AZ Water Association
Professionals Dedicated To Arizona's Water

ADEQ Arizona Department of Environmental Quality
Clean Air, Safe Water, Healthy Land for Everyone

The AZ Water Association, **Water Treatment Committee,** in collaboration with the **Arizona Department of Environmental Quality**, presents:

Thursday, February 1, 2024, 7:00 a.m. to 5:00 p.m.

Desert Willow Conference Center
4340 E Cotton Center Blvd, Phoenix, AZ 85040

Arizona PFAS Forum:
Industry Perspectives on Solutions

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4340 E Cotton Center Blvd, Phoenix, AZ 85040
Program Thursday, February 1, 2024, 7:00 a.m. to 5:00 p.m.

7:00 to 7:30 a.m.	**Breakfast & Registration**	Lobby and Vendor Breakout Area	
Time	Topics	Speaker (moderator)	Location
7:30 to 7:55 a.m.	Welcome, Opening Remarks, and breakfast **"Introduction to PFAS in Arizona"**	Frederick Tack – WTC Chair Jeanne Jensen – *President, AZ Water Association* Trevor Baggiore – *Director of Water Quality, ADEQ*	Cottonwood
	Regulatory and Technology Strategies Sessions		
8:00 to 8:25 a.m.	**ADEQ PFAS Updates:** Activities, Programs, Rules, and Regulations	Sara Konrad – *Technical Assistance Grants Project Manager, ADEQ* (Julie Woodworth)	Cottonwood
8:30 to 8:55 a.m.	**Funding Opportunities and the Application Process**	Lindsey Jones – *Assistant Director of Water Projects, WIFA* (Julie Woodworth)	Cottonwood
9:00 to 9:25 p.m.	**Permitting Considerations by ADEQ**	Jasmina Markovski – *Senior Engineer, ADEQ* (Julie Woodworth)	Cottonwood
9:30 to 9:55 a.m.	**Technologies and Strategies for Producing Low-PFAS, EPA-Compliant Drinking Water**	Christian Kassar & Doug Rice – *Process Engineers, Black & Veatch* (Julie Woodworth)	Cottonwood
9:55 to 10:20 a.m.	*Break, refreshments, and networking*		Saguaro
	Critical Insights Sessions		
10:20 to 10:50 a.m.	**Competing Ions:** Competition for adsorption sites on PFAS removal media	Lee Odell – *Technical Practice Leader, Water Treatment, Consor Engineers* (Frederick Tack)	Cottonwood
11:00 to 11:50 a.m.	**PFAS Treatment**: Planning and Implementation Panel	Scott Schladweiler – *Tucson Water* Viking Edeback – *Carollo Engineers* Kirtipal Barse Ph.D., PE – LANXESS Cathy Swanson – *Purolite* Eli B. Townsend – *Calgon Carbon Corp.* (Frederick Tack)	Cottonwood
	Keynote Address and Lunch		
Noon to 12:50 p.m.	**How Unique PFAS Properties Influence Behavior in Water Treatment Processes**	Dr. Paul Westerhoff & Dr. Bruce Rittmann *Arizona State University* (Julie Woodworth & Frederick Tack)	Saguaro / Cottonwood
	Treatment Technology Sessions		
1:00 to 1:25 p.m.	**GAC and IX for PFAS Removal:** Pilot-Scale Case Studies and Impact on Full-Scale Implementations	Eli Townsend – *Applications Engineer, Calgon Carbon Corp.* (Ed Mears)	Cottonwood
1:30 to 1:55 p.m.	**Case Study:** FLUORO-SORB® 200 Media Implementation	Douglas Craver – *Southwest Technical Sales Manager, AdEdge* (Ed Mears)	Cottonwood
2:00 to 2:25 p.m.	**PFAS Treatment with Ion Exchange:** Meeting the EPA Proposed MCL	Cathy Swanson – *Environmental Sustainability Segment Manager, Purolite* (Ed Mears)	Cottonwood
2:30 to 3:00 p.m.	**The PFAS Residuals Dilemma**: Strategies and Solutions	Mary Lou Romero – *Principal Engineer, Brown & Caldwell* (Julie Woodworth)	Cottonwood
Attendees are cordially invited to stay for: AZ Water Association; Water Treatment Committee **Vendor Exposition & Networking Event** 3:00 to 5:00 p.m. in the Vendor Area			

Attendee registration was free. Registration was limited and sold out.

Professionals Dedicated To Arizona's Water

AZ Water Association **Water Treatment Committee** (WTC) presents:

Arizona PFAS Forum: Vendor Exposition and Networking

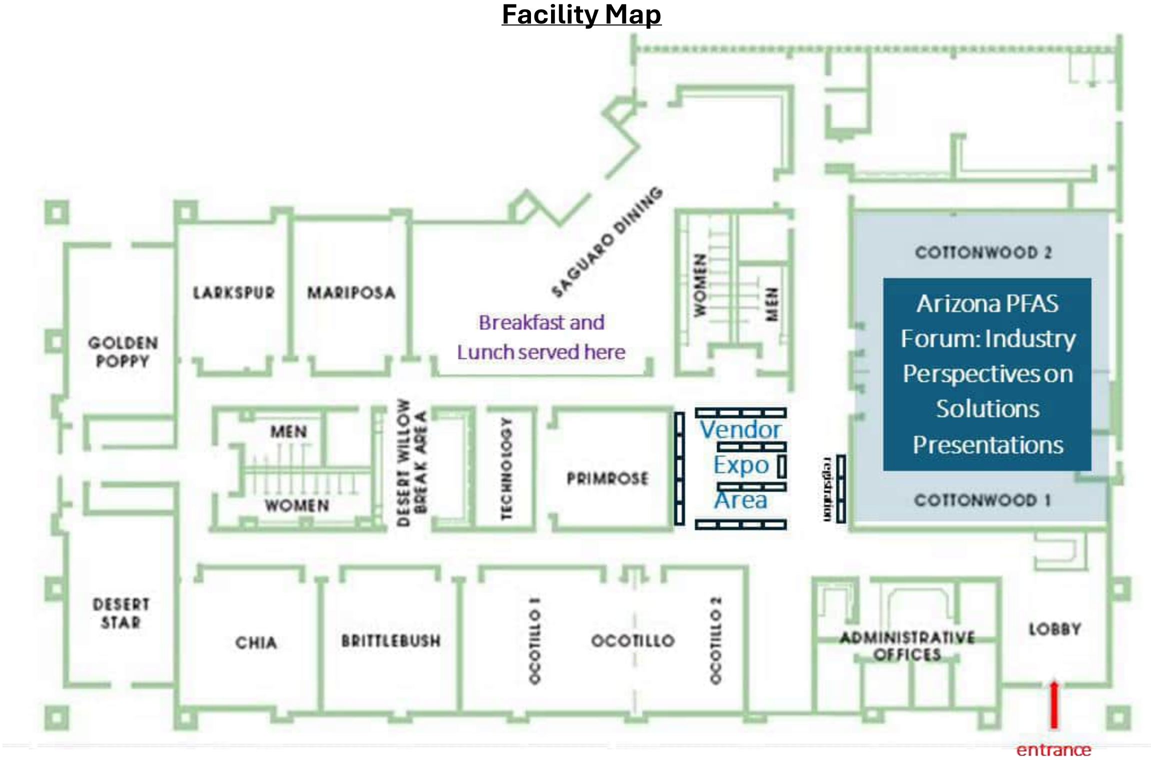
Desert Willow Conference Center
4340 E Cotton Center Blvd, Phoenix, AZ 85040
Thursday, February 1, 2024, 3:00 p.m. to 5:00 p.m.

Uniquely, this year the WTC will be hosting a vendor exposition and networking event after the presentations and lectures, in conjunction with the day's activities. Seven vendors will be present with a variety of ways for attendees to elevate their awareness with review and discussions about industry vendors, products, and services relating to PFAS treatment and project delivery.

This portion of the event is hosted by the AZ Water Association, WTC and sponsors and is ***not affiliated*** with ADEQ.

Attendees are cordially invited to stay for: **AZ Water Association; Water Treatment Committee Vendor Exposition & Networking** **3:20 to 5:00 p.m. in the Vendor Breakout Area**			
Times	Topics	Speaker (moderator)	Location
3:00 to 4:50 p.m.	**Vendor Exposition and Industry Networking**		Vendor Breakout Area
4:50 to 5:00 p.m.	**Closing Comments**	(Frederick Tack & Julie Woodworth)	Cottonwood

Facility Map



The AZ Water is a 501(c)(3) nonprofit educational organization founded in 1928 with a membership of 2,700 water/wastewater professionals dedicated to preserving and enhancing Arizona's water environment. AZ Water is the Arizona section of the American Water Works Association (AWWA) and the Arizona member association of the Water Environment Federation (WEF).

Water Treatment Committee Purpose:
Advancing water treatment knowledge to safeguard our communities' health, sustain life, and to increase the awareness of the ***value of water treatment*** *across our communities and industry.*

AZ Water Association

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AZ Water Association, **Water Treatment Committee** presents:

Arizona PFAS Forum: Vendor Exposition and Networking

Thursday, February 1, 2024, 3:00 p.m. to 5:00 p.m.

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ADEQ Arizona Department of Environmental Quality
Clean Air, Safe Water, Healthy Land for Everyone

WATER INFRASTRUCTURE FINANCE AUTHORITY OF ARIZONA

Keynote Address - How Unique PFAS Properties Influence Behavior in Water Treatment Processes

Starting from a national perspective, PFAS in wastewater effluents discharged to the environment have a large impact on PFAS levels in surface waters and downstream drinking water intakes. There is a need to treat PFAS in surface, ground, and reclaimed waters. The presentation will discuss how unique PFAS chemical attributes act as a surfactant influence performance of commercially available and emerging PFAS removal technologies. Implications of PFAS removal on end-of-life processes will be overviewed.

Speaker Biography's

Dr. Paul Westerhoff

Dr. Paul Westerhoff is a Regents Professor and Fulton Chair of Environmental Engineering in the School of Sustainable Engineering and the Built Environment at Arizona State University. Since joining ASU, he has held various administrative positions. After serving as the Civil and Environmental Engineering Department Chair, he was the Founding Director for the School of Sustainable Engineering and the Built Environment and served later as Associate & Vice Dean of Research in Engineering and ASU Vice Provost for Academic Programming.

Dr. Westerhoff is the Deputy Director of a NSF ERC for Nanotechnology Enabled Water Treatment and co-Deputy Director of the NSF STC Science and Technologies for Phosphorus Sustainability Center. His research group addresses questions related to: What pollutants exist in the environment? If they occur, do they matter? If they occur and matter, what do we do to address them? with a focus on pollutants in natural and engineered water systems.

He has over 375 journal publications (H-index>100) and multiple patents. He is the recipient of the 2020 A.P. Black Award, 2019 NWRI Clarke Prize, 2015 ASU Outstanding Doctoral Mentor, 2013 ARCADIS/AEESP Frontier in Research Award, and 2006 Paul L. Busch Award. He was elected to the National Academy of Engineering in 2023.

Dr. Bruce E. Rittmann

Dr. Bruce E. Rittmann is Regents' Professor of Environmental Engineering and Director of the Biodesign Swette Center for Environmental Biotechnology at Arizona State University. His research focuses on the science and engineering needed to "manage microbial communities to provide services to society." Dr. Rittmann is a member of the National Academy of Engineering; a Fellow of AAAS, WEF, IWA, AEESP, and NAI; and a Distinguished Member of ASCE. Dr. Rittmann is the co-winner of the 2018 Stockholm Water Prize. Dr. Rittmann has published over 820 journal articles, books, and book chapters, and he has 21 patents.

Welcome & Opening Remarks

Jeanne Jensen – *President , AZ Water Association and CIP Project Supervisor, Town of Gilbert*

Jeanne Jensen is the CIP Supervisor serving utilities in the Town of Gilbert, AZ. Jeanne holds a Bachelors Degree in Chemical Engineering, and Masters Degree's in Civil Engineering and Public Administration from ASU. In addition to holding two PE's, Jeanne is a 4x4 operator, and a Fellow of the Duke University Water Innovation Leadership program. She serves as the President for AZ Water Association, and has been an active AWWA / WEF member at the local and national levels for more than 17 years.

Trevor Baggiore, PE – *Director of Water Quality, ADEQ*

Trevor Baggiore has been the Director of the Water Quality Division for the Arizona Department of Environmental Quality since 2015. As a native of Arizona and a two-time graduate of Arizona State University, with a Bachelor's in Chemical Engineering and a Master's in Business Administration, he has been advocating for Arizona's environment since 2001. Trevor is registered in Arizona as a professional engineer and is a champion of Arizona's efforts to deliver faster, better, cheaper government.

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ADEQ PFAS/PFOA Updates: Activities, Programs, Rules, and Regulations

ADEQ staff will provide an update on the current state of EPA's proposed PFAS regulations as well as describe technical assistance available from EPA for piloting PFAS treatment systems.

An overview of ADEQ's activities related to PFAS in drinking water will follow. ADEQ is nearing completion of its sampling project to identify PFAS contamination at public water systems that will be regulated by the proposed rule. Data from the sampling project are provided to public water systems and will also be used by ADEQ to prioritize and select public water systems to receive direct assistance. This direct assistance is available through two funding sources specific to PFAS which together total $47 million. These funds will be primarily used to provide direct assistance to small and disadvantaged communities. The direct assistance will result in PFAS mitigation strategies such as treatment, consolidation, or a new water source, as determined to be most appropriate for a community.

ADEQ is reducing barriers to access these funds by contracting directly with design engineers and construction contractors. The status of current projects financed through this funding will be presented and technical PFAS resources developed by ADEQ for communities will be shared.

Speaker Biography

Sara Konrad – *Technical Assistance Grants Project Manager, ADEQ*

Sara Konrad joined the Arizona Department of Environmental Quality in August 2023 to manage the Emerging Contaminants in Small or Disadvantaged Communities Grant Program. Previously, Sara was the Senior Program Administrator with the Water Infrastructure Finance Authority of Arizona (WIFA), where she managed grants and loans for drinking water and wastewater systems. Earlier in her career, Sara worked for the ADEQ, monitoring streams and lakes in the Total Maximum Daily Load Unit and administering construction and municipal stormwater permits. Her career in water quality also took her to Minnesota, where she was a compliance and enforcement officer in the construction stormwater program with the state's Pollution Control Agency. From 1998 to 2000, she served in the U.S. Peace Corps in Kenya where she was assigned to the Ministry of Forestry. Sara holds a Masters Degree in Watershed Management from the University of Arizona and a Bachelors Degree in Geology from the University of Wisconsin.

Funding Opportunities and the Application Process

Since 1989, the Water Infrastructure Finance Authority (WIFA) has invested nearly $3 billion in Arizona's communities through our State Revolving Funds (SRFs). In 2022, the Bipartisan Infrastructure Law infused significant new resources into our SRFs, especially for projects addressing emerging contaminants and lead service line replacement. That same year, the Arizona Legislature tasked WIFA with administering a $1.4 billion investment in water conservation and augmentation. What has WIFA done to deploy these resources and how can you benefit? Learn more in this update.

Speaker Biography

Lindsey Jones – *Assistant Director of Water Project, WIFA*

Lindsey Jones is the Assistant Director of Water Projects for the Water Infrastructure Finance Authority of Arizona (WIFA). She has a bachelor's degree in Conservation Biology and Ecology from Arizona State University and a master's degree in Environmental Science and Policy from Northern Arizona University. Her thesis work focused on water contamination issues in unregulated wells on the Navajo Nation. She has been working at WIFA since 2019.

Permitting Considerations by ADEQ

This presentation provides an overview of minimum design criteria and engineering assistance available when permitting PFAS treatment for drinking water systems through ADEQ. ADEQ recommends, but does not limit, the installation of best available technologies as those options already have demonstrated effectiveness at full scale in the field. The permitting goals of ADEQ for PFAS treatment are long-term and simultaneous compliance of water systems, which is not different from any other water treatment projects. The uniqueness of PFAS contamination, challenging treatment goals and existing knowledge gaps, however, trigger more comprehensive analysis in comparison to traditional contaminants. Specifically, minimum design criteria of PFAS treatment requires an understanding of PFAS and background water quality, testing performance of selected technology and operational parameters, predicting the impact of treated water quality on the existing water infrastructure elements, and managing residuals in line with specific regulations.

To demonstrate the importance of this design approach, this presentation shows lessons learned from the perspective of: (1) Water quality-based selection of pretreatment strategies for dealing with inability to backwash granular media; (2) Preparation needed before starting pilot, rapid small-scale column, or batch adsorption testing; (3) Modeling benefits when transitioning to full scale. To facilitate the permitting process, ADEQ's permitting engineers and technical assistance team are proactively working with public water systems with identified PFAS issues. ADEQ/industry partnership is an ongoing project whose goal is to provide additional support for such systems in the form of design tools such as technology decision trees, testing protocols, cost models and Arizona specific residual management options. The status of permitting assistance efforts is provided in this work.

Speaker Biography

Jasmina Markovski – *Senior Engineer, ADEQ*

Jasmina Markovski is a Senior Engineer with Safe Drinking Water Section of ADEQ. Jasmina holds a BS/MS/PhD in Chemical/Polymer/ Environmental engineering and PE in Chemical Engineering in the State of Arizona. She has 11 years of experience in the industry. Jasmina is specialized in adsorption and ion-exchange drinking water treatment technologies. She is author of 4 patents, 22 peer-reviewed publications, 4 book chapters and 30+ conference proceedings and presentations.

Technologies and Strategies for Producing Low-PFAS, EPA-Compliant Drinking Water

The EPA's proposed PFAS National Primary Drinking Water Regulations indicate water treatment plants will soon be required to produce drinking water that abides by new, stringent PFAS limits. Given the widespread prevalence and recalcitrant nature of PFAS, the proposed regulation poses significant challenges to water utilities. This presentation reviews established methods for PFAS removal, approaches to assessing and selecting appropriate PFAS treatment technologies, and strategies for retrofitting PFAS treatment technologies into existing water infrastructure.

Speaker Biographies

Doug Rice, Ph. D, PE – *Process Engineer, Black & Veatch*

Doug Rice is a Process Engineer at Black & Veatch. He has experience in a variety of water, wastewater, reuse, and desalination projects, both in the United States and abroad. He is particularly interested in direct potable reuse, fit-for-purpose reuse, concentrate management, and advanced water treatment processes. Doug received his PhD from Arizona State University, where his research focused on membranes, fouling, and electrochemistry.

Christian Kassar – *Process Engineer, Black & Veatch*

Christian Kassar is a Process Engineer at Black & Veatch. Christian specializes in evaluating alternative treatment methods, particularly emerging technologies, for the complete on-site removal and degradation of PFAS from landfill leachate. Christian's previous research at Arizona State University, included utilizing ion exchange (IX) for PFAS removal and the desorption of PFAS from impacted media using complex regeneration solutions. Currently, Christian is involved in breakthrough modeling aimed at optimizing pilot and full-scale implementation of PFAS treatment systems.

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Competing Ions:
Competition for Adsorption Sites on PFAS Removal Media

This presentation will describe factors that affect removal efficiency and lifecycle costs of PFAS compounds for Ion Exchange, GAC, Fluoro-Sorb and membrane treatment. Much of what we know about PFAS removal is based on laboratory testing under a specific set of conditions, and new technologies and application are being installed all the time. This talk will provide some useful considerations in selecting treatment and conducting pilot testing on treatment alternatives. We will specifically look at the removal mechanisms for each type of treatment and describe which ions or other water quality or treatment factors affect PFAS removal.

Speaker Biography

Lee Odell, PE – *Technical Services Lead Water Treatment, Consor Engineers*

Lee has a wide range of experience managing projects in water resources, water quality and treatment, water reuse design and facilities planning. One of the hallmarks of his career has been helping utilities find innovative and unique ways to address their specific problems. Mr. Odell has 33 years of experience as an engineering consultant and 4 years of experience as a water treatment plant operator and operations supervisor.

Lee has helped many utilities find innovative, cost-saving methods for removing and treating contaminants from drinking water supplies. His groundwater treatment experience includes designing more than 75 treatment plants for iron, manganese, arsenic, disinfection, corrosion control, chromium, nitrate, radium, uranium, and other contaminants. He led the design of the world's largest nitrate removal drinking water plant, and managed projects for Seattle, Tacoma, Vancouver BC, and Portland for the design and operation of their surface water supplies. Lee has prepared more than 200 water treatment conceptual design reports and has completed more than 50 water master plans.

FILTRATION EQUIPMENT

Activated Carbon
Ion Exchange Resins
Novelty Medias: Arsenic and PFAS

UTILITIES & APPURTENANCES

Custom Fabricated Pipe to ASME B31.1-B31.3
Ductile Iron, Carbon & Stainless Steel
Waterworks Piping
Waterworks Fittings
Casing Spacers

CERTIFICATIONS

NAICS Codes
221310, 221320, 237110
325998, 326122, 331210
332919, 333318, 423720
423830, 423850, 424690
486990

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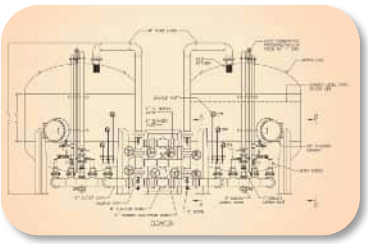
AqueoUSVETS®

Experienced. Proven. Reliable.

Aqueous Vets® (AV®) is a multidisciplinary firm that focuses on process equipment for water treatment. AV® offers a technically superior line of products for various treatment requirements. These advanced technology products include: filtration equipment, on-site chlorine generation, tank mixing/monochloramine control, chemical feed as well as industry-leading ion-exchange resin and activated carbon systems to successfully address their groundwater, drinking water, and waste water.



Capabilities & Expertise

Our principals represent a combined 85+ years of direct market development, leadership, engineering and construction services, project management and technical experience in the water and waste water industry. This experience is complemented with problem solving skills in material science, engineering and design, economic analysis, and business management.

Our design, manufacturing, and field experience, combined with our technology partner relationships, provide the best solutions for our clients' water treatment needs and is what makes Aqueous Vets® stand out among our peer water treatment companies. Our staff brings extensive knowledge and field experience to every project. We can provide engineering support for:

- Treatment design;
- Constructability reviews for field system selection;
- On-site installation support; and
- Multiple sources for best available media recommendations.

System Fabrication & Integration

AV® established our primary manufacturing facility in Redding, California. Our facility is focused on pressure vessel systems for use in water filtration using granular activated carbon and ion exchange resins. In addition to system fabrication we provide multiple technology system integration and custom welded steel pipe from carbon steel and stainless steel pipe materials meeting ASME B33.1, B33.3 standards.

Installations in Arizona with:

City of Tucson · Marana AZ · Avondale · City of Scottsdale · Tempe · City of Phoenix

PFAS Treatment Planning and Implementation Panel

Panel Member Biography's

Scott Schladweiler – *Deputy Director, Tucson Water*

Scott Schladweiler is the Deputy Director at Tucson Water where he currently oversees the Planning and Engineering, Source Water, Water Quality, and New Area Development Divisions. He has over 25 years of experience in the operation and management of municipal water and wastewater systems, including over 13 years with Tucson Water. Scott also served as the Deputy Director and Director for the Town of Marana Water Department during the discovery of PFAS in its potable water systems and subsequent implementation of treatment solutions. Scott is a native Tucsonan, a registered Professional Engineer in the State of Arizona, and holds a Bachelor and Master of Science in Civil Engineering from the University of Arizona. Bear Down!

Eli B. Townsend – *Applications Engineer, Calgon Carbon Corp.*

10 years of water treatment experience across research, consulting, and application optimization. Eli holds a Master's of Science Degree in Engineering from University of Colorado, Boulder (2014).

During his tenure in graduate school at the University of Colorado at Boulder, Eli concentrated on the removal of organic contaminants through coagulation and activated carbon techniques. His master's research specifically delved into the elimination of taste and odor compounds using powdered activated carbon in conjunction with a coagulation process. Subsequently, Eli ventured into the realm of consulting for nearly 5 years, where his primary focus revolved around assessing and selecting technologies for drinking water utilities, predominantly on the west coast. In his consulting capacity, Eli played a pivotal role in successfully executing numerous water treatment selection projects. He conducted site-specific treatability testing and compiled comprehensive final reports for clients. Eli transitioned to Calgon in early 2019 and assumed leadership in conducting nearly 20 pilot-scale evaluations of granular activated carbon and ion exchange for PFAS removal across the United States. Notably, Eli's involvement extended beyond pilot evaluations, encompassing full-scale design and implementation of PFAS systems. Throughout this process, he consistently provided technical support to utilities for the entire duration of the system's operation.

Dr. Kirtipal Barse – *Drinking Water Segment Manager, LANXESS Corporation*

Kirtipal Barse is the Segment Manager at LANXESS Corporation. At LANXESS, he is responsible for managing the ion exchange resins offering for Drinking Water and PFAS market segments. He has 6 years of experience in water treatment industry including municipal, industrial and residential market. Prior to LANXESS, he worked as a Product Manager at Watts Water Technologies and Senior Applications Engineer at Jacobi Carbons Inc. His expertise includes using media filtration technologies such as ion exchange resins and activated carbon for water treatment applications. Dr. Barse has M.S. and Ph.D. in Chemical Engineering, both from the University of North Dakota. He is a licensed Professional Engineering in State of North Dakota. Dr. Barse currently serves on the AWWA Ion Exchange Resin Subcommittee.

Cathy Swanson – *Environmental Sustainability Segment Manager, Purolite*

Based in Southern California, Cathy has specialized in groundwater treatment with ion exchange for over 15 years, including perchlorate, nitrate, arsenic, uranium, and now PFAS systems. She has also worked on technologies ranging from GAC to biological to reverse osmosis. Her project portfolio includes both remediation and drinking water sites. She received her BS in Chemical Engineering at Northwestern University in the Chicago area and her MBA from UNC Chapel Hill.

Viking Edeback – *Project Manager, Carollo Engineers*

Viking Edeback is a Project Manager at Carollo Engineers with over 10 years of experience in water treatment planning, process engineering, design, construction administration, and startup/operations assistance. Viking received his Masters Degree in Environmental Engineering from North Carolina State University. His focus is on PFAS treatment for drinking water. He has completed more than a dozen PFAS treatment projects including feasibility studies, bench scale testing coordination, detailed design, and operations and maintenance coordination of full-scale facilities.

GAC & IX Pilot Testing Case Studies: Meeting a New Regulation

As more public water systems chose treatment to remove per- and polyfluoroalkyl substances (PFAS) from their water supplies, a common question is arising: What treatment is the best option to meet the new MCL for PFAS: granular activated carbon (GAC) or ion exchange (IX)?

Calgon Carbon has been working collaboratively with utilities in California, Colorado, Delaware, Wisconsin, Washington and around the country to address this question on a case-by-case basis. The best way to compare GAC and IX for PFAS treatment is through pilot testing tailored to mimic the performance of specific full-scale designs for GAC and IX. Many factors impact the decision and through investigation, these tend to include but are not limited to background water quality; biological activity; empty bed contact time; surface loading rates; and other site-specific constraints. The case studies presented examine both performance and non-performance factors, and ultimately recommend a treatment technology based primarily on ongoing operational costs and space constraints.

One of the pilot studies presented biological contamination of the system and was forced to investigate disinfection strategies to maintain minimal biological growth within the IX resin. This pilot was operated with a continuous chlorine dose applied to the IX resin; traditionally IX resin cannot operate with free chlorine applied due to the oxidation of the cross-linking holding the resin bead together. Another study focused on differences when operating GAC at high and low loading rates for PFAS removal. This study harnessed the EPA's AdDesigns™ modeling software to predict full-scale performance under non-ideal and/or tested operating conditions through a calibration step.

Participants in this session will review GAC and IX treatment and two or three pilot-scale case studies. The results are used to guide participants through development of a derivation of probable cost, and a high-level introduction to modeling GAC for PFAS removal.

Speaker Biography

Eli Townsend – *Applications Engineer, Calgon Carbon Corp.*

Reference PFAS Treatment: Planning and Implementation Panel – Panel Biography's

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Case Study: FLUORO-SORB® 200 Media Implementation

Abstract

In 2021, a community in Maine discovered their well field was contaminated by PFAS due to its proximity to a local naval air station. The collection of wells is a critical part of the supply of drinking water producing up to 1.5 million gallons per day, so an emergency project was initiated to evaluate options and develop a solution. The decision was made to treat a portion of the well field and land apply the treated water, effectively pulling the PFAS plume away from the larger producing well fields and existing drinking water plant. In combination with this novel hydrological approach, the project team looked to ChartWater's AdEdge Water Technologies for an equally novel PFAS treatment approach. AdEdge provided a treatment solution with FLUORO-SORB® 200 media, proven for its ability remove PFAS compounds at low capital costs and low operating costs, and delivered the emergency treatment system within 8 weeks. The treatment system has been operating since June 2022, effectively removing PFAS compounds and meeting the Maine Sum of Six PFAS interim drinking water standard.

Speaker Biography

Douglas Craver – AdEdge Western Regional Manager

Douglas (Doug) Craver joined AdEdge Water Technologies, LLC in March 2011 and is the Western Regional Manager covering 11 states. Doug is headquartered in Scottsdale, Arizona and has more than 35 years of experience in the water treatment industry, serving in capacities ranging from application engineering, system design, sales, and system start-up. Technologies applied through his career include Specialty Filtration, Reverse Osmosis, Seawater Desalination, Ultrapure Water, UV Disinfection, Ozonation and Industrial Process Water. Doug has spent several years now for AdEdge helping pioneer the commercial development of the biota biological treatment systems for groundwater treatment of Nitrate, Perchlorate and VOC's. Doug earned a BS degree in both Aquatic Biology and Chemistry from Northern Arizona University in 1981.

PFAS Treatment with Ion Exchange: Meeting the EPA Proposed MCL

The objective of this presentation is to review success stories using PFAS Selective Ion Exchange Resin for treatment of per - and polyfluoroalkyl substances, including why resin was chosen, how it works, and lessons learned. The presentation will walk through the decision process of when to use ion exchange and how to design and implement a full-scale system from modeling to piloting to site considerations. Case studies, with a focus on Arizona, and lessons learned will be reviewed. The audience will walk away with an appreciation of why states like California have chosen ion exchange resin in 80% of their PFAS treatment installations. Highlights will include:

- Review pending regulations and how ion exchange stacks up to other technologies.
- Show the process of going through the steps of design and modeling, piloting, and finally full-scale implementation for water sites with PFAS Selective Single Use Ion Exchange Resin.
- Review the accuracy of the throughput models.
- Discuss why ion exchange was chosen over alternative technologies for each site.
- Discuss the cost modeling and compare to GAC treatment.
- Show how resin deals with both short chain and long chain PFAS.
- Discuss how buffered resins can be provided where there are corrosivity and chloride to sulfate mass ratio (CSMR) concerns.
- Discuss best practices for disposal of spent resin.

Speaker Biography

Cathy Swanson – *Environmental Sustainability Segment Manager, Purolite*

Reference PFAS Treatment: Planning and Implementation Panel – Panel Biography's

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The PFAS Residuals Dilemma: Strategies and Solutions

New PFAS regulations, with stringent health advisory levels and an expanded list of compounds, have transformed the landscape for drinking water utilities. Compliance necessitates a thorough grasp of available water residuals treatment technologies. This presentation offers an overview of PFAS treatment technologies and delves into destructive technologies. Attendees will understand technology versatility, scalability, and economic considerations. The presentation presents byproduct formation during PFAS treatment and related management challenges. Furthermore, it assesses the real-world feasibility of implementing these technologies, providing practical insights for attendees to navigate the evolving PFAS treatment landscape.

Speaker Biography

Mary Lou Romero – *Prinicpal Engineer, Brown and Caldwell*

Mary Lou serves as a Principal Engineer at Brown and Caldwell, bringing extensive experience in wastewater and biosolids management planning and design. Additionally, in her role as Brown and Caldwell's PFAS lead for wastewater and biosolids, Mary Lou is dedicated to providing innovative solutions and ensuring compliance with evolving PFAS regulations. She is a part of BC's research team evaluating PFAS destruction technologies via bench scale and full-scale studies.

Moderator Biography's

Water Treatment Committee Chair

Frederick Tack – *Principal & National Wastewater Technical Practice Leader, Consor Engineers*

Frederick current serves as the chair of the AZ Water Association, Water Treatment Committee, and is a session moderator for this seminar. He also serves a Principal and with Consor Engineers.

Frederick is a licensed Civil Engineer, registered in Arizona, Colorado, Texas, and Washington. He is a 4x4 ADEQ Certified Water & Wastewater Operator, a Board-Certified Water Resource Engineer, and is a Certified Sustainability Professional. He holds a Bachelor of Science in Engineering Degree in Civil Engineering with a Minor in Urban Planning, and a Master of Science Degree in Civil, Environmental, and Sustainable Engineering from Arizona State University, and is a graduate of the Water Environment Federation, Water Leadership Institute in 2018, and was acknowledged as the AZ Water Association Engineer of the Year in 2016.

He has authored eight publications, over 45 conference and workshop presentations, and was an editor on the recent WEF/WPI Wastewater Treatment Fundamentals III, Advanced Treatment operations training manual released in 2022.

In addition to his role with AZ Water Association, he is also the current President of the National Society of Professional Engineers, Arizona Chapter, the Program Committee Chair for the Tri-State Conference, Reuse and Reclamation tracks, and is a member and advisory for the Arizona State University Friends of Civil & Environmental Engineering program, and for the University of Phoenix, Industry Advisory Council for Environmental Science degrees.

The focus of his practice over the past 23 years has been on conventional and advanced water treatment, with a unique focus on inland desalination and groundwater treatment, and wastewater treatment and reclamation design, operations, and management. Fredericks' personal mission is leading through innovation and collaboration, demonstrating proficiency, and spearheading sustainable initiatives and fostering improved equity in water utility infrastructure and management.

Water Treatment Committee Purpose:
Advancing water treatment knowledge to safeguard our communities' health, sustain life, and to increase the awareness of the ***value of water treatment*** *across our communities and industry.*

AZ Water Association
Professionals Dedicated To Arizona's Water

Water Treatment Committee Vice-Chair

Julie Woodworth – ***Engineering Manager, Black & Veatch***

Julie is an Engineering Manager at Black & Veatch, where she has been a key leader on water treatment plant expansion and improvement projects. She obtained her Bachelor of Science in Civil Engineering with a focus in Environmental from Purdue University. Her experience is inclusive of each aspect of a project, from design through construction. She has expertise in evaluating project elements through decision making based on life cycle costs and value-added, strong coordination skills with the project team, and in depth understanding on the intricacies of plant processes. Julie is a licensed Professional Engineer in the State of Arizona.

Water Treatment Committee Member

Ed Mears - *Business Development Manager, Garney Construction*

Ed started his career as a hydrogeologist investigating and treating soil and groundwater contaminants for private, state, and federal agencies across the US, Mexico, and Canada. Over the years he became more involved in estimating and proposal development eventually working in heavy civil construction as a Business Development Manager. Ed joined Garney's Phoenix office in 2023. Ed is a retired US Army Engineer Officer, serving 23 years in the Army Reserve with one-year deployment to Iraq in 2003 and one-year deployment to Afghanistan in 2010 and awarded two Bronze Star Medals. Ed has an associate degree from New Mexico Military Institute, Bachelor of Science from University of Texas at Arlington, and Master's in Business Administration from Arizona State University. Ed and his wife Deidre have two girls ages 15 and 11 and reside in Chandler.

PFAS Treatment Solutions

- Proven media solutions for PFAS; FLUORO-SORB, GAC, and IX
- Any size system and flow rate
- Skid-mounted, modular, and containerized systems available
- Standard designs or customized solutions to meet site-specific constraints
- Pre-and-post treatment processes and equipment for multi-contaminant removal challenges
- Treatment as a Service (TaaS) options (systems for emergency treatment with a monthly fee)

ADEDGE EXPERTISE IS THE KEY

Many suppliers provide equipment that can be used for PFAS treatment, but cost effectively treating PFAS requires a more thorough understanding of how to combine process design and equipment design. Each potential solution has advantages and limitations and there is no “one size fits all” approach. AdEdge has the expertise and experience to guide you to the solution with the lowest total life-cycle cost – considering all aspects of the project, including site limitations, water quality, and permit requirements.

ATTENDEES

Help us improve!

We value your feedback and want to hear from you about this event. Let us know about your experience: scan the QR code and take a few minutes to complete the survey.

Arizona Department of Environmental Quality

Clean Air, Safe Water, Healthy Land for Everyone

2024 Arizona PFAS Forum: Industry Perspectives on Solutions

Presentations

ADEQ PFAS Updates

Sara Konrad, ADEQ TA Grants Project Manager

Arizona PFAS Forum:
Industry Perspectives on Solutions

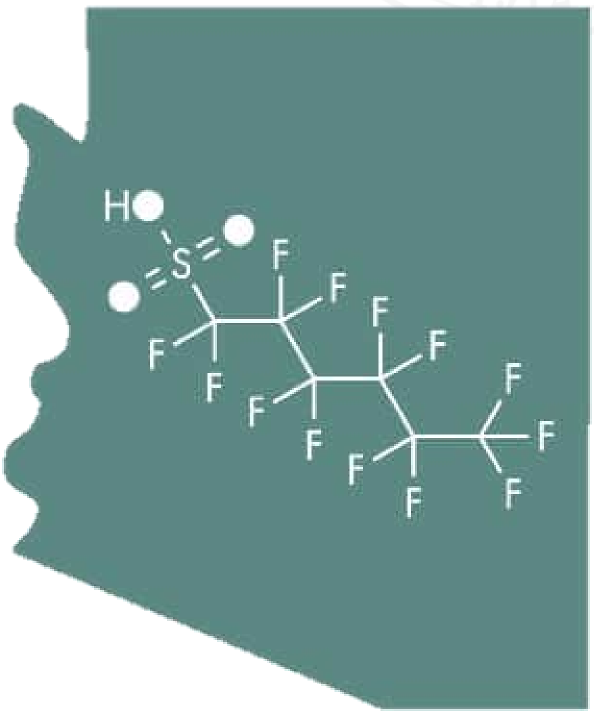
February 1, 2024

ADEQ
Arizona Department of Environmental Quality

Clean Air, Safe Water, Healthy Land for Everyone

Outline

- EPA Updates
  - Timeline of Proposed Rule
  - PFAS Piloting Assistance
  - UCMR 5 Sampling
- ADEQ Updates
  - ADEQ Sampling Project
  - Resources
  - Hydrogeologic Studies
  - Funding Resources



Timeline of Proposed Rule

- March 14, 2023: EPA announced the proposed National Primary Drinking Water Regulation (NPDWR) for six PFAS:
  - PFOA
  - PFOS
  - PFNA
  - HFPO-DA, commonly referred to as GenX Chemicals
  - PFHxS
  - PFBS
- December 15, 2023: EPA sent the PFAS NPDWR to the White House Office of Management & Budget (OMB)
- Early 2024: EPA expects to finalize rule

EPA PFAS Piloting Assistance

ADEQ Arizona Department of Environmental Quality

EPA United States Environmental Protection Agency

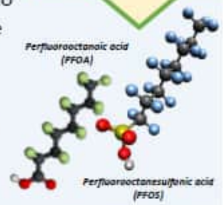
Technical Assistance Project for Treating Emerging Contaminants

Nicholas Dugan and Thomas Speth
Office of Research and Development (ORD)

EPA is looking for additional communities!

Introduction

- EPA's ORD is conducting a technical assistance project to help communities determine the most cost-effective approaches for removing emerging contaminants (EC) from drinking water.



- **The initial focus is on PFAS,** but other contaminants will be considered, such as lithium; manganese; and 1,4 dioxane.

Approach

- Partnering with systems that are **piloting**, running a **full-scale emergency treatment unit**, or have installed a **permanent full-scale unit.**
- Working with systems that are contemplating **residuals treatment**, specifically, reverse osmosis concentrate, granular activated carbon reactivation, and ion exchange regeneration.
- Optimizing treatment approaches with systems and developing a national database of approximately 50 systems so that all utilities can benefit.

Community Benefits

☑ **EPA-funded evaluation of the performance and operation of your EC treatment system.**

- EPA will pay for bottles, shipping, training, and analytical costs.
- All sampling results will be shared with the community.
- Results will be used to provide support for design (if evaluating a pilot system) and long-term operational optimization.
- EPA will pay for the residual treatment pilot systems, and in rare cases, the primary treatment pilot systems.

☑ **Tools, apps, and informational guides on the design, performance, operation, and cost of EC treatment systems.**

- The tools and apps will be trained with the data from your community's system for increased accuracy for further optimization evaluations.
- The tools and apps will allow your utility to see what other utilities have done.

☑ **Direct access to EPA/ORD technical experts.**

☑ **A connection to other EPA technical assistance programs (DWSRF application support, final design, AWOP, etc.).**

☑ **Depending on your state, ability to use the results for compliance sampling.**

☑ **An opportunity to collaborate on presentations and publications, including material for your community.**

Specific Needs/Criteria/Prioritization

What's needed from a prospective community

1. **Engage in a long-term sampling project for at least one year.**
2. **Collect samples after initial training.**
3. **Share water quality, design, cost, and operational data with EPA.**

Water quality criteria for system selection

- Sites with relatively high PFAS/EC concentrations.
- Sites that have different concentrations of water quality constituents (e.g., TOC, sulfate, nitrate, phosphate, chloride).
- Will prioritize systems with co-occurring contaminants (e.g., nitrate and cyanotoxins).

General system criteria for system selection

- Address unique residual stream issues/concerns.
- Start sampling at initial system startup or immediately following media replacement.
- Media columns with available mid-point sampling (preferred) to resolve breakthrough curves prior to media changeout.
- **Will prioritize small and/or underserved communities, including non-transient non-community water systems** (e.g., schools and hospitals), but will consider larger utilities if they offer unique water quality conditions.

