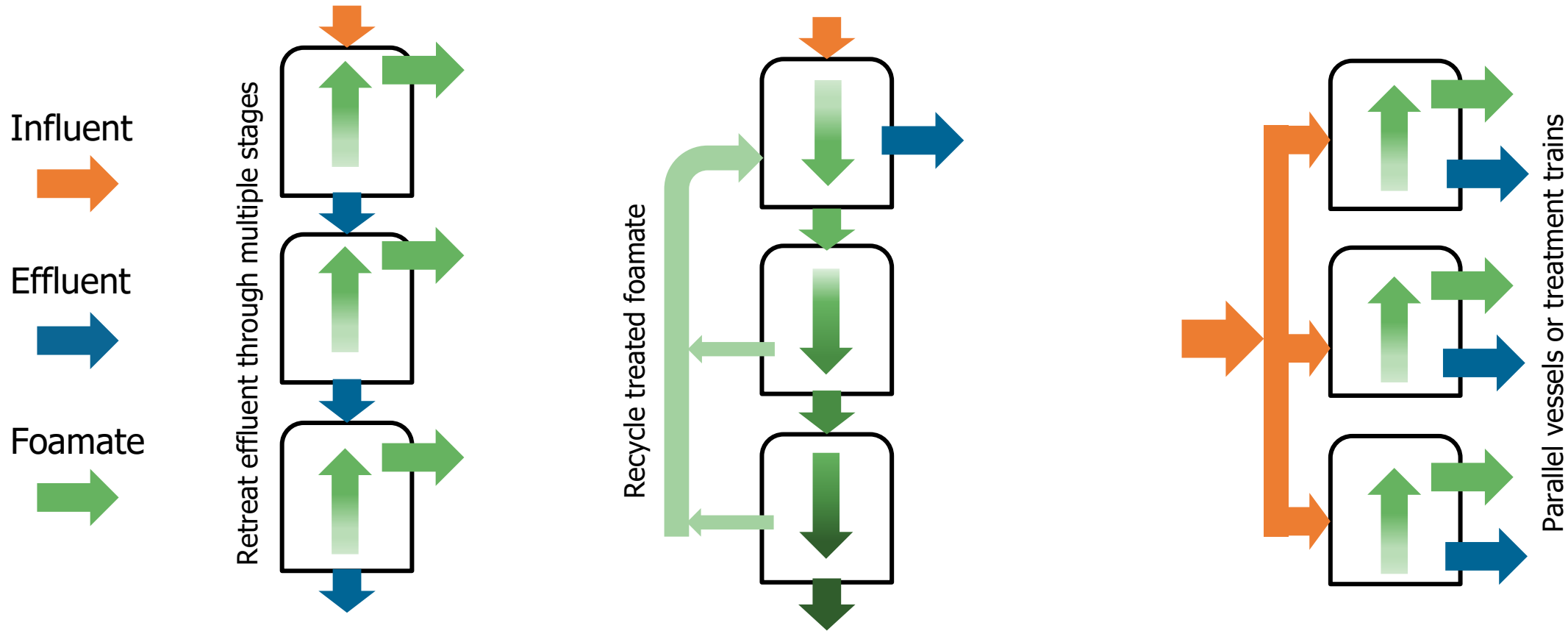
Systems can be skid mounted, inside containers, or constructed on site

Operating Modes – Multi-stage Foam Fractionation

- Multiple Vessels in Series (sequential treatment)
- Boost PFAS Removal Rate

- Multiple Vessels in Series (sequential enrichment)
- Reduce waste volumes

- Multiple Vessels in Parallel
- Increase throughput

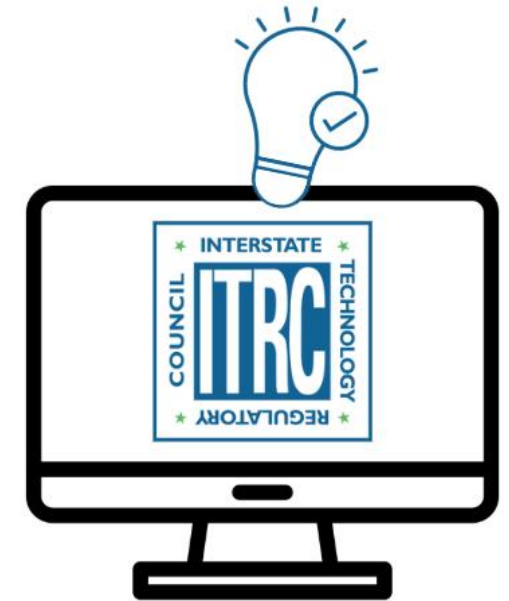


Systems can use combinations of vessel configurations to achieve objectives

Poll Question

Check
In!

- Which of the gases below have you used or heard about using most often for foam fractionation?
 - A) Air
 - B) Ozone
 - C) Nitrogen
 - D) Other



Gas Types

Air

- Most commonly used
- Lowest cost
- Some oxidation of precursors and co-contaminants
- Easy

Ozone

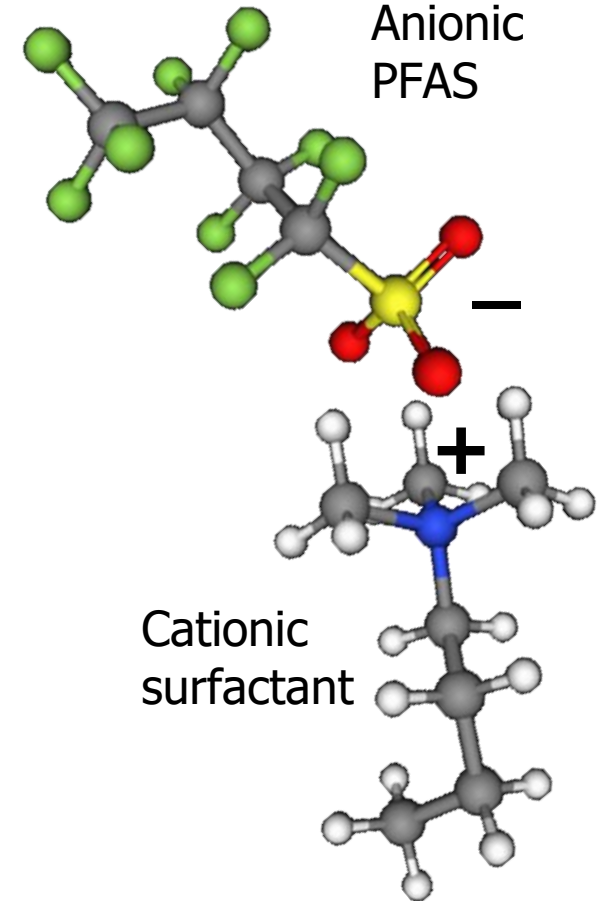
- Oxidation of precursors and co-contaminants
- Higher cost
- Potential byproduct formation (e.g., bromate)
- Lower total PFAS removal
- Can reduce waste volumes

Nitrogen

- Limited field applications
- May be used to prevent oxidation of metals and PFAS precursors

Foaming Additives

- **Foaming additive:** surfactant or other chemical added to enhance foaming or PFAS removal
- Co-surfactants to improve adsorption coefficient
 - Cationic surfactant typical to aid removal of anionic PFAS
 - Boosts short chain adsorption coefficient
 - Forms complexes with PFAS and stabilized foam
 - Helps if low PFAS influent concentrations (boost and maintain foam)
 - 98% removal of 4 carbon-chain PFAS w/1 mg/L or less
- Non-ionic and biologically derived surfactants
 - Improve PFAS removal & biodegradable
 - Lower toxicity (end up in foamate and possible effluent water)
- Salt can improve fractionation, but will increase maintenance



Anionic PFAS and cationic surfactants can form a more surface-active complex to enhance removal

Considerations for Source Waters

Applicable Waters	Not-Applicable Waters
Groundwater	High (>10 ppm) PFAS concentrations (e.g., AFFF)
Landfill Leachate	
Process Waters	Liquids w/ densities >1.15 (e.g., sludge w/ solids >1%)
Soil Wash Water	
Reverse Osmosis (RO) Reject Water	Oily Waters (without pre-treatment to remove oils)
Drinking Water	
Pre-treatment for bulk PFAS removal	
Wastewater (sewerage or industrial)	
Oily waters (w/ pre-treatment to remove oils)	

Foam fractionation often most cost-effective for:

- PFAS > 100 ng/L and flow rate < 0.2 MGD
- Waters with high co-contaminant loadings

Pretreatment Considerations

- **Most waste streams require little or no pre-treatment**
- Can be placed anywhere in the treatment train
 - Ideally prior to generation of organic solids (settle w/PFAS sorption) but would increase maintenance
 - Place to avoid odor generation with sewage treatment (e.g., FF after secondary treatment)
- Most co-contaminants will not affect PFAS removal but may have maintenance/design concerns