Source: EPA's Office of Research and Development

Conditions to Capture

A wide variety of conditions are needed

- Concentrations of emerging contaminants (EC) / PFAS
- Background water quality
- Other contaminants
- Size of system
- Technical assistance needs
- Choice of technology
- Residual treatment
- Timing
- Desire to work with EPA
- Desire to commit to a long-term project
- Geographic dispersion

Slide source: EPA December 2023 presentation "ORD's Technical Assistance Program for Emerging Contaminants"

Community Selection: Eligibility

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Arizona Department
of Environmental Quality

Eligible for this program *(Any system that can access the DW-SRF)*

Non-Profit (public)

- Community
- Non-Transient Non-Community
- Transient Non-Community

For Profit (private)

- Community

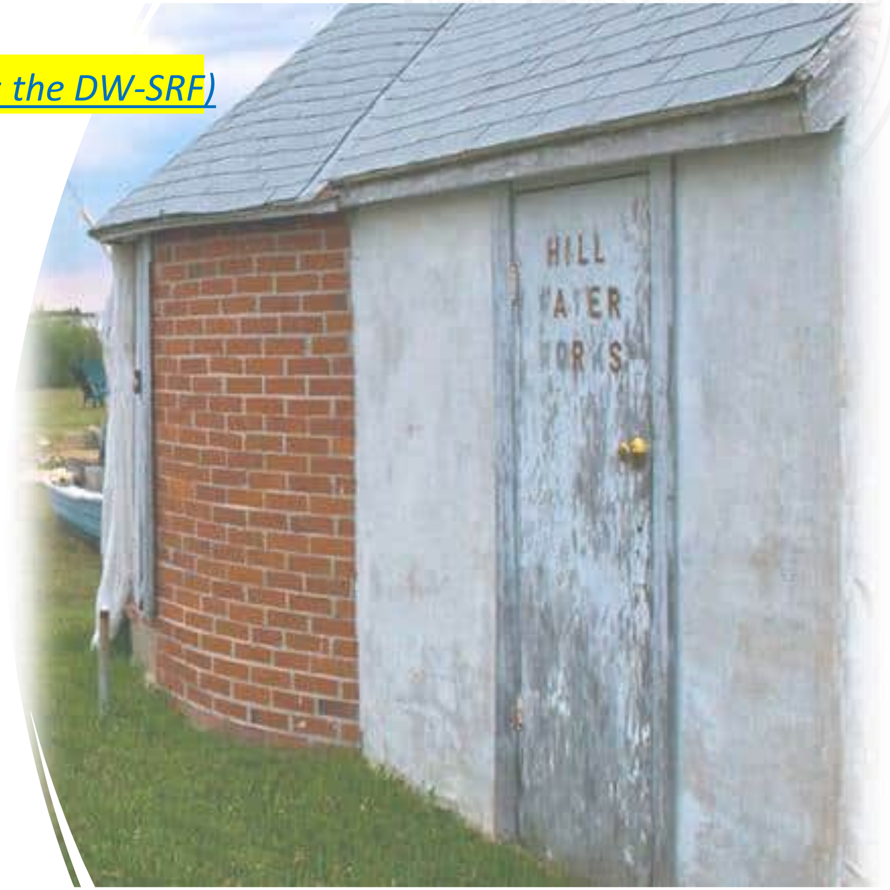
Tribally-owned systems

Not eligible

For-Profit (private)

- Non-Transient Non-Community
- Transient Non-Community

Federally-owned tribal systems



Slide source: EPA December 2023 presentation “ORD’s Technical Assistance Program for Emerging Contaminants”

Benefits to the system/community

ADEQ Arizona Department of Environmental Quality

- EPA-funded in-depth evaluation of the performance and operation of EC/PFAS treatment systems (6 months to multiple years)
  - Data collected with be made available to help local decision making on optimization of both the new technology and entire treatment scheme
- Access to new tools, apps, and informational guides on the design, performance, operation, and cost of EC/PFAS treatment technologies trained with the utility's data
  - Direct access to EPA's technical experts
- Potential use of EC/PFAS data for use as regulatory sampling (state dependent)
- An opportunity to collaborate with the EPA on presentations, publications, and other materials especially for the local community

Slide source: EPA December 2023 presentation "ORD's Technical Assistance Program for Emerging Contaminants"

EPA PFAS Piloting Assistance Contacts

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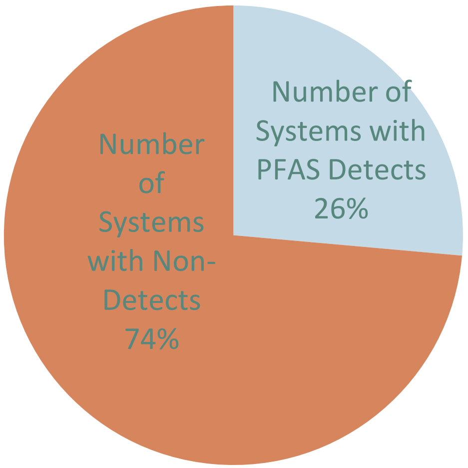
Slide source: EPA December 2023 presentation “ORD’s Technical Assistance Program for Emerging Contaminants”

EPA UCMR 5 Sampling

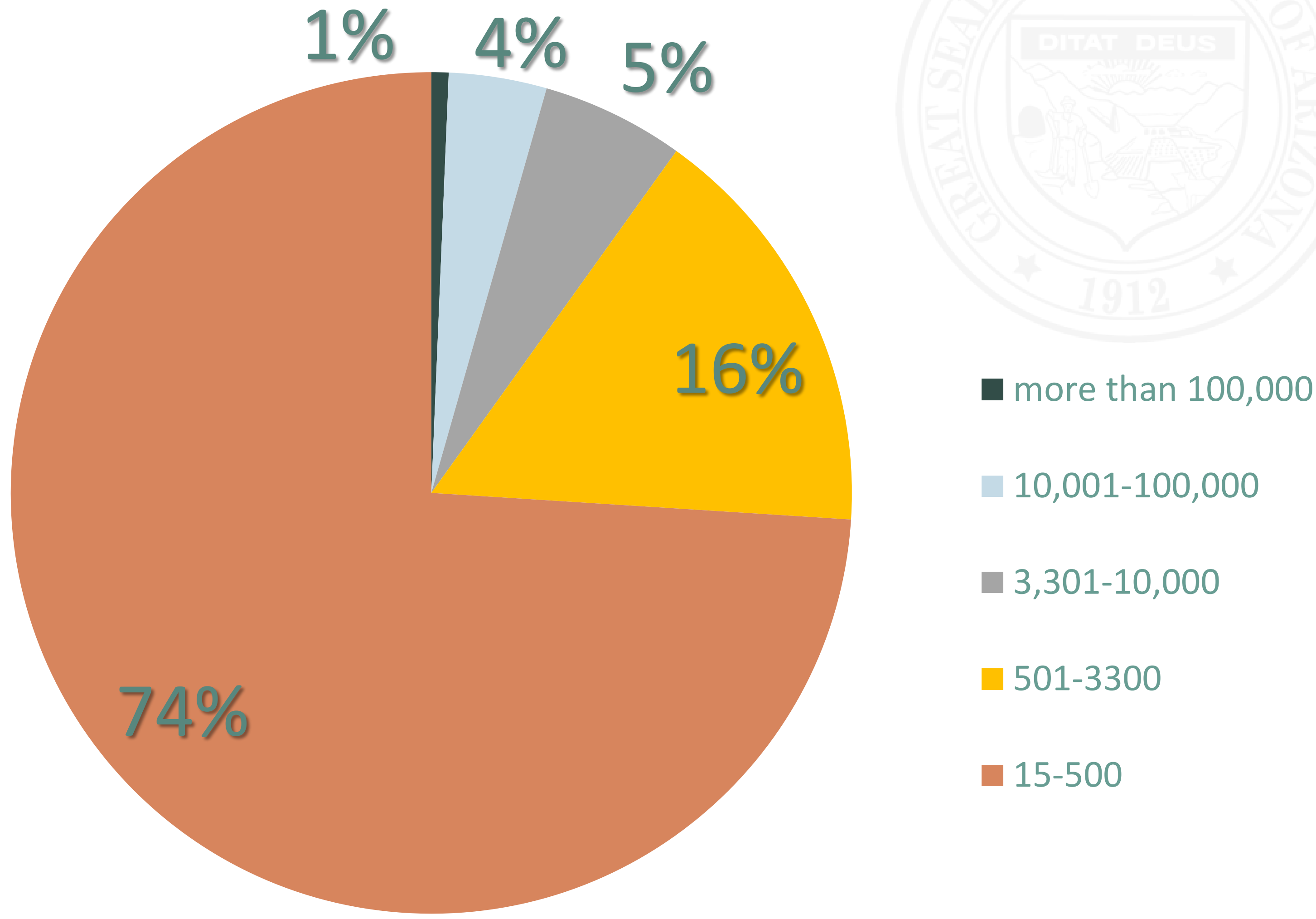
- Unregulated Contaminant Monitoring Rule (UCMR)
  - Established in 1996 to monitor drinking water for contaminants that are not yet regulated under the Safe Drinking Water Act (priority unregulated contaminants)
- UCMR 5
  - Applies to public water systems (PWS) serving 3,300 people or more
  - Between 2023 and 2025
  - Requires sample collection for 29 PFAS compounds
    - EPA Method 533 and EPA Method 537.1

Arizona UCMR 5 Results to date

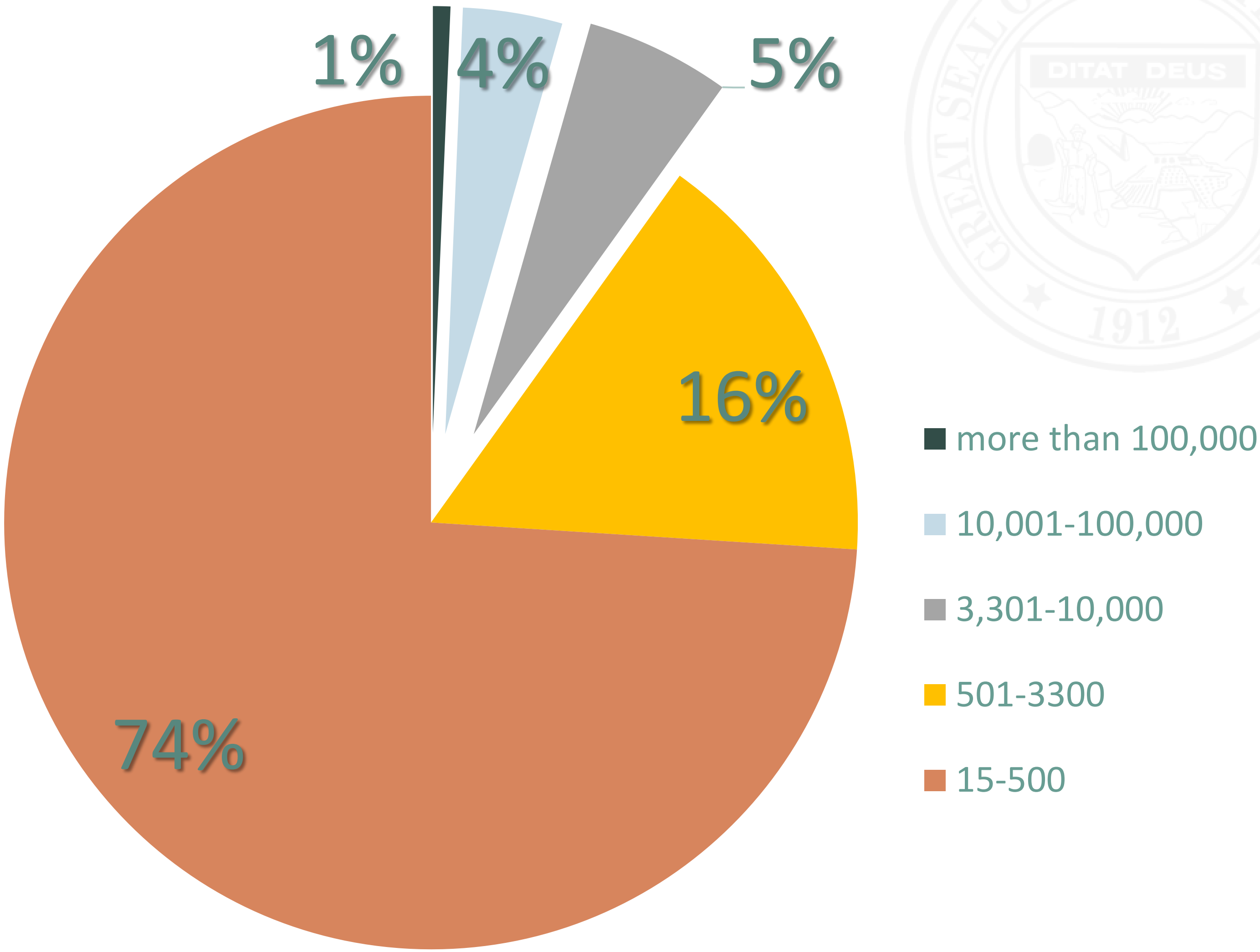
(53 systems sampled)



Arizona PWS Size, by Population Served



Arizona PWS Size, by Population Served



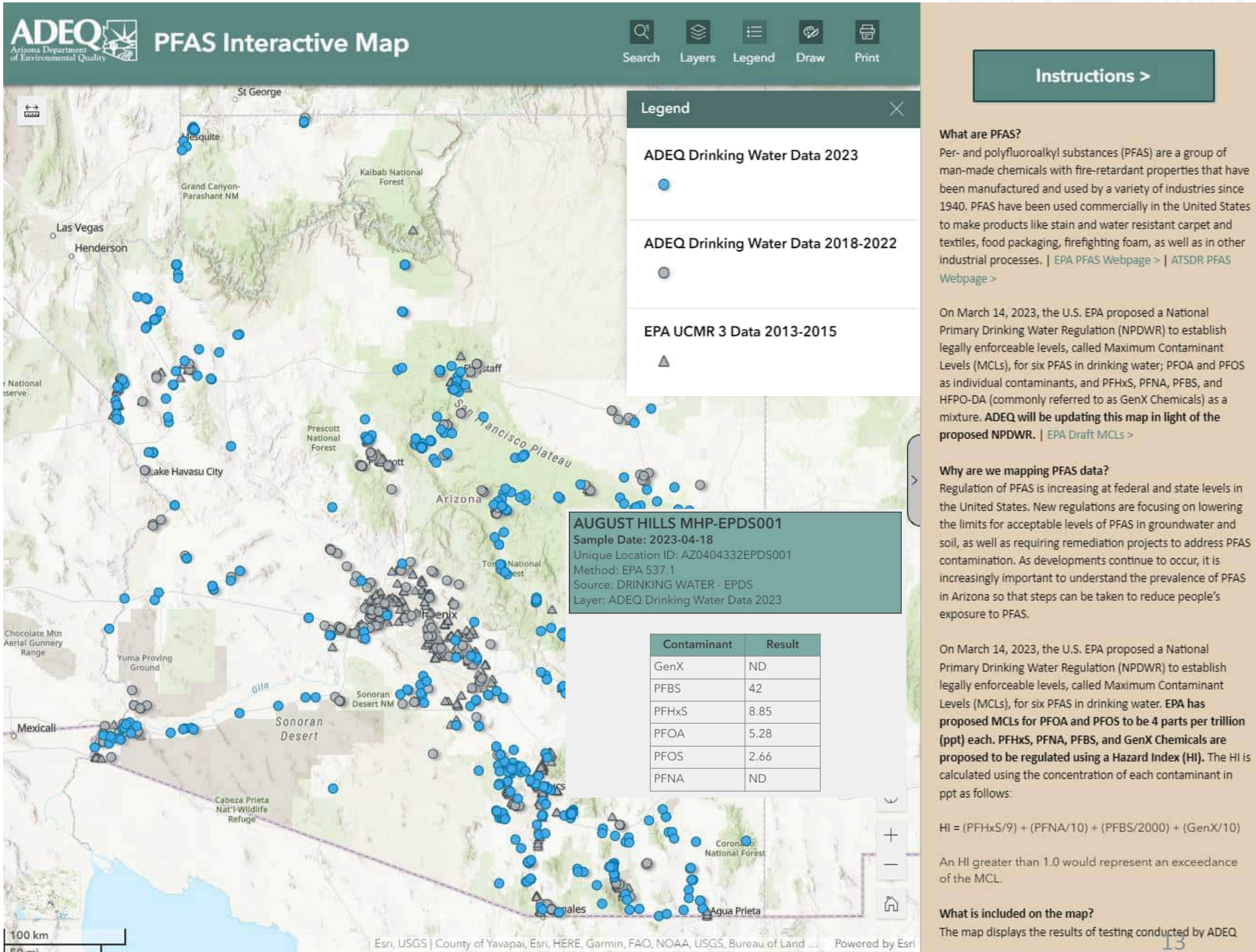
ADEQ Sampling Project

December 16, 2022
PRESS RELEASE
ADEQ Initiates Proactive $3M Public Water System Sampling Plan to Protect Arizona's Drinking Water from Per- and Polyfluoroalkyl Substances (PFAS) Contamination

bit.ly/AZSampling-PFAS

- Free baseline screening for small water systems
- Provide results to PWS owners
- Supply data to ADEQ PFAS Interactive Map

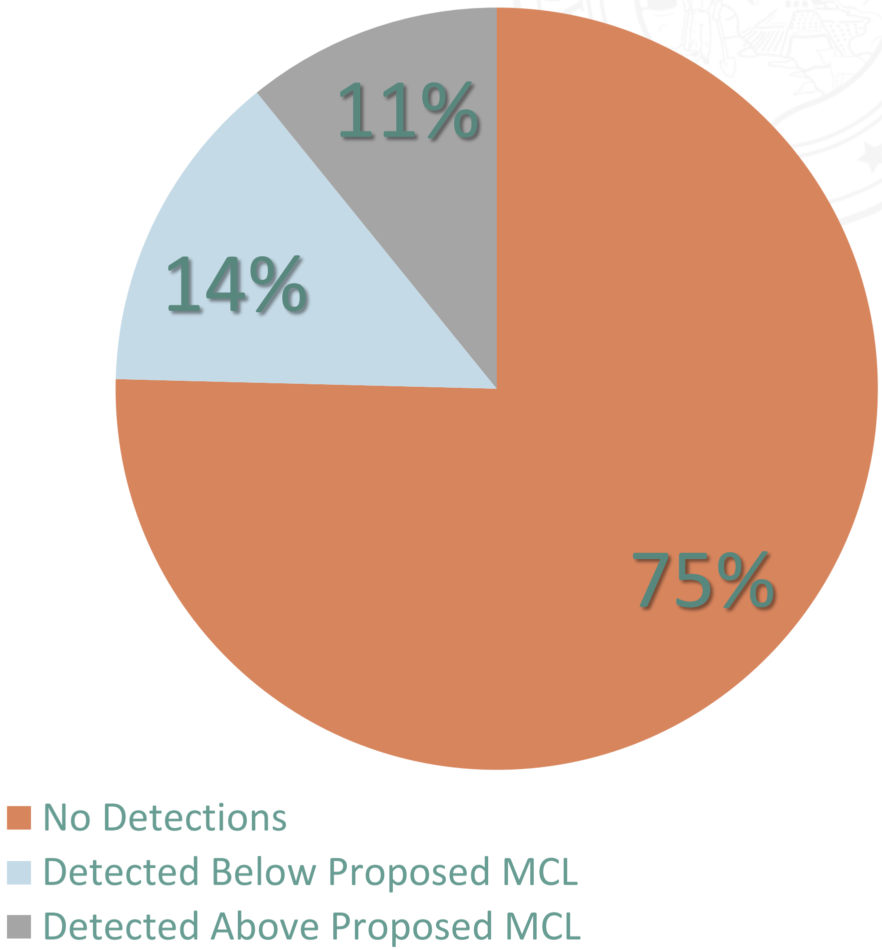
PFAS Interactive Map



bit.ly/myPFASmap

Current Sampling Status

- Sampling ≈750 PWSs for PFAS compounds
- As of 1/30/24
  - **90% complete**
  - Completing first round of testing
  - Beginning second round of testing



www.azdeq.gov/pfas-resources

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Arizona Department of Environmental Quality

— PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)

PFAS Resources

Revised on: August 19, 2023 - 12:01 a.m.

ADEQ is monitoring scientific, regulatory and legal developments related to PFAS (per- and polyfluoroalkyl substances) and participating in related discussions with federal, state and local agency partners. PFAS exposure is linked to potential adverse human health outcomes and is the subject of increasing regulation and litigation. To keep the public and other stakeholders informed, ADEQ will update this PFAS Resources webpage with new information as it becomes available.

What are PFAS?

PFAS are a group of man-made chemicals with fire-retardant properties manufactured and used by various industries since the 1940s. PFAS have been used commercially in the United States to make products like stain and water-resistant carpets and textiles, food packaging, firefighting foam, and other industrial processes. The most studied PFAS compounds in the environment are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). Since 2000, many industries have phased out the use of some PFAS | Learn More ATSDR PFAS >

- PFAS 101 Fact Sheet | View/Download >

What PFAS regulations are there?

PFAS regulations are increasing at federal and state levels in the United States. New regulations are focusing on decreasing their use in manufacturing, lowering the limits for acceptable levels of PFAS in groundwater and soil, and requiring remediation projects to address PFAS contamination.

What is the Environmental Protection Agency (EPA) doing?

In March 2023, EPA proposed a National Primary Drinking Water Regulation (NPDWR) to establish legally enforceable levels, called Maximum Contaminant Levels (MCLs), for six PFAS in drinking

— INTRODUCTION TO PFAS IN ARIZONA

Watch a Video

CONTACT

SEE MORE

- AFFF Resources >
- AFFF Pilot Program Map >
- Industry & PWS Screening >
- PFAS 101 >
- PFAS Map >
- PFAS & You >
- Protecting Tucson's Water >
- Luke AFB Area PWS Data >

ADDITIONAL RESOURCES

www.azdeq.gov/pfas-resources

ADEQ Arizona Department of Environmental Quality

perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). Since 2000, many industries have phased out the use of some PFAS | Learn More ATSDR PFAS >

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PFAS regulations are increasing at federal and state levels in the United States. New regulations are focusing on decreasing their use in manufacturing, lowering the limits for acceptable levels of PFAS in groundwater and soil, and requiring remediation projects to address PFAS contamination.

What is the Environmental Protection Agency (EPA) doing?

In March 2023, EPA proposed a National Primary Drinking Water Regulation (NPDWR) to establish legally enforceable levels, called Maximum Contaminant Levels (MCLs), for six PFAS in drinking water; PFOA and PFOS as individual contaminants and PFHxS, PFNA, PFBS, and HFPO-DA (commonly referred to as GenX Chemicals) as a mixture.

Additional information on EPAs website:

- PFAS | View >
- EPA Actions | View >
- EPA Draft MCLs | View >

What is Arizona doing?

- Industry & Public Water System Screening | Learn More >
- Public Water System PFAS Data (Luke Air Force Base Area) | Learn More >
- Protecting Tucson's Drinking Water Supply | Learn More >

ADDITIONAL RESOURCES

Agency for Toxic Substances and Disease Registry

- PFAS & Your Health >
- Toxicological Profile for Perfluoroalkyls >

Advisory Panel on Emerging Contaminants

- About APEC >
- Final Report 2016 >

ADEQ

- AZ Public Water System PFAS Toolkit >
- Guidance for the Public >
- Guidance for Utilities >
- How to Sample Your Tap for PFAS >
- Letter to Health and Vector Control >
- Screening for PFOA/PFOS Report 2018 >

Arizona Department of Health Services

- PFAS Information Webpage >
- PFAS Infographic >
- Well Water Quality >

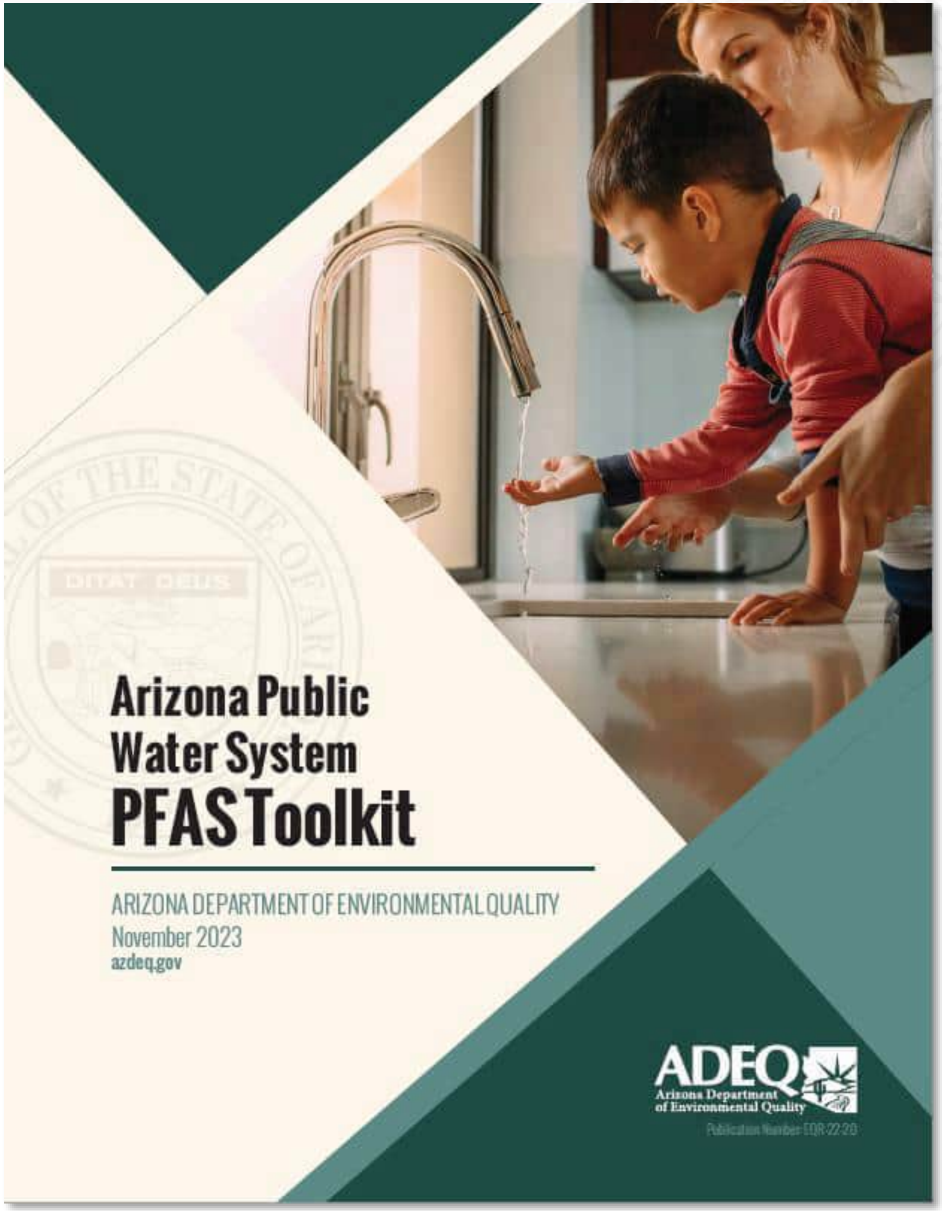
EPA

- PFAS >
- PFAS Action Plan & Updates >
- Drinking Water Health Advisories >

Arizona Public Water System PFAS Toolkit

- What are PFAS?
- Where do PFAS come from?
- Health Advisory Levels
- Test Methods
- Where to Sample
- What to do if you have PFAS
- Funding
- Non-Treatment Options
- Treatment Options
- Additional Resources

bit.ly/pfas-toolkit



Resources

azdeq.gov/pfas-resources

Coming soon:

- PFAS Decision Trees
- Protocols and Guidance for PFAS Pilot Testing

PFAS Decision Trees

ADEQ Arizona Department of Environmental Quality

Kimley»Horn

DRAFT

PFAS TREATMENT

DECISION TREES

Purpose

This document includes general Per- and Polyfluoroalkyl Substance (PFAS) treatment information and design considerations for specific PFAS treatment processes recommended by the U.S. Environmental Protection Agency (USEPA). The document is intended to assist the utility in making informed decisions about the most suitable treatment removal methods for addressing PFAS concerns found in their specific systems before delving into detailed design considerations. At the time of this document, the USEPA has proposed the National Primary Drinking Water Regulation (NPDWR) for six (6) PFAS and the document has not been finalized. This document is subject to revisions as the proposed NPDWR regulation is revised and finalized.

Introduction

Many factors must be considered when navigating the various PFAS treatment technologies. Despite many water systems not originally designed for PFAS removal, existing systems may unintentionally achieve it. Existing Granulated Activated Carbon (GAC), Ion Exchange (IX), Reverse Osmosis (RO), and Nanofiltration (NF) systems might currently be treating for PFAS in their source water, even if not originally designed to do so. Optimizing existing treatment processes can be a practical choice for utilities. The utility should collaborate with the Arizona Department of Environmental Quality (ADEQ) drinking water program to coordinate the evaluation, selection, and implementation process.

The quality of the source water influences the effectiveness of PFAS removal processes. Consequently, the process performance, the related operation and maintenance needs, and the disposal of residuals, determines the viability of a specific treatment approach. It is recommended that utilities diligently monitor water quality at all active sources in the initial stages to make well-informed decisions when selecting a treatment method. Background water quality is extremely important to keep in consideration when choosing a PFAS removal technology and pre-treatment is highly recommended or required in almost all instances. In addition, post-treatment disinfection is recommended due to potential for microbial growth on the media and membranes used in PFAS removal technologies.

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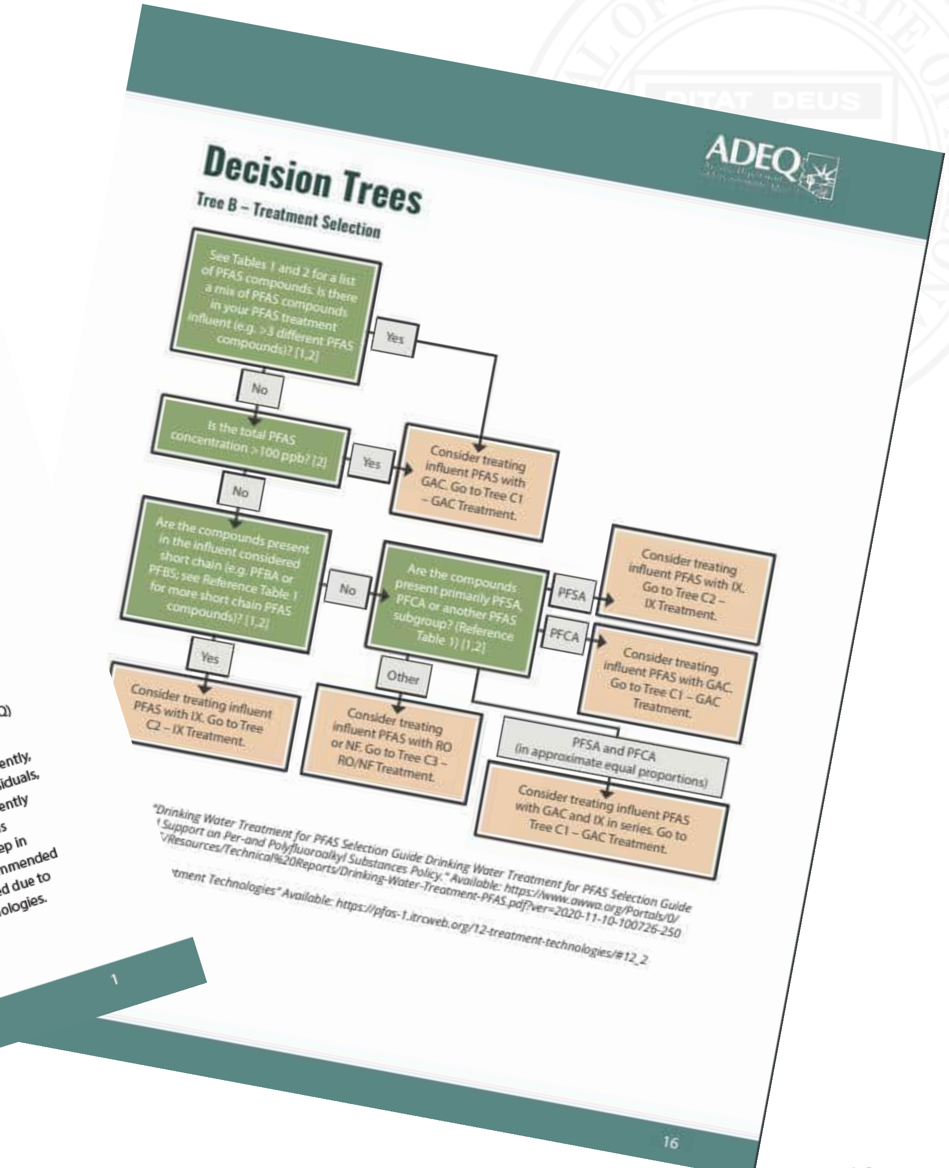


ADEQ

Decision Trees

Tree B – Treatment Selection

"Drinking Water Treatment for PFAS Selection Guide Drinking Water Treatment for PFAS Selection Guide
... Support on Per-and Polyfluoroalkyl Substances Policy." Available: https://www.awwa.org/Portals/0/
.../Resources/Technical%20Reports/Drinking-Water-Treatment-PFAS.pdf?ver=2020-11-10-100726-250

...tment Technologies" Available: https://pfas-1.itrcweb.org/12-treatment-technologies/#12_2

16

Protocols and Guidance for PFAS Pilot Testing

Past PFAS Trainings

ADEQ Arizona Department of Environmental Quality

PFAS Drinking Water Treatment Webinar

- Audience: engineering firms (technical content)
- November 2, 2023
- Recording available on ADEQ's YouTube channel https://rb.gy/vfpzvp

PFAS 101 Workshop

- Audience: water system owners and operators
- November 6, 2023
- Recording available on ADEQ's YouTube channel https://rb.gy/vfpzvp

rb.gy/vfpzvp

Today's Forum hosted by ADEQ

Hydrogeologic Studies

- Conduct hydrogeologic studies to evaluate potential treatment alternatives
  - Evaluate all existing hydrogeologic information and PFAS sampling data
  - Fill data gaps by conducting fieldwork (e.g., sampling, monitoring well installation, etc.)
  - Create a conceptual site model for targeted counties
- Ultimate goal: help water providers assess alternatives
- Targeted areas:
  - Prescott/Prescott Valley/Chino Valley vicinity, Yavapai County
  - Globe/Payson, Gila County
  - Santa Cruz River Vicinity, Santa Cruz County/Southern Pima County

PFAS Funding	
Amount	$47,000,000
Restrictions	• Emerging contaminants • Public water systems that serve <10,000 people or serve a disadvantaged community
Uses	• Projects for public water systems ($45M) • Hydrogeologic Studies ($1M) • Outreach, training, reference materials ($1M)
Timeframe	October 1, 2023 – September 30, 2028

PFAS Mitigation Strategies

- ADEQ will select public water systems most in need
  - Highest levels of PFAS
  - Small or disadvantaged
  - Non-competitive
  - Appropriate solutions
  - System must agree to participate
- ADEQ will contract directly with design engineers and construction contractors
  - ADEQ will handle all payments

PFAS Mitigation Strategies

Appropriate solutions for small or disadvantaged systems:

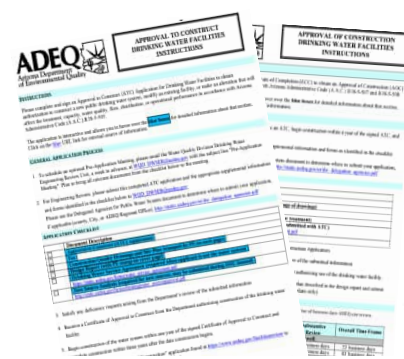
- Treatment not always best approach
- Cost must be commensurate with benefit
- Non-treatment alternates such as consolidation, interconnection, deeper wells may be better approach
  - Fast, cost-effective, sustainable
  - Long-term O&M of treatment system
    - Cost of media
    - Change out of media
    - Disposal of spent media
  - Technical, managerial, financial capability
    - Ease of operation
    - Level of operator certification

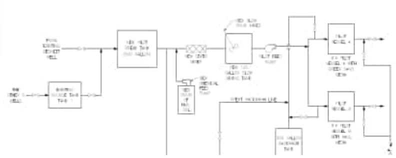
Eligible Uses of Funds

- Confirmation sampling and water quality parameter sampling
- Compliance Option Evaluation
- Design
- Permitting fees
- Project management
- Cost overruns
- PFAS mitigation
  - Treatment
  - New well
  - Restructuring
  - Consolidation



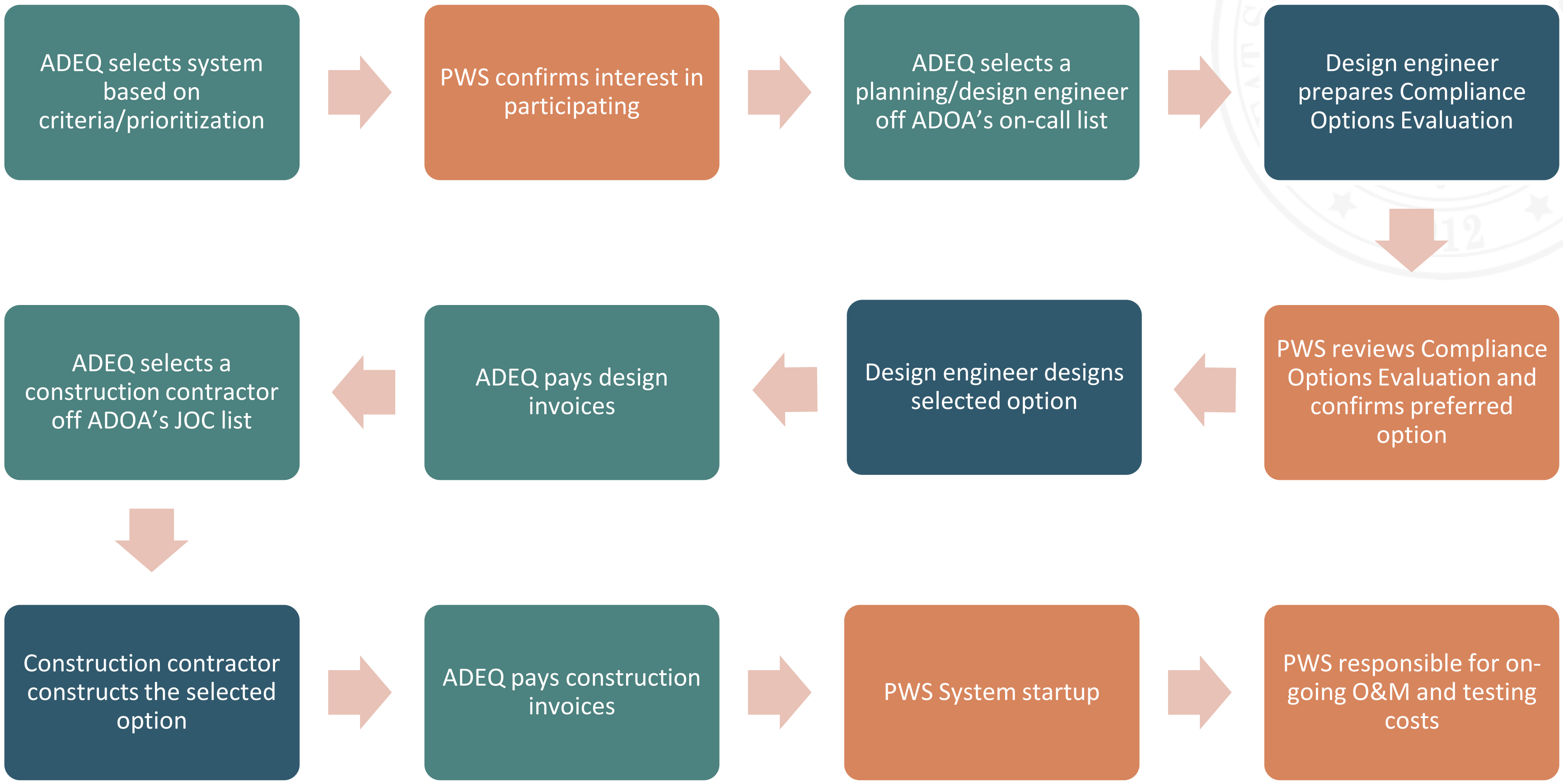






- *Can address other contaminants but must be primarily for PFAS / emerging contaminants*

Process


ADEQ selects system based on criteria/prioritization
PWS confirms interest in participating
ADEQ selects a planning/design engineer off ADOA's on-call list
Design engineer prepares Compliance Options Evaluation
PWS reviews Compliance Options Evaluation and confirms preferred option
Design engineer designs selected option
ADEQ pays design invoices
ADEQ selects a construction contractor off ADOA's JOC list
Construction contractor constructs the selected option
ADEQ pays construction invoices
PWS System startup
PWS responsible for on-going O&M and testing costs

In the News

AZCentral | The Arizona Republic

Globe will receive state support to deal with PFAS-contaminated water

Clara Migoya, Arizona Republic

Two mobile home parks outside Globe's city limits will be connected to the municipal water system due to concerns over PFAS water contamination.

The Arizona Department of Environmental Quality detected some chemicals in private wells that supply residents in HAV Properties and August Hills. A partnership between the agency and the city will help connect these residents to the city supply, which is PFAS free, said Globe City Manager Paul Jepson.

PFAS, short for perfluoroalkyl and polyfluoroalkyl substances, are chemicals of increasing concern worldwide.

Industries have manufactured and used PFAS chemicals in a wide variety of products for decades and traces of them can now be found globally in water and soil. Many of them don't break down easily and are difficult to get rid of, they've been dubbed "forever chemicals."

Scientific evidence shows that long term exposure to some of these chemicals can cause severe health issues that include cancer, developmental effects and reproductive disorders. Exposure to PFAS through drinking water is a main concern, but currently, there are no rules enforcing limits on public water systems.

KTAR NEWS 92.3 FM

ARIZONA NEWS

Globe, 2 other Arizona water systems to receive funding to combat PFAS

(Google Maps screenshot)

BY TOM KUEBEL
KTAR.com

PHOENIX – Three public water systems will receive funding to help ensure drinking water is not contaminated by perfluoroalkyl and polyfluoroalkyl substances (PFAS).

Governor Katie Hobbs and the Arizona legislature allocated $5 million to the Arizona Department of Environmental Quality to determine what water sources were vulnerable to PFAS chemicals.

"The City of Globe, HAV Properties and August Hills Mobile Home Park are the first three public water systems in the state to benefit from this important PFAS funding," ADEQ cabinet executive officer Karen Peters said in a release.

ADEQ PFAS Contacts

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$42M Grants Project Manager

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Jasmina Markovski, PhD, PE

Senior Engineer

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Matthew Olson

$5M Grants Project Manager / PFAS Sampling Project Manager

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azdeq.gov/pfas-resources

ADEQ

Arizona Department of Environmental Quality

Clean Air, Safe Water,
Healthy Land for Everyone

WATER INFRASTRUCTURE
FINANCE AUTHORITY OF ARIZONA

Funding Opportunities and the Application Process

2024 AZ PFAS Forum: Industry Perspectives on Solutions Seminar

Lindsey Jones
Assistant Director – Water Projects
Water Infrastructure Finance Authority
www.azwifa.gov

WIFA'S MISSION

To ensure the sustainability of Arizona's present and future water supply through financial investments in effective augmentation, conservation, reuse, and water quality actions.

LEGISLATIVE DIRECTION

WIFA is established for the benefit of current and future residents, the economy, and the environment of this state. WIFA shall accomplish its purposes of helping to meet existing and future water needs of this state by developing or facilitating water conservation, reuse, and augmentation projects.

WATER INFRASTRUCTURE
FINANCE AUTHORITY OF ARIZONA

WIFA'S FUNDING OPPORTUNITIES

→ **Clean Water SRF**
Loans, technical assistance to political subdivisions for wastewater and stormwater projects

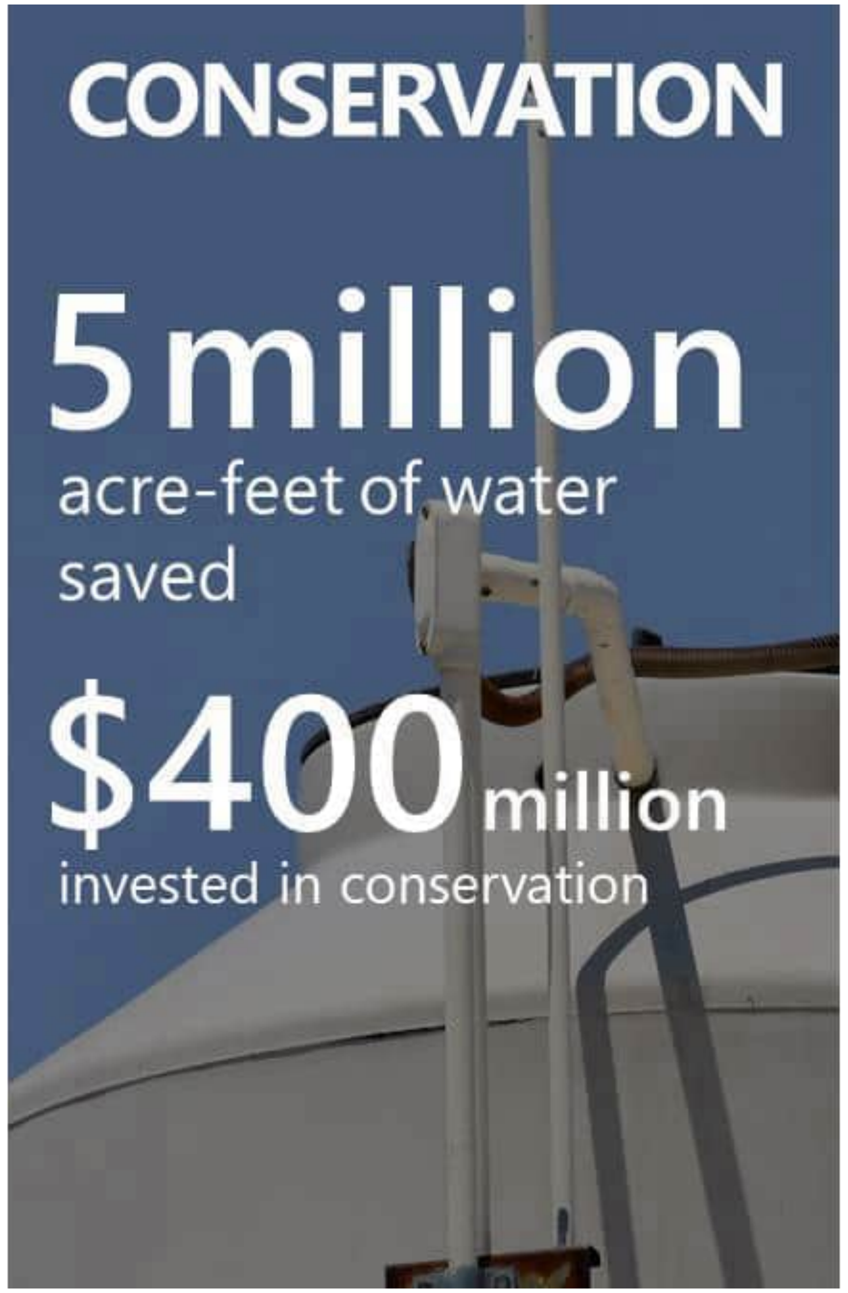
→ **Drinking Water SRF**
Loans, technical assistance to public water systems for drinking water infrastructure

→ **Water Supply Development RF**
Loans and technical assistance for water supply development outside of urban centers

→ **Water Conservation Grant Fund**
Grants to governmental and non-governmental organizations for projects that promote conservation and decrease water use

→ **Long-Term Water Augmentation Fund**
For projects that import water into Arizona and in-state augmentation projects

FIVE-YEAR STRATEGIC FRAMEWORK



RELIABILITY

Water Supply Development Revolving Fund

Goals of Fund

- Allowing communities without ready access to a variety of water supplies to acquire water or water rights to augment their water supply

- Plan, design, build, and develop facilities for conveyance, storage, reuse, groundwater replenishment, and conservation

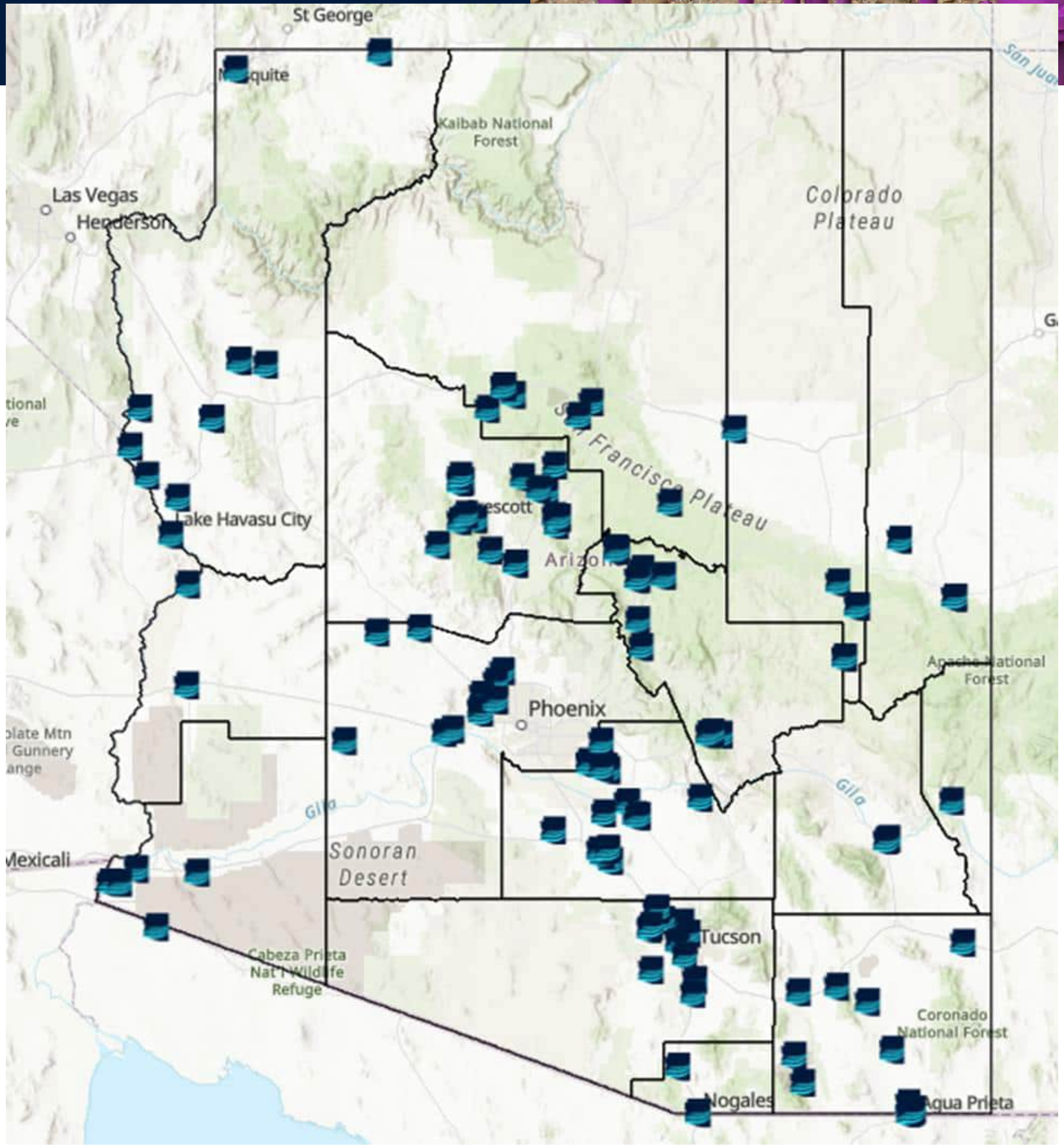
Funding Availability

- $190M available for grants (up to $2M) and loans (up to $3M)

Eligible Entities

- Water Providers (§ ARS 49-1201)
- Located outside of the Phoenix, Pinal, or Tucson AMAs

RELIABILITY



Nearly $3 Billion

In loans since 1989

$150+ Million

In forgivable principal since 2009

211 Borrowers

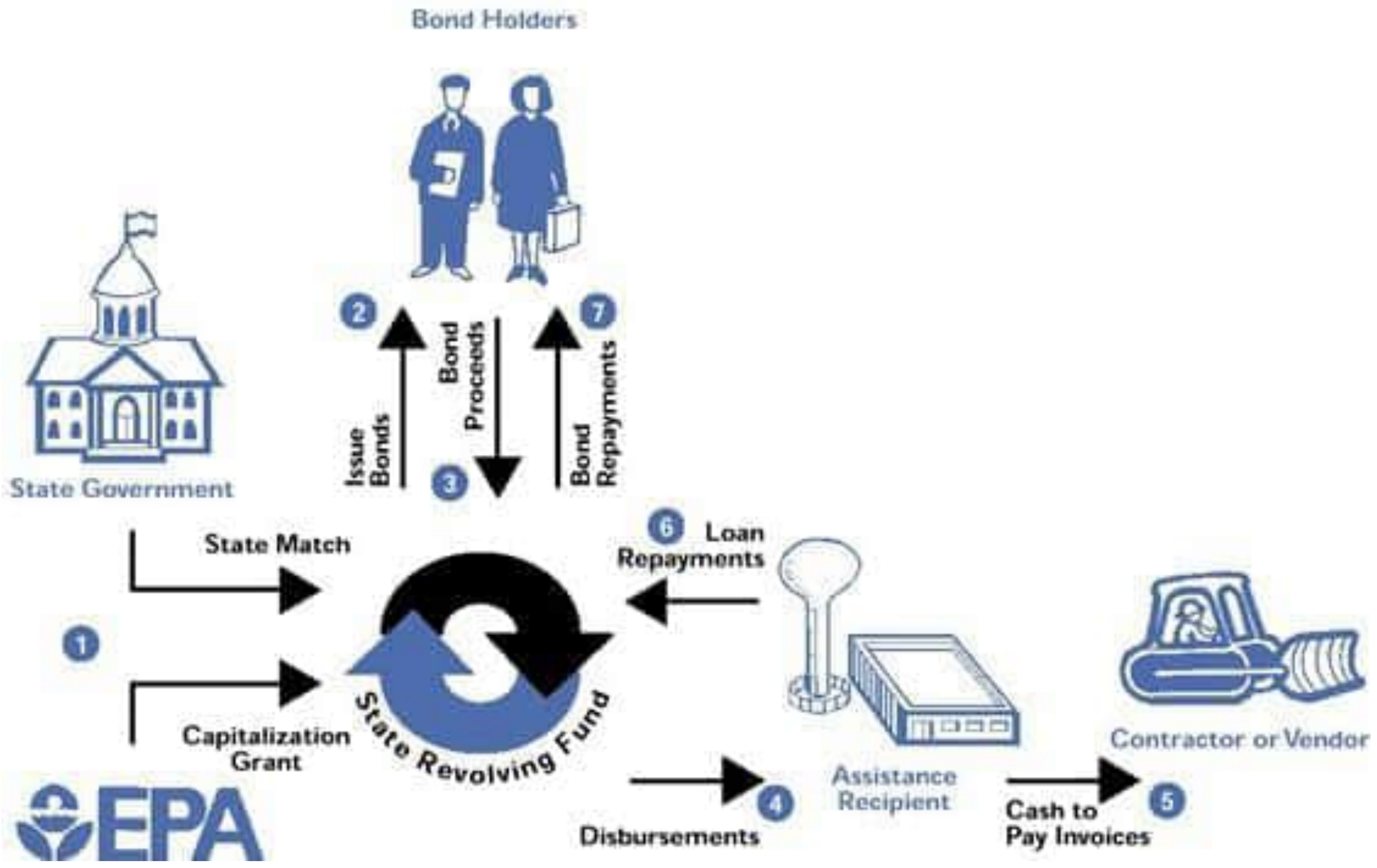
Throughout all of Arizona's Counties

AAA Credit Rating

With all major bond rating agencies

Low-Cost Lending Tools

- Subsidized Interest Rates
  - All WIFA loans are made at below-market interest rates.
  - Expressed as a Financial Assistance Index
- Forgivable Principal
  - Many WIFA loans only require the borrower to repay a portion of the principal - “forgiving” the remainder.
  - The amount of a loan that is considered forgivable principal is determined on an individual basis.



Bipartisan Infrastructure Law:

Goals

- **Target resources to disadvantaged communities.** It is a top priority for the EPA to ensure communities that have historically struggled to access SRF funding are prioritized.

- **Make rapid progress on lead-free water for all.** There is no safe level of exposure to lead, yet millions of families across America still suffer from lead contamination in their drinking water. President Biden has set an ambitious goal of replacing 100 percent of the nation's lead service lines.

- **Tackle forever chemicals.** The BIL provides an unprecedented level of funding dedicated to addressing perfluoroalkyl and polyfluoroalkyl substances (PFAS) and other emerging contaminants.

Forgivable Principal

WIFA FY2024 Base and IIJA Funding

As of: 7/01/2023

Fund	Grant	Available Forgivable Dollars
Drinking Water	Base	$4,232,620
	Supplemental (BIL)	$18,048,170
	Emerging Contaminants (BIL)	$13,365,000
	Lead Service Lines (BIL)	$14,038,500
Clean Water	Base	$2,026,800
	Supplemental (BIL)	$6,898,710
	Emerging Contaminants (BIL)	$1,436,000

WATER INFRASTRUCTURE
FINANCE AUTHORITY OF ARIZONA

Fund Source	Loan forgiveness or grant amount
FFY 22 DWSRF EC	$13,587,000
FFY 22 CWSRF EC	$632,000
FFY 23 CWSRF EC	$1,436,000
FFY 24-FFY 26 CWSRF EC *(estimate)*	$4,308,000
FFY 23-FFY 26 DWSRF EC *(estimate)*	$54,348,000
SRF Subtotal	**$74,311,000**
FFY 22 and FFY 23 BIL – SDC-EC Grant	$42,196,000
FFY 24 – FFY 26 BIL – SDC-EC Grant *(estimate)*	$63,294,000
Small Disadvantaged Community EC Subtotal	**$105,490,000**
Grand Total	**$179,801,000**

Application Process

Milestones

01

Preliminary Application

Preliminary application is submitted through our online portal at www.applicant.azwifa.gov

02

Obtain Debt Authorization

Applicant's governing body obtains Debt Authorization and completes the Project Finance Application.

03

Board Review and Approval

Applicant attends a bi-monthly Federal Programs Committee Meeting.

Recommended projects presented to Board the following month for approval

Loan is executed and funding is available

Project Priority List

PPL Ranking Criteria

Drinking Water	Clean Water
Current Condition Based on ADEQ's Master Priority List - higher score for smaller systems and systems with a need to resolve violations	**Current Condition** Higher score if project resolves surface/groundwater pollution issue
Water System Improvement Higher score if project resolves deficiency identified by EPA/ADEQ	**Water Quality Improvement** Higher score if project protects surface/groundwater quality, resolves non-point source pollution, or protects wellhead area
Water and Energy Efficiency Higher score for green projects such as adding solar to system	**Water and Energy Efficiency** Higher score for green projects such as adding solar to system
Consolidation and Regionalization Higher score for consolidating systems or extending services to unserved population	**Consolidation and Regionalization** Higher score for septic to sewer
Prior Year Funding Higher score if project received funding in previous funding cycle	**Prior Year Funding** Higher score if project received funding in previous funding cycle
Local Fiscal Capacity Based on MHI, user rates, and debt per connection. Communities with low MHIs, high water/wastewater rates, high levels of existing/proposed debt, and low population levels will score higher	**Local Fiscal Capacity** Based on MHI, user rates, and debt per connection. Communities with low MHIs, high water/wastewater rates, high levels of existing/proposed debt, and low population levels will score higher

Project Priority List

The Project Priority List (PPL) application allows us to:

- Score and rank a project
- Determine if the community qualifies as disadvantaged
- Determine the level of discount that will be applied to an interest rate
- Assign a project manager who will walk applicant through the next steps

WATER INFRASTRUCTURE
FINANCE AUTHORITY OF ARIZONA

Thank you!

Lindsey Jones
Assistant Director – Water Projects
Water Infrastructure Finance Authority
www.azwifa.gov

PFAS Treatment: Permitting Considerations and Engineering Support

Jasmina Markovski
Senior Engineer
2/1/2024

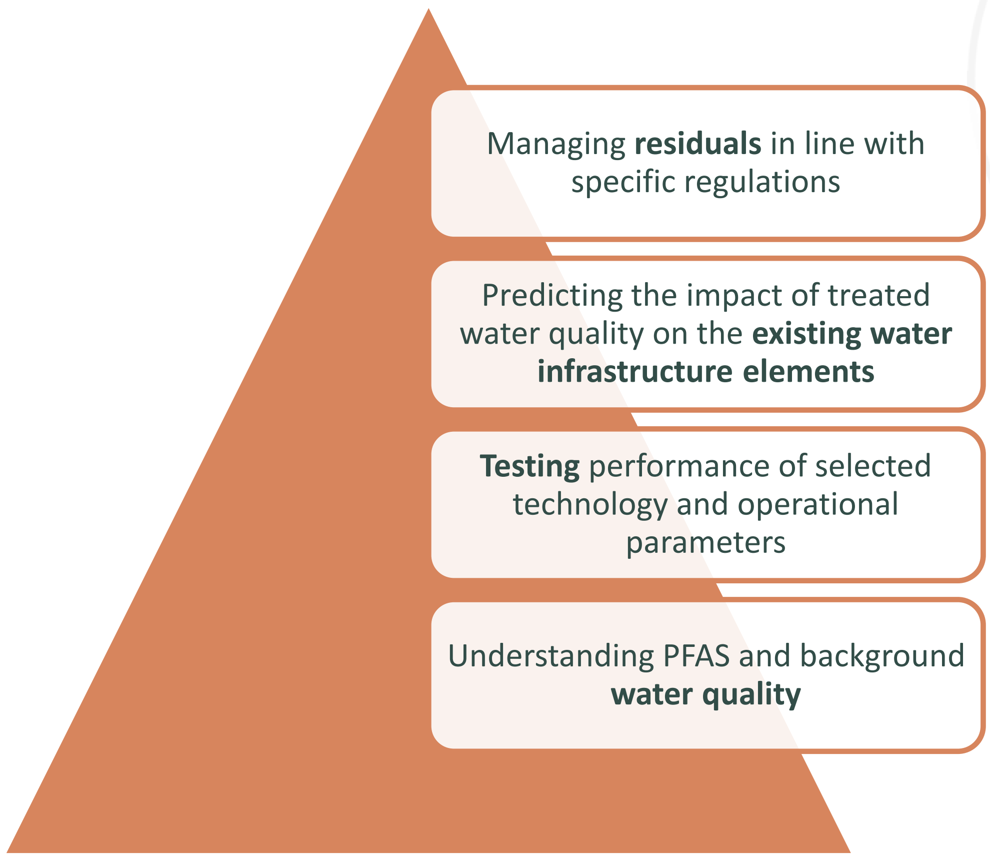
ADEQ
Arizona Department of Environmental Quality
Clean Air, Safe Water, Healthy Land for Everyone

Outline

- Permitting Goals and Objectives
- Treatment Approach
- Six Steps in the Permitting Process
- Lessons Learned
  - Pretreatment
  - Preparation Upfront Testing
  - Modeling
- ADEQ Engineering Support

Permitting Goals and Objectives

Long Term and Simultaneous Compliance



Complexity of PFAS contamination
Challenging treatment goals
Existing knowledge gaps

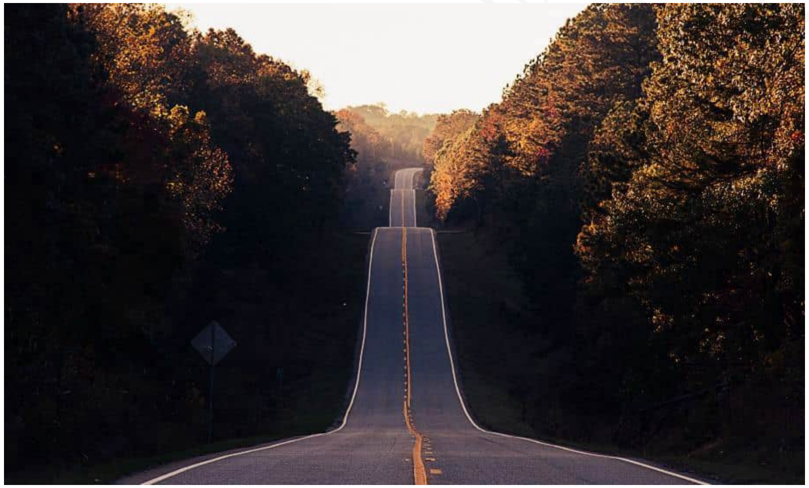
Treatment Approach

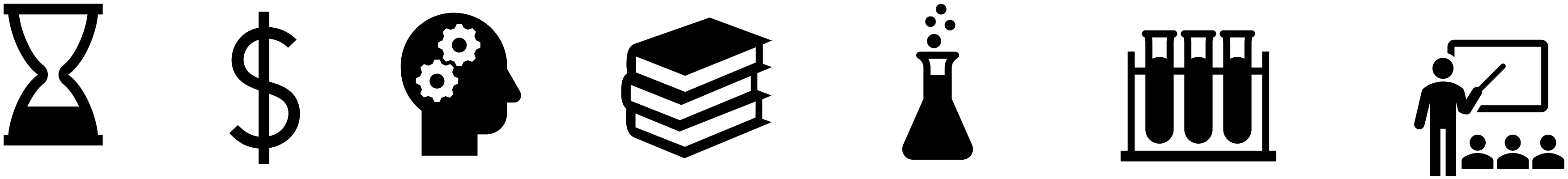
ADEQ **recommends but does not limit** the installation of best available technologies (BAT) as the most reliable options that already have demonstrated effectiveness at full scale in the field.

BAT

vs

Innovations





Six Steps in the Permitting Process

ADEQ Arizona Department of Environmental Quality

1 **Sampling and Analysis of Water Quality Parameters (WQPs)**
To determine PFAS speciation and interferences.

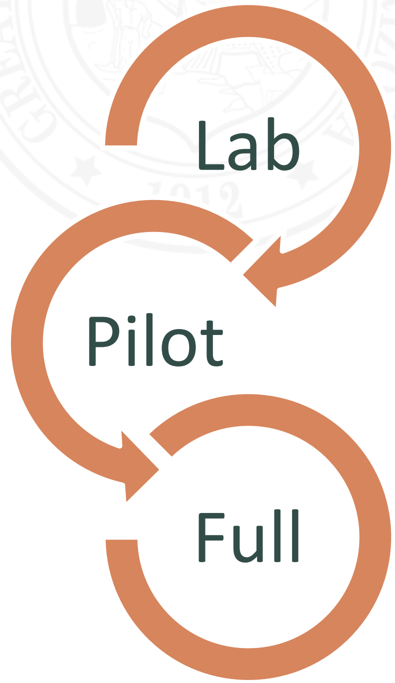
2 **Preliminary Design**
To select technology type most suitable for system need and technical managerial and financial (TMF) capacity.

3 **Testing**
To select optimal media and operational parameters.

4 **Approval to Construct (ATC)**
To permit final design and start installation.

5 **Start-up**
To confirm treatment suitability in regards to approved design.

6 **Approval of Construction (AOC)**
To start serving PFAS treated water.



ADEQ permitting starts with ATC but requires results from the previous three steps.
Pre-application meeting is highly-recommended.

Lessons Learned - Pretreatment

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Arizona Department of Environmental Quality

Picture Rocks

Marana
5,318 people
Groundwater
PFOA + PFOS ~ 80 ppt
1,4 D
Treatment: UV/AOP > **GAC**
2 x lead/lag vessels
2 MGD
Since 2021

Valley Utilities

Glendale
5,263 people
Groundwater
PFOA + PFOS ~ 200 ppt
As
Treatment: **IX** > E33
3 x lead/lag vessels
1.2 MGD
Since 2021

Central Tucson

Tucson
Remediation project
Groundwater
PFOA + PFOS ~ 2,500 ppt
NA
Treatment: **IX**
1 x lead/lag vessels
0.3 MGD
Since 2021 (December)

Picture Rocks - GAC

Desanders:

Percent solids removal (by weight)		
Greater than 50 mesh	%	100
Between 50 and 100 mesh	%	99.9
Between 100 and 200 mesh	%	84
Less than 200 mesh	%	10

Bag filter:
Pore size adjusted during operation (25 > 35 > 50 um)

GAC:
Backwashed 1 time
(after 2 years of operation)

Valley Utilities - IX

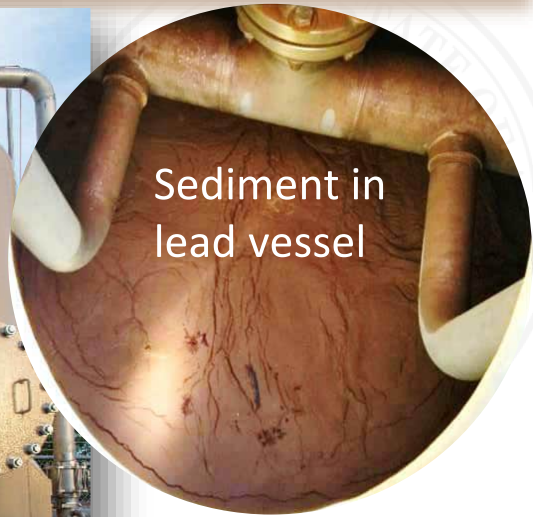
ADEQ
Arizona Department of Environmental Quality

Desanders

Bag filters:
Pore size 10 um

IX:
Purolite PFA694EBF (gel resin)
Never backwashed

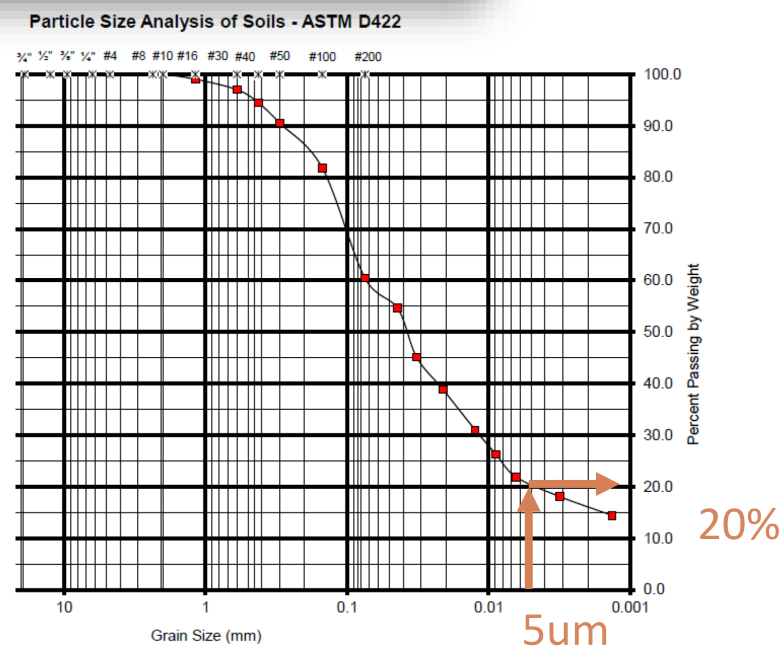
Central Tucson - IX



Bag filters:
Pore size 5 um
Replacement every 1-2 weeks

CTPP Sample Location	6/16/2022		8/30/2022	
	Total Iron (mg/L)	Dissolved Iron (mg/L)	Total Iron (mg/L)	Dissolved Iron (mg/L)
Raw water	0.027	0.0086	0.006	NS
IX influent	0.024	0.0036	0.005	NS
IX treated	<0.0031	<0.0031	NS	NS

- Differential pressure of 20 psi reached in lead vessel – 5 months after startup
- Partial media changeout was conducted in the lead vessel
- Currently exploring options for additional pre-filtration



Lessons Learned – Preparation Upfront Testing

What is missing?

Piloting checklist:

- Analyze background WQPs
  - Identify and quantify competing and fouling analytes, catch variations
- Do media selection
  - Narrow testing media based on WQPs, previous testing, supply availability, modeling
- Add pretreatment to avoid backwashing
  - Typical is green sand and 10 um bag filters
- Keep hydraulics similar to full-scale
  - EBCT and HLR
- Calculate pilot duration
  - Based on WQPs, vendors' model estimates
- Install sampling ports
  - 25% increments to allow extrapolation
  - Add perforated plates to preserve media separation
- Prepare monitoring plan (PFAS & background WQPs)
  - Usually biweekly at 25% EBCT (based on model)
  - Influent and effluent
  - Align with budget

Lessons Learned - PFAS Modeling

Are PFAS models available?
- Free of charge models are available

EPA or manufacturers

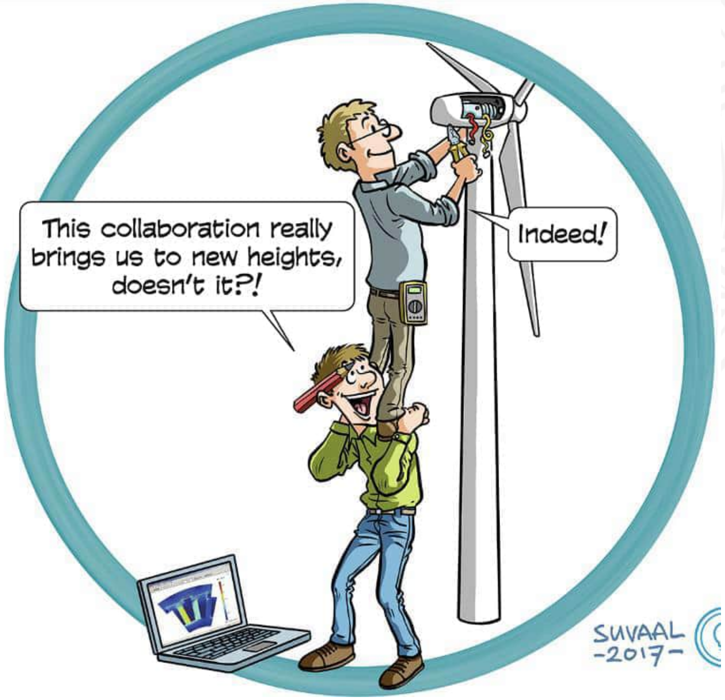
What is purpose?
- Optimize & predict

Operational param., media selection, media replacement intervals, cost

When to use?
- Preliminary design stage
- Testing protocols
- Scale up *(pilot to full)*
- Optimization at full scale *(operation, media)*

Can modeling replace testing?
- Modeling does not replace testing

Rather, it supplements testing



COLLABORATION

INTERPRETATION

What is accuracy of model estimates?
- Depends on model input parameters/calibration

Literature parameters > Isotherms > RSSCTs > Pilot > Full

ADEQ Engineering Support

Trainings

November 2023

- PFAS Treatment: Permitting Considerations

https://www.youtube.com/watch?v=mulSbm1voCQ

- PFAS Treatment: Operation Considerations

https://www.youtube.com/watch?v=O-whbXveCiA

Guidance Documents

- Technology decision trees (non-/treatment selection)
- Testing protocols (isotherms, RSSCTs, pilot, modeling)
- Cost models
- Residual management options

Review

- Testing plan
- Connection with EPA and participation in testing project
- Pre-application documents

Key Takeaways

1. PFAS treatment is complex (this is not a traditional contaminant)
2. Plug and play solutions are not available
3. Understanding your WQPs is a must but data may be perishable (time sensitive)
4. Media backwashing must be avoided
5. Protect media by adding pretreatment
6. Do pilot testing even if you do not have time for full breakthrough
7. Do modeling instead of guessing and waiting to see what will happen
8. Work with ADEQ from the very beginning (do not wait for the ATC stage)

Questions?

Contact info:

Jasmina Markovski

Senior Engineer

Safe Drinking Water

Engineering Review Unit

Email:

Markovski.Jasmina@azdeq.gov

ADEQ

Arizona Department of Environmental Quality

Clean Air, Safe Water,
Healthy Land for Everyone

Supporting Information

1. Sampling and Analysis of WQPs

Define:

- What to test?
- Where to test?
- How many tests?

Determine:

a) PFAS
b) Competing and fouling background water quality parameters
c) Other potential water quality-related interferences
d) Variability

ADEQ Recommended Screening List

- ✓ **PFAS speciation**: 29 compounds from the UCMR5 list
- ✓ **Cations**: Calcium, Magnesium, Sodium, Potassium, Iron, Manganese, Total Hardness
- ✓ **Anions**: Sulfate, Nitrate, Arsenic, Fluoride, Perchlorate, Bicarbonate, Uranium, Chloride
- ✓ **Other**: TOC, DOC, Silica, TDS, pH, Temperature, Alkalinity, Suspended Solids, Oil and Grease, Chlorine Residual, Bacteriological Quality (Total Coliform)

2. Preliminary Design

Define:

- Treatment goals
- Existing conditions
- Methodology for cost analysis

Determine:

Cost – benefits based on:

a) Retrofitting need/potential
b) TMF capacity
c) Technology capital cost
d) O&M requirements
e) Residual management
f) Implications

3. Testing

Define:

- Testing goals
- Budget available
- Time available
- Type of test(s)
  - Piloting
  - Rapid small-scale column tests (RSSCTs)
  - Isotherms
  - Modeling

Determine:

- Media lifetime
- Optimal operation
- Scale-up
- Cost

4. ATC

Submit:

- Application
- Design Report
  - Media lifetime as a result of testing is required
  - Waste management solution may require obtaining permits from other ADEQ departments
  - Cost estimates (capital and O&M)
- Construction Plans
- Start-up Plan
- Process Monitoring Plan
- *O&M Manual

Give Information about:

- Final (100%) design. All information provided so that:
  - Construction can start
  - Testing results after construction can be collected in line with approved start-up and process monitoring plans
  - *O&M is approved and in place from start-up

*O&M recommended to submit the O&M manual early - during the ATC phase.

Start-up plan must be approved with the ATC

Checklist #5

The start-up plan shall provide answers on how/who to:

- ✓ Keep **equipment clean** and taped up
- ✓ Keep **media containers sealed** and in a cool dry place
- ✓ Do equipment and piping **disinfection** per AWWA C653-20 standard
- ✓ Rinse and **remove all chlorine** residual from equipment and piping
- ✓ Confirm **total coliform** negative samples
- ✓ Fill GAC/IX beds by a qualified professional to **minimize air bubbles** and trapped air
- ✓ Address **pre-rinsing requirements**; GAC/IX may be pre-rinsed off-site or rinsed on-site with non-chlorinated water
- ✓ Collect initial **bacteriological and water quality samples** to confirm that treatment objectives are met

6. AOC

Submit:

- Application
- As-builts
- Tests

Provide Information about:

- Design after construction (justified changes)
- Chlorination, bacti, pressure results
- PFAS in treated water
- Other results (As if GAC, VOC if IX)

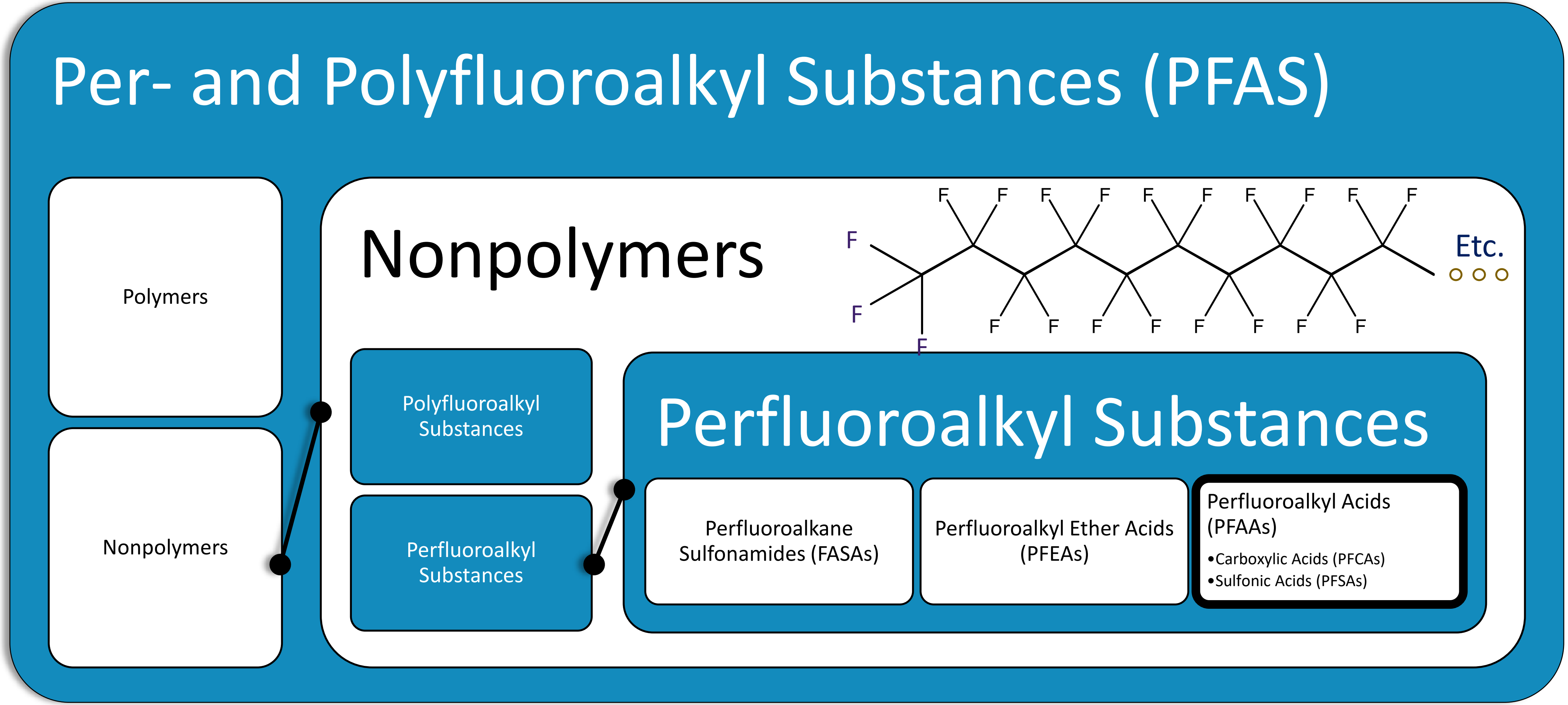
BLACK & VEATCH

Technologies and Strategies for Producing Low-PFAS, EPA-Compliant Drinking Water

February 1st, 2024

Christian Kassar, E.I.T.
Doug Rice, P.E., Ph.D

PFAS Family



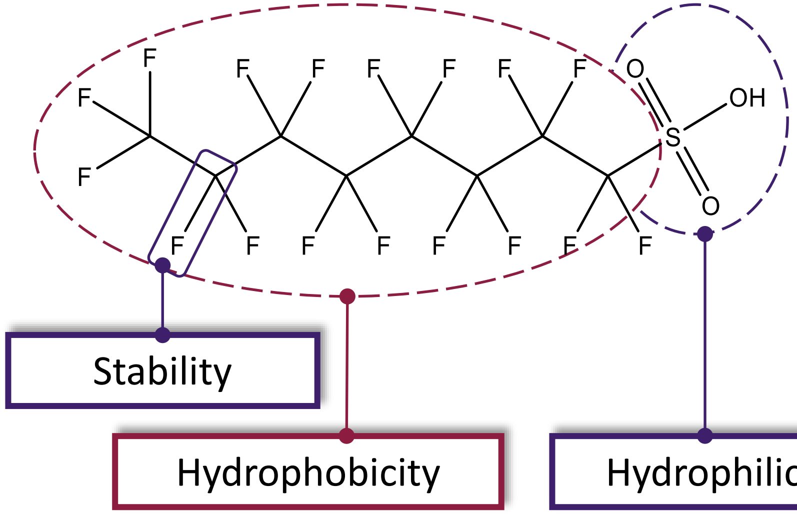
PFAS are a Family of Over 14,700 Compounds and are not Just Limited to Legacy Compounds (PFOS, PFOA, PFHxS, PFNA)

PFAS

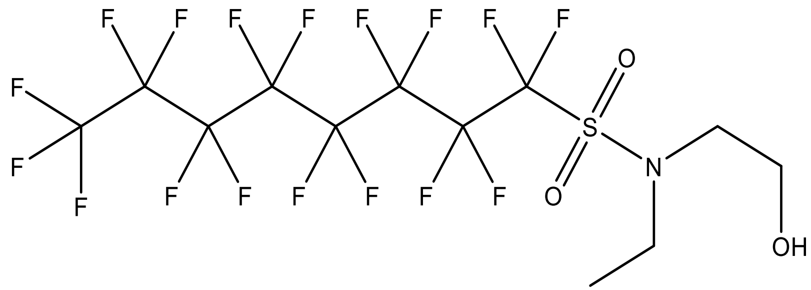
Legacy Compounds

- Stain-resistant coating
- Consumer Products
- Fluids for Aircrafts
- FFF

PFOS



N-EtFOSE precursor



$$pK_a \leq 1.07$$

Gagliano et al. 2020

PFAS Regulatory Movement in Every Market

Timeline: 2016 | 2017 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029

2016 – PFOA and PFOS LHA
- Combined 70 ppt
- Non-enforceable

2017–2021 – Hot Spot Source Identification
- Agencies monitor and sample for PFAS
- Groundwater wells > 70 ppt are treated or turned off

2022
State Land Application Regs
- **AZ,** CA, ME, MI, MA, VT, WI, NH, CO

EPA Proposed Aquatic Life Criteria

CO Fracking Fluid Ban

LHA Update
- PFOA (0.02 ppt) and PFOS (0.004 ppt)
- Non-enforceable

CERCLA Proposed Rule
- PFOA and PFOS

2023 – MCLG and MCL Proposed Rule
- PFOA and PFOS
- Not yet enforceable

2024
MCLG and MCL Final Rule
- PFOA and PFOS
- Enforceable

Monitor Industrial PFAS
- EPA to monitor where phaseout is projected (pulp, paper, cardboard, and airports)

CERCLA Final Rule
- PFOA
- PFOS

WQS Final Rule

Biosolids Risk Assessment
- EPA completes risk assessment to inform additional regulation

2027 – MCLs go into effect

2029 – End of MCL Grace Period

Legend
- Drinking Water
- Wastewater
- Industrial
- Oil & Gas
- Common

PFAS Regulatory Movement in Every Market

MCLG and MCL Proposed Rule
- PFOA and PFOS
- Not yet enforceable

MCLG and MCL Final Rule
- PFOA and PFOS
- Enforceable

End of MCL Grace Period

PFOA and PFOS LHA
- Combined 70 ppt
- Non-enforceable

2016 | 2017 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029

MCLs go into effect

Legend
Drinking Water

LHA Update
- PFOA (0.02 ppt) and PFOS (0.004 ppt)
- Non-enforceable

Regulation Summary

PQL = Practical Quantification Level
MCLG = Maximum Contaminant Level Goal
HI = Hazard Index

Proposed Drinking Water Limits

<table>
<tr><th>PFAS</th><th>MCL</th><th>MCLG</th><th>PQL</th></tr>
<tr><td>PFOA</td><td>4.0 ppt (ng/L)</td><td>0 ppt</td><td>4.0 ppt</td></tr>
<tr><td>PFOS</td><td>4.0 ppt</td><td>0 ppt</td><td>4.0 ppt</td></tr>
<tr><td>PFHxS</td><td colspan="2" rowspan="4">Hazard Index (HI) = 1.0</td><td>3.0 ppt</td></tr>
<tr><td>GenX Chemicals</td><td>5.0 ppt</td></tr>
<tr><td>PFNA</td><td>4.0 ppt</td></tr>
<tr><td>PFBS</td><td>3.0 ppt</td></tr>
</table>

MCLs for PFOA and PFOS are set at the Practical Quantitation Limit (PQL)

Hazard Index Equation

$$\mathrm{HI} = \sum\left(\frac{\text{Measured PFAS Concentration}}{\text{Health Based Water Concentration}}\right)$$

$$\mathrm{HI} = \frac{[\mathrm{PFHxS}]}{9.0\text{ ppt}} + \frac{[\mathrm{GenX}]}{10.0\text{ ppt}} + \frac{[\mathrm{PFNA}]}{10.0\text{ ppt}} + \frac{[\mathrm{PFBS}]}{2{,}000\text{ ppt}}$$

Compliance Determined by Running Annual Average (RAA) of four quarterly samples.