Water Quality	Issue	Example Solutions
Total Suspended Solids (TSS) or carbonaceous material	Can sorb PFAS and prevent removal	Pre-filtration, higher air injection rates, chemical addition
Oil & Grease >100ppm/NAPL	Oils coating air bubbles	Oil-water separator, dissolved air flotation
Volatile co-contaminants (e.g., benzene, Hg)	Partition into gas and emitted in exhaust	Treatment of exhaust (e.g., vapor phase granular activated carbon [GAC])
Metals	Precipitation and increased maintenance	Pretreatment, chemical addition
Hard water/carbonates	Scaling and increased maintenance	pH control

Emissions Considerations

- Foam fractionation can generate gas, mist, and/or aerosols
 - Most PFAS are not volatile but may be present in aerosols or mists (large air-water interfaces)
 - Volatile components in the water may volatilize (e.g., VOCs, BTEX)
- Off-gas treatment (e.g., VGAC) works best for dry air
- Mist treatment (or recirculation) prior to off-gas treatment
 - Demisting pads, cyclonic demister system, sorbent beds/canisters, condensers
- No clear emissions limits or air quality standards
 - Some states may require permits or have indoor/ambient air guidance for certain PFAS
e.g., Michigan air screening levels:

PFOA	0.0001 $\mu\text{g}/\text{m}^3$	24-hour average
PFOS	0.0004 $\mu\text{g}/\text{m}^3$	24-hour average
6:2 FTSA	1 $\mu\text{g}/\text{m}^3$	Annual average

Air Testing Methodologies

- USEPA Other Test Method 45 (OTM-45) – isokinetic sampling method may be cost prohibitive and cannot be used on most small systems without modifications
 - Isokinetic – sampling probe nozzle velocity matches velocity of gas stream. Requires specific temperature and pressure controls
- Modified USEPA Method TO-13A (non-isokinetic) for collection with OTM-45 analysis
- OTM-50 – different analyte list than typical aqueous analyses and may not provide much information

Advantages and Disadvantages

Advantages

- Produces PFAS-enriched liquid waste without solid media
 - Suitable for emerging destruction technologies
- Costs do not scale with PFAS concentration
 - Rapid breakthrough of GAC/IX at high PFAS concentrations
- Limited pre-treatment requirements
- Smaller footprint

Disadvantages

- Current commercial offerings have limited capacity
- Less easily scaled
- Lower short chain removal
 - Also faster short chain breakthrough with GAC/IX

Site Specific Considerations

Level hardstand

Secondary containment

Suitable power availability

- 3-phase vs. 1-phase, sufficient amperage

Source of water to be treated

- Storage/break tanks for intermittent flow
- Location of influent/effluent connections

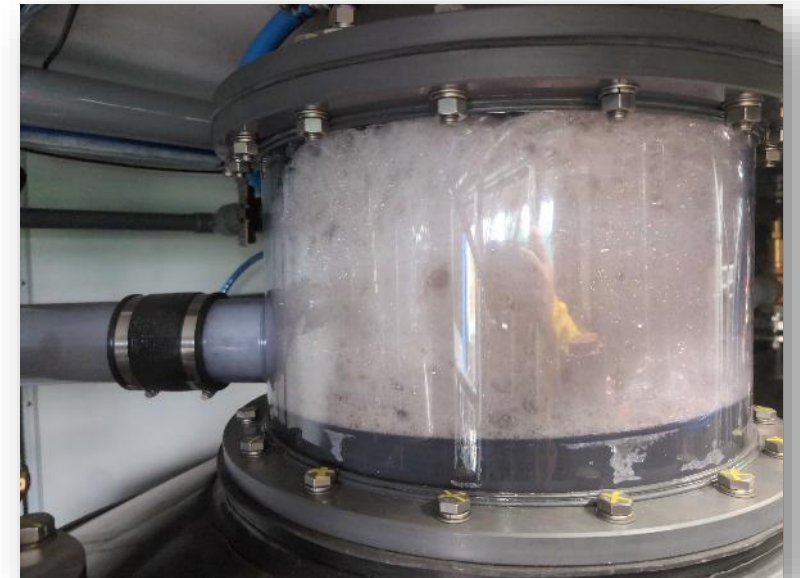
Location and types of discharge

- Direct discharge (e.g., NPDES) vs sewer discharge (POTW Pretreatment)