Results below PQL count as 0 for compliance calculation

PFAS Occurrence and Treatability

HBWC = Health Based Water Concentration
HI = Hazard Index

GenX < PFBS < PFOA < PFNA ≈ PFHxS < PFOS

GenX — HBWC = 10 ppt
Only substantively detected in two US watersheds from point source pollution into the **Cape Fear River** and the **Ohio River**

PFBS — HBWC = 2,000 ppt
Does not contribute significantly to HI at environmentally relevant concentrations

PFOA — MCL = 4 ppt
Most likely to control treatment design and the first proposed regulated long-chain to break through

PFNA — HBWC = 10 ppt
Low environmental concentration

PFHxS — HBWC = 9 ppt
More selective to media than PFOA and higher treatment goals

PFOS — MCL = 4 ppt
High occurrence, but observed to co-occur with PFOA and much easier to adsorb

Treatment Approach—Carbon Media

Technology	CAPEX	OPEX	Advantages	Disadvantages
GAC	$$	$ - $$	• PFAS removal ↑↑ • Removes wide range of organics • Reactivation destroys PFAS • BAT (Best Available Technology)	• Non-specificity to PFAS • Lower HLR → larger footprint • Reduced removal of short-chain PFAS
PAC	$	$ - $$	• PFAS removal ↑ • Removes wide range of organics • Small footprint	• Non-specificity to PFAS • Reduced removal of short-chain PFAS • Challenging operation and residuals disposal • Not considered BAT

Treatment Approach—Non-Carbon Media

Technology	CAPEX	OPEX	Advantages	Disadvantages
IX	$$	$$	• PFAS removal ↑↑↑ • Targeted removal of PFAS • Infrequent media replacement • High loading rates → reduced footprint • BAT	• Single use media • Early breakthrough of short chain PFAS • Removes few other contaminants • Sensitive to water quality: TSS, organics, oxidants, pH, Fe/Mn, scalants
Clay-Based Media	$-$$	$$	• PFAS removal ↑↑↑ • Targeted removal of PFAS • High HLR→ reduced footprint • Lower sensitivity to water quality (organics, oxidants, TDS)	• Single use media • Less established technology • 1 mgd max install at the moment • Single manufacturer • Metal leaching at acidic pHs • Contactor effluent and BW • Creates fines for headloss • Not considered BAT

Treatment Approach—Membranes

Technology	CAPEX	OPEX	Pros	Cons
RO	$$$- $$$$	$$$$	• PFAS removal ↑↑↑↑↑ • Removes nearly all contaminants, including all TDS • BAT	• High volume of concentrated waste stream (PFAS + other constituents) • High water loss • No PFAS destruction • Complex operation • Requires pre- and post-treatment
NF	$$$- $$$$	$$$ - $$$$	• PFAS removal ↑↑↑↑ • Removes most contaminants • **Lower energy requirements than RO** • BAT	• High volume of concentrated waste stream (PFAS + other constituents) • High water loss • No PFAS destruction • Complex operation • Requires pre- and post-treatment • **Low removal of monovalent and small ions**

Treatment Approach—Blending

Technology	CAPEX	OPEX	Pros	Cons
Pumps & Pipes	$	$	• Cost effective • Simple • Offers bridge until more enduring solution implemented	• No PFAS removal • Only possible if water quality permits • Changes in water quality may abruptly lead to non-compliance • Poses high risk of implementation due to limits of quantification of PFAS • Lab maximum sensitivity/accuracy at 2-4 ppt • Public perception • Not a long-term solution • Not considered BAT

Treating & Retrofitting Considerations

Technical Considerations

- Water quality
- Existing upstream treatment
- Downstream goals—PFAS and otherwise
  - TOC
  - Salinity
- Ripple effects
- Backwash waste and concentrate disposal
- Ultimate fate of PFAS

Practical Considerations

- Decision to treat at wellhead or water treatment plant
  - If at WTP, where within treatment train?
- Space
  - Footprint
  - Height
- Power
- Cost
- Construction timelines vs. regulatory timelines

Retrofitting PFAS Treatment into Existing Infrastructure

Technology	Wellhead Treatment Approach & Design Guidelines	WTP Treatment Approach & Design Guidelines
GAC	• Lead-lag contactors • HLR: 4-8 gpm/ ft^2 (contactors) • EBCT: 10-20 min	• Convert GMF to GAC or add contactors at end of plant (pre Cl_2) • HLR: 2-6 gpm/ ft^2 (GMF) • EBCT: 10-20 min
PAC	N/A	• Retrofit PAC system at head of plant • 15-30 mg/L dose at 15-30 min CT (solids limited)
IX	• TSS removal followed by lead-lag contactors • HLR: 6-18 gpm/ ft^2 • EBCT: 1.5-7.5 min	• Add IX at end of plant (pre Cl_2) • HLR: 6-18 gpm/ ft^2 • EBCT: 1.5-7.5 min
Clay-Based Media	• Lead-lag (may require pH adjust) • HLR: 6-18 gpm/ ft^2 • EBCT: 1.5-7.5 min	• Lead-lag pressure vessels likely upstream of filtration • HLR: 6-18 gpm/ ft^2 • EBCT: 1.5-7.5 min
RO	N/A, though RO and NF often used for treatment of high TDS groundwater	• Add at end of plant (feed < 1-3 SDI; Cl_2) • Flux: 7.5-17.5 gal/ ft^2 / d • Recovery: 75-85%
NF		• Add at end of plant (< 1-3 SDI; Cl_2) • Flux: 7.5-17.5 gal/ ft^2 / d • Recovery: 75-85%

Retrofitting Case Study

PFAS Compliance Using Adsorption

Upstream Manganese Treatment Considerations

Pretreatment

Manganese Pretreatment
- Manganese Filtration
- Chlorine to achieve dissolved Mn removal goal

OR

Biological Filters
- Higher TOC removal
- Provides benefit for downstream media adsorption of PFAS

Outcome

- No biological filters permitted
- More DBP precursor pass-through
- Impact to PFAS treatment

- Chlorine injection not possible upstream of biological filters
- Metals removal is not reliable

High TOC | Low Metals

Tradeoff

High Metals | Low TOC

PFAS Waste Management

Implemented at Full-scale — *Technology Readiness Level* → *On-going Research needed*

	Landfill Disposal	Incineration	Deep Well Injection	Electrooxidation	SCWO	Thermal Plasma
Form of Influent PFAS-Laden Waste	**Any PFAS-laden media**	**Brine, Spent Media**	**Brine, IX Regenerant, Foam Fractionate**	**Foam Fractionate, IX slurry, Brine**	**Foam Fractionate, Spent Media**	**Foam Fractionate, IX Regenerant, Brine**
∑PFAS Removal	No removal	Variable but may be as high as 99%	No removal	90 – 98% ~50% Short-chains	**>99.9%**	>98%
Main Advantages	Low-cost, minimal operational requirements, hazardous waste landfills	Destruction of PFAS, PFAS-laden media can be incinerated, existing infrastructure in place	Low-cost, minimal operational requirements, Isolated from DW sources	Relatively Low-energy	High treatment efficiency, not inhibited by organics	Low footprint
Major Limitation	**Permitting, potential for PFAS leaching, no destruction**	**Potential emissions of undestroyed PFAS products, high energy requirements**	**Potential for groundwater contamination, no destruction, earthquakes, geology must be conducive to injection**	**Frequent Electrode Changeout (Passivation)**	**Fouling and Salt Precipitation, High Energy**	**Difficulties Scaling up at Higher Flowrate**

Conclusion

PFAS Regulation

- Final Regulation Q1 2024
- Enforced Q1 2027
- Grace Period 2029
- PFOA Expected to Drive Treatment

Treatment

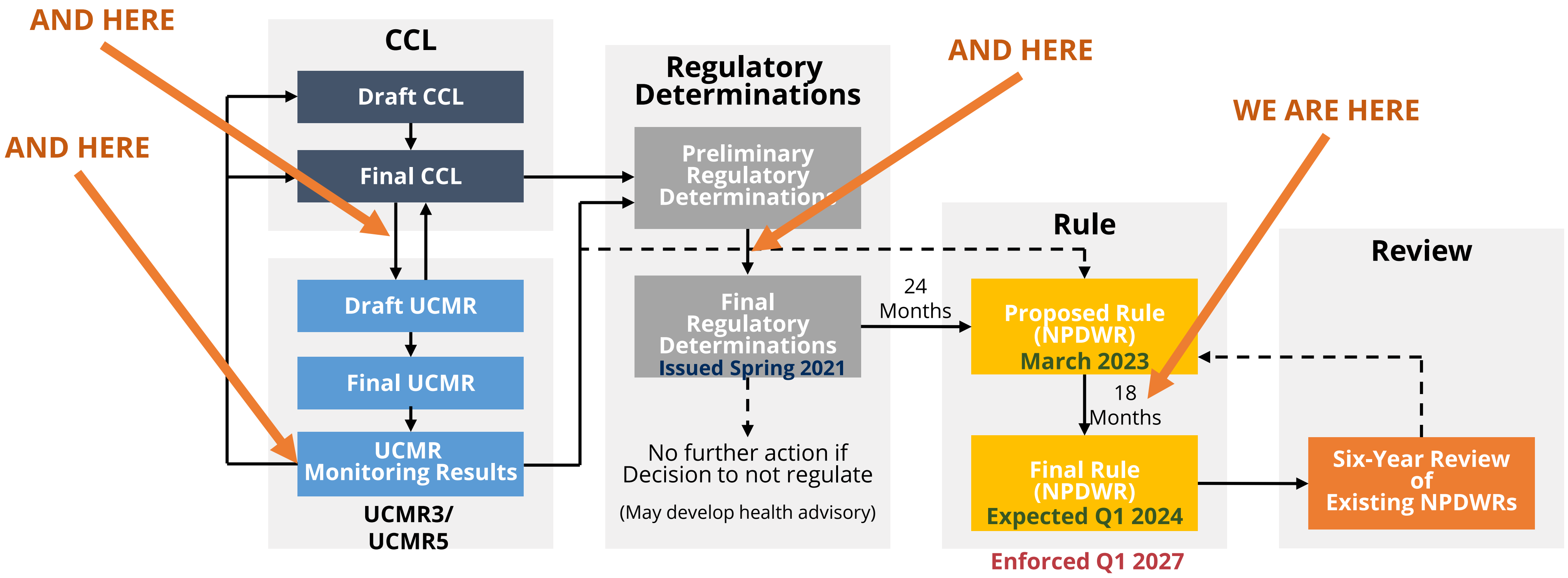
- BAT: GAC, IX, RO, and NF
- Clay-based and PAC offer promising, alternative methods that warrant further study
- Best approach depends on variety of technical and practical considerations
- Look for innovation in new technologies, and applications of existing technologies, as regulations come into place


PFAS
THANK YOU
AZ Water Association
Professionals Dedicated To Arizona's Water
American Water Works Association ArizonaSection
Water Environment Federation

Supplemental Slides

PFAS Background

PFAS Federal Rulemaking Update



PFAS Treatment – Competing Ions and other Factors that Affect Treatment Efficiency

Lee H. Odell, PE

Consor Drinking Water Treatment Technology Lead

Overview

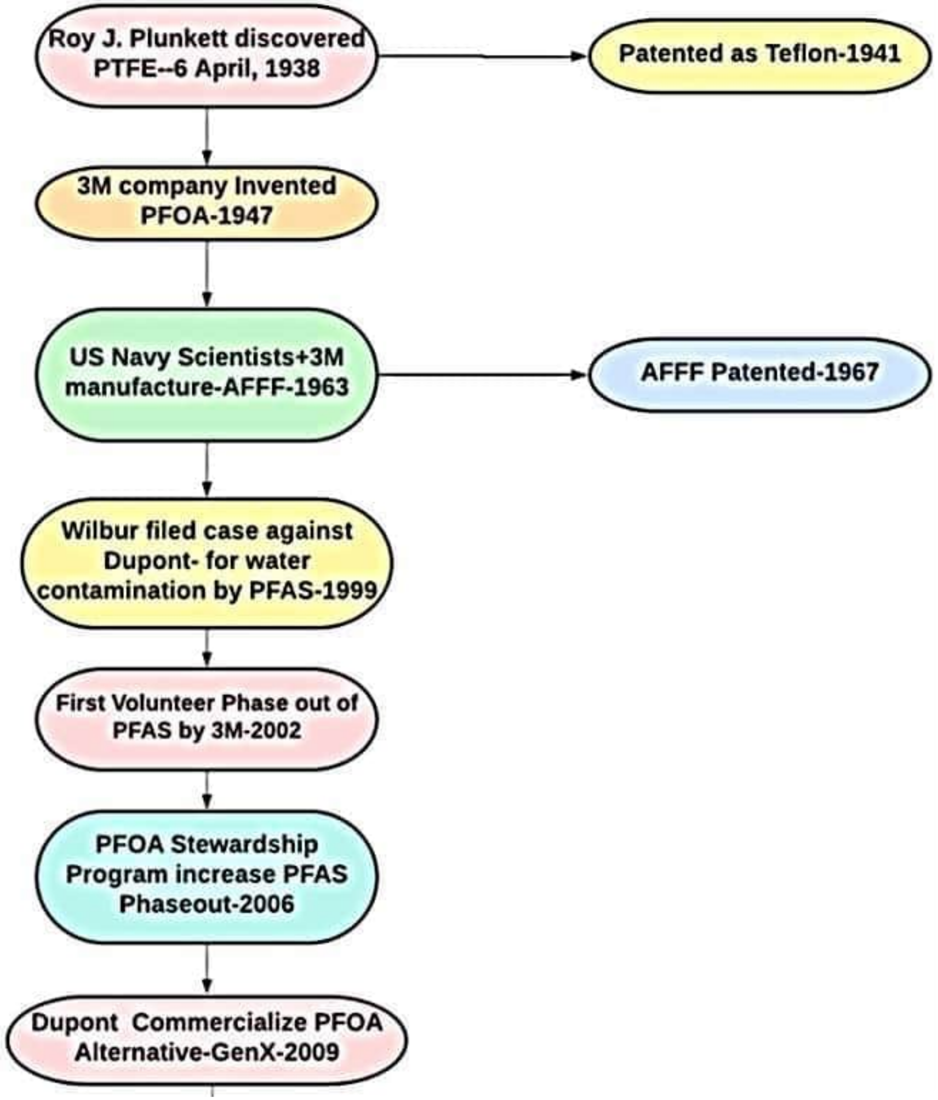
PFAS Compounds

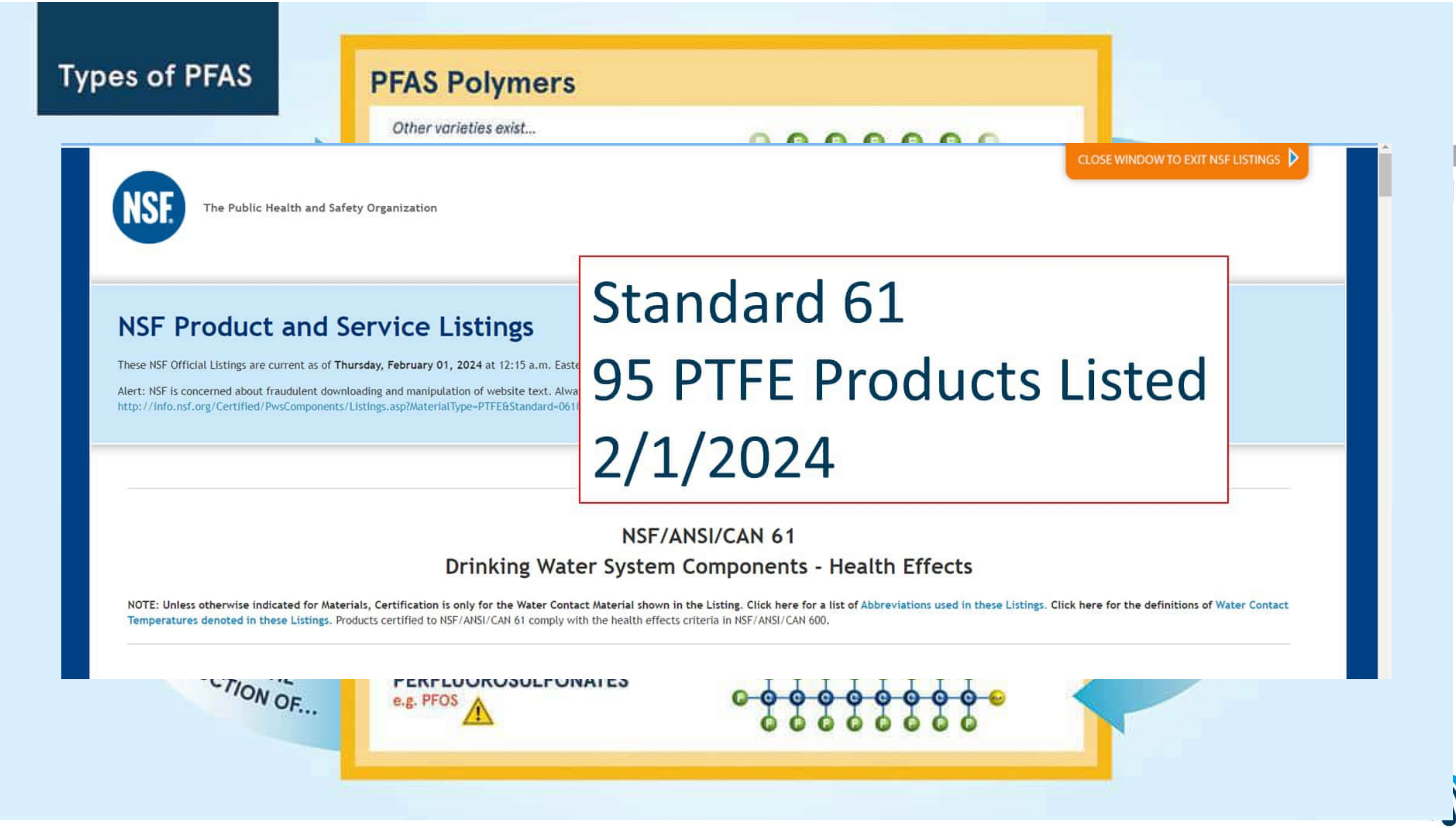
PFAS Treatment

- Ion Exchange
- Granular Activated Carbon
- Modified Clays
- RO and NF Membranes

- Foam Fractionation
- In Situ
- Many Others

Figure 1. Timeline of the PFAS transformation with the passage of time from 1938 to 2024.




Types of PFAS
PFAS Polymers
Other varieties exist...
CLOSE WINDOW TO EXIT NSF LISTINGS
NSF
The Public Health and Safety Organization
NSF Product and Service Listings
These NSF Official Listings are current as of Thursday, February 01, 2024 at 12:15 a.m. Easte
Alert: NSF is concerned about fraudulent downloading and manipulation of website text. Alwa
http://info.nsf.org/Certified/PwsComponents/Listings.asp?MaterialType=PTFE&Standard=061
Standard 61
95 PTFE Products Listed
2/1/2024
NSF/ANSI/CAN 61
Drinking Water System Components - Health Effects
NOTE: Unless otherwise indicated for Materials, Certification is only for the Water Contact Material shown in the Listing. Click here for a list of Abbreviations used in these Listings. Click here for the definitions of Water Contact Temperatures denoted in these Listings. Products certified to NSF/ANSI/CAN 61 comply with the health effects criteria in NSF/ANSI/CAN 600.
e.g. PFOS

PFAS Classification Based On Chain Length

Organization for Economic Co-operation and Development (OECD)

Short Chain PFAS

- PFCA Compounds with seven carbon atoms and fewer
- PFSA Compounds with five carbon atoms and fewer

Long Chain PFAS

- PFCA Compounds with eight carbon atoms and higher
- PFSA Compounds with six carbon atoms and higher

- Hexafluoopropylene oxide dimer acid (HFPO-DA) – "GenX"
- F-53B
- (6:2 Cl – PFESA) chlorinated polyfluoroalkyl ether sulfonate

Table 1
Emerging anionic, cationic and neutral PFAS.

Compound Class	Example	Formula	*m/z*	Ionic Charge
N-dimethyl ammonio propyl perfluo-sulfonamido propanoic acid	N-dimethyl ammonio propyl perfluorethane sulfonamido propanoic acid (AmPr-FEtSA-PrA)	$C_{10}H_{17}O_4N_2SF_5$	357.090	Neutral
N-methylethyl-carboxymethyl dimethyl ammonio propyl perfluoro- amide	N-methylethyl-carboxymethyl dimethyl ammonio propyl perfluoroethane amide (MeEtCMeAmPr-FPeAd)	$C_{15}H_{21}O_3N_2F_9$	447.134	Neutral
N-dimethyl ammonio propyl perfluoro-sulfonamide	N-dimethyl ammonio propyl perfluoroethane sulfonamide (AmPr-FEtSA)	$C_7H_{13}O_2N_2SF_5$	285.069	Neutral
N-trimethylammoniopropyl Perfluoro- sulfonamide	N-trimethylammoniopropyl Perfluoropropane sulfonamide (TAmPr-FPrSA)	$C_9H_{15}O_2N_2SF_7$	349.082	Positive
N-carboxy ethyl dimethyl ammonio propylperfluoro-sulfonamido propanoic acid	N-carboxy ethyl dimethyl ammonio propylperfluoroethane sulfonamido propanoic acid (CEtAmPr-FEtSAPrA)	$C_{13}H_{21}O_6N_2SF_5$	429.111	Negative
Keto-perfluoro- sulfonate	Keto-perfluoropentanesulfonate (K-PFPeS)	$C_5HO_4SF_9$	326.938	Negative
Hydrido-perfluoroalkanoic acid	Hydrido-perfluorohexanoic acid (H-PFHxA)	$C_6H_2O_2F_{10}$	294.982	Negative
Chloro-perfluorosulfonate	Chloro-perfluorobutanesulfonate Cl-PFBS	$C_4HO_3SClF_8$	314.913	Negative
N-carboxy methyl dimethyl ammonio propylperfluoroalkane sulfonamide	N-carboxy methyl dimethyl ammonio propylperfluorobutane sulfonamide (CMeAmPr-FBSA)	$C_{11}H_{15}O_4SN_2F_9$	441.054	Negative
PFOS-Alternatives	2-(6-chloro-1,1,2,2,3,3,4,4,5,5,6,6-dodecafluorohexyloxy (F–53B))	$C_8ClF_{16}O_4SK$	570.67	Negative
Monoether-PFCA/PFSA	Perfluoro-2-methoxyacetic acid (PFMOAA)	$C_3HF_5O_3$	178.97	Negative
Polyether fluoroalkyl carboxylates/sulfonates	Perfluoro (3.5-dioxahexanoic) acid (PFO_2HxA)	$C_4HF_7O_4$	244.96	Negative

*Data obtained from (Gao et al., 2017; Nickerson et al., 2020; Place and Field, 2012; Rand and Mabury, 2012; Rodowa et al., 2020; Schaefer et al., 2020a; Zhang et al., 2016).

Treatment Technologies for PFAS

Ion Exchange	Activated Carbon	Clay Modified Adsorbent	High Pressure Membranes

Sometimes Combined – Lead GAC/Lag IX

High Level Comparison of Alternatives

Treatment	Anion Exchange	Granular Activated Carbon	Modified Clay Adsorption	High Pressure Membranes
Effectiveness	**Good for Short and Long Chain PFAS**	**Good for Long Chain PFAS**	**Good for Long and Short Chain PFAS**	**Good for Long and Short Chain PFAS**
Pretreatment	<10-micron, Fe/Mn	Fe/Mn	<10 Micron, Fe/Mn	Turb, SDI, Fe/Mn, TOC,
Typical Design Criteria	2-6 min EBCT 5-12 gpm/sq ft	10-20 min EBCT 5-8 gpm/sq ft	2-5 min EBCT 5-10 gpm/sq ft	MWCO <200 (400-500 PFOA/PFOS) gpd/sq ft 10-16 gfd
Typical BV to Breakthrough	10,000 – 200,000 Selective (100-200k)	10,000-80,000	120,000-350,000+	N/A
Capital Costs	Lowest	Medium	Lowest	Highest
Major Lifecycle Cost Factors	Resin Replacement and Disposal	GAC Reactivation and Replacement	Media Replacement and Disposal	Energy Costs, Cleaning, Labor, Membrane Replacement
Operational/ Mechanical Complexity	Moderate	Simple	Simple	Complex
Residuals	Typically Incinerated	Typically Re-activated	Typically Landfilled	Liquid Stream

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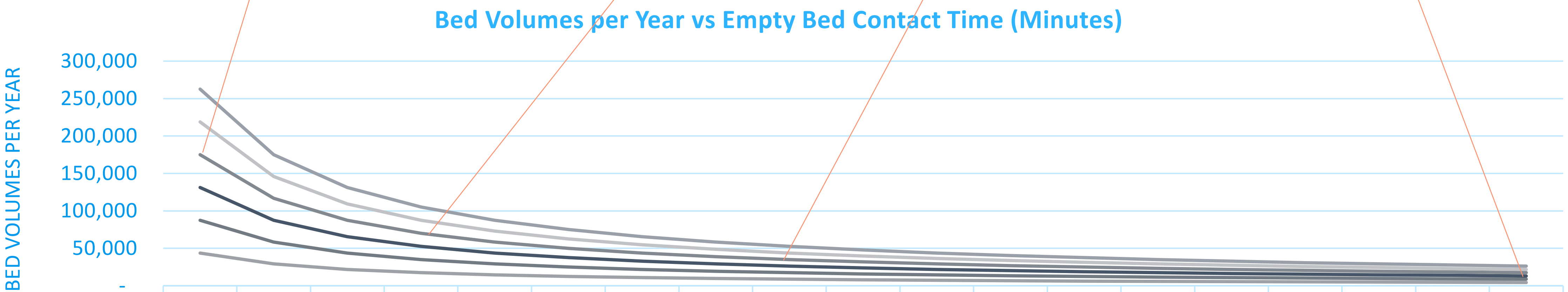
Bed Volumes Per Year Varies with EBCT and Pumping

2 Min EBCT,12 hr/day
131,000 BV/yr

5 Min EBCT,12 hr/day
53,000 BV/yr

10 Min EBCT,12 hr/day
26,000 BV/yr

20 Min EBCT,12 hr/day
13,000 BV/yr



	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4 Hr Oper.	43,80	29,20	21,90	17,52	14,60	12,51	10,95	9,733	8,760	7,964	7,300	6,738	6,257	5,840	5,475	5,153	4,867	4,611	4,380
8 Hr Oper.	87,60	58,40	43,80	35,04	29,20	25,02	21,90	19,46	17,52	15,92	14,60	13,47	12,51	11,68	10,95	10,30	9,733	9,221	8,760
12 Hr Oper.	131,4	87,60	65,70	52,56	43,80	37,54	32,85	29,20	26,28	23,89	21,90	20,21	18,77	17,52	16,42	15,45	14,60	13,83	13,14
16 Hr Oper.	175,2	116,8	87,60	70,08	58,40	50,05	43,80	38,93	35,04	31,85	29,20	26,95	25,02	23,36	21,90	20,61	19,46	18,44	17,52
20 Hr Oper.	219,0	146,0	109,5	87,60	73,00	62,57	54,75	48,66	43,80	39,81	36,50	33,69	31,28	29,20	27,37	25,76	24,33	23,05	21,90
24 Hr Oper.	262,8	175,2	131,4	105,1	87,60	75,08	65,70	58,40	52,56	47,78	43,80	40,43	37,54	35,04	32,85	30,91	29,20	27,66	26,28

IX Treatment

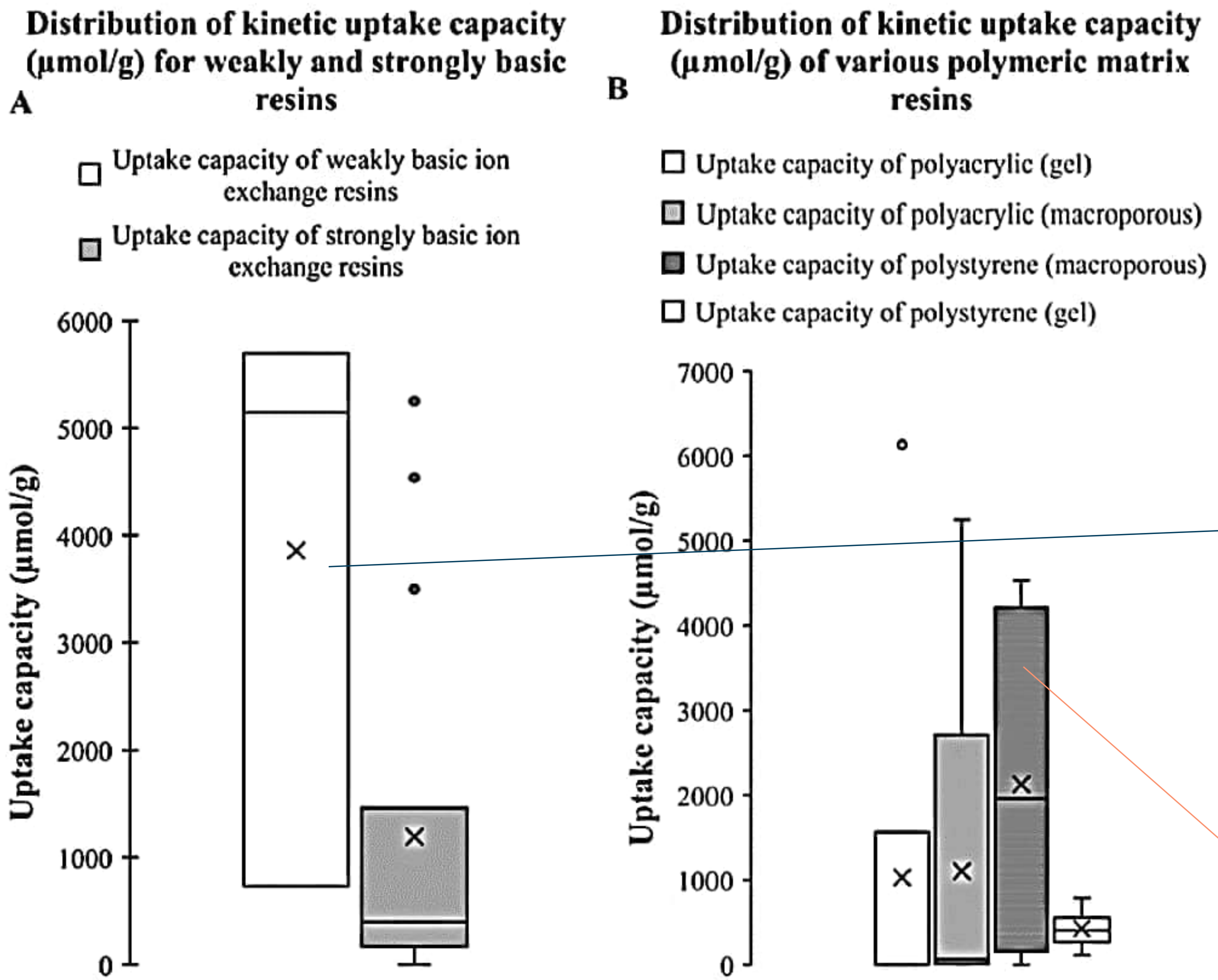
PFAS Specific Resins

Ion Exchange Resin Resin	Source/Manufacturer
AMBERLITE™ PSR2 Plus (g)	DuPont Water Solutions
Purolite® A592E (g) Purolite A6594E (m)	Purolite
CalRes 2301	Calgon Carbon Corporation
Sorbix PURE LC	ECT2 Inc.
ResinTech SIR-110-HP	ResinTech Inc.

- Most Important Factors
  - Type of Resin
  - PFAS Compound
  - Water Quality
    - Foulants
    - Competing Ions
    - pH
  - Cost of Resin
  - Cost of Disposal

IX Treatment

PFAS Compounds and Anion Exchange

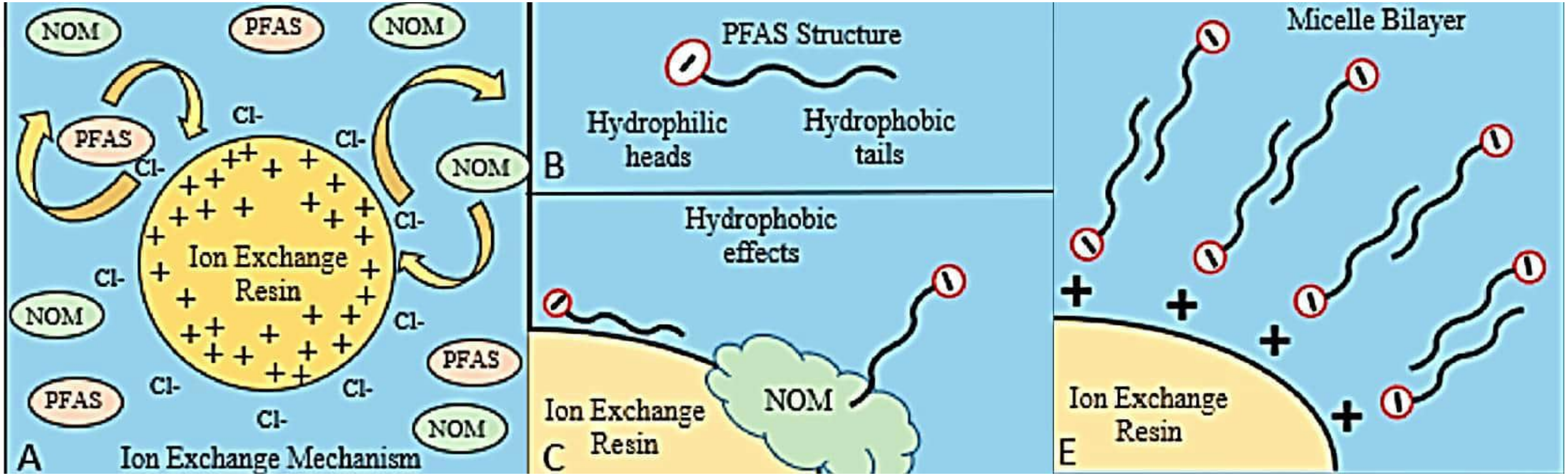


Source: F. Dixit, R. Dutta, B. Barbeau, et al, 2021

- Anion Exchange Resins
  - Structure: Macro-porous > Gel
  - Type: Weakly Basic (WBA)Resins > SBA
  - Functional group: complex amino functional groups> quaternary or tertiary amines
  - Composition: polystyrene

IX Treatment

- Longer-chain perfluoroalkyl acids (PFAAs) are characterized by lower solubility and stronger hydrophobic interactions and therefore, more efficient removal.
- Long-chain perfluoroalkyl sulfonic acids (PFSAs) tend to exhibit more efficient removal compared to long-chain perfluoroalkyl carboxylic acids (PFCAs) based on IX resins' substantially higher adsorption capacity of sulfonates relative to carboxylates. Source: Murray CC, Marshall RE, Liu CJ, Vatankhah H, Bellona CL., 2021



Source: F. Dixit, R. Dutta, B. Barbeau, et al, 2021

IX Treatment

PFAS Foulants with IX

- Natural Organic Matter (NOM)
- Humic acids can interfere by covering site on microporous resin – limited testing with PFAS
- Polystyrenic Resins provide preferential PFAS removal to NOM
- Kinetics can be slowed for some compounds
- A592E achieved >99.9% removal of short-chain PFCA and PFSA (C0 ¼ 10 mg/L) within 15 min of contact time at 0.4 mL/L dosage (Dixit et al., 2020c). Similarly, emerging PFAS such as GenX and other perfluorinated ether acids were captured within 10 min with 5 mg/L background NOM concentrations.
- PFAS precursor compounds such as 6:2 fluorotelomer sulfonate (FTS) and 8: 2 FTS were removed at much slower rates (>45 min).

- Iron & Manganese can foul ion exchange resin
  - Pretreatment (removal/blending) recommended for
    - Iron >0.3 mg/L
    - Manganese >0.02 mg/L

IX Treatment

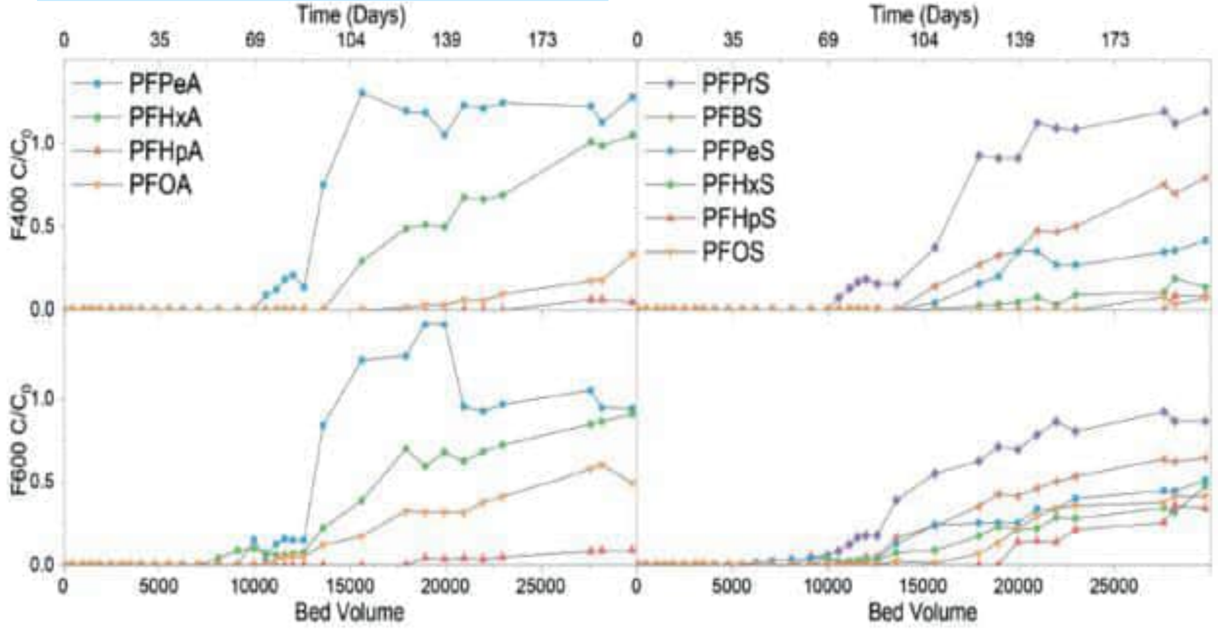
- PFAS removal declines with increasing pH
  - The presence of electrostatic interactions during the IX process has been verified by the effect of changing solution pH upon PFAS uptake (Dixit et al., 2019; Gagliano et al., 2020; McCleaf et al., 2017).
  - The surface charge on IX can be varied via protonation of surface functional groups with changing pH which directly affects the uptake of anionic PFAS (Du et al., 2014a; Zhang et al., 2019).

- Competing Ions
  - Sulfate, phosphate and nitrite are the most competitive inorganic ions for PFAS;
  - fulvic acid and other smaller molecular weight organics can also compete for IX sites.

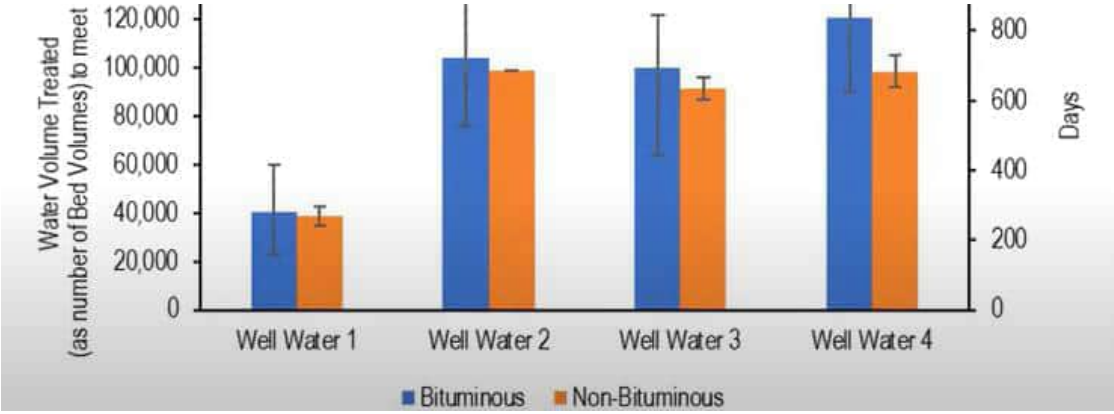
GAC Treatment

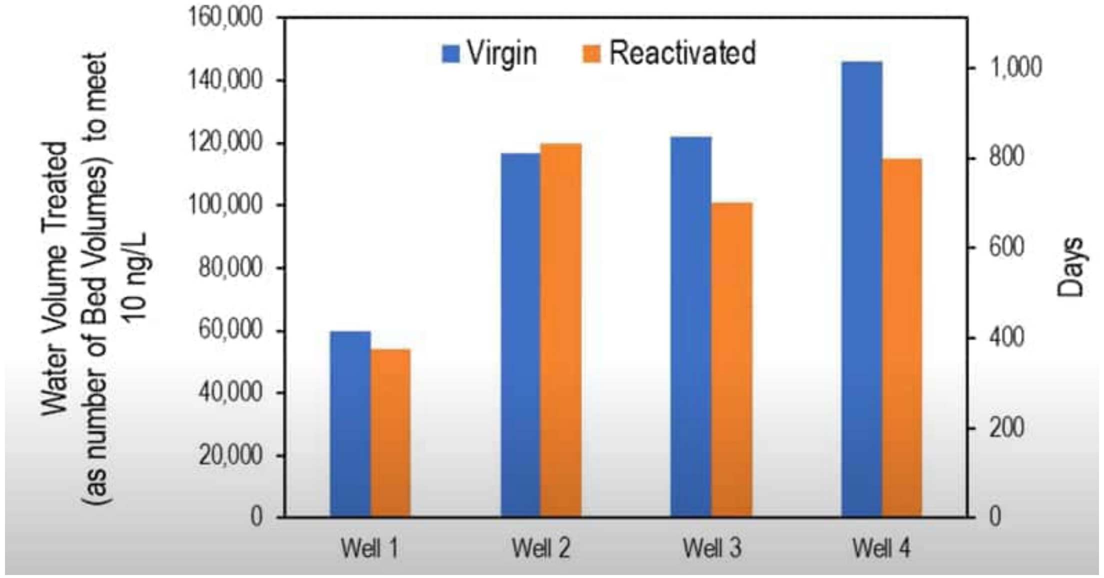
GAC Performance

- Lower removal rates for perfluoroalkyl acids and short-chain PFAS
- Possibility of competitive adsorption with other compounds present, such as TOC
- Low rate of adsorption in GAC result higher EBCTs



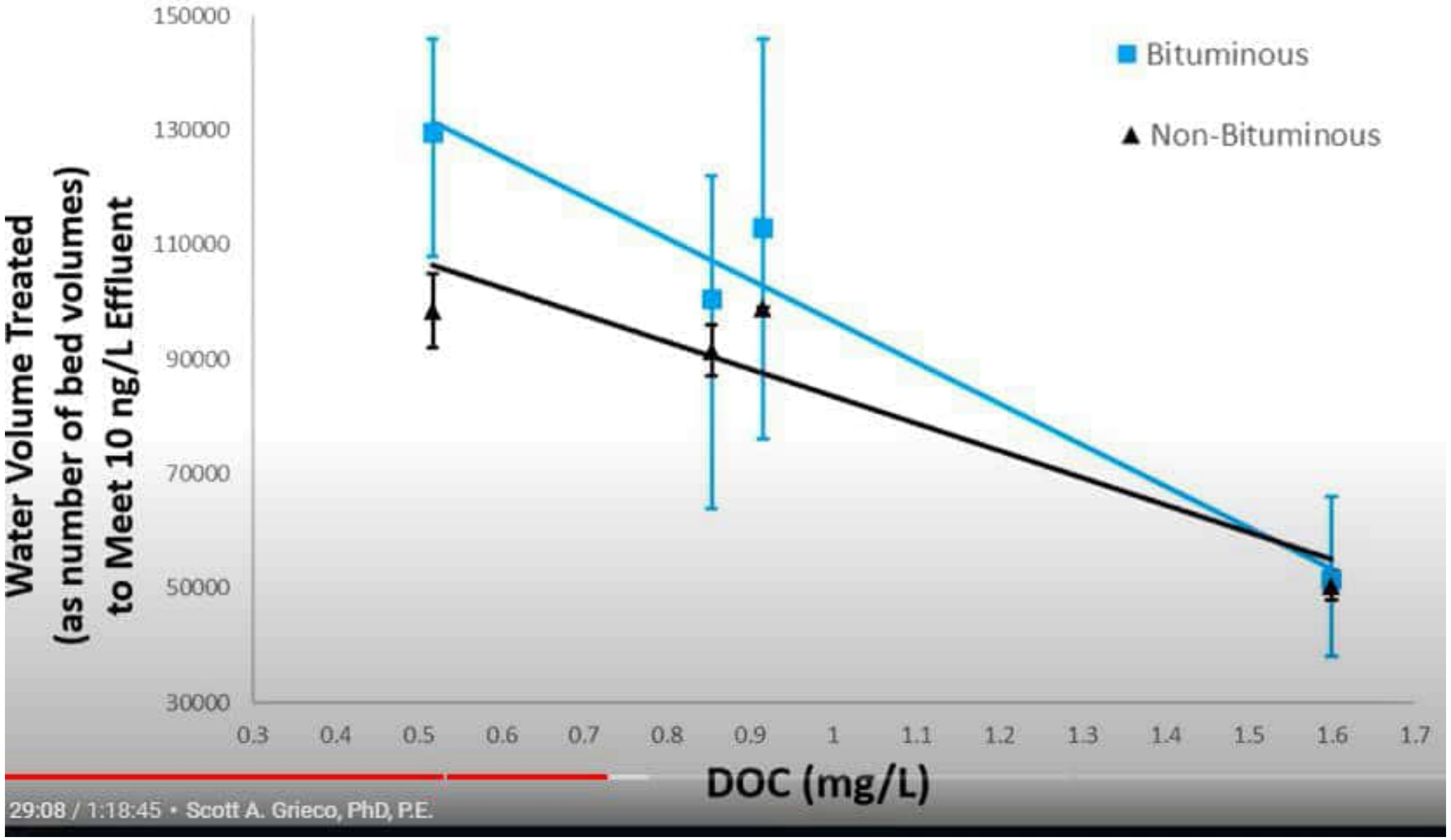
Liu, Werner, Bellona 2019





GAC Treatment

GAC Performance update from Orange County Workshop 6/23/2020



SM Clay Treatment

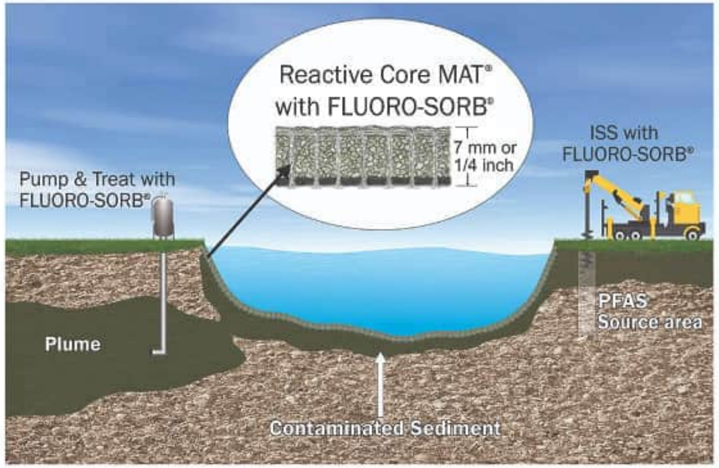
Fluoro-Sorb (CETCO)

FLUORO-SORB® 100 **FLUORO-SORB® 200** **FLUORO-SORB® 300** **FLUORO-SORB® 400**

FLUORO-SORB adsorbent is available in a variety of grain sizes and blends to maximize efficiency on each project.

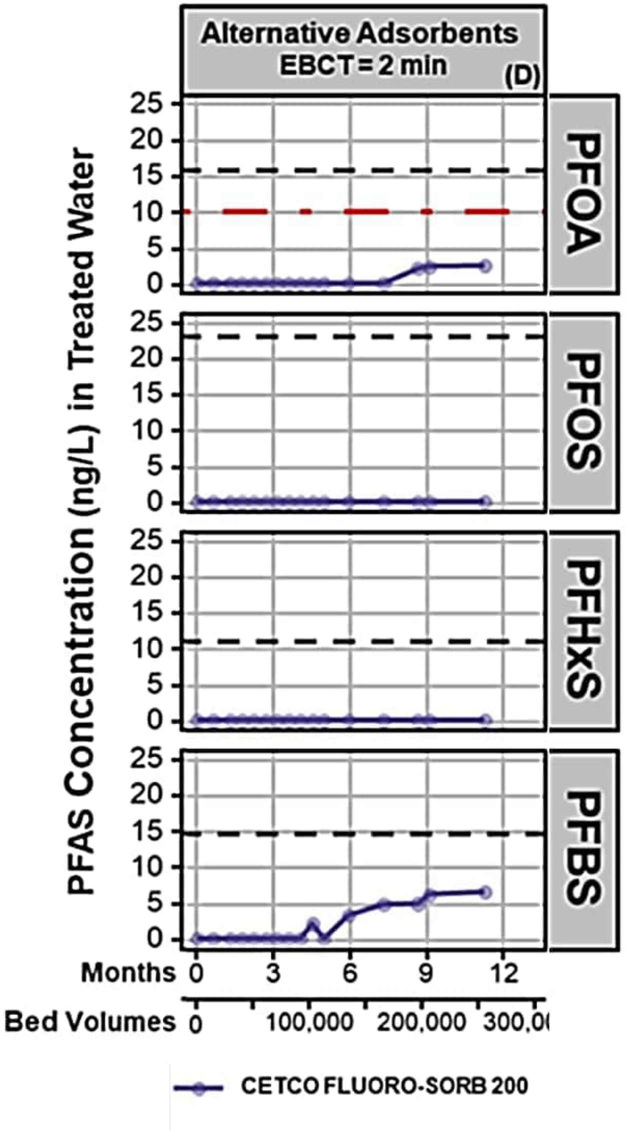
- FLUORO-SORB 100: In-Situ Solidification & Stabilization (ISS)
- FLUORO-SORB 200: Pump & Treat, Permeable Reactive Barrier (PRB)
- FLUORO-SORB 300: High Organics Wastewater Treatment
- FLUORO-SORB 400: Pump & Treat, Permeable Reactive Barrier (PRB)

Available in 1500lb (680.4 kg) supersacks.



SM Clay Treatment

Orange County CETCO Fluoro-Sorb 200 surface modified clay



EBCT 2.0 Min

Source: Orange County Water District PFAS Phase I

Pilot-Scale Treatment Study Final Report

SM Clay Treatment

CETCO Fluorosorb Co-Contaminants

TOC
1 & 100 mg/L

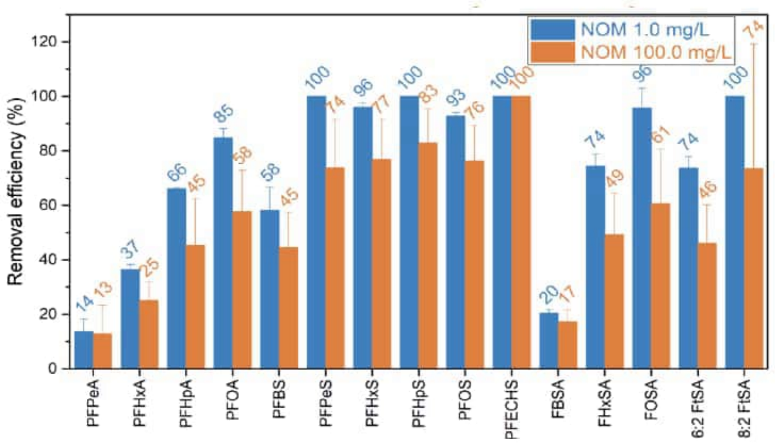


Figure 3: Effect of 1.0 mg/L and 100 mg/L of NOM on the adsorption of PFAS by FLUORO-SORB® 200 Adsorbent.

Calcium
100& 150 mg/L

Sodium
10 & 150 mg/L

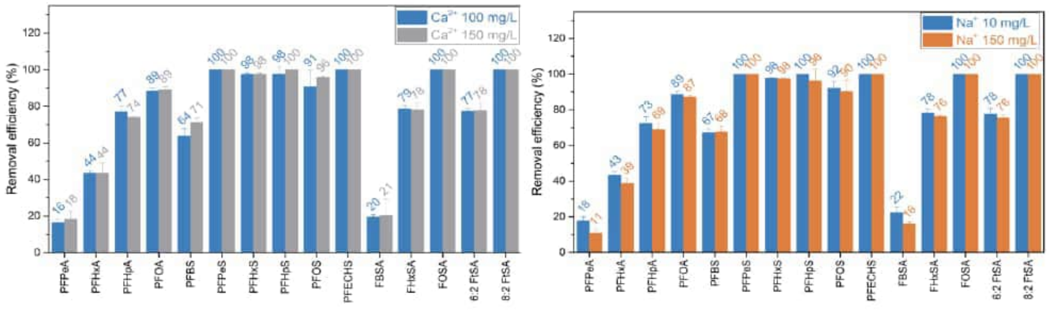
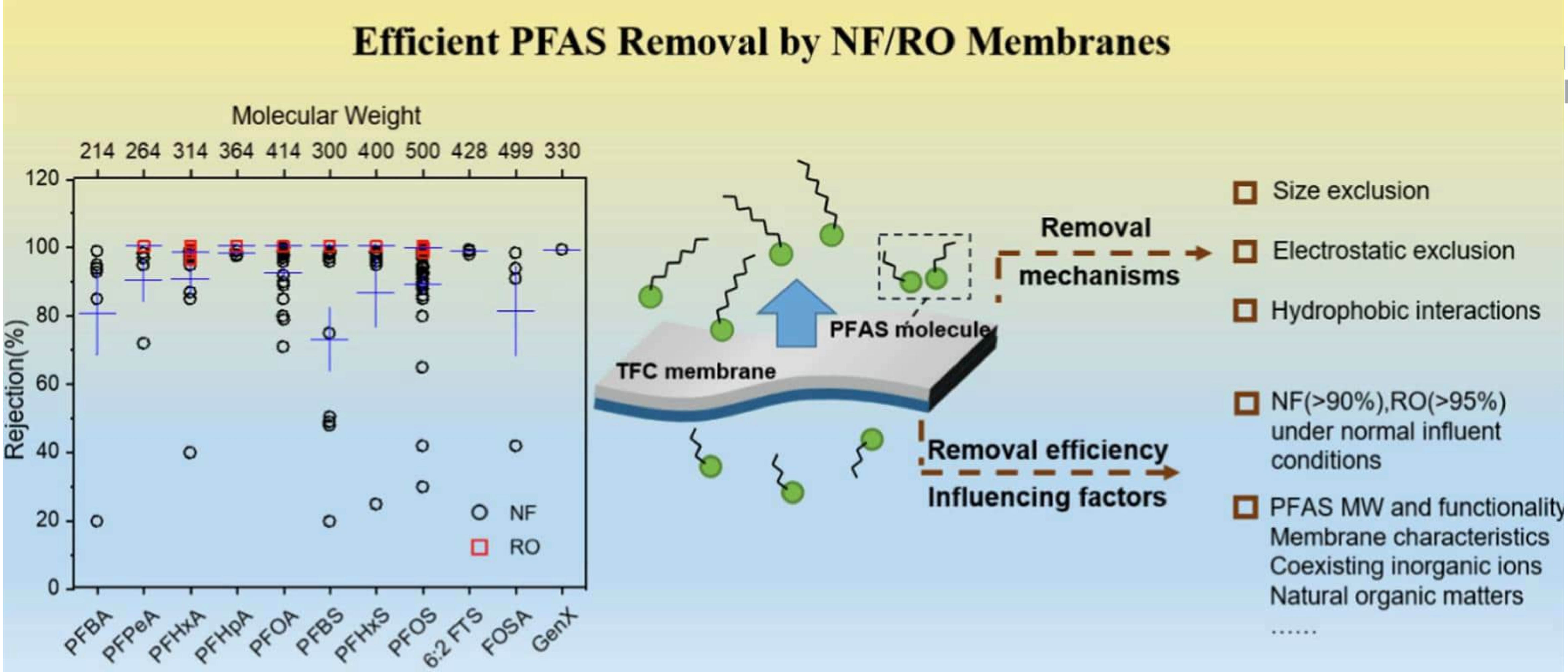


Figure 4: Effect of various amounts of cationic calcium and sodium on the adsorption of PFAS by FLUORO-SORB® 200 Adsorbent

Reference: Yan, B., Munoz, G., Sauvé, S., and Liu, J. (2020) “Molecular mechanisms of per- and polyfluoroalkyl substances on a modified clay: a combined experimental and molecular simulation”, Water Research, 184, 116166.

HP Membrane Treatment

PFAS Removal with Membranes



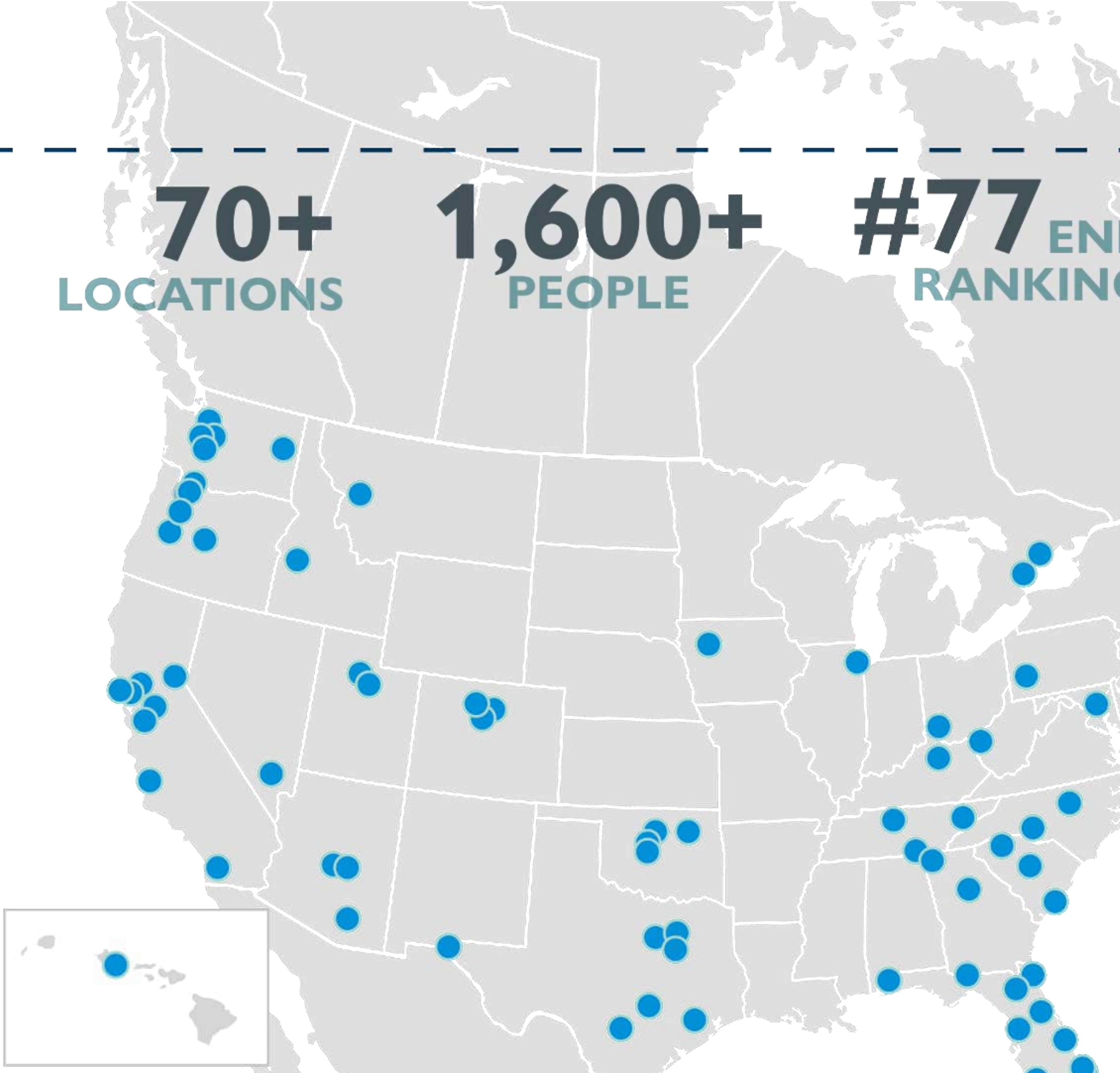
Source: Evaluating the efficiency of nanofiltration and reverse osmosis membrane processes for the removal of per- and polyfluoroalkyl substances from water: A critical review, C. Liu, Et al. Separation and Purification Technology Volume 302, 1 December 2022, 122161

PFAS Treatment Summary

- Still Gathering Lots of Data
- Limited models available
- Capital, Life-cycle Costs, Residuals Management, and Operability key decisions
- Pilot testing is very useful for site specific information, but takes a long time
- Manufacturer/Equipment Suppliers are good sources of information

consor

Questions?



How Unique PFAS Properties Influence Behavior In Water Treatment Processes

Prof. Paul Westerhoff, PE, BCEE, NAE

Regents Professor & Fulton Chair of Environmental Eng.

Prof. Bruce E. Rittmann, NAE

Director, Biodesign Swette Center for Environmental Biotechnology

Arizona State University

Nanotechnology-Enabled Water Treatment

Arizona Water Innovation Initiative

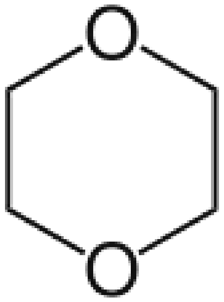
Global Center for Water Technology

Outline

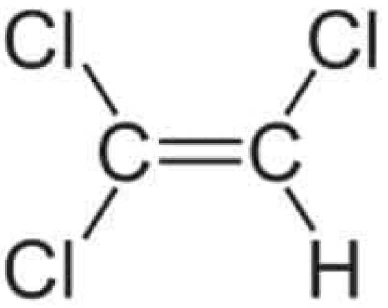
- **Unique properties of PFAS** relative to other friends we know well
- Knowing **what you measure is important** before we try to remove anything
- **PFAS are surfactants** – what does that mean ?
- Membrane separation
- **Hydrophobicity controls everything**
  - Activated carbon adsorption & relationship to bioaccumulation
  - Thermal regeneration of GAC & destruction of PFAS
  - Electrocatalysis
  - Photocatalysis versus ”Homogeneous” Advanced Oxidation Processes (AOP)
- **Hydrogenation is different than oxidative defluorination**
  - Influence of **biodegradation of PFAS**
- Summary and Ongoing Research

Structures of PFAS & *other friends we know well*

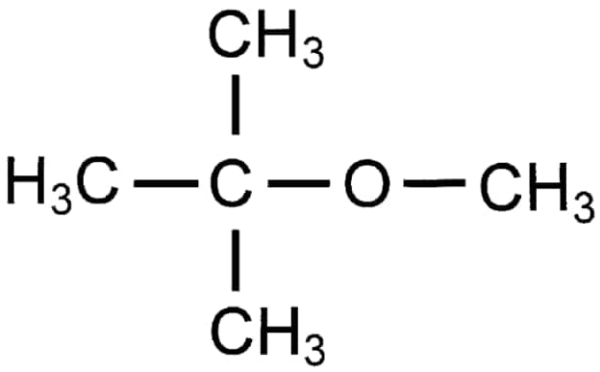
Neutral (but polar) organics



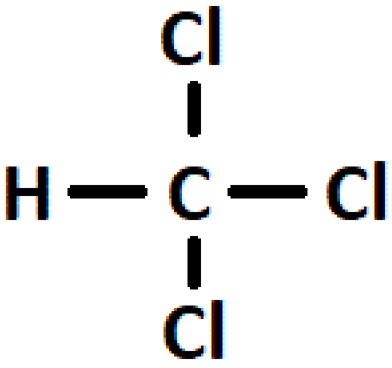
1,4 - Dioxane



trichloroethylene

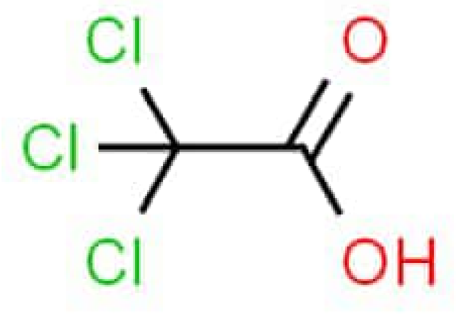


MTBE

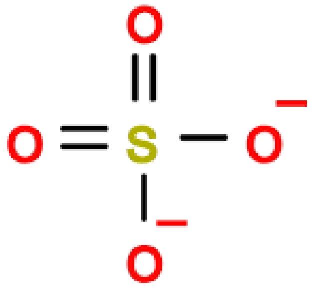


Chloroform

Acids

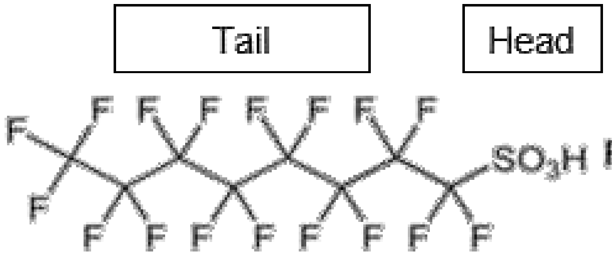


Trichloroacetic acid

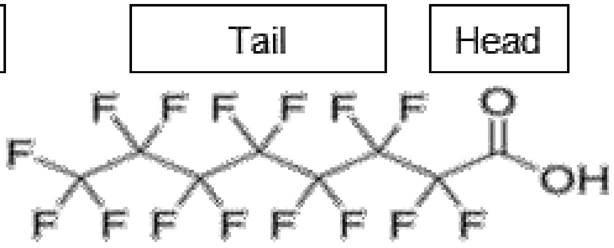


Sulfate ion

Surfactants

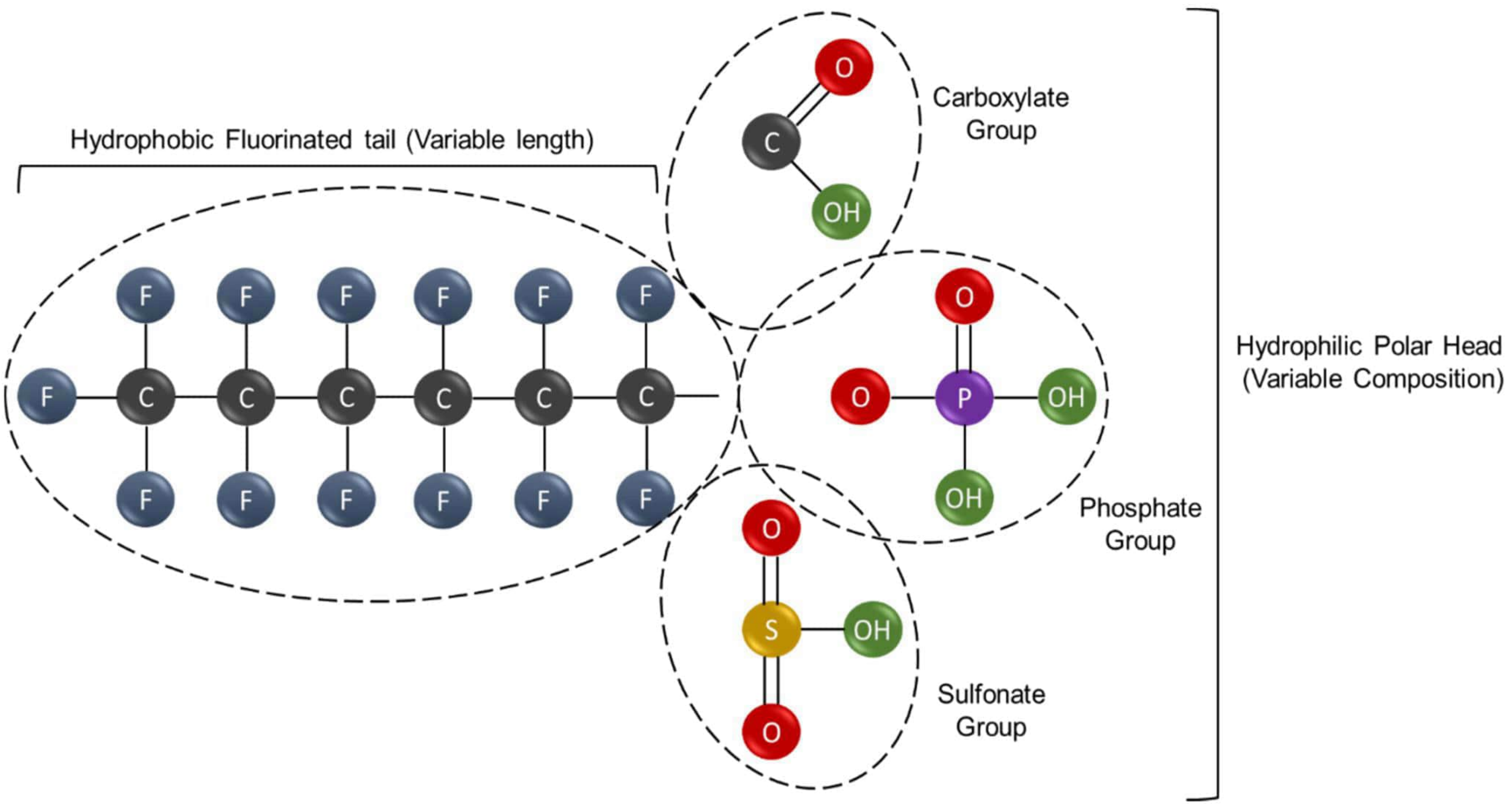


Perfluorooctanesulfonic Acid (PFOS)

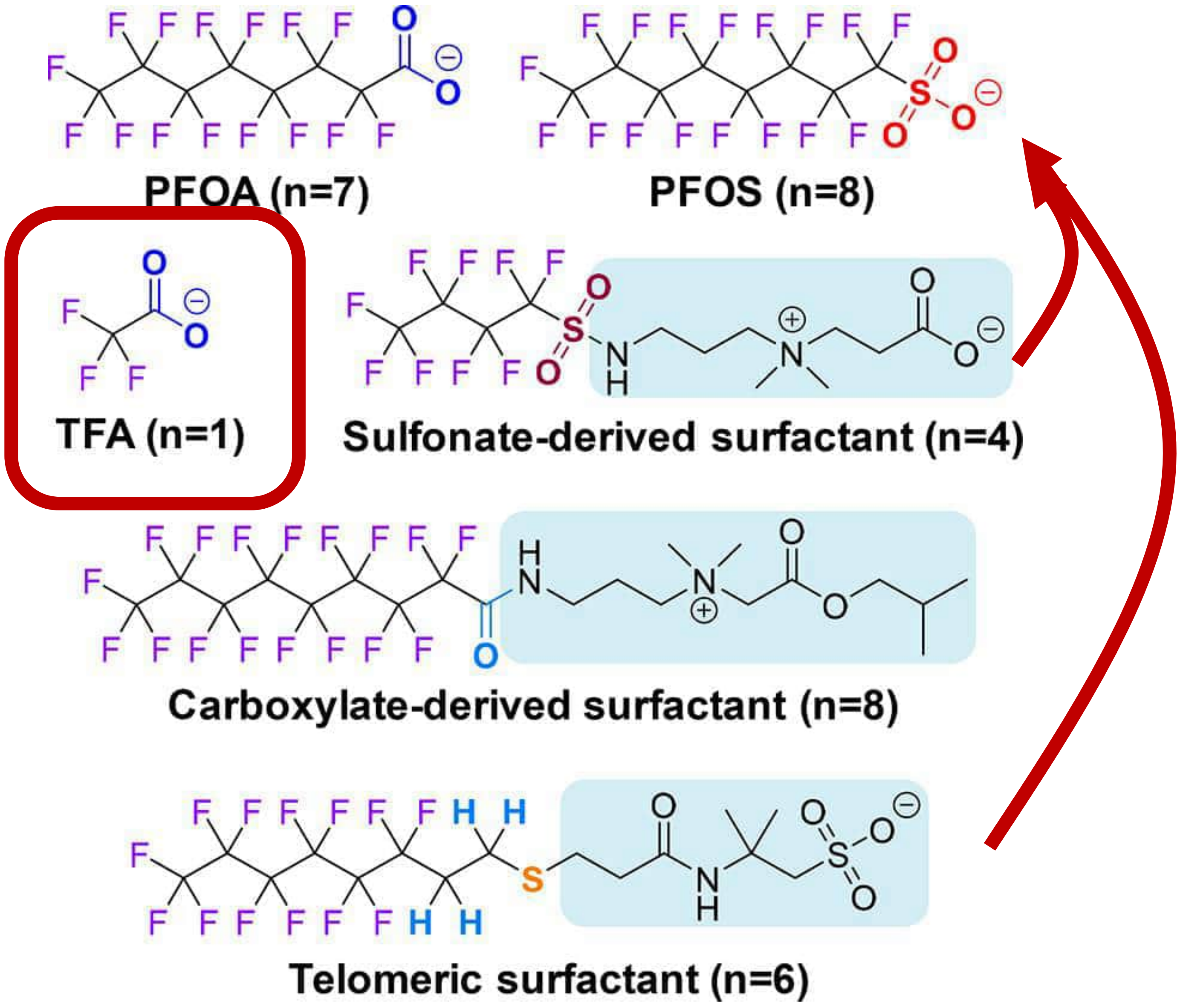


Perfluorooctanoic Acid (PFOA)

What influences Hydrophobicity ?

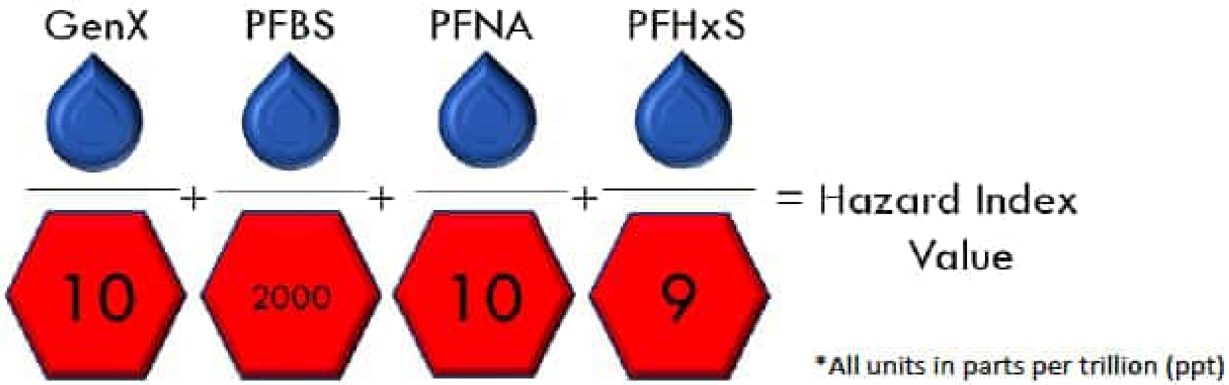


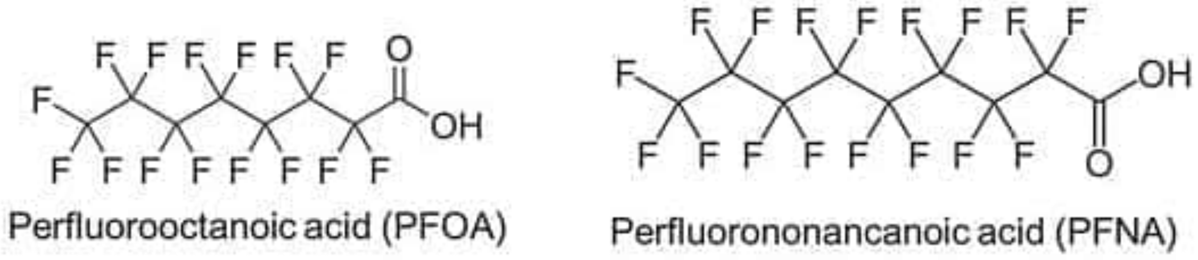
Families of PFAS

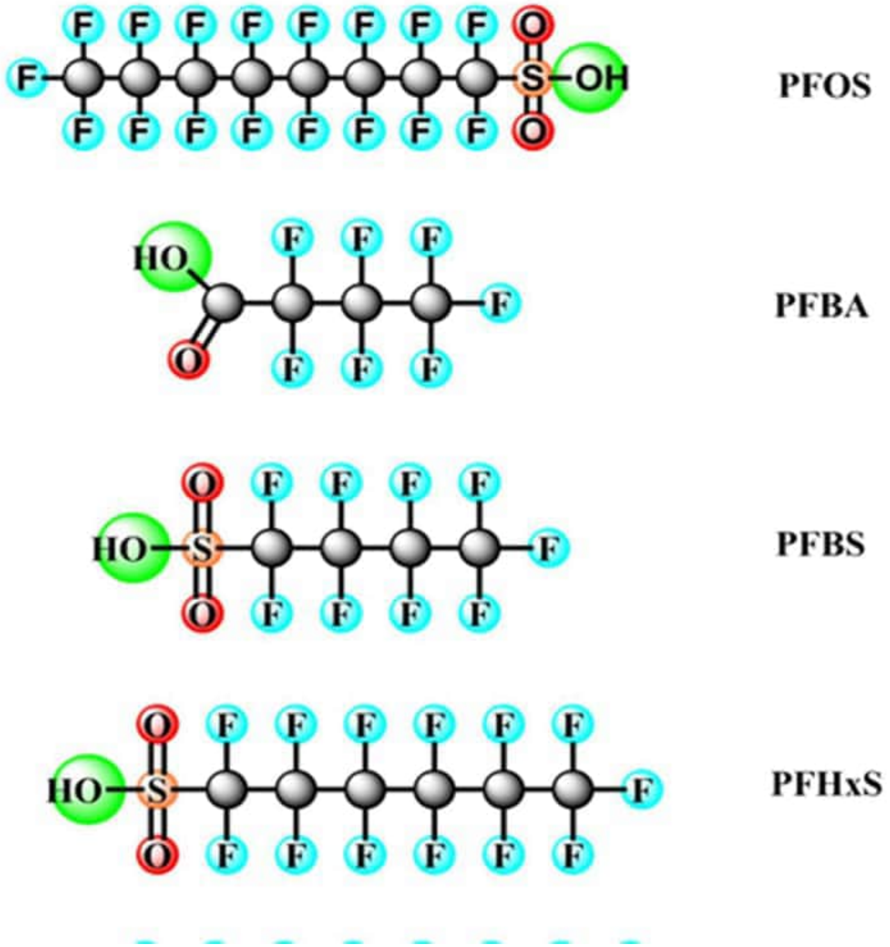


Likely to be Regulated PFAS structures

PFOA Proposed MCL = **4.0 ng/L**
PFOS Proposed MCL = **4.0 ng/L**



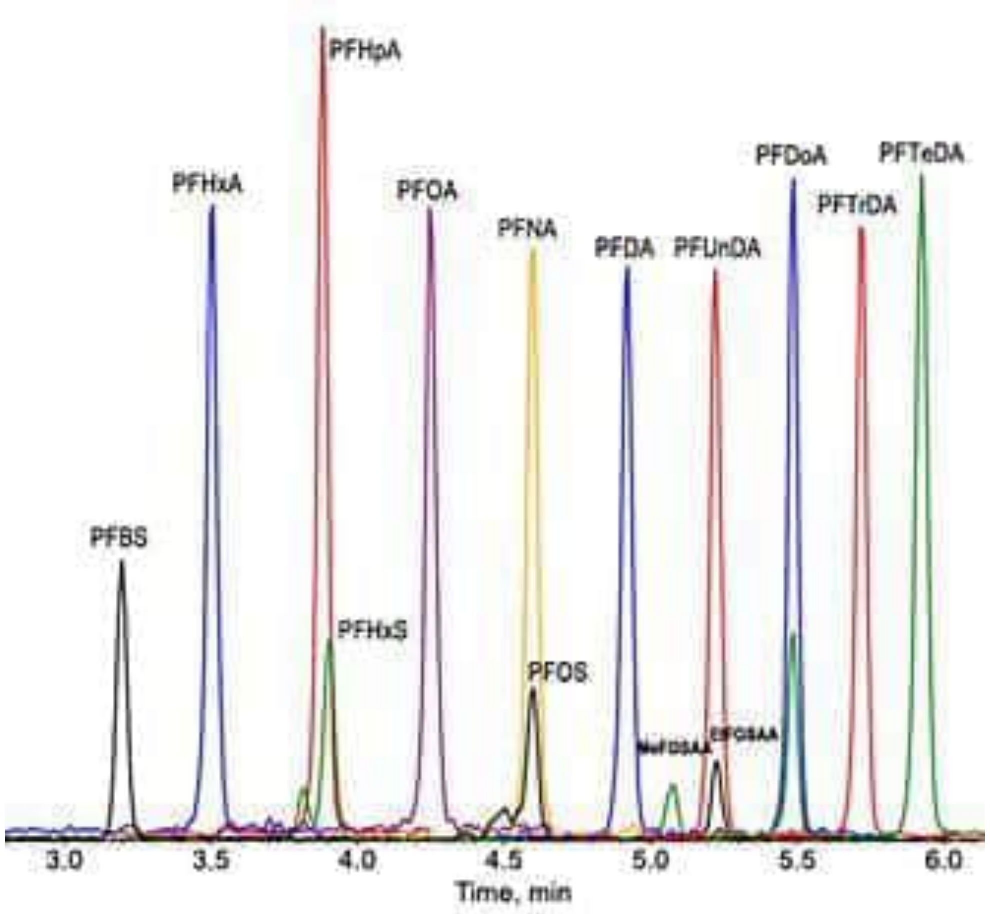




Only ~30 PFAS Routinely Measured

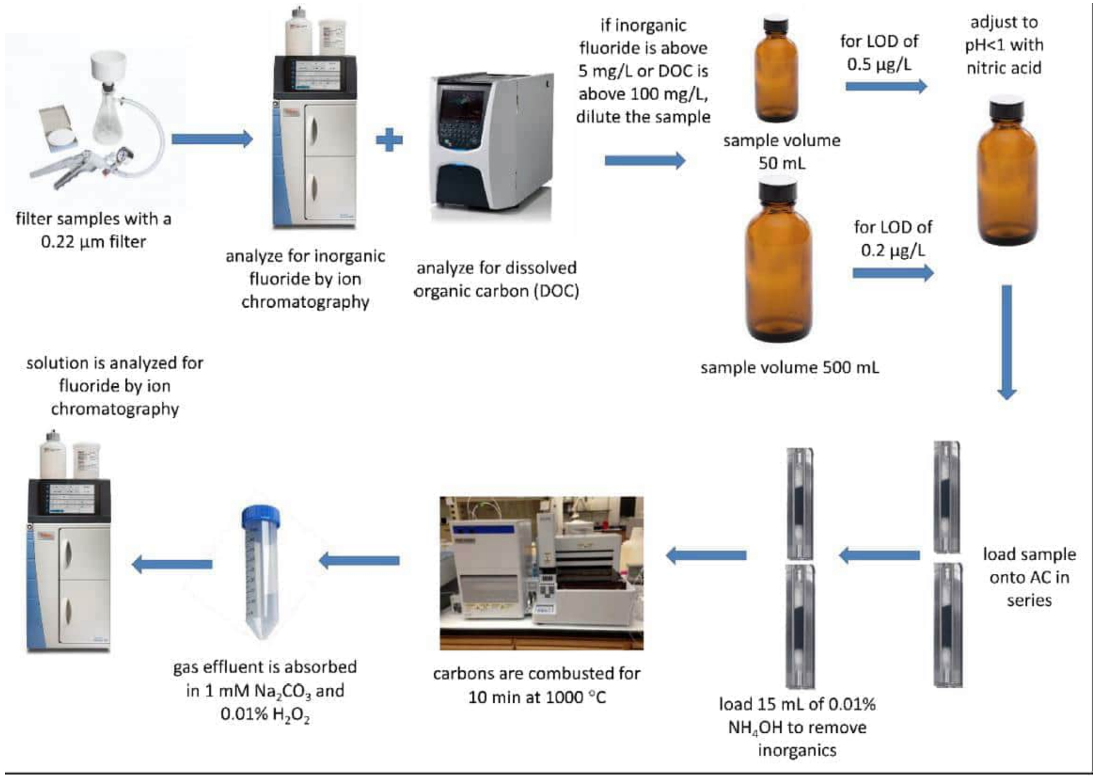
- US EPA Methods (533, 537.1)
  - Internal surrogates/isotopes
  - Solid phase extraction (polystyrenedivinylbenzen)
  - LC-MS/MS
  - Reports 29 unique PFAS

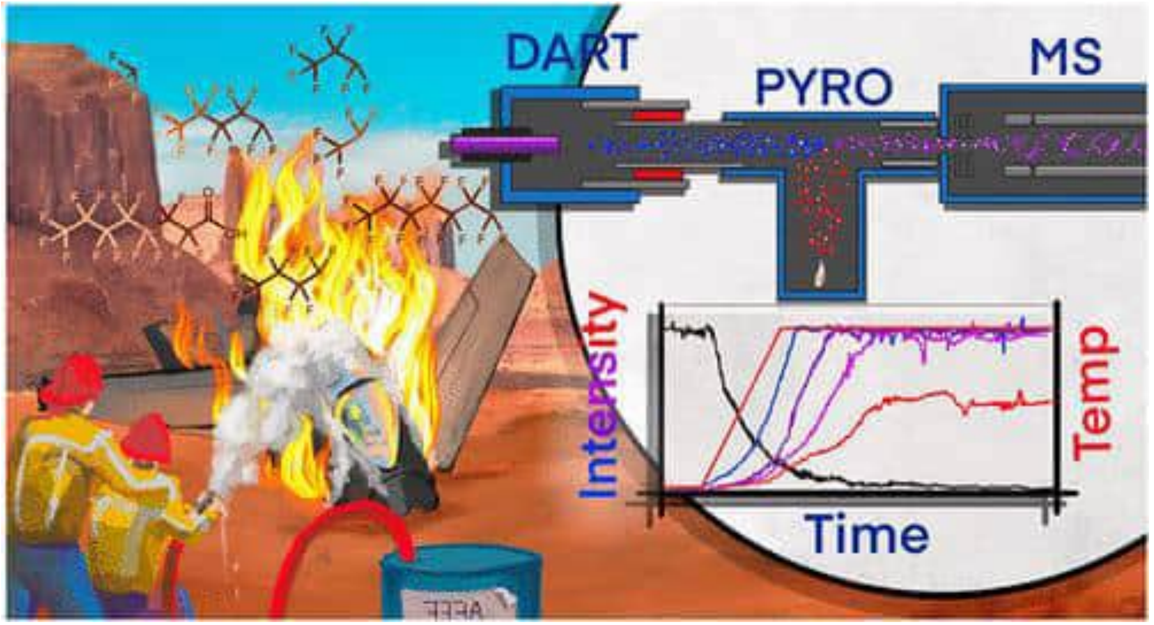
- Versus non-target workflows
  - > 4000 PFAS likely exist



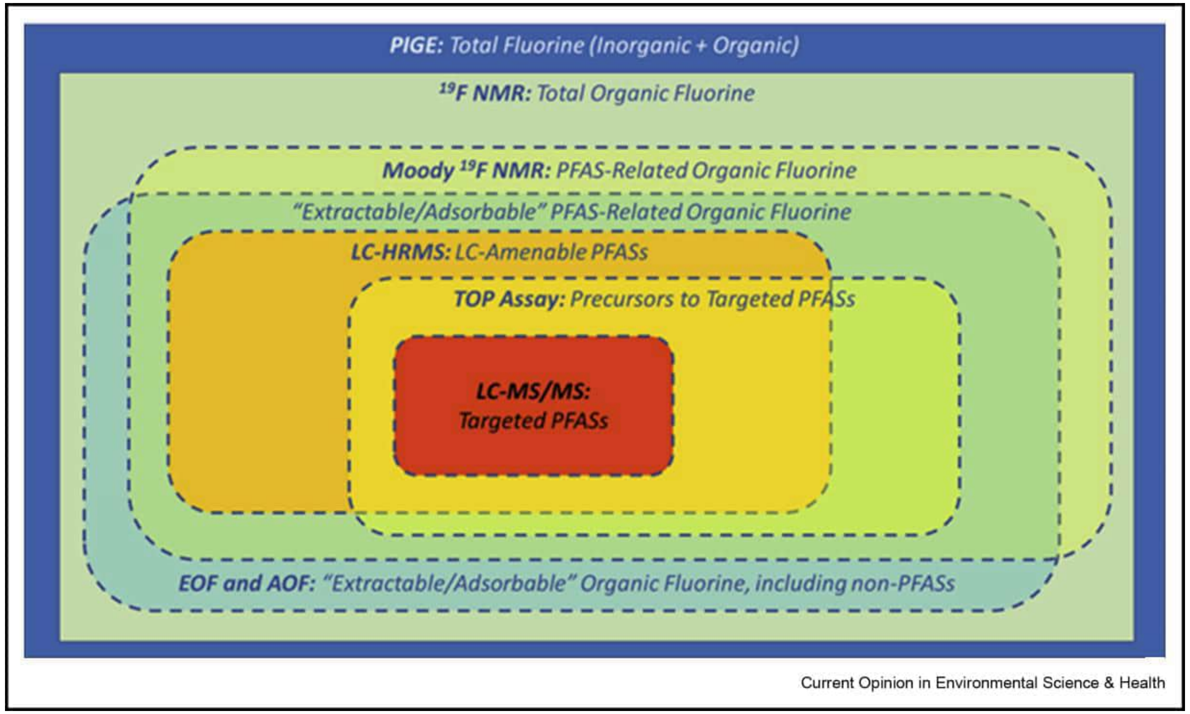
Adsorbable Organo-fluorine Analysis

Improved Non-Target Analysis



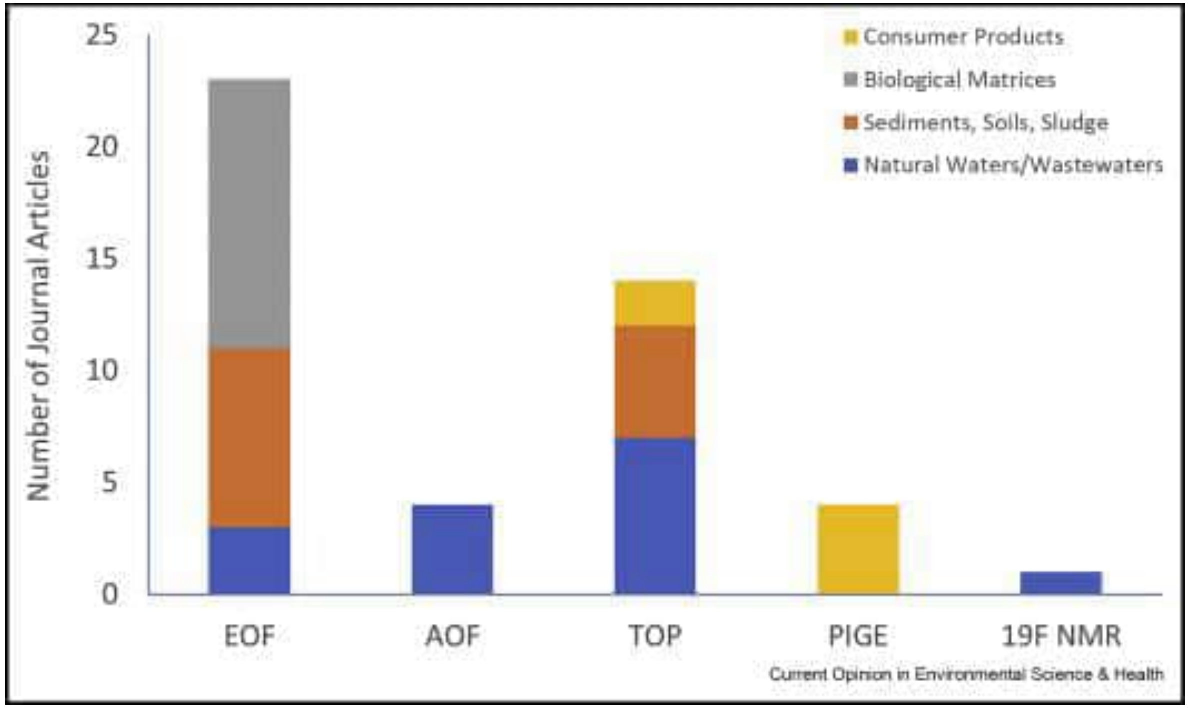


Target PFAS versus “total” fluorinated materials



Surrogates for organo-fluorine

Not all organo-fluorine is PFAS though



Outline

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- Knowing **what you measure is important** before we try to remove anything
- **PFAS are surfactants** – what does that mean ?
- Membrane separation
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- **Hydrogenation is different than oxidative defluorination**
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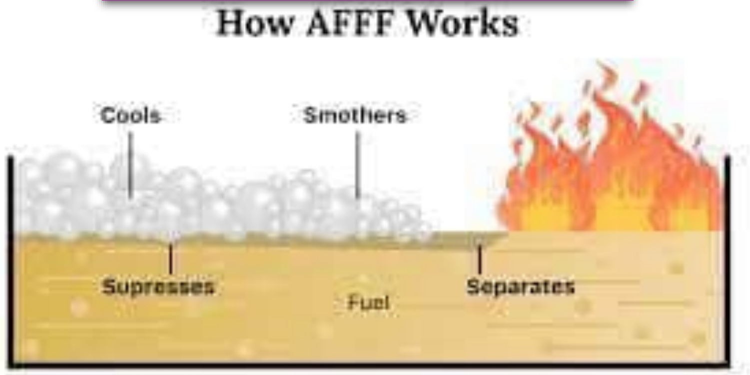
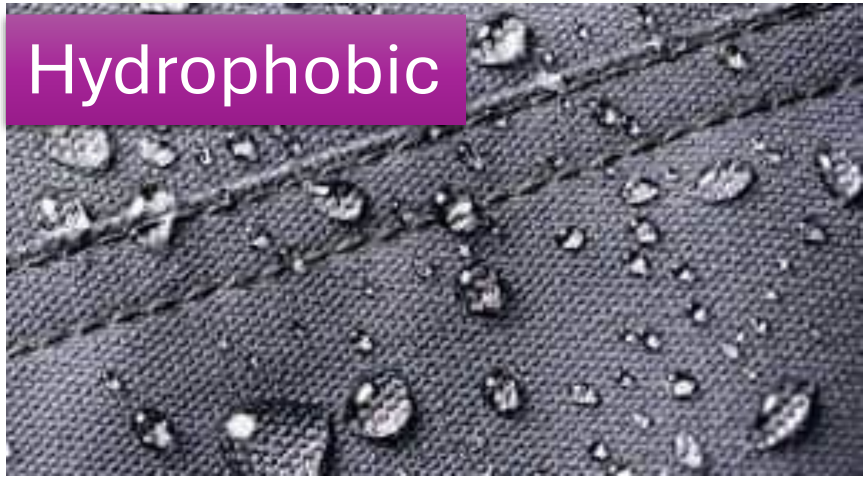
- Summary and Ongoing Research