Where to safely store concentrated PFAS

Performance Modeling

- Foam fractionation occurs in a turbulent, multiphase system
- Numerical models derived from first principles are lacking and would require numerous assumptions/simplifications
- Empirical models can be developed based on removal from similar waters but may not be representative due to difference in water chemistry, system geometry, or other unknown factors
- Due to the limited availability of predictive models, physical testing is recommended
 - May include benchtop, field pilot, and/or full-scale field testing



Source: Allonnia. Used with Permission

Performance Evaluation – Considerations

Questions to Consider

- Can foam fractionation remove sufficient PFAS to meet project objectives?
- How much waste will be generated?
- What are the optimal operating conditions/system configuration?
- What are the total life-cycle costs?

Potential Performance Evaluation Parameters

- Performance of different gases
- Effect of bubble size
- Air flow rates and optimal aeration patterns
- Optimal vessel fill height
- Batch treatment time/hydraulic residence time
- Use/dose of foaming additives

Foamate Evaluation

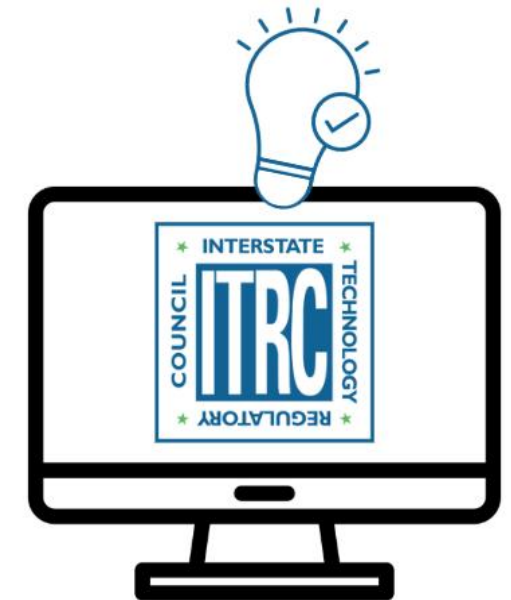
- Primary removal method: foam, bubble, aerosol
- Quantity of foam generated: insufficient foaming or excessive foaming
- Foam stability
- Volumetric concentration
- Site use of anti-foaming agents
- Foamate removal system

Knowledge Check

Check
In!

A shake test shows no foam formation. This means that Foam Fractionation will not work.

True or False?



Performance Evaluation – Considerations

Summary of Performance Test Options for Evaluating Foam Fractionation

Test Type	Relative Time to Completion	Relative Cost	Ability to Assess PFAS removal?	Predictability of Full-Scale Performance
Shake and Foamability Tests	Shortest	Least	No	Poor
Modeling	Short	Low	Maybe	Low
Bench Scale Testing	Moderate-Low	Moderate-Low	Yes	Moderate
Pilot	Moderate-High	Moderate-High	Yes	High
Full-Scale Demonstration	Longest	Highest	Yes	Best

Performance Evaluation – Bench Testing

- Shake and foamability testing
 - Shake a fixed volume of liquid and measure the foam height
 - Column foaming tests – aerate a known volume of liquid and measure foam height
 - Should also measure foam stability (e.g., time to collapse)
 - Will not evaluate PFAS removal but can indicate if foaming additives or foam suppression are needed



Source: Allonnia. Used with Permission

Performance Evaluation – Bench Testing

- Bench-top fractionation tests
 - Small-scale system to mimic larger operation
 - Can collect influent/effluent samples to assess PFAS removal
 - Collect foamate to measure volume and enrichment
 - Different geometry/setup may limit prediction of upscaled system
- May have limited volumes to perform laboratory tests which limits the size of equipment and number of conditions tested



Source: Allonnia. Used with Permission

Performance Evaluation – Pilot Testing

- Field pilot testing is the preferred method to evaluate foam fractionation performance
- Consider balance between cost and data quality
- May require site infrastructure upgrades
 - Power, plumbing, hardscape

	Full-Scale Pilot Test	Smaller Pilot Test Unit
Advantages	Provides exact performance comparison	Lower Cost
Disadvantages	Higher Cost Only possible with portable/modular units	Need to consider scaling of data
“Trial to buy” type agreements may be appropriate for full-scale pilot testing		