How PFAS works

Influences mechanisms of PFAS transformation / removal during water treatment

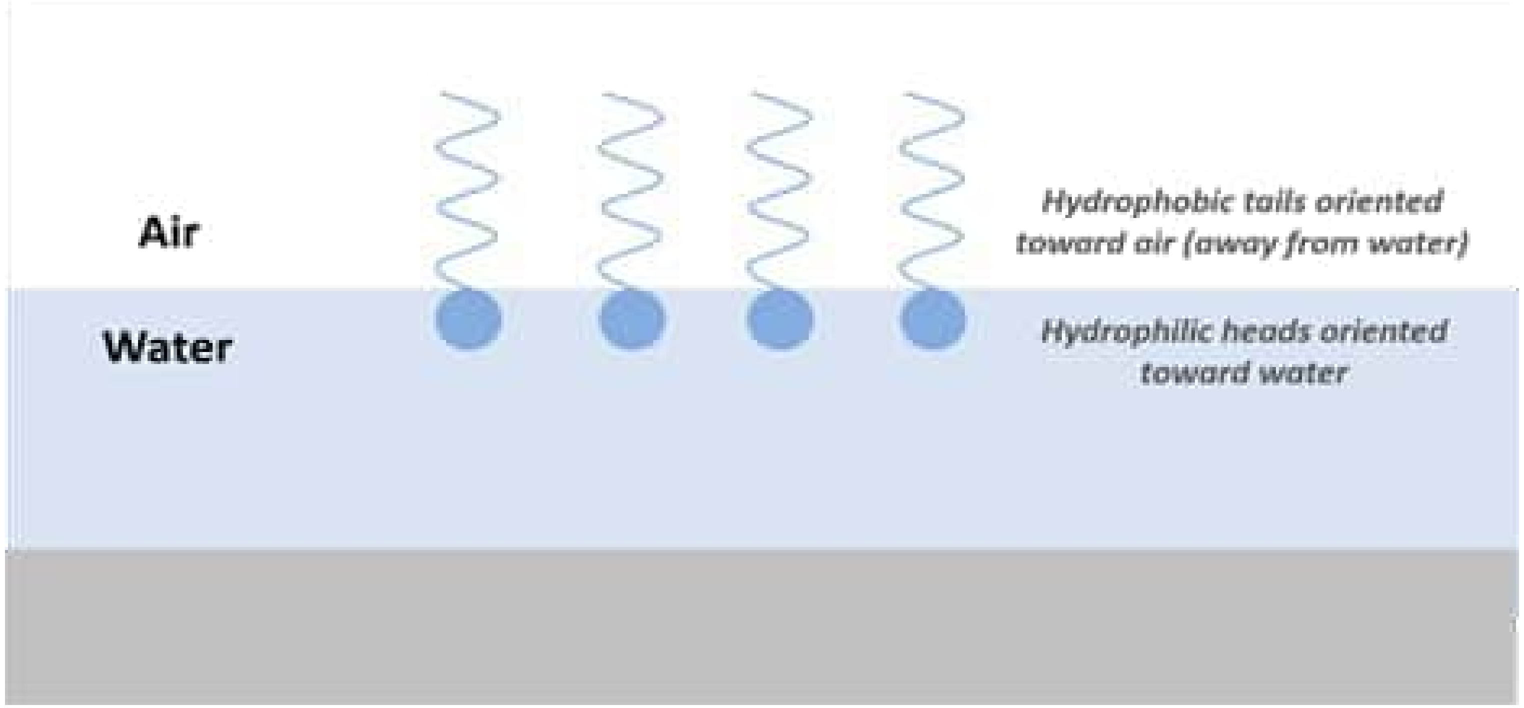
Doesn’toxidize

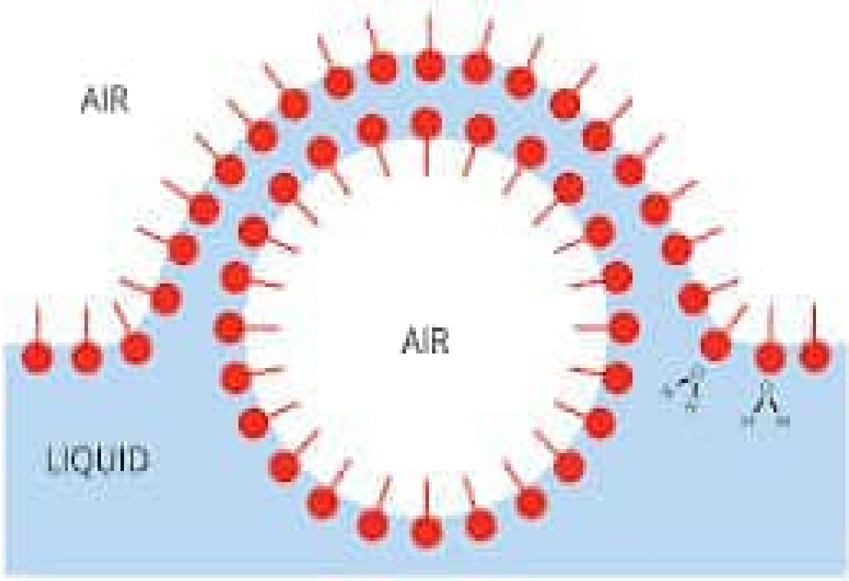




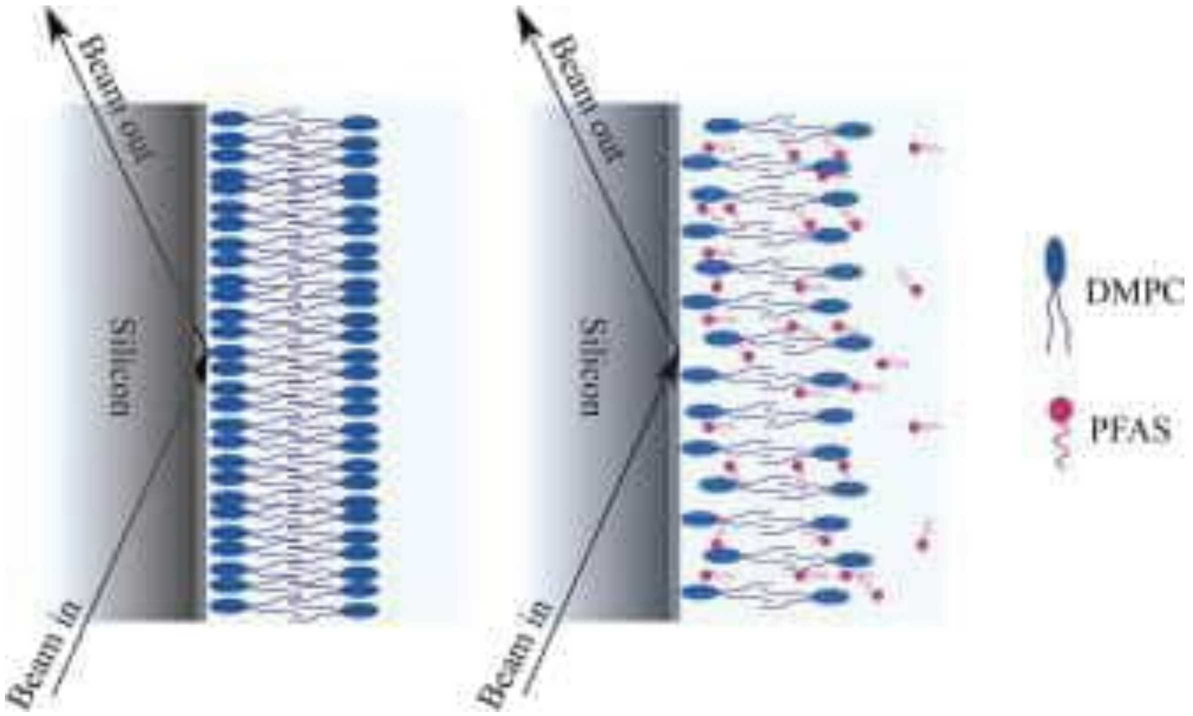
As Surfactants…

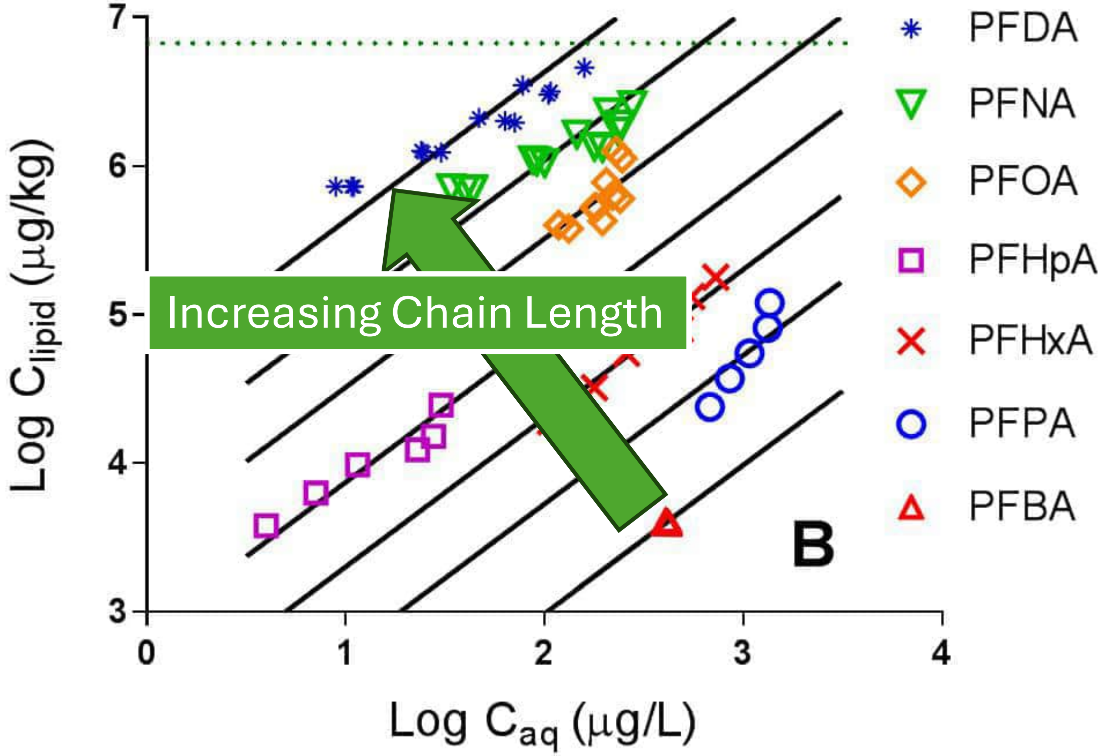
PFAS Loves Interfaces



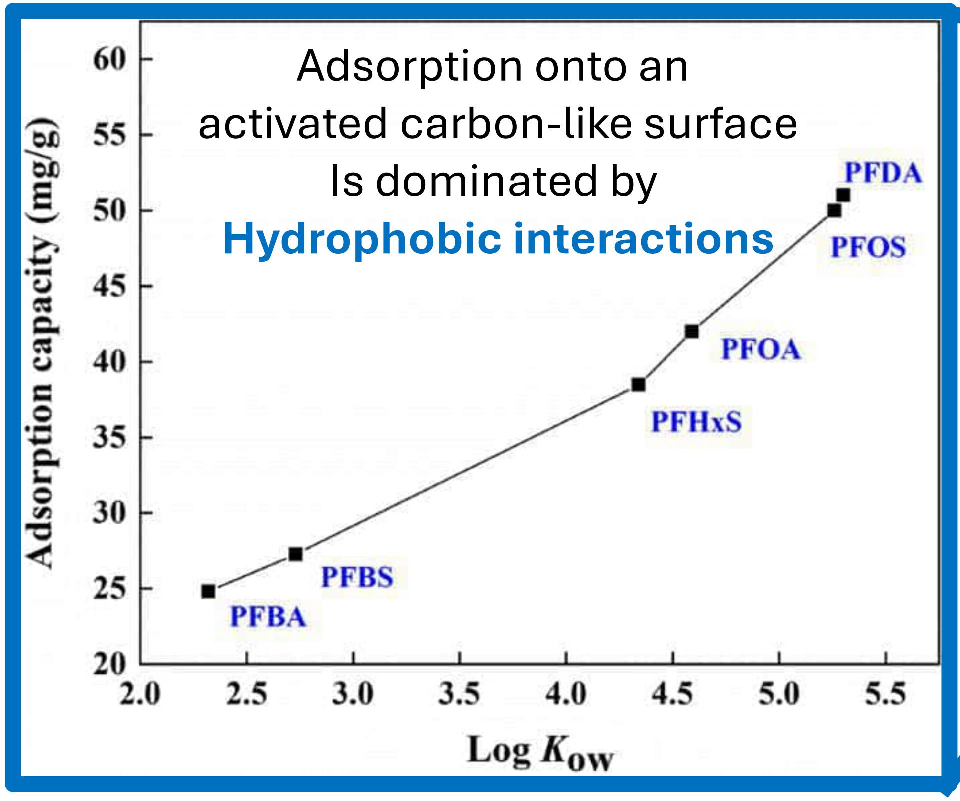


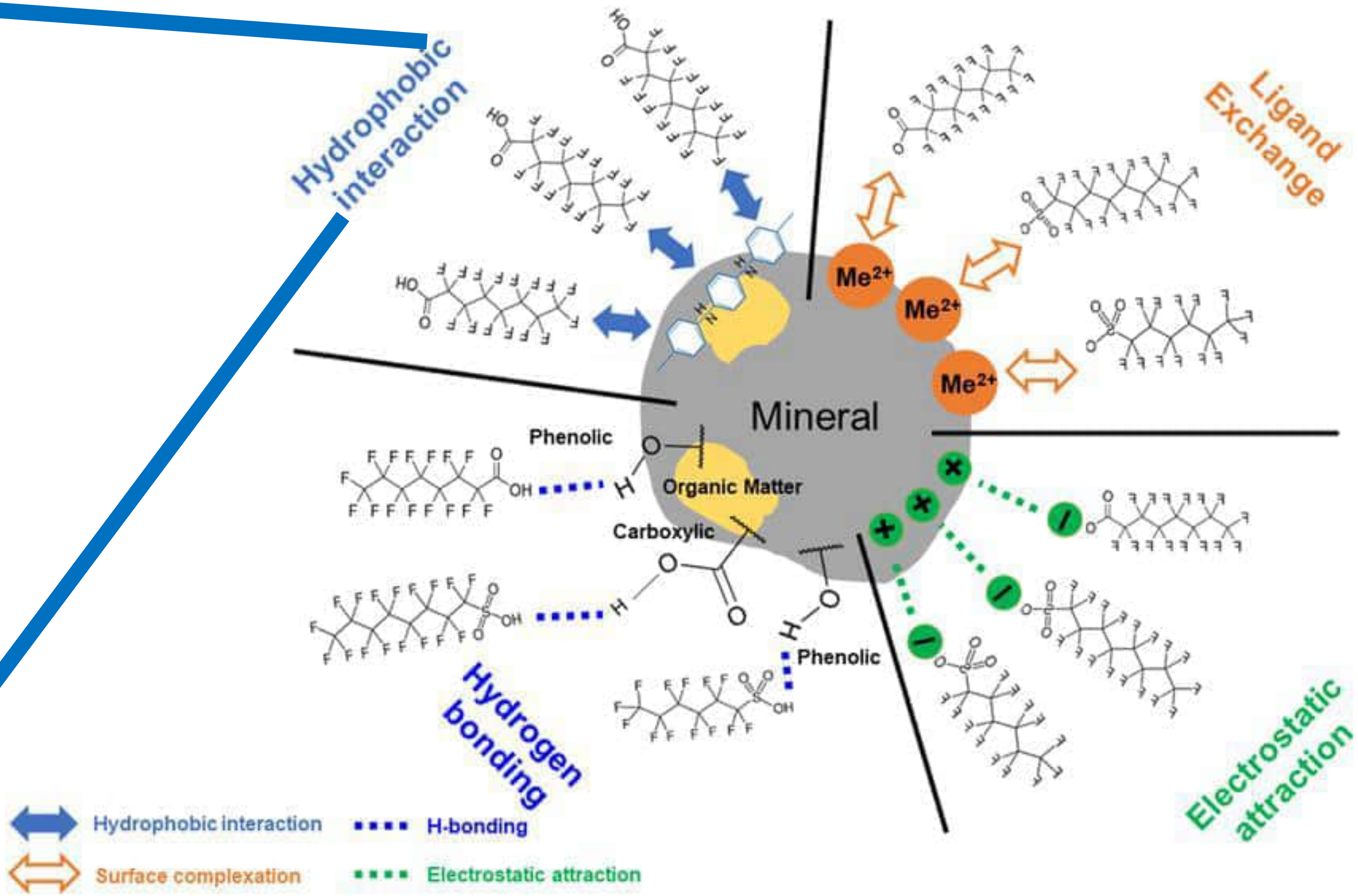
PFAS Partitioning into lipid bilayers





Adsorption on surfaces is complex





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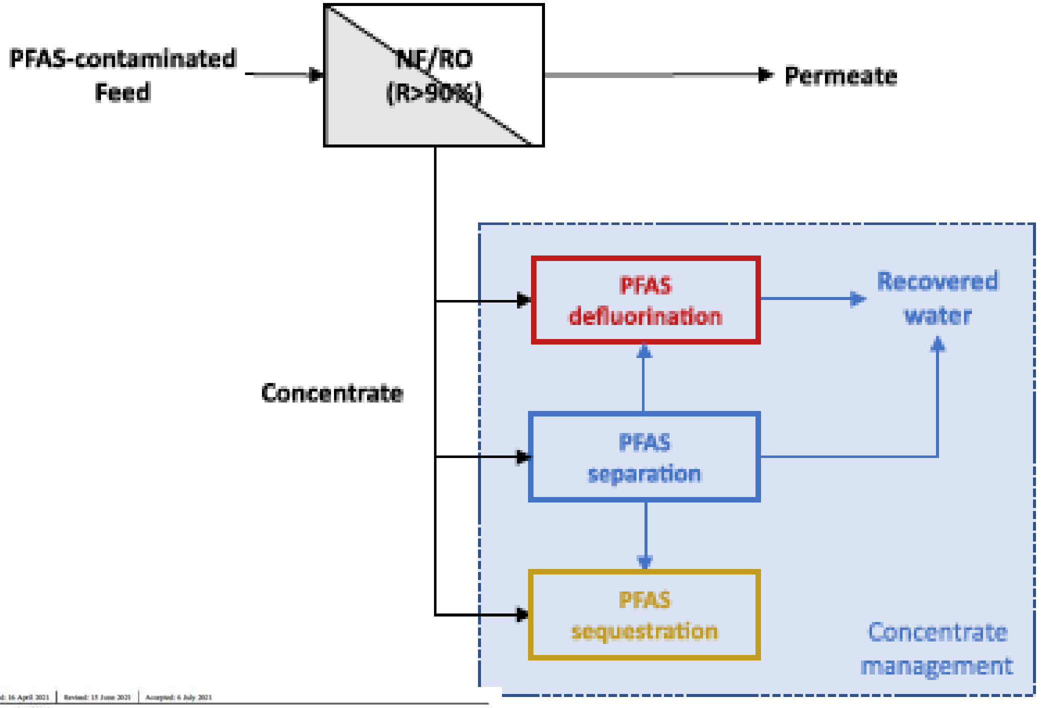
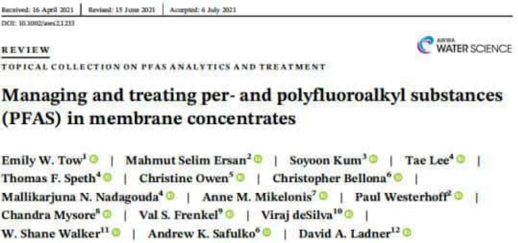
Nanofiltration & Reverse Osmosis achieve > 90% PFAS removal, *but then what ??*





Received: 16 April 2021 | Revised: 15 June 2021 | Accepted: 6 July 2021
DOI: 10.1002/aws2.1233
AWWA WATER SCIENCE
REVIEW
TOPICAL COLLECTION ON PFAS ANALYTICS AND TREATMENT

Managing and treating per- and polyfluoroalkyl substances (PFAS) in membrane concentrates

Emily W. Tow[1] | Mahmut Selim Ersan[2] | Soyoon Kum[3] | Tae Lee[4] | Thomas F. Speth[4] | Christine Owen[5] | Christopher Bellona[6] | Mallikarjuna N. Nadagouda[4] | Anne M. Mikelonis[7] | Paul Westerhoff[2] | Chandra Mysore[8] | Val S. Frenkel[9] | Viraj deSilva[10] | W. Shane Walker[11] | Andrew K. Safulko[6] | David A. Ladner[12]

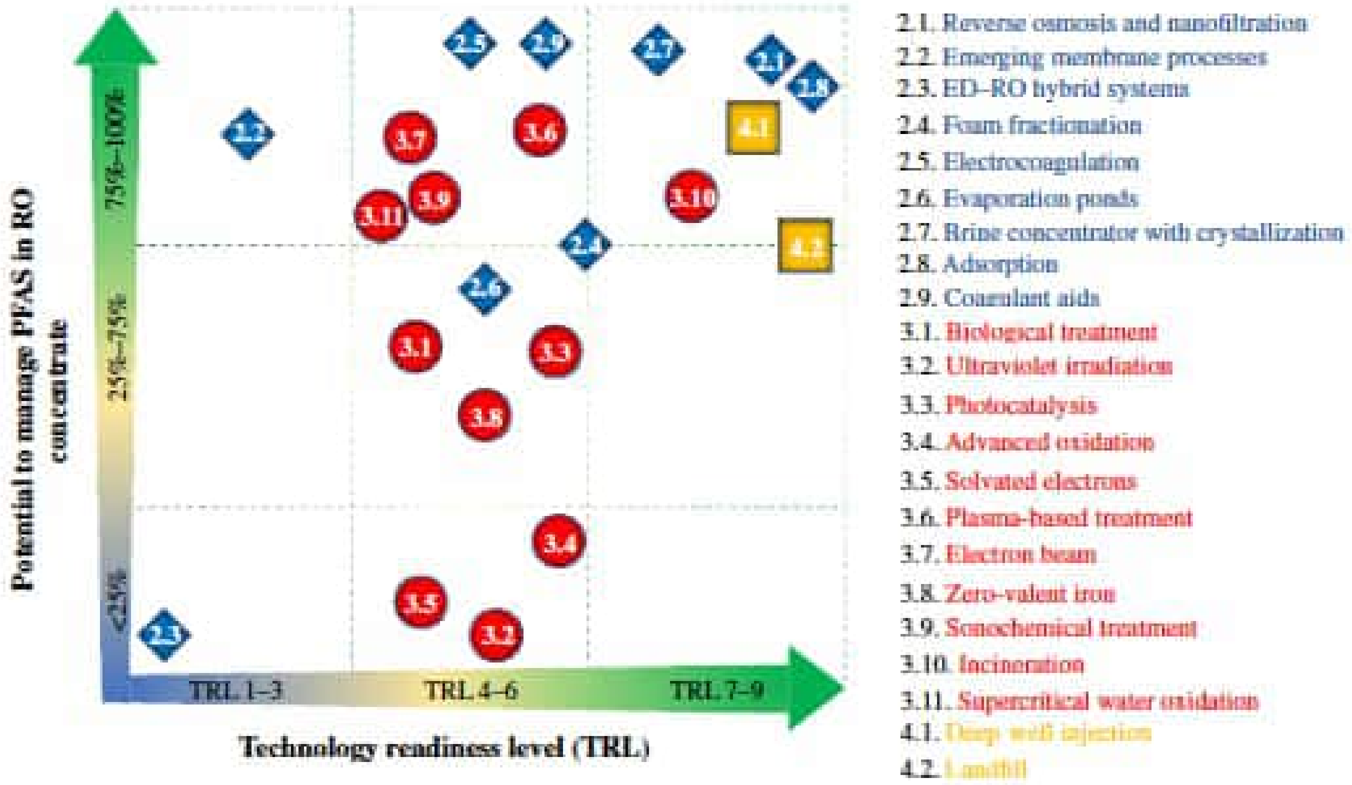


FIGURE 4 Operation of industrial wastewater plant with electron beam. (a) Injection of wastewater through nozzles. (b) Wastewater under treatment (reprinted from [Han et al., 2012] with permission from Elsevier)

FIGURE 3 (a) Foam fractionation column treating PFAS-laden water (photo courtesy of Evocra Pty Ltd). (b) Foam fractionation system (photo courtesy of OPEC systems and Dora Chiang, CDM Smith)

Outline

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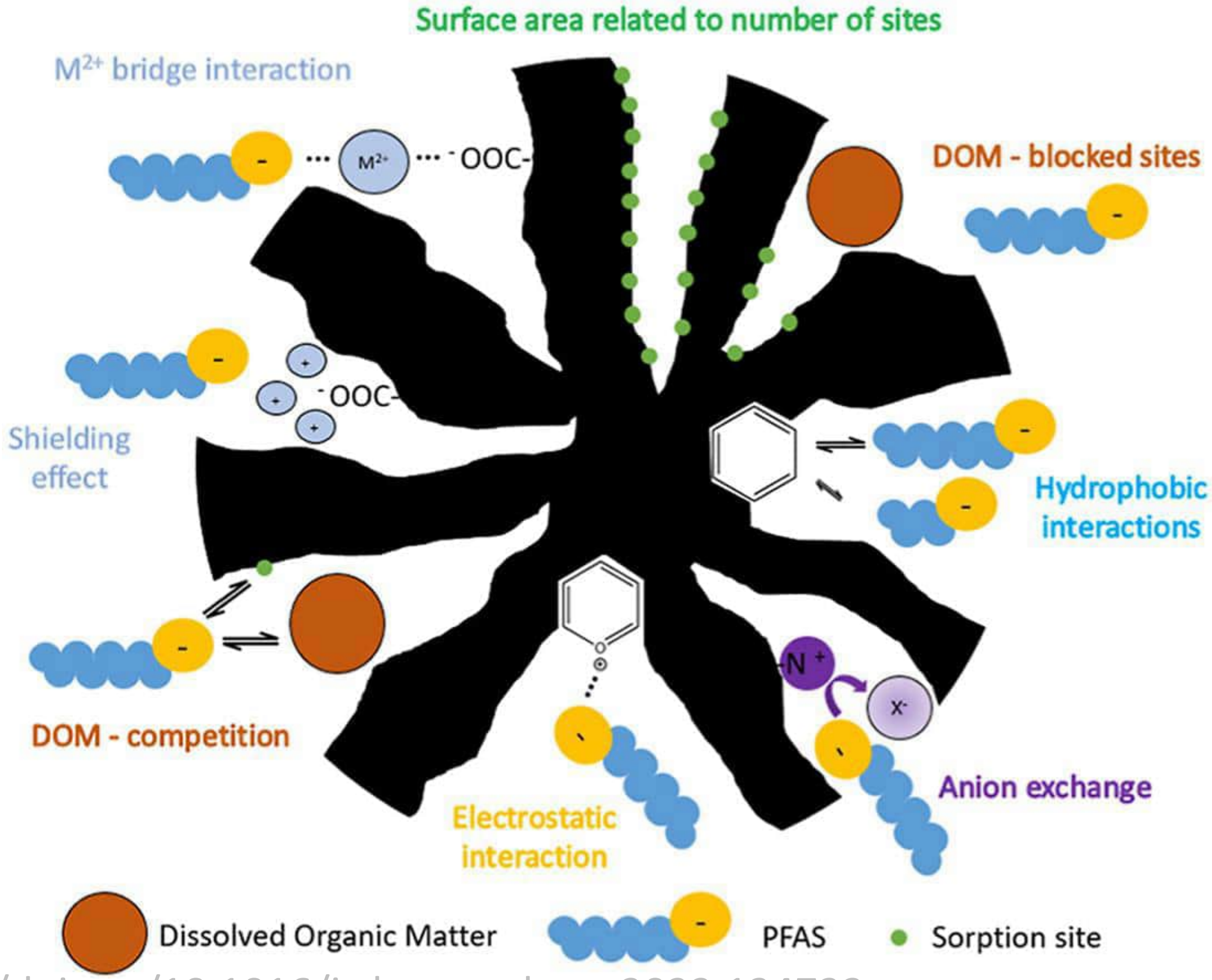
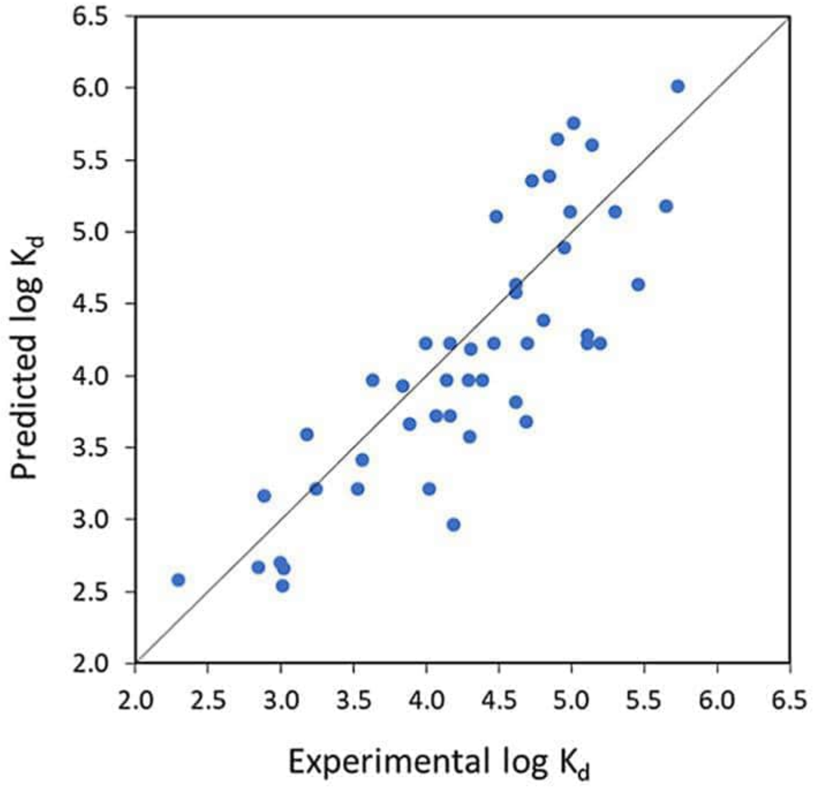
Adsorption: Packed Bed Treatment

We are pretty good at understanding PFAS interactions with GAC



K_d: solid - liquid distribution coefficient

$$\log K_d = f\,(C_{ORG}/O,\ SSA,\ CF_2)$$



https://doi.org/10.1016/j.chemosphere.2022.134733

Consider some Arizona Groundwaters

Zeng, Atkinson, Sharma, Ashani, Hjelmstad, Venkatesh, Westerhoff, *J. Water Sci., 2020*

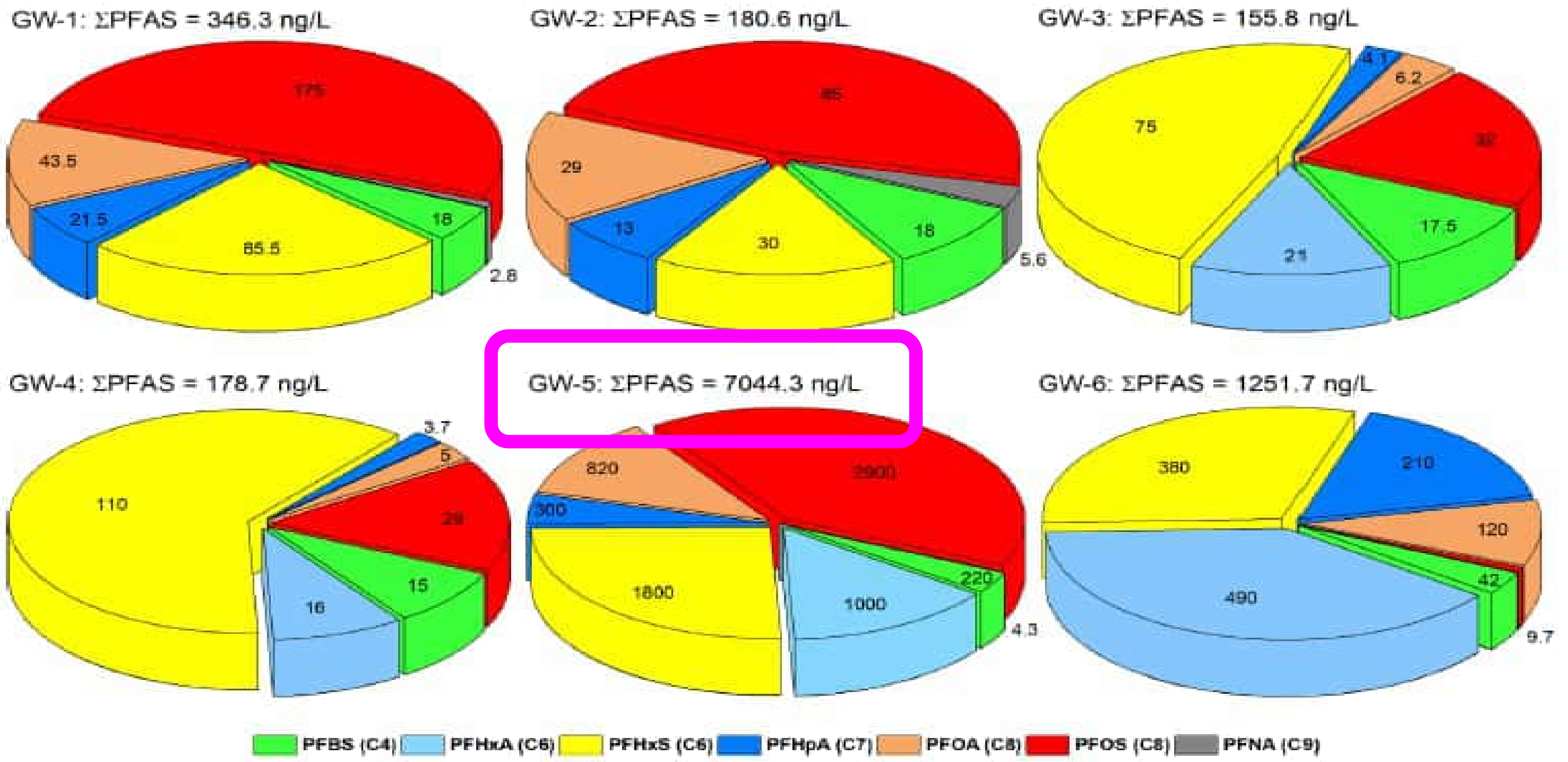
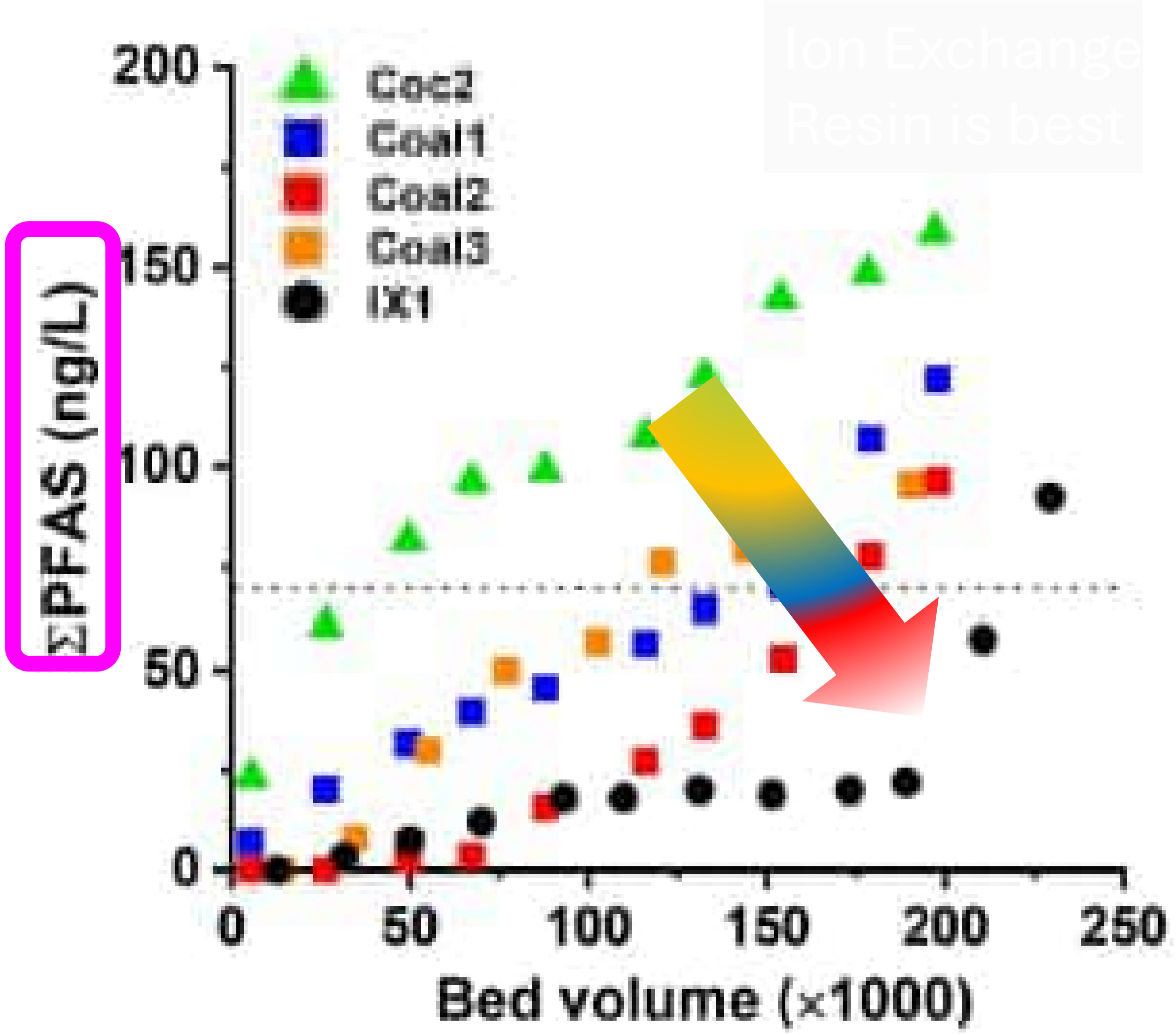


FIGURE 1 Per- and polyfluoroalkyl substances (PFAS) occurrence in the six groundwaters used in this study. The numbers in the pie charts show the concentrations of individual PFAS detected in the water

Activated Carbon adsorption

Zeng, Atkinson, Sharma, Ashani, Hjelmstad, Venkatesh, Westerhoff, J. Water Sci., 2020

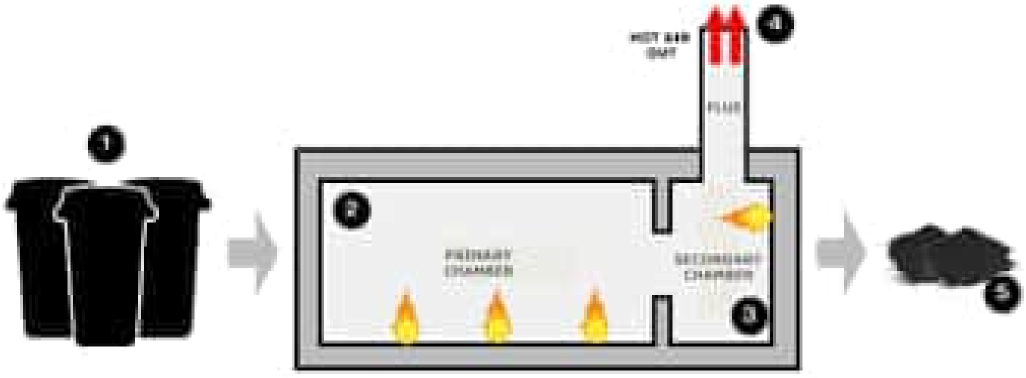


- Selective Ion Exchange resins adsorb PFAS better than Activated Carbon
- Type of Activated Carbon Matters
- Longer-chain PFAS removed better than Shorter-Chain PFAS
- Sulfonated-PFAS removed better than Carboxylated-PFAS

Activated Carbon adsorption - regeneration

Adsorption* → Clean Water
↓
Destruction

- What temperature is needed to Volatilize PFAS from GAC?
- What are oxidation by-products in gas phase ?
- What temperature is needed to produce HF only?
- Hotter incineration has higher costs !




Environmental Science & Technology

pubs.acs.org/est Critical Review

Critical Review of Thermal Decomposition of Per- and Polyfluoroalkyl Substances: Mechanisms and Implications for Thermal Treatment Processes

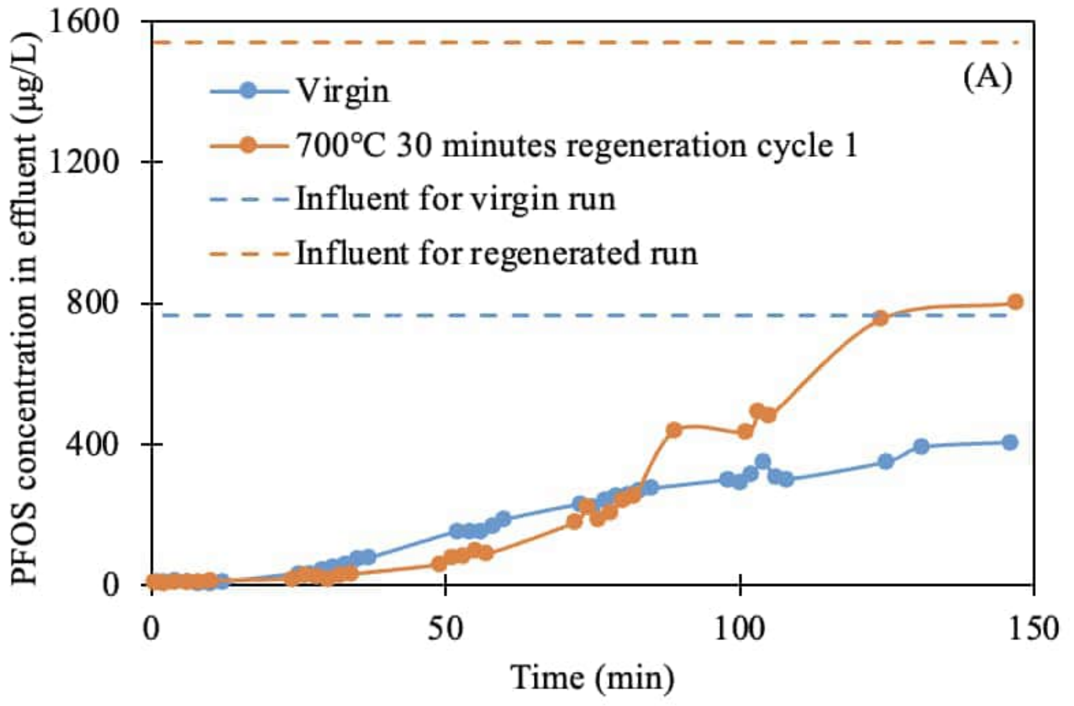
Junli Wang, Zunhui Lin, Xuexiang He, Mingrui Song, Paul Westerhoff, Kyle Doudrick,* and David Hanigan*

Cite This: Environ. Sci. Technol. 2022, 56, 5355−5370 Read Online

Total fluorine removal from spent GAC in nitrogen atmosphere at > common regeneration temps

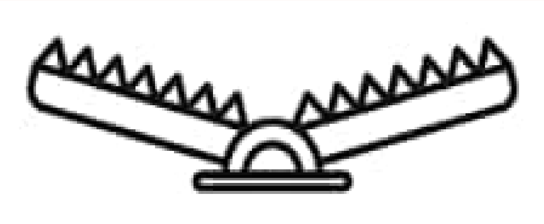
Temperature (℃)	Heating duration (min)		
	15	30	60
700	65±5	40±6	
800	88±7	49±3	>99
900	>99	98±3	

GAC Breakthrough virgin vs "regen"



Thermal treatment / regeneration of GAC

GAC “traps” PFAS on the surface



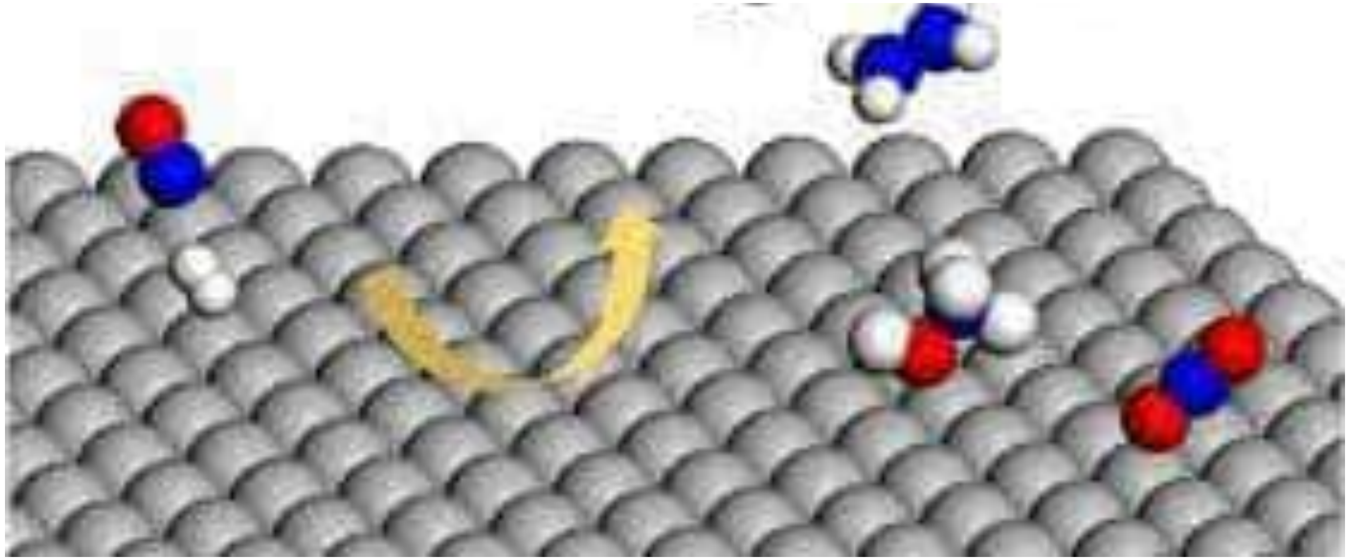
Thermal regeneration

Thermal decomposition on surface in presence of oxygen (from gas phase or within the GAC)

Desorbs PFAS into gas phase

Thermal decomposition in gas phase in presence of oxygen

What about Trap-and-Zap “in water” ?



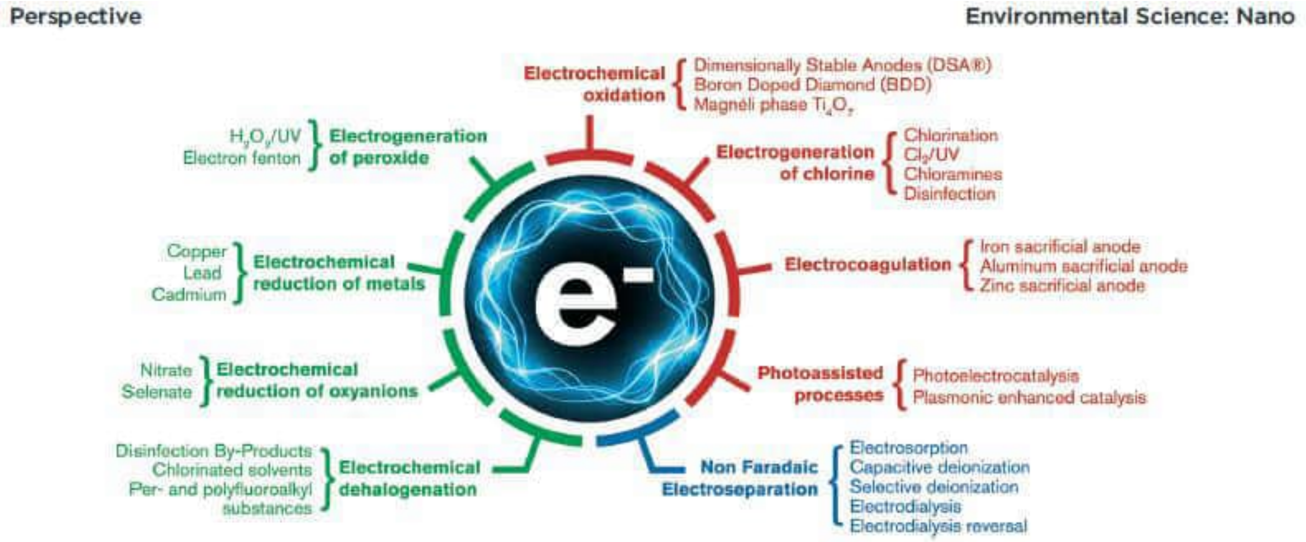


Fig. 1 Electrochemically-driven processes classified as reductive faradaic processes (green), oxidative faradaic processes (red), and physical separation through non-faradaic processes (blue).

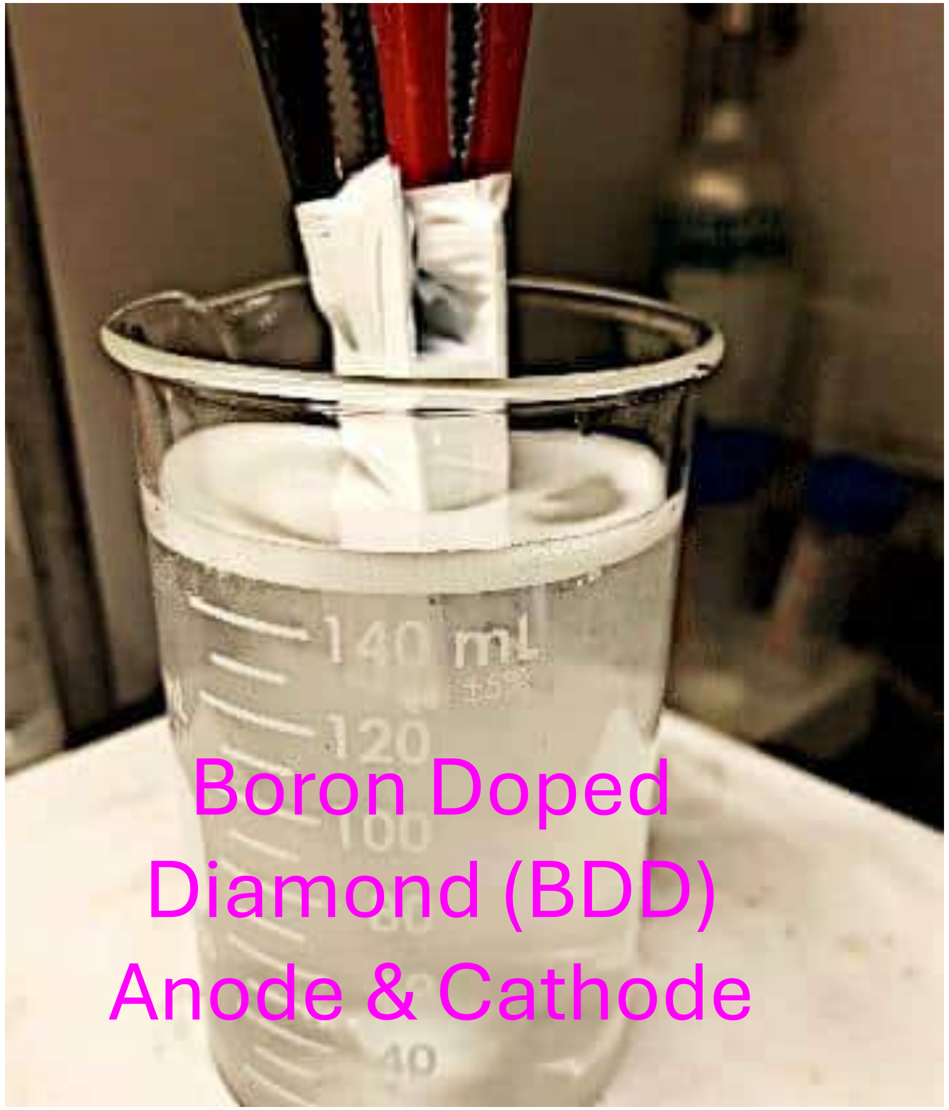
Surface catalysis

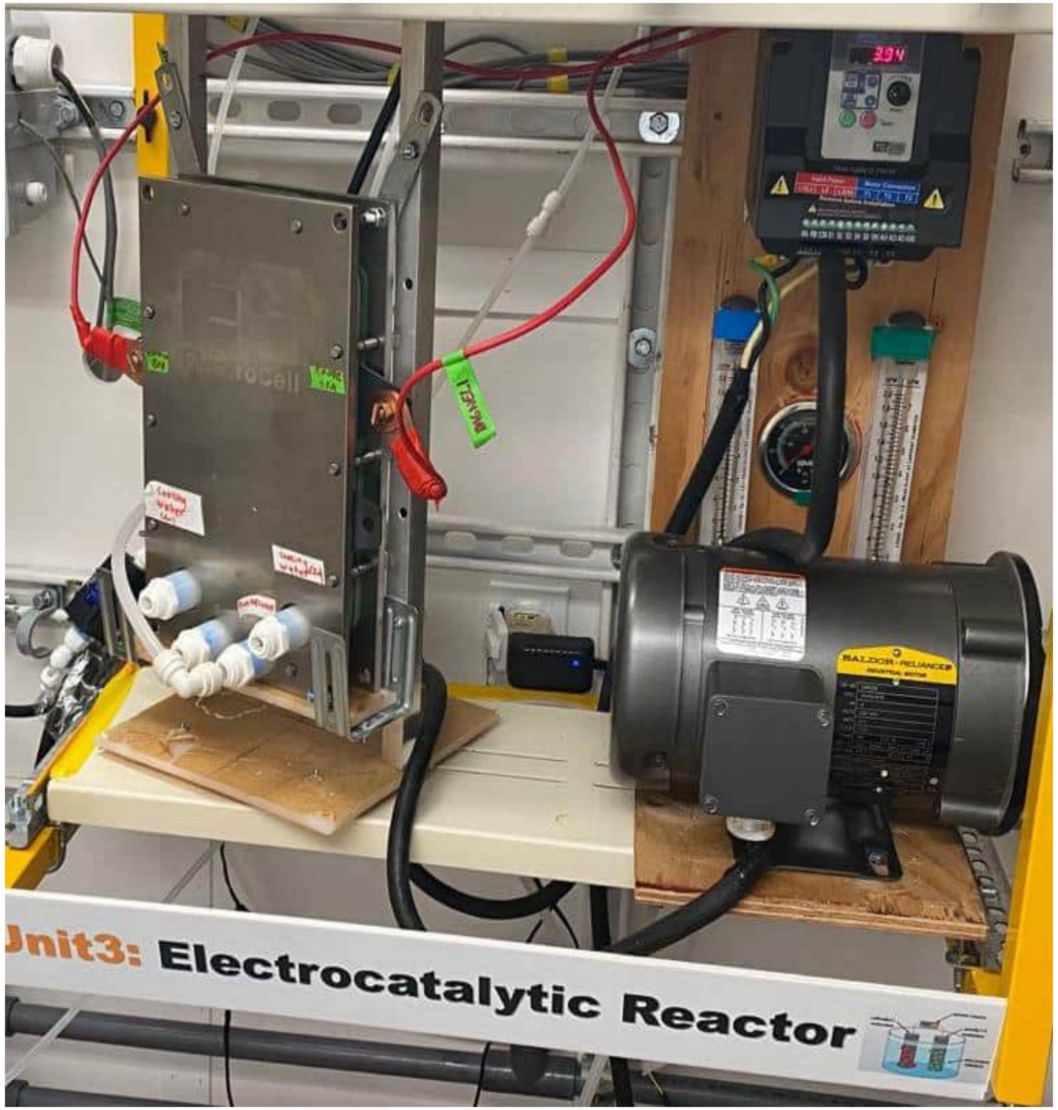
PFAS adsorption to surface

Transformation on surface

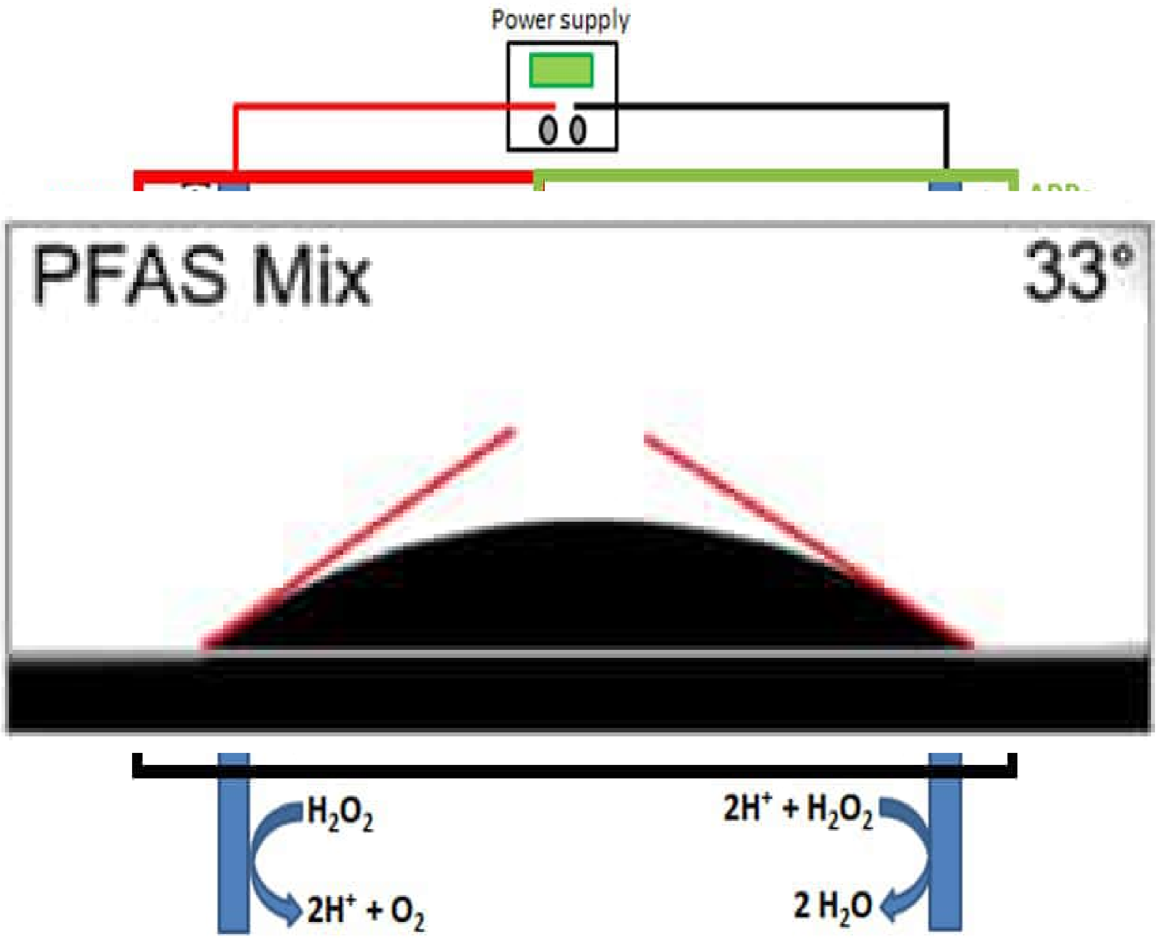
Desorption of by-products from the surface

Electrocatalytic PFAS Transformation

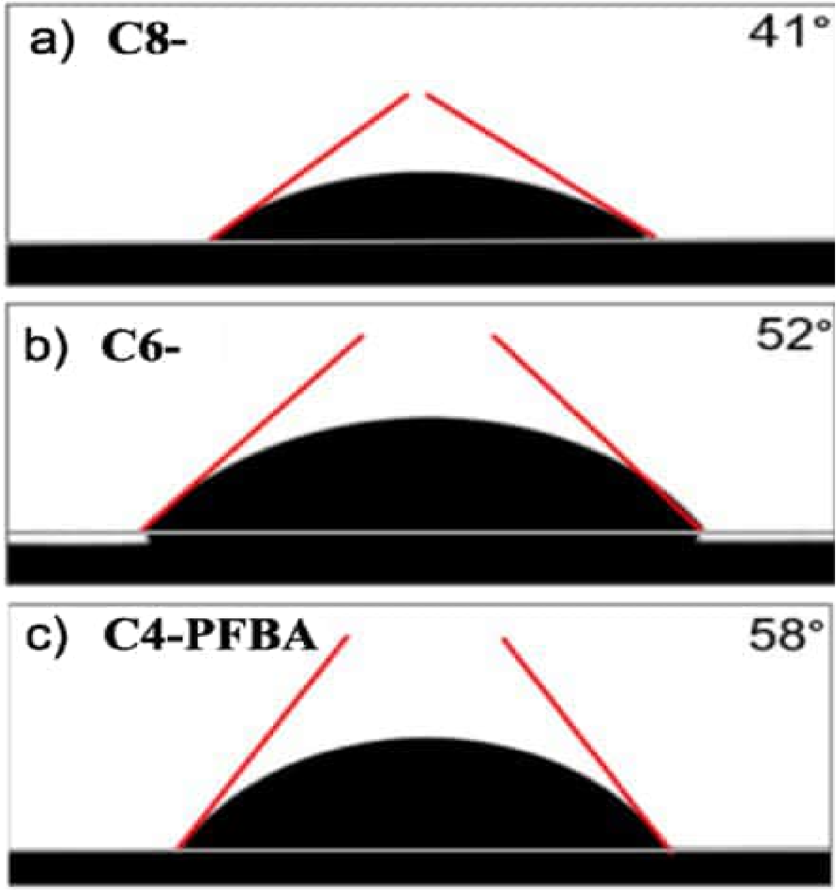




Heterogeneous Electrocatalytic Requires PFAS Hydrophobic Interactions with Electrode Surface



Surface contact angle on Boron Doped Diamond (BDD) Electrode varies for each PFAS



Electrocatalytic degradation of Target PFAS & By-Product Formation

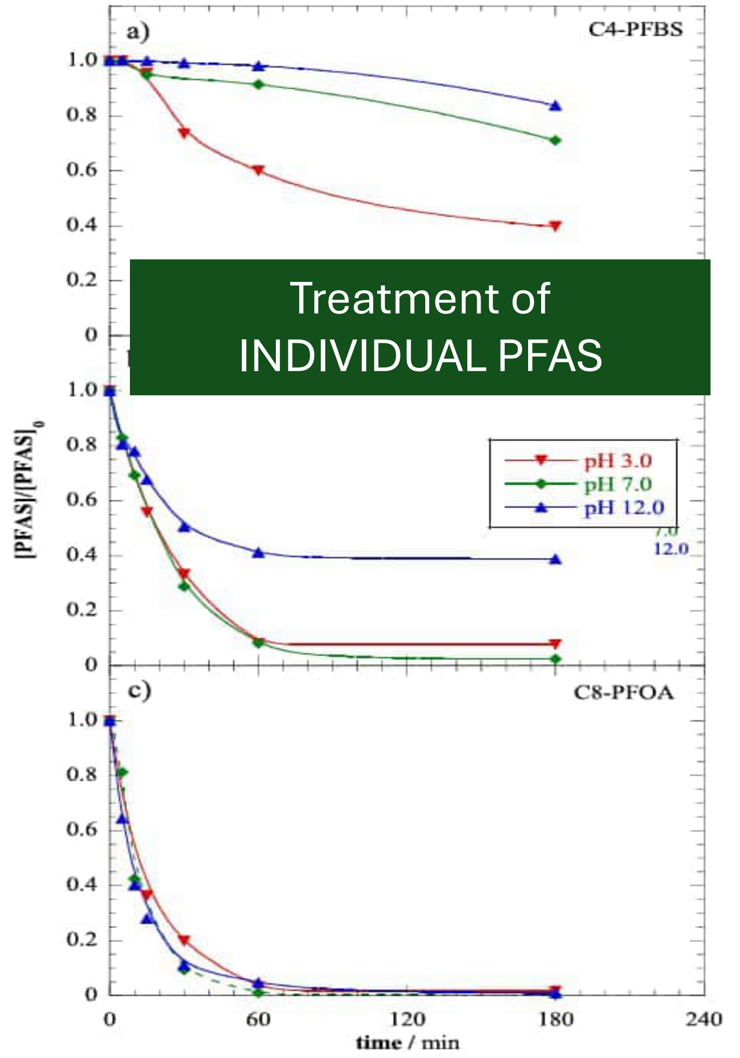


Fig. 4. Electrochemical degradation of 0.33 μM solutions of PFAS at 100 mA/cm2 at different pH (▼) 3.0, (◆) 7.0, and (▲)12.0 and chain length: (a) C4-PFBS, (b) C6-PFHxS, and (c) C8-PFOA.

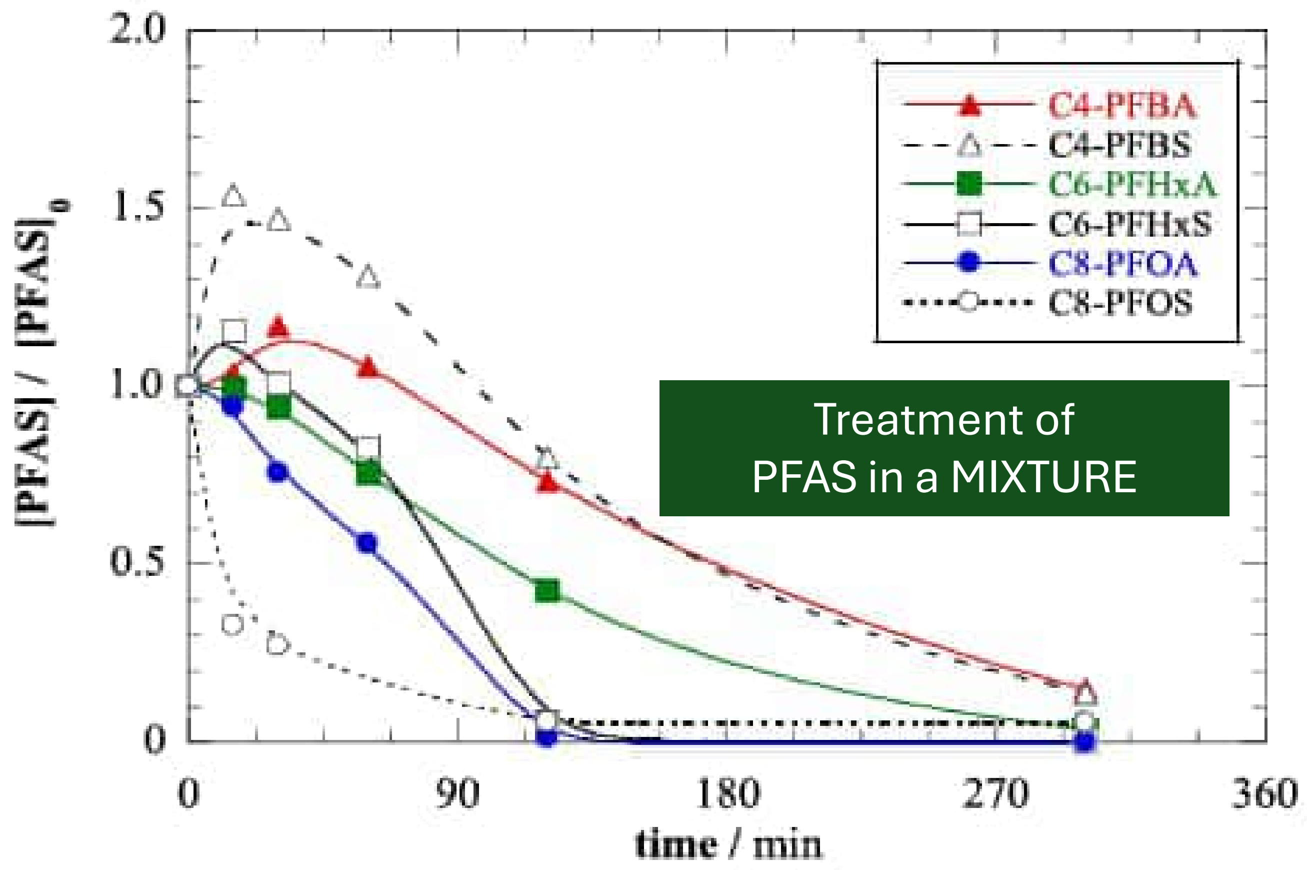


Fig. 6. Electrochemical treatment (100 mA/cm^2) at pH 12 of multi-solute model wastewater matrix containing 0.33 μM C4-PFBA, 0.33 μM C4-PFBS, 0.33 μM of C6-PFHxA, 0.33 μM C4-PFHxS, 33 μM C8-PFOA, and 0.33 μM C8-PFOS.

Real Semiconductor Wastewater

Electrocatalytic PFAS Transformation

Table 1

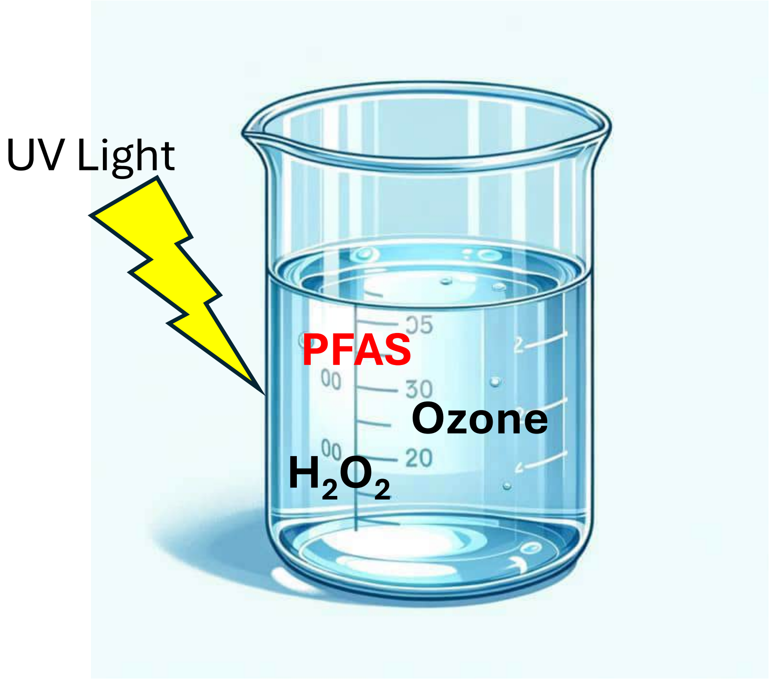
Characteristics of RO concentrate from semiconductor manufacturing industrial wastewater containing PFAS before and after electrochemical treatment with BDD electrodes at 100 mA/cm^2 for 300 min.

Parameter	Before ECO	After ECO
pH	11.5	11.0
Conductivity (mS)	34.9	44.5
COD (mg L^{-1})	692	664
C4-PFBA (ng L^{-1})	3210	1530
C4-PFBS (ng L^{-1})	2810	550
C6-PFHxA (ng L^{-1})	790	50
C6-PFHxS (ng L^{-1})	<MRL	<MRL
C8-PFOA (ng L^{-1})	130	<MRL
C8-PFOS (ng L^{-1})	<MRL	<MRL

MRL = minimum reporting limit, which was 2 ng/L for all the parameters.

Does Advanced Oxidation Processes (AOPs) degrade PFAS in Water ?

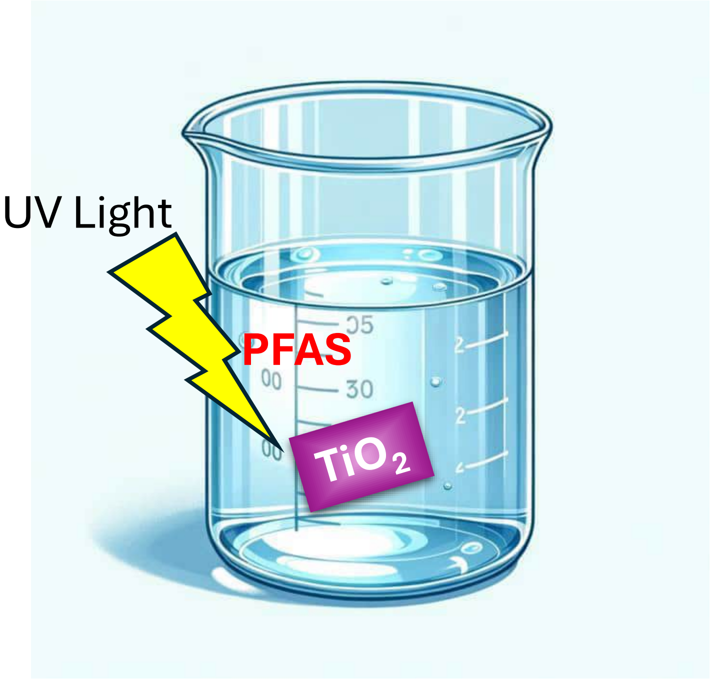
Homogeneous Catalysis



All reacts are "dissolved"

Remember – works for 1,4-Dioxane

HETEROgenous Catalysis



Contains "dissolved" & Particulate or surface solids where PFAS can first adsorb

Example: REAL Groundwater

Groundwater characterization

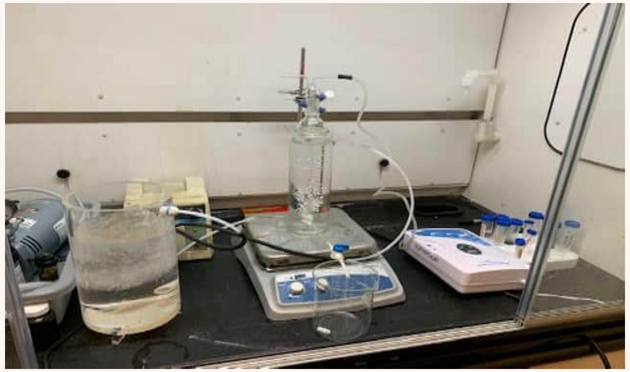
Parameters	Groundwater
pH	7.61
Conductivity (µS/cm)	843
Alkalinity (mg/L as CaCO3)	264
Turbidity (NTU)	0.36
DOC (mg/L)	0.69
UV 254 (cm-1)	0.003
Chloride (mg/L)	109.68
Nitrate (mg/L as N)	3.1
Sulfate (mg/L as SO4)	54.3

EPA Method 533 (25 PFAS) [MDL= 2ng/L]

PFASs	Groundwater (ng/L)
PFDA (C10)	2
PFNA (C9)	2
PFOA (C8)	580
PFOS (C8)	52
PFHpA (C7)	67
PFHxA (C6)	70
PFHxS (C6)	32
PFPeA (C5)	52
PFPeS (C5)	6
PFBA (C4)	51
PFBS (C4)	6
∑ PFAS	920

Mixtures are common

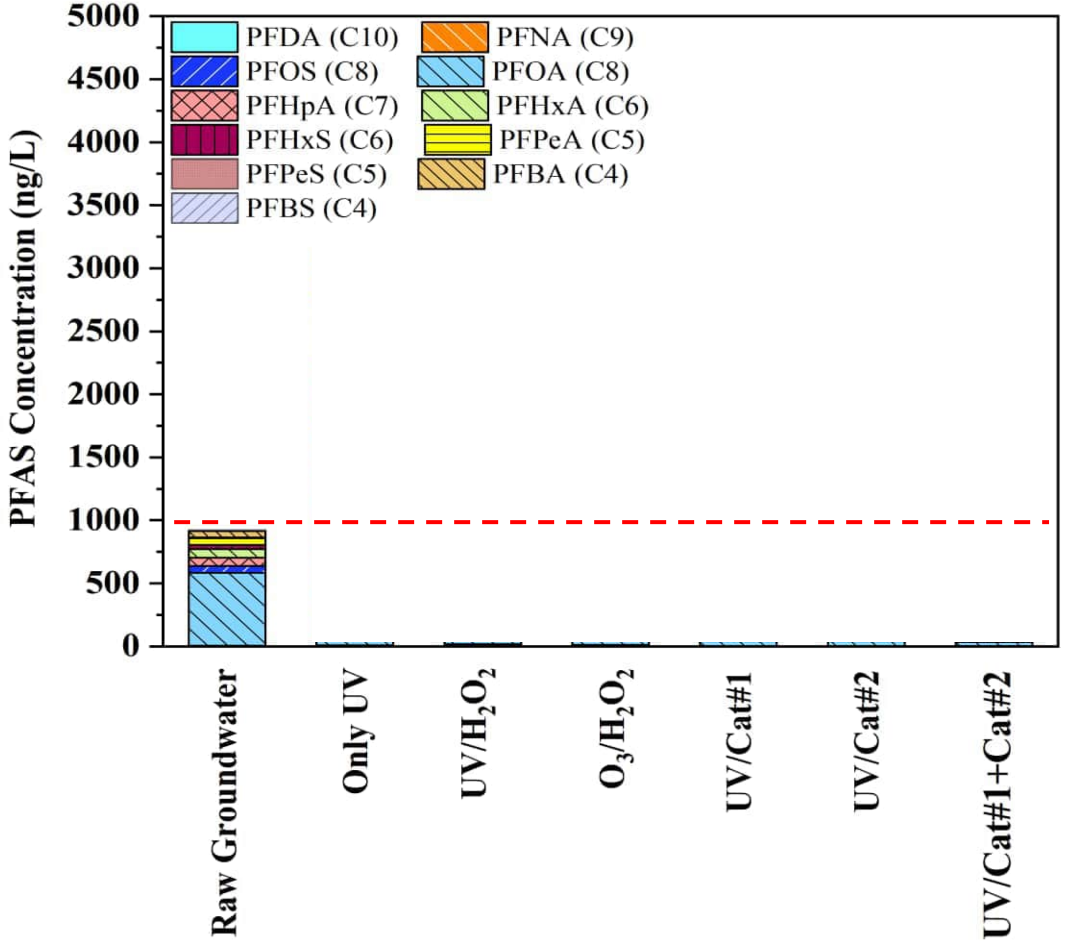
3 Homogeneous + 3 Heterogeneous Catalysis Oxidation Processes



AOPs	Catalyst Dose (g/L)	Ozone dose (mg/L)	H_2O_2 dose (mg/L)	Contact Time (hr)
Only UV	N/A	N/A	N/A	4
UV/H_2O_2	N/A	N/A	$C_{initial}$: 20 C_{final}: 12	4
O_3/H_2O_2	N/A	$[O_3]_{initial}$: 3.64 $[O_3]_{final}$: 0.74	$[H_2O_2]_{initial}$: 20 $[H_2O_2]_{final}$: <DL	2
UV/Cat#1	1	N/A	N/A	4
UV/Cat#2	1	N/A	N/A	4
UV/Cat#1+Cat#2	1+1	N/A	N/A	4

AOPs for PFAS removal

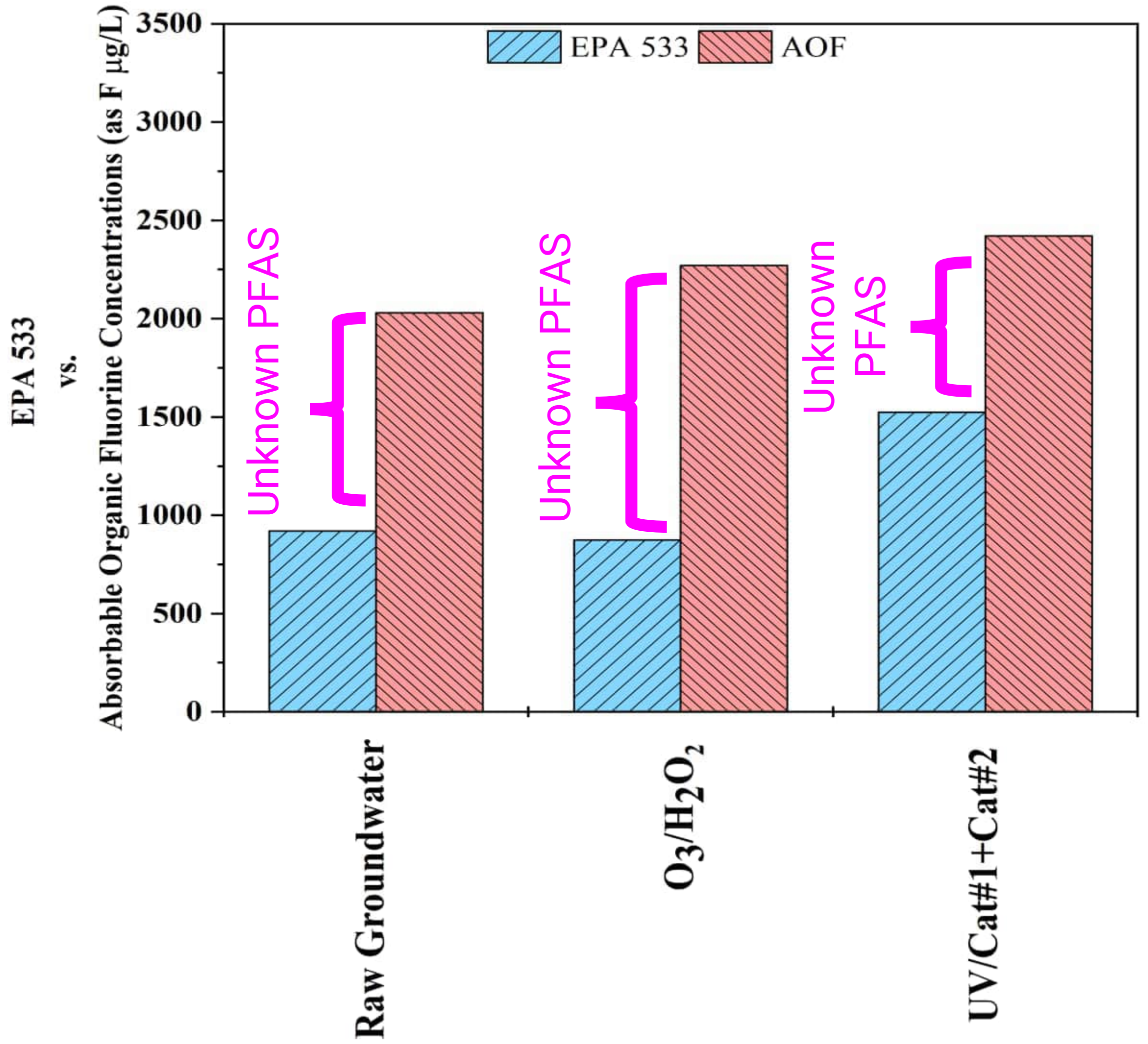
EPA 533 (25 PFAS)



Ersan et al. ACS 2023 & (under review)

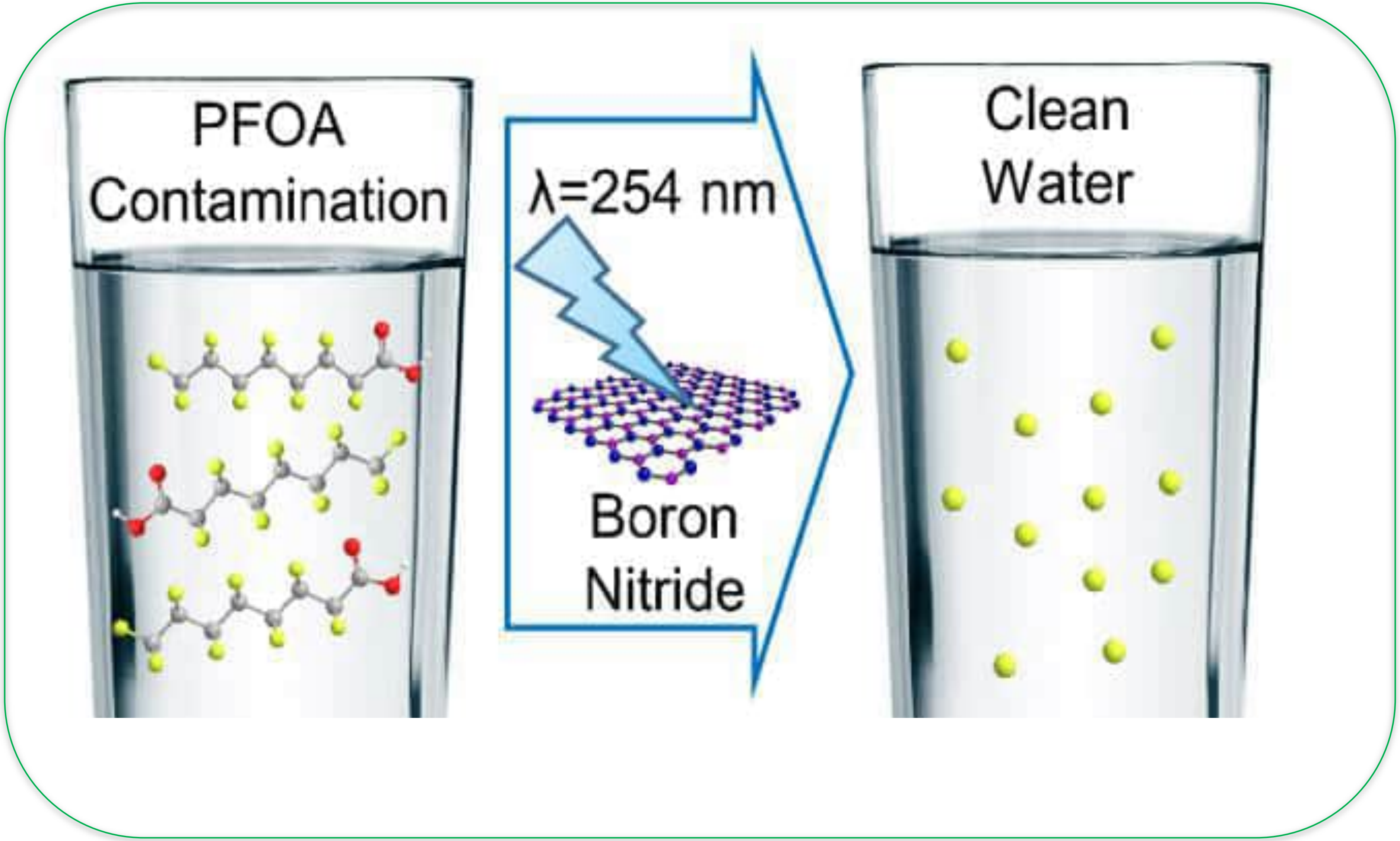
- Longer-chain PFAS converted into shorter-chain PFAS
- O_3/H_2O_2, UV/Cat#2, and UV/Cat#1+Cat#2 were effective degrading PFOA

Screening of AOPs for PFAS removal

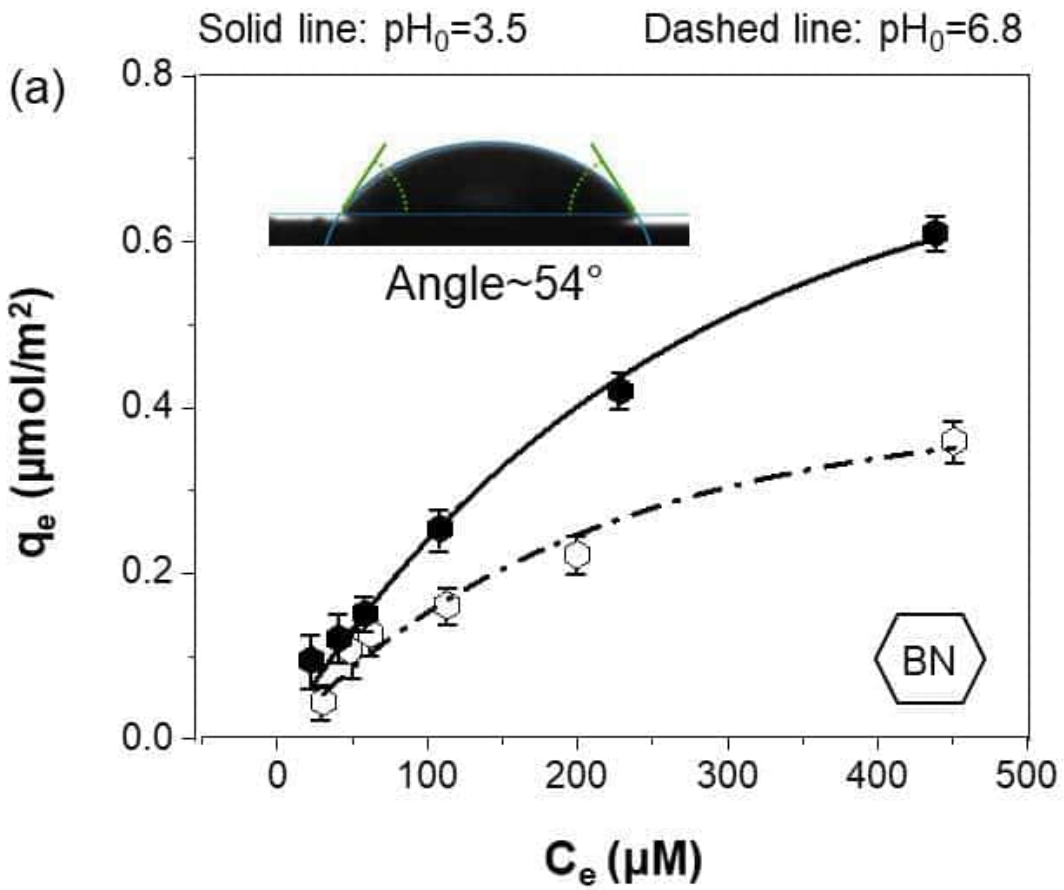


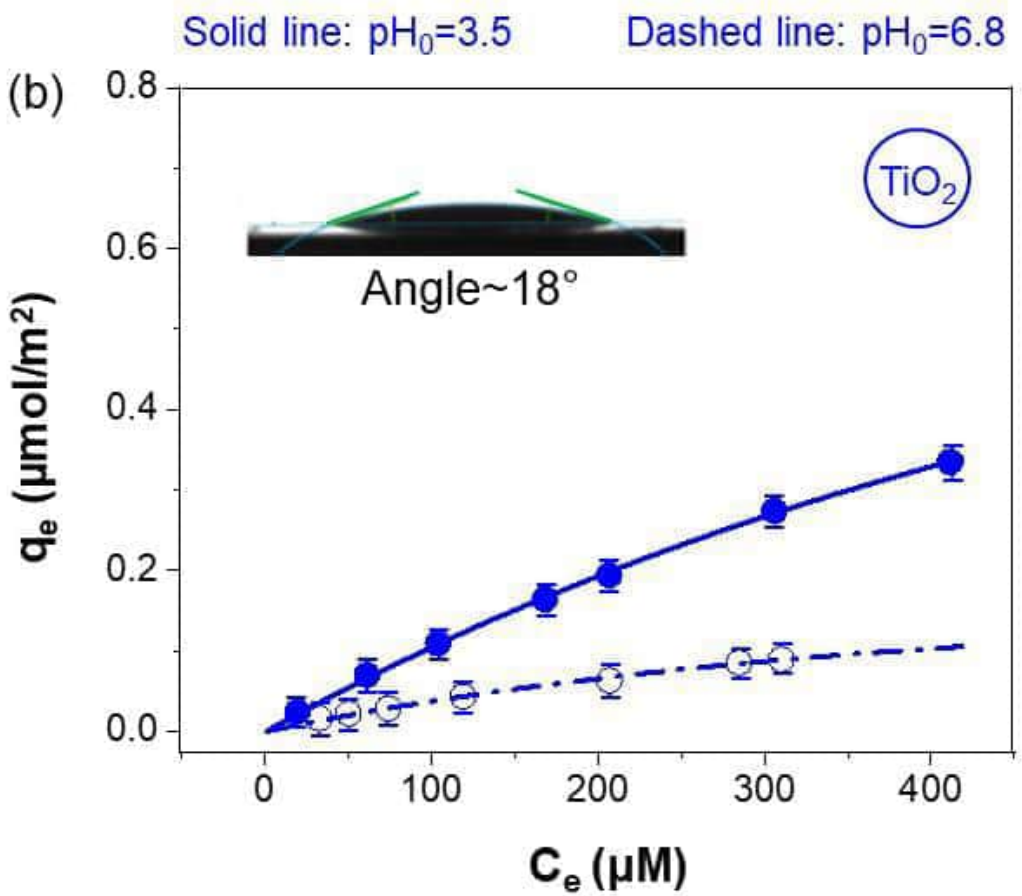
Ersan et al. ACS 2023 & (under review)