Performance Evaluation – Interpretation and Decisions

Data	Evaluation
Rates of removal for each PFAS	Assess conditions that improve removal rates
Post-treatment PFAS concentrations	Determine if foam fractionation is sufficient to meet objectives or if additional treatment (polish) needed
Rate of foamate production	Determine appropriate storage/disposal and assess cost
Operating parameters (e.g., air flow, liquid flow rates, batch/residence times)	Used to size system and determine flow rates and estimate costs
System downtime/maintenance requirements/ease of operations	Assess labor needs, costs, and need for redundancy and/or pretreatment
Electricity use	Determine site power needs and costs

Foamate Management

- Considerations for foamate disposal:
 - Location and cost of off-site treatment
 - Need for on-site management (closed loop)
 - Commercial availability
 - Permitting/regulatory acceptance

Commercially available disposal options:

Solidification/encapsulation
High temperature incineration
(haz waste incinerator)
Deep well injection
Supercritical Water Oxidation

Emerging PFAS destruction technologies:

Hydrothermal alkaline treatment
Electrochemical Oxidation
Plasma technologies
Photolysis/photochemical oxidation

Foam Fractionation Summary

Foam Fractionation: cost effective and sustainable tool to remove PFAS from aqueous streams

No solid media is used; waste product is a PFAS-concentrated liquid (foamate)

- Can be disposed of or destroyed using both existing and emerging technologies

Numerous configurations for foam fractionation can be assessed

Suitable for a variety of water types; most efficient for removal of high concentrations and long-chain PFAS

- Foaming additives can enhance short-chain PFAS removal or create foam in non-foaming waters

Field pilot studies are the best tool to predict performance and optimize designs

- Bench testing and empirical models are also available



Decision-making & Technology Selection

Decision-making & Technology Selection

You know technology basics + have site data + pilot results... now what?

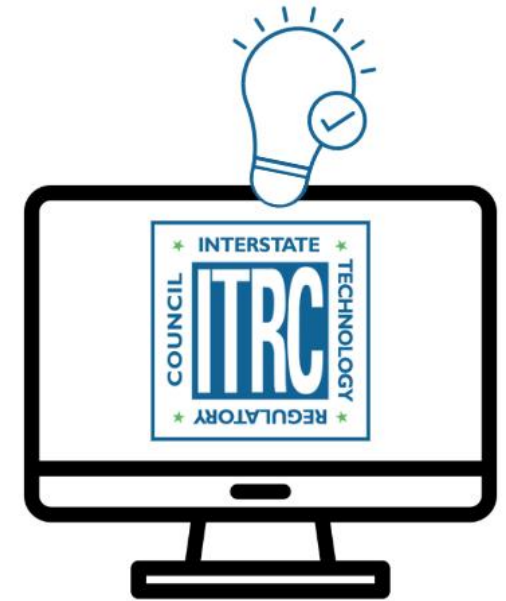
- Performance alone **does not determine** the right technology.
- The *best* technology depends on:
 - Treatment objectives (drinking water MCLs vs. discharge limits)
 - Waste stream/co-contaminants
 - Pretreatment requirements
 - Capital + O&M Costs
 - Flow rates and technology scalability
 - Residuals management/delivery logistics
 - Community & stakeholder considerations
- Must integrate **technical metrics + life cycle cost + sustainability + site constraints** into a holistic decision.

Knowledge Check

Check
In!

“The IX resin treated way more bed volumes to breakthrough than the GAC in the pilot. IX resin must be the way to go.”

- Definitely
- Maybe
- No way

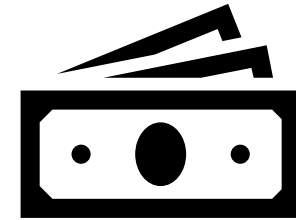


Financial Capability Tools

.....Are there tools I can use?

Tool #1: Clean Water Act Financial Capability Assessment Guidance

- Helps utilities understand **affordability** and **financial stress** when planning PFAS treatment.
- Factors evaluated:
 - Median household income
 - Existing debt burden
 - User rate impacts
 - Community economic indicators
 - Useful for comparing O&M-heavy technologies (GAC changeout, IX regeneration, FF O&M).
 - Informs whether phased implementation or design alternatives are necessary.



Estimating Costs

...What tools I can use?

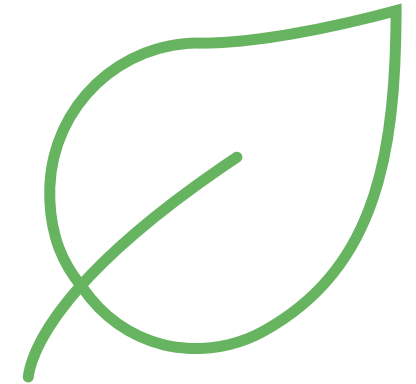
- **Tool #2: EPA Work Breakdown Structure (WBS)** cost models can estimate:
 - **Capital:** vessels, media, pumps, pre- & post-treatment, infrastructure, contractors
 - **O&M:** media replacement/regeneration freq., energy, sampling, disposal, labor
 - **Residuals:** spent media handling, regenerant disposal, GAC reactivation
 - Provides standardized cost curves for:
 - Fixed-bed GAC
 - Fixed-bed IX
 - Reverse Osmosis/Nanofiltration
 - Point of use (POU) and point of entry (POE) systems
 - FF not well represented yet (limitation)
 - Helps convert pilot data (EBCT, bed volumes to breakthrough) into annualized lifecycle cost.

Lifecycle & Sustainability Tools

...What tools I can use?

EPA Sustainability and Green Remediation/Footprint Assessment Tools:

- Environmental footprint calculators (energy, GHG, water use)
- TRACI / lifecycle impact tools (Human health and ecotoxicity impacts)
- Green Remediation best practices (CLU-IN)
- Use for side-by-side comparisons of:
 - Media changeout Impacts (materials, waste, transport, energy)
 - Transportation/haul distances (fuel use, emissions)
 - Regeneration vs disposal
 - Chemical consumption
 - Energy intensity (especially for FF)



Purpose:

Helps teams evaluate long-term environmental and social impacts, not just cost.

Decision Summary

- Selection of treatment technology depends on:
 - **Performance:** % removal, breakthrough volume, pretreatment sensitivity
 - **Cost:** capital, O&M, indirect costs, residual handling
 - **Sustainability:** energy, waste generation, GHG footprint
 - **Site Constraints:** footprint, utilities, operator availability/skills
 - **Risk:** modeling capabilities/reliability, regulatory uncertainty, community acceptance

Takeaway:

- No single technology "wins" universally
- Selection depends on situation-dependent priorities

Key Barriers and Challenges

- Technology and regulatory evolution
- Operator & infrastructure capacity
- Co-contaminants & variable water quality
- Residuals management
- Difficulty of predictive modeling
- Limits of analytical techniques
- Short chain PFAS
- Lack of consensus and standards



Looking to the Future

- **Novel sorbents**
 - Cyclodextrins, modified clays, and more
- **Residuals minimization & destruction**
 - Plasma, SCWO, hydrothermal, and others
- **Updated test methods**
 - Treatment verification



ITRC PFAS Treatment Technologies Team, 2026-2027
<https://itrcweb.org/pfas-treatment-technologies-team/>


- Guidance Document
- Fact Sheets
- Data Tables & Figures

PFAS Home Page

This Interstate Technology & Regulatory Council (ITRC) PFAS website is designed to provide a working knowledge of the current state of PFAS science and practice (as of date of publication). This website includes the following resources:

- **PFAS Technical and Regulatory Guidance Document (Web-based Guidance)**
 - [Priority Topics](#) (January 2026)
 - [Sorption-Based Technologies for Separation and Concentration of PFAS from Water](#) (January 2026) (*Full PDF – Coming Soon*)
 - [Sections 2-17](#) (September 2023, with small updates January 2026)
 - [Case Studies](#) (2020, 2023, January 2026)
- [Data Tables](#) (various dates of last update)
- [Fact Sheets](#) (September 2023)
 - [Vapor-forming PFAS and the Vapor Intrusion Pathway](#) (January 2026)
- [Training Resources \(various archived webinars\)](#)
 - Archived webinars; live classes can be found on the [ITRC Training webpage](#).

ITRC PFAS Training

- PFAS Introductory Training 
- PFAS Chemistry Explained
- PFAS & Biosolids: Sources, Occurrence, Transport, and Treatment
- PFAS - Practical Approaches for PFAS Fate & Transport Evaluation
- PFAS Sorption Based Technologies for Separation & Concentration of PFAS from Water

PFAS Trainings



Questions



<https://pfas-1.itrcweb.org/>

Feedback Form & Certificate of Completion: <https://www.clu-in.org/conf/itrc/PFAS-sorption-techs/>