- GW contained 63% unknown PFAS
- EPA 533 only captures target PFAS, waters with large quantity of unknown PFAS species have risk of forming detectable PFAS


PFOA
Contamination
λ=254 nm
Boron
Nitride
Clean
Water

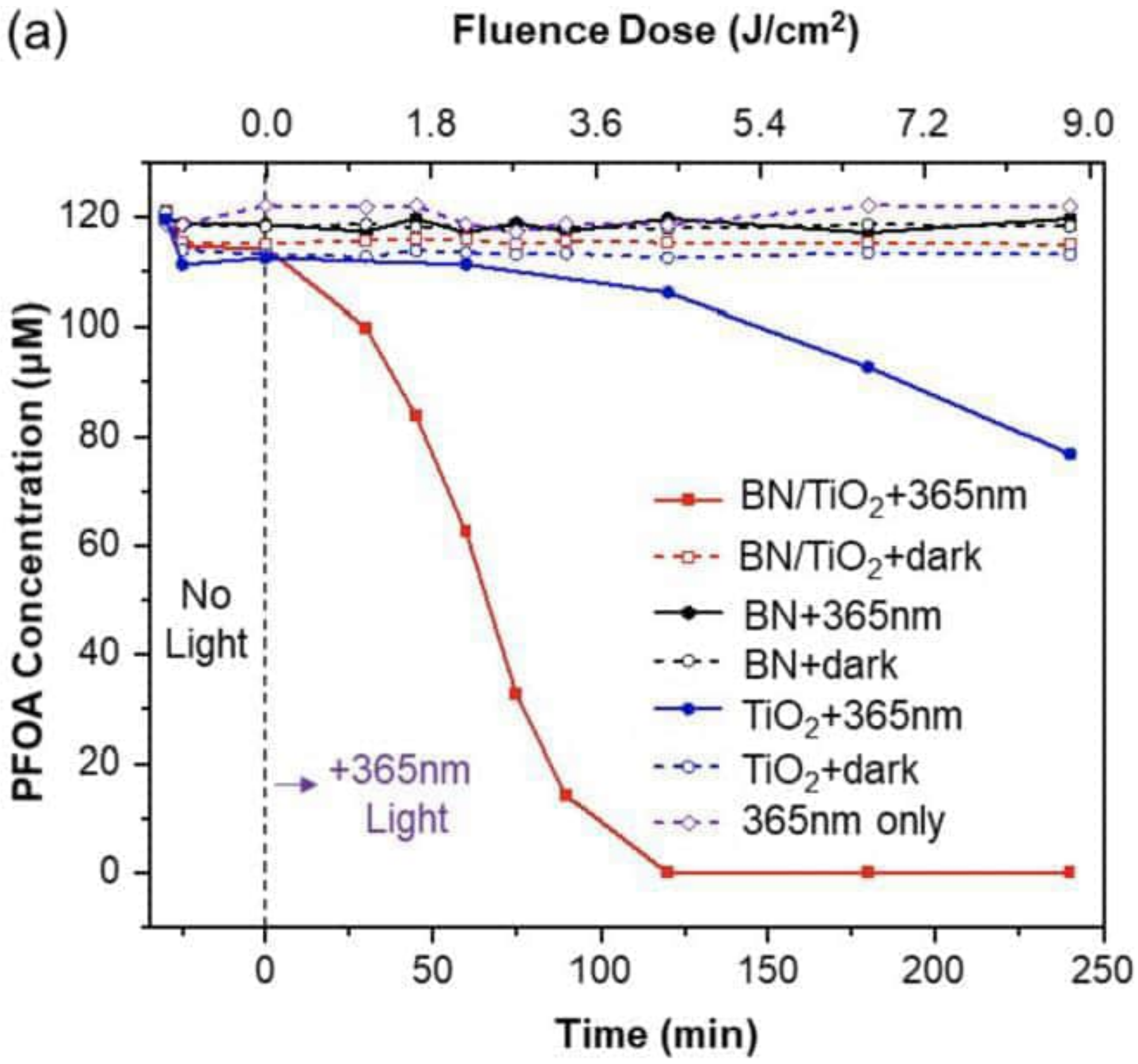
PFOA sorption isotherms for (a) BN and (b) TiO2 at pH 3.5 (solid line) and 6.8 (dashed line)



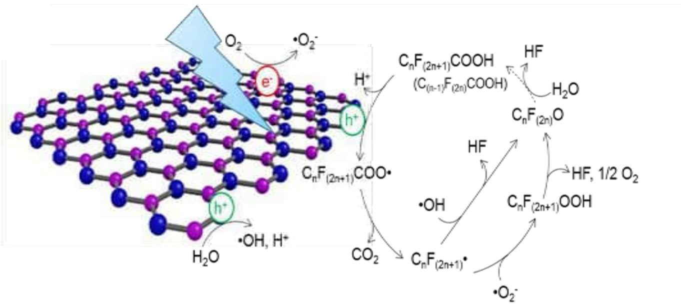


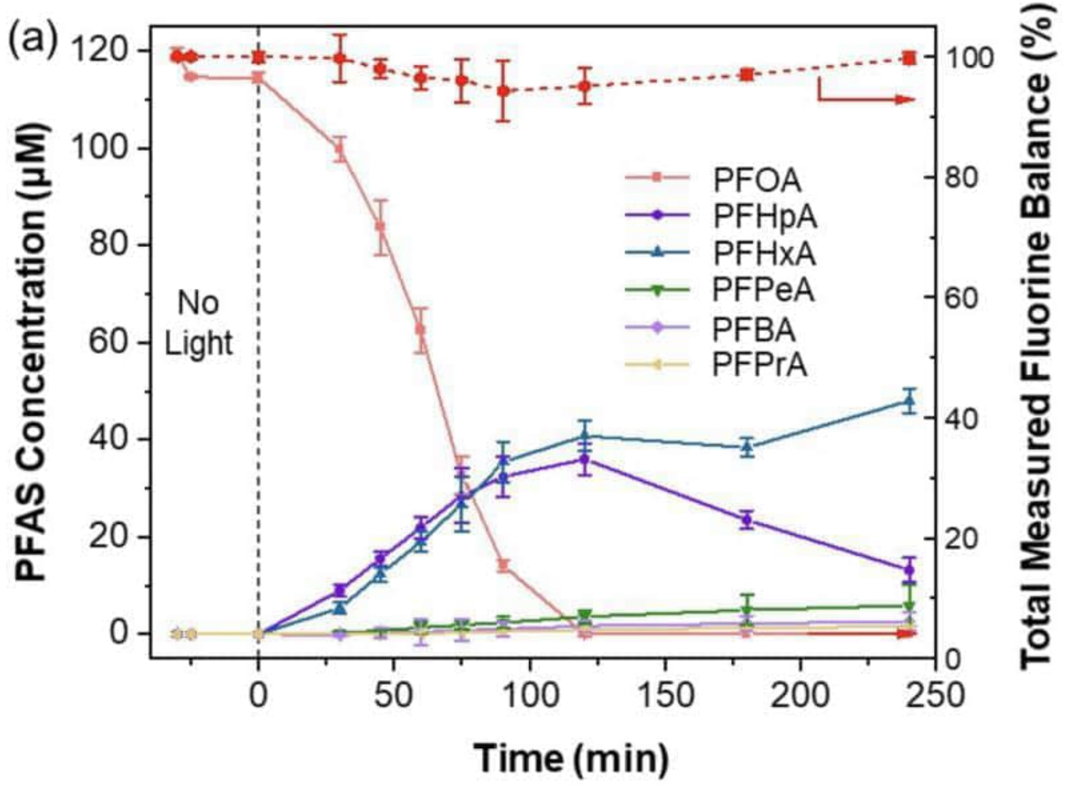
Boron nitride (BN) offers a more HYDROPHOBIC surface that "traps" PFOA better than TiO_2

Combining BN+TiO_2 Photocatalysts ***Traps-And-Zaps*** PFOA



Duan et al, *Chemical Engineering Journal* 448 (2022) 137735





Outline

- **Unique properties of PFAS** relative to other friends we know well
- Knowing **what you measure is important** before we try to remove anything
- **PFAS are surfactants** – what does that mean ?
- Membrane separation
- **Hydrophobicity controls everything**
    - Activated carbon adsorption & relationship to bioaccumulation
    - Thermal regeneration of GAC & destruction of PFAS
    - Electrocatalysis
    - Photocatalysis versus ”Homogeneous” Advanced Oxidation Processes (AOP)
- **Hydrogenation is different than oxidative defluorination**
    - Influence of **biodegradation of PFAS**
- Summary and Ongoing Research

ASU Biodesign Institute
Arizona State University
Swette Center for Environmental Biotechnology

Reductive Defluorination and Mineralization of Perfluoroalkyl Substances (PFAS)

Sponsored through NEWT by Xylem

Dr. Bruce E. Rittmann, Director

Acknowledgements of collaborators:
Essential ASU researchers for the MCfR + MBfR work: Drs. Chen Zhou, Min Long, Yihao Luo, and Jie Cheng
Rice University: Dr. Mike Wong, Dr. Thomas Senftle, Dr. Welman Elias, Juan Donosa, Kimberly Heck, Aishi Wang, Yu Chen.

https://biodesign.asu.edu/environmental-biotechnology Rittmann@asu.edu

Two Key Properties of PFAS – High bond-dissociation energy of C-F bond and high electronegativity of F

Bond dissociation energy	
Bond	kcal/mol
C-F	105.4
C-H	98.8
C-O	84.0
C-C	83.1

$\overset{\delta+}{C}$—$\overset{\delta-}{F}$

Table 1 Electronegativities of selected elements on the Pauling scale[5]

H (2.1)				
Li 1.0	C 2.5	N 3.0	O 3.5	**F** **4.0**
Na 0.9	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8				Br 2.8
Cs 0.7				I 2.5

We would love to biodegrade PFAS, but it is difficult because……

The C-F bond is so strong
Perfluorination prevents enzyme access to target sites

So, let's "knock off" some F substituents by taking advantage of the the strong electronegativity of F.

Reductive defluorination!

The Synergistic Platform

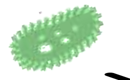
■ Stage 1:

H_2-induced defluorination catalyzed by precious-metal nanoparticles, e.g.,

$$C_7F_{15}COOH + H_2 \longrightarrow C_7H_nF_{15-n}COOH + nF^- \quad (1 \leqslant n \leqslant 15)$$

■ Stage 2:

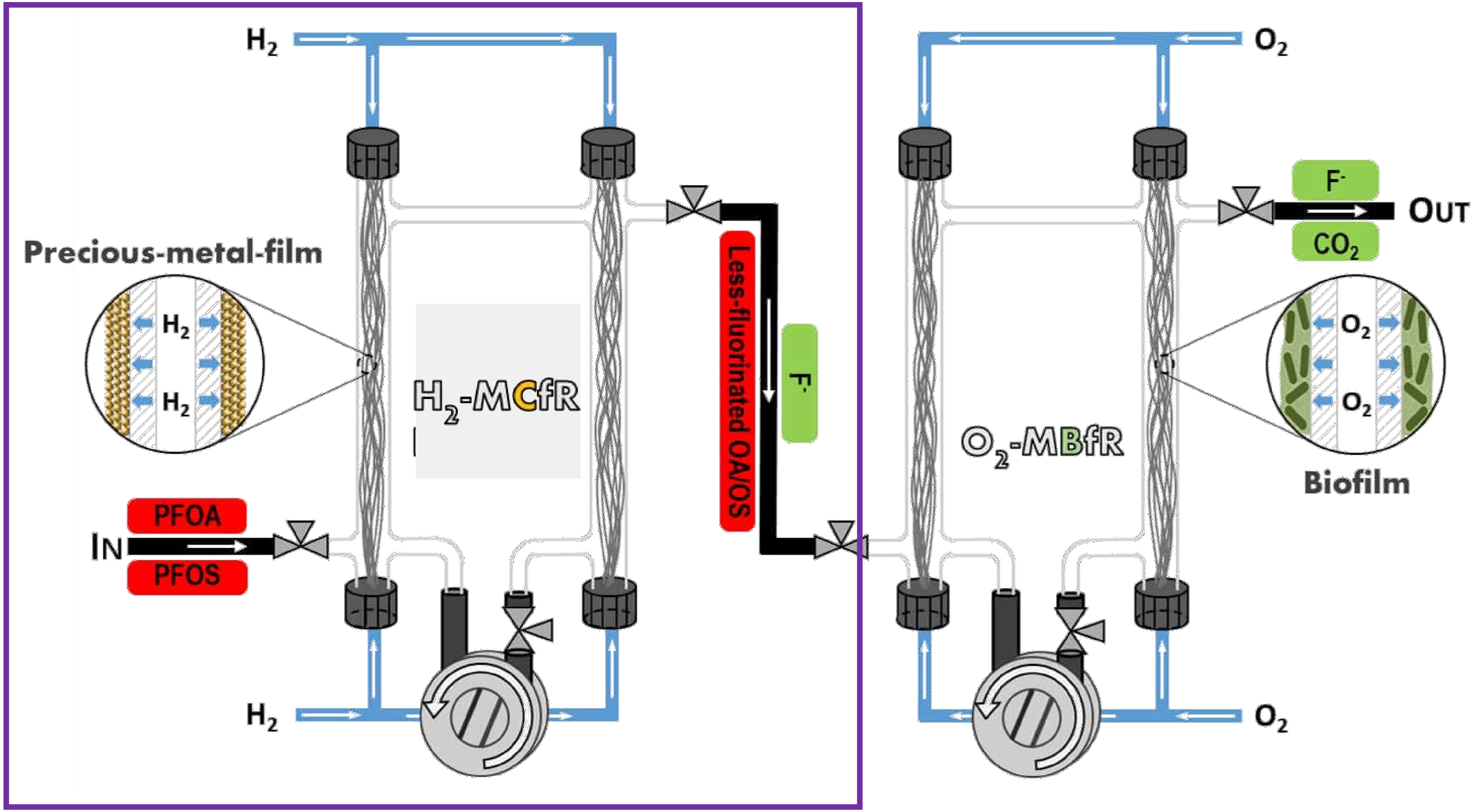
O_2-induced mineralization mediated by microorganisms, e.g.,



$$C_7H_nF_{15-n}COOH + O_2 \longrightarrow 8CO_2 + (15-n)F^- \quad (1 \leqslant n \leqslant 15)$$

THE SYNERGISTIC PLATFORM

Defluorination and mineralization of PFAS



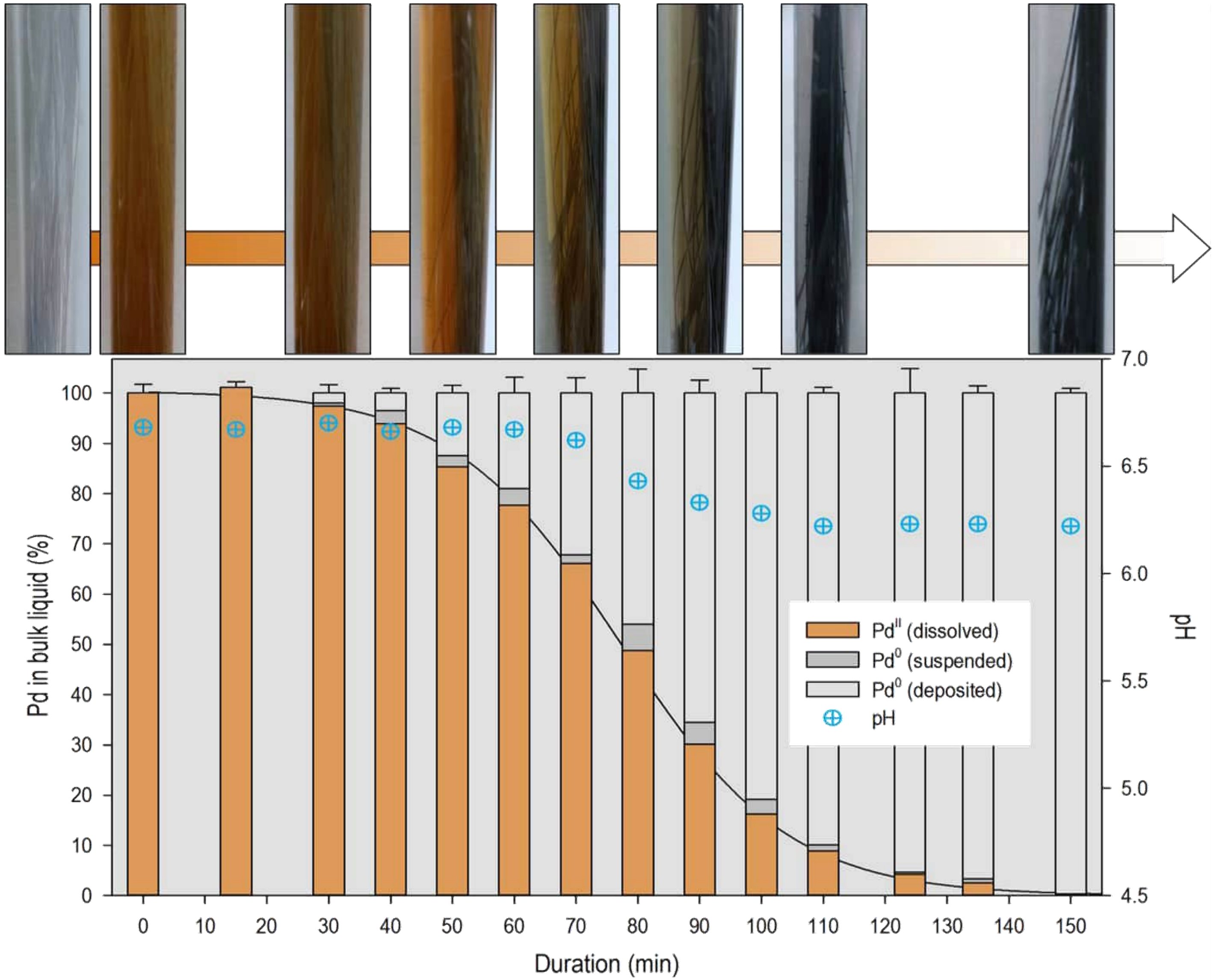
I will present extensive results for PFOA today.

We also have extensive results for PFOS, and they are similar to the results for PFOA.

Less-extensive, but growing results are likewise similar for GenX, PFBS, PFNA, and PFHXS.

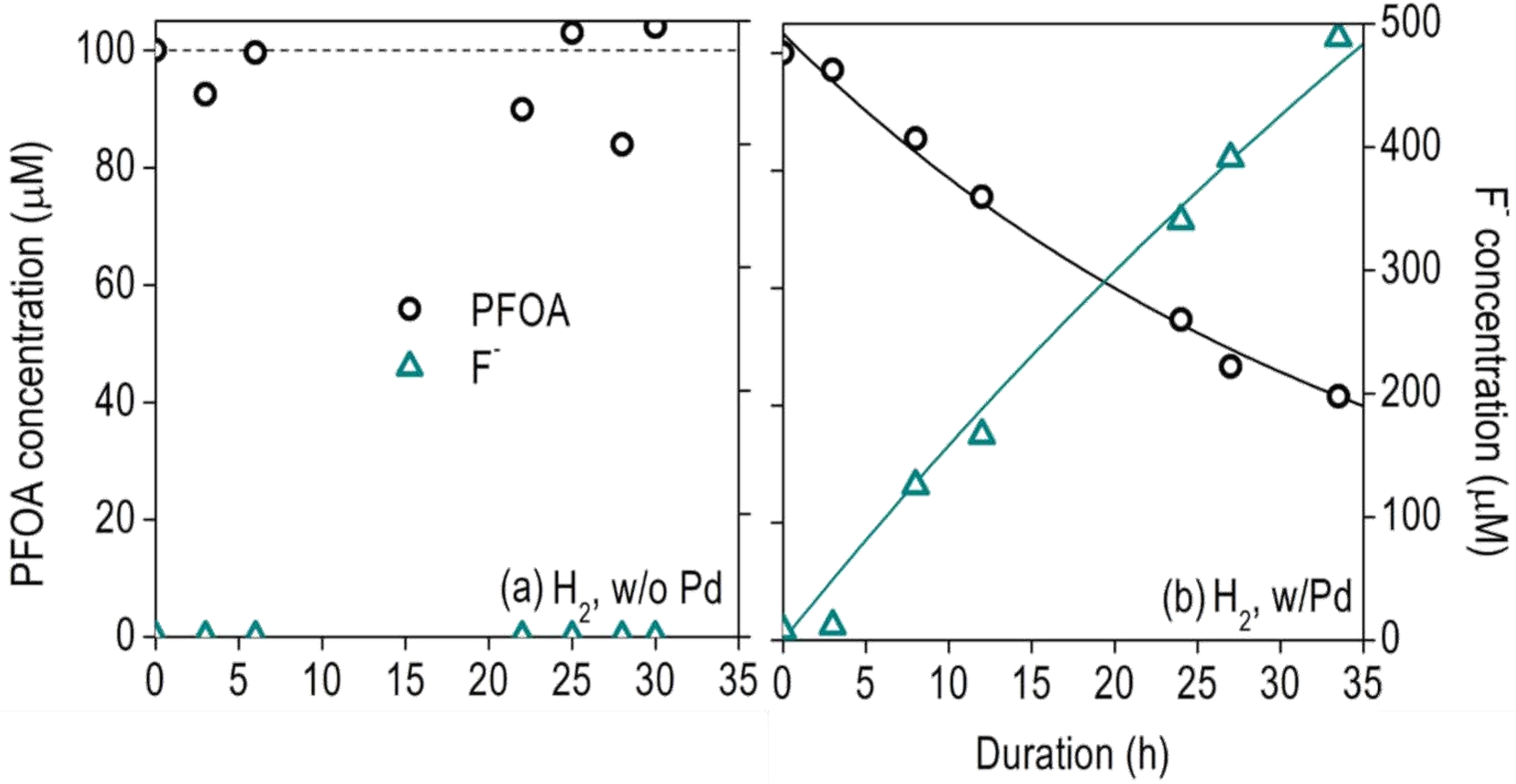
Reductive Defluorination in the H_2-based MCfR

In situ Synthesis and Deposition of Pd^0 on gas-transfer membranes



Catalytic defluorination in the H_2-MCfR (1)

Pd^0 is capable of catalyzing reductive defluorination of PFOA



Catalytic defluorination in the H_2-MCfR (2)

Products of Pd-catalyzed defluorination:

partially to totally defluorinated OAs

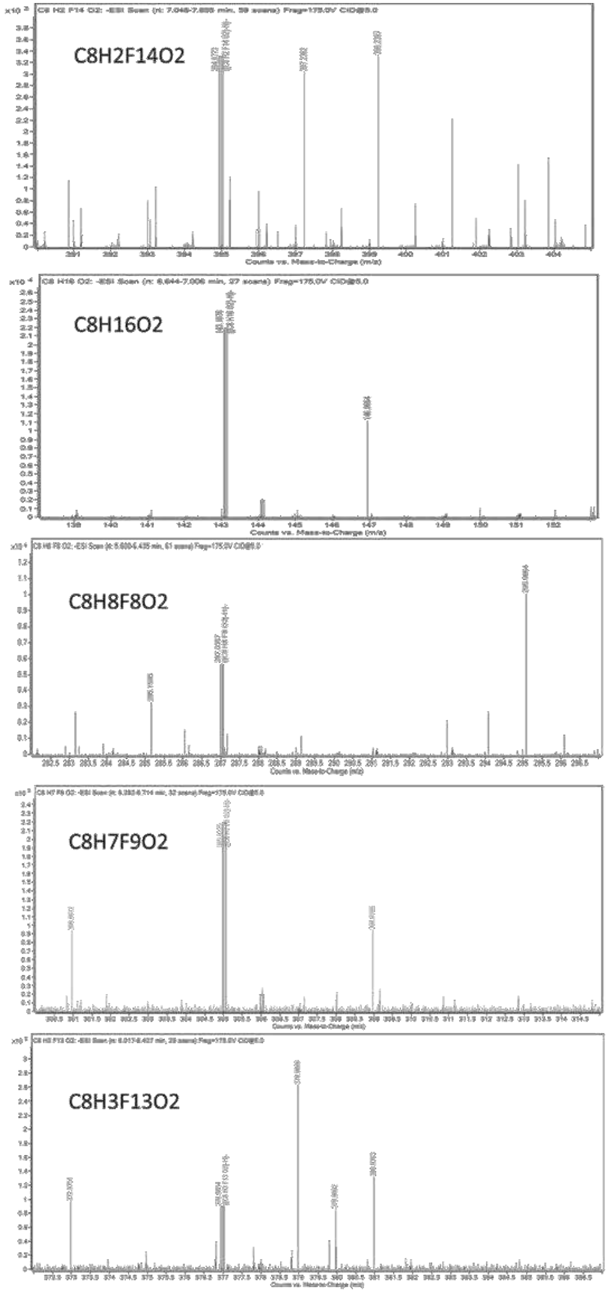
$C_8F_{15}O_2^- + 2H_{ads}^* \rightarrow C_8HF_{14}O_2^- + F^- + H^+$

$C_8F_{15}O_2^- + 4H_{ads}^* \rightarrow C_8H_2F_{13}O_2^- + 2F^- + 2H^+$

$C_8F_{15}O_2^- + 12H_{ads}^* \rightarrow C_8H_6F_9O_2^- + 6F^- + 6H^+$

$C_8F_{15}O_2^- + 14H_{ads}^* \rightarrow C_8H_7F_8O_2^- + 7F^- + 7H^+$

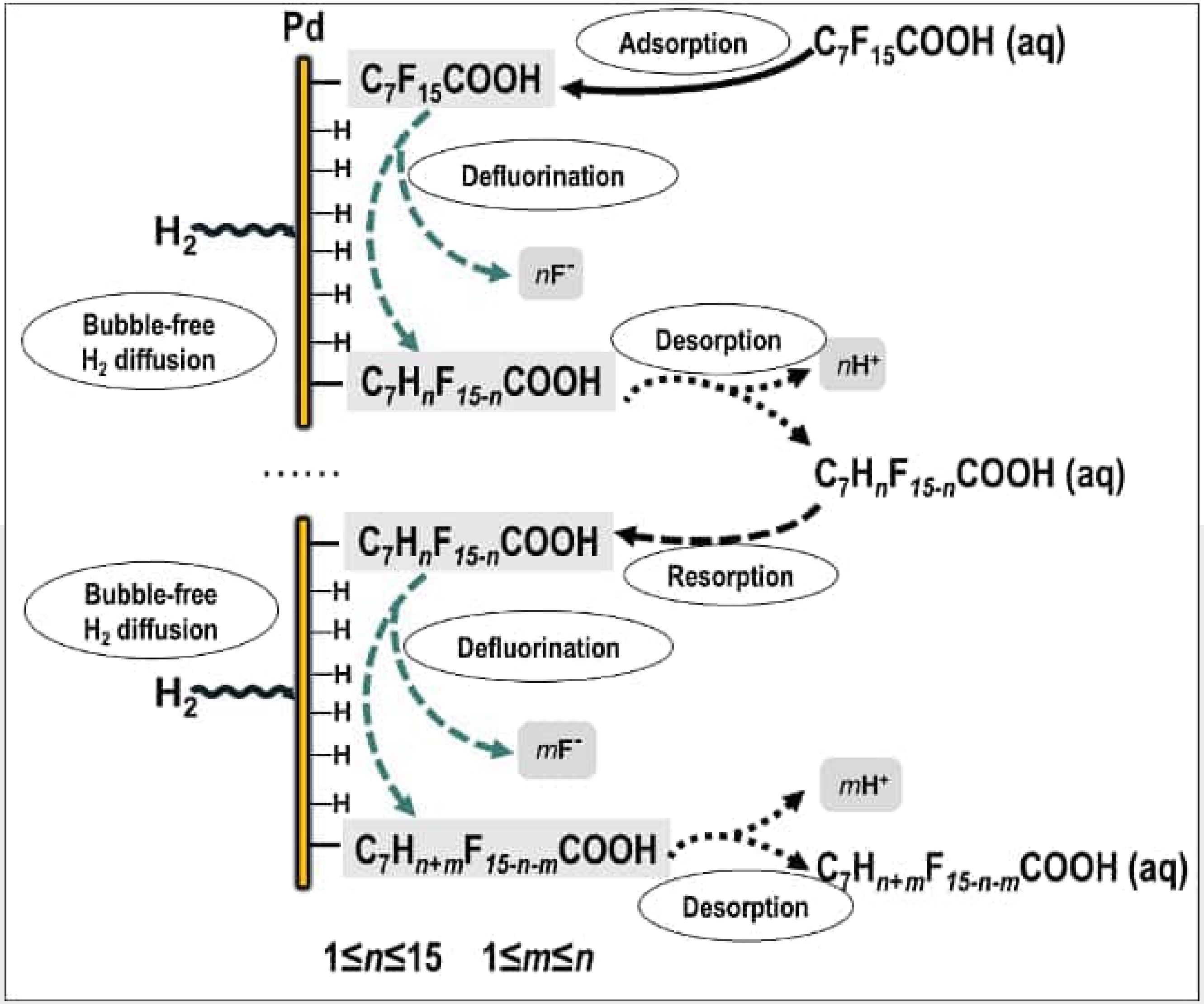
$C_8F_{15}O_2^- + 30H_{ads}^* \rightarrow C_8H_{15}O_2^- + 15F^- + 15H^+$



HPLC-QTOF-MS analyses

Catalytic defluorination in the H_2-MCfR (3)

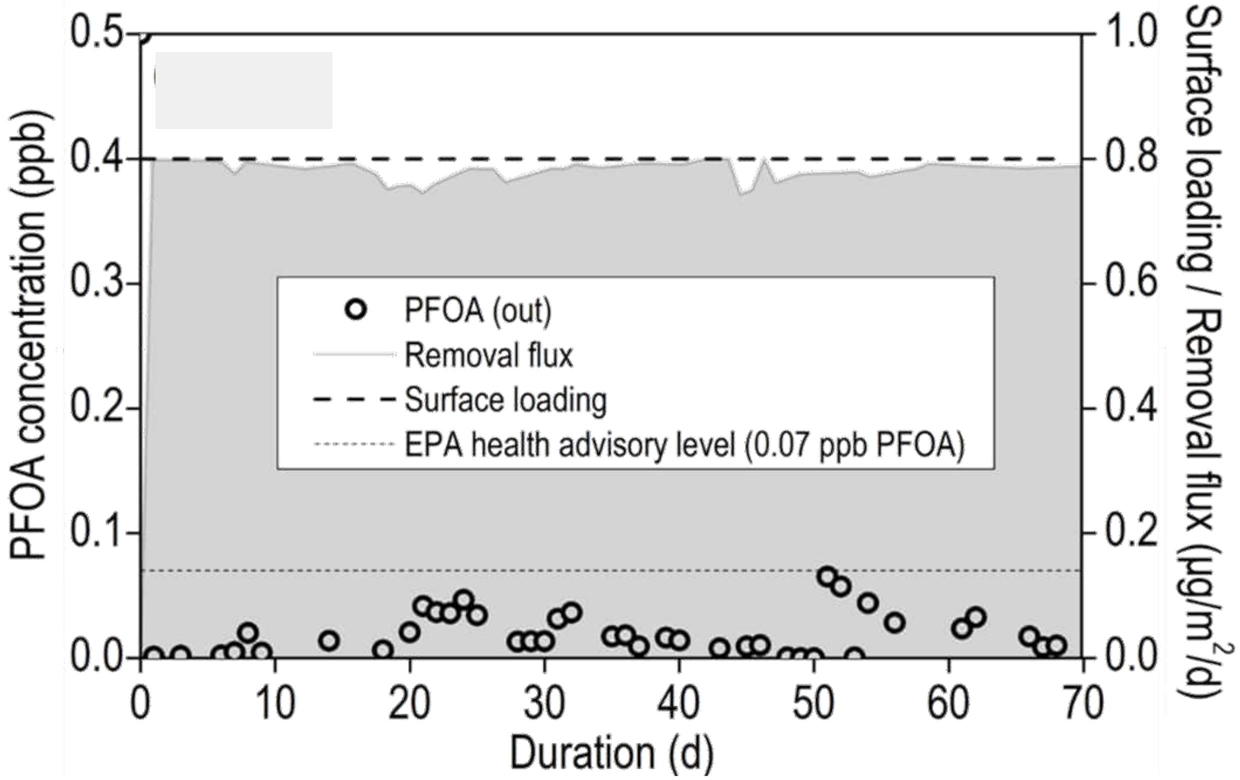
Mechanisms – Adsorption and Hydrodefluorination



Catalytic defluorination in the H_2-MCfR (4)

70-day continuous tests

- >99% PFOA removal within one day
- Effluent PFOA 20±16 μg/L (less than 1/3rd the EPA health-advisory level)

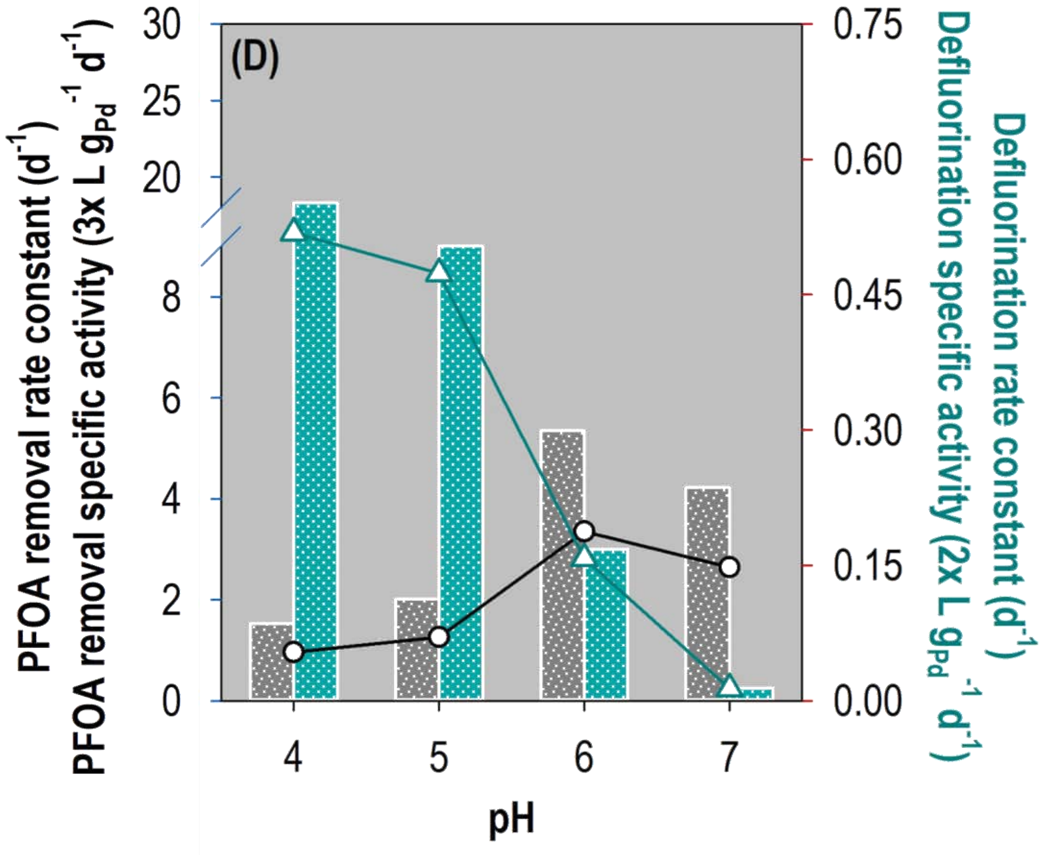


- 400 μg/L PFOA
- 0.9 mg/m^2 Pd^0NPs
- 2.4 atm H_2 supply
- pH 4

Catalytic defluorination in the H_2-MCfR (5)

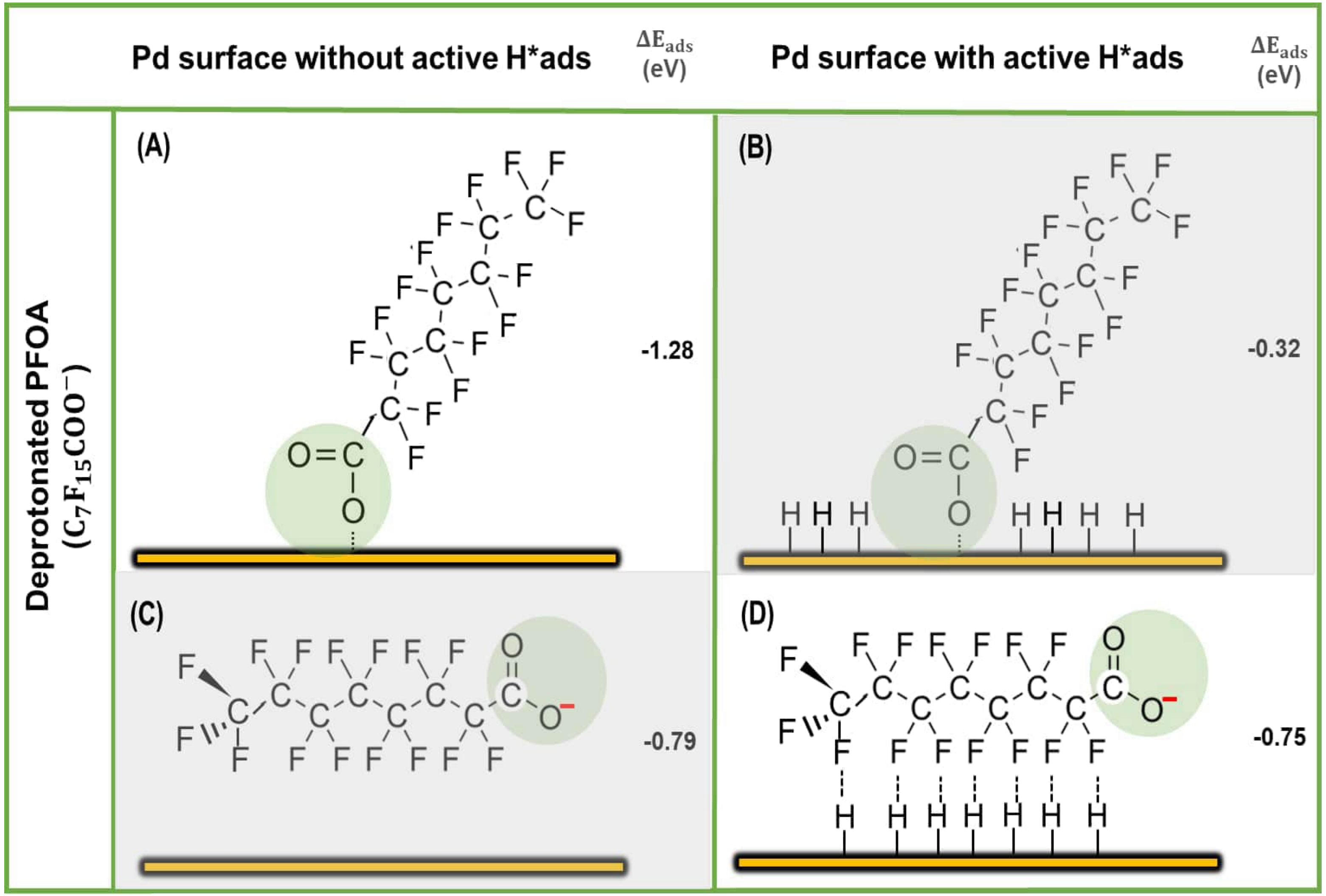
A potential pitfall of monometallic precious-metal catalysts:

- Slower defluorination at increasing pH over 4
- Minimal defluorination for neutral pH



Catalytic defluorination in the H_2-MCfR (6)

Density Function Theory (DFT) tells us why the large pH effect. At higher pH, the PFOA anion outcompetes H for chemisorption. Low-pH physisorption allows adsorption of reactive H.



Catalytic defluorination in the H_2-MCfR (7)

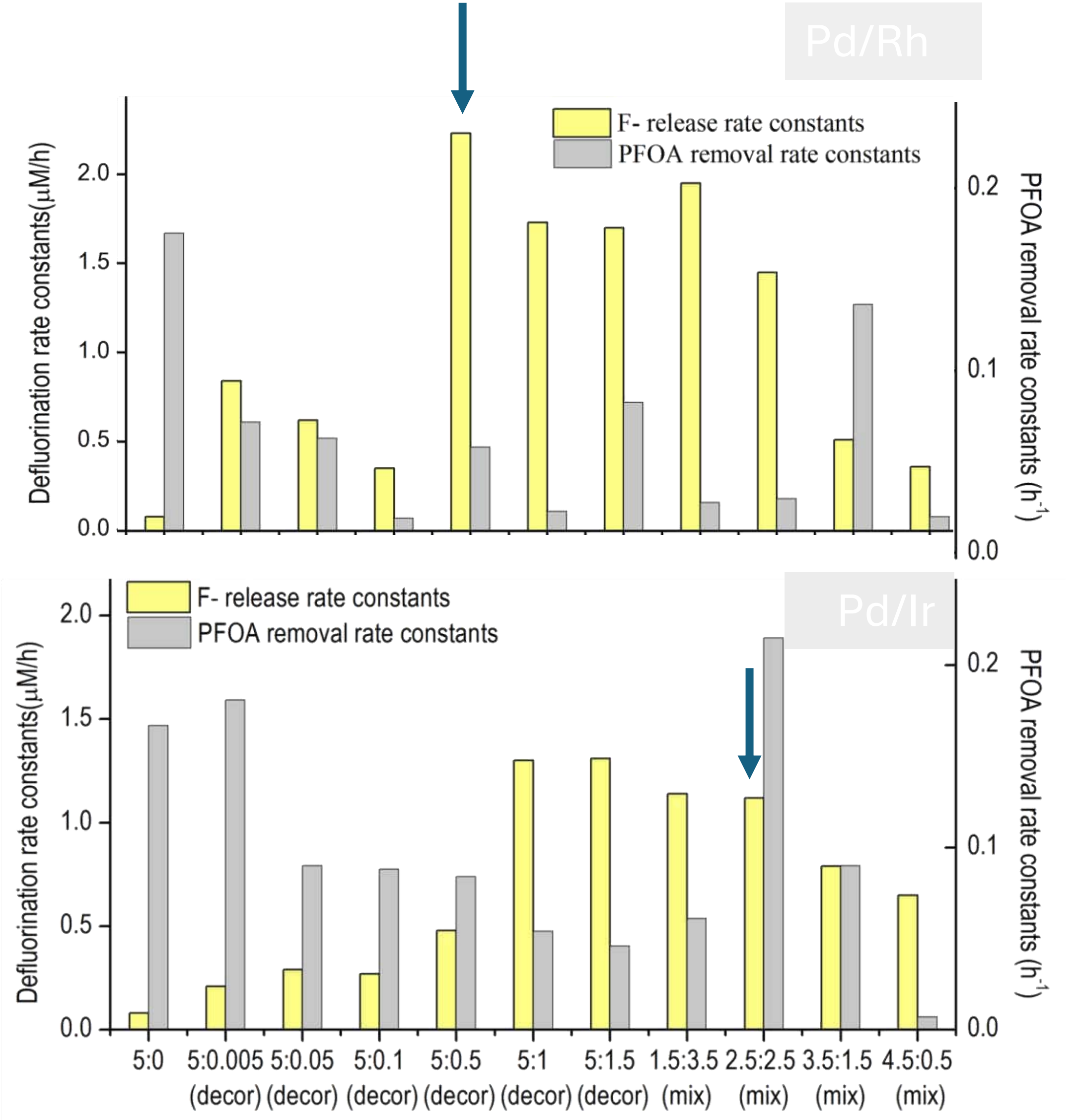
Pd-based Bimetallic catalysts:

- Type, coating method, and mass ratio affect defluorination efficiency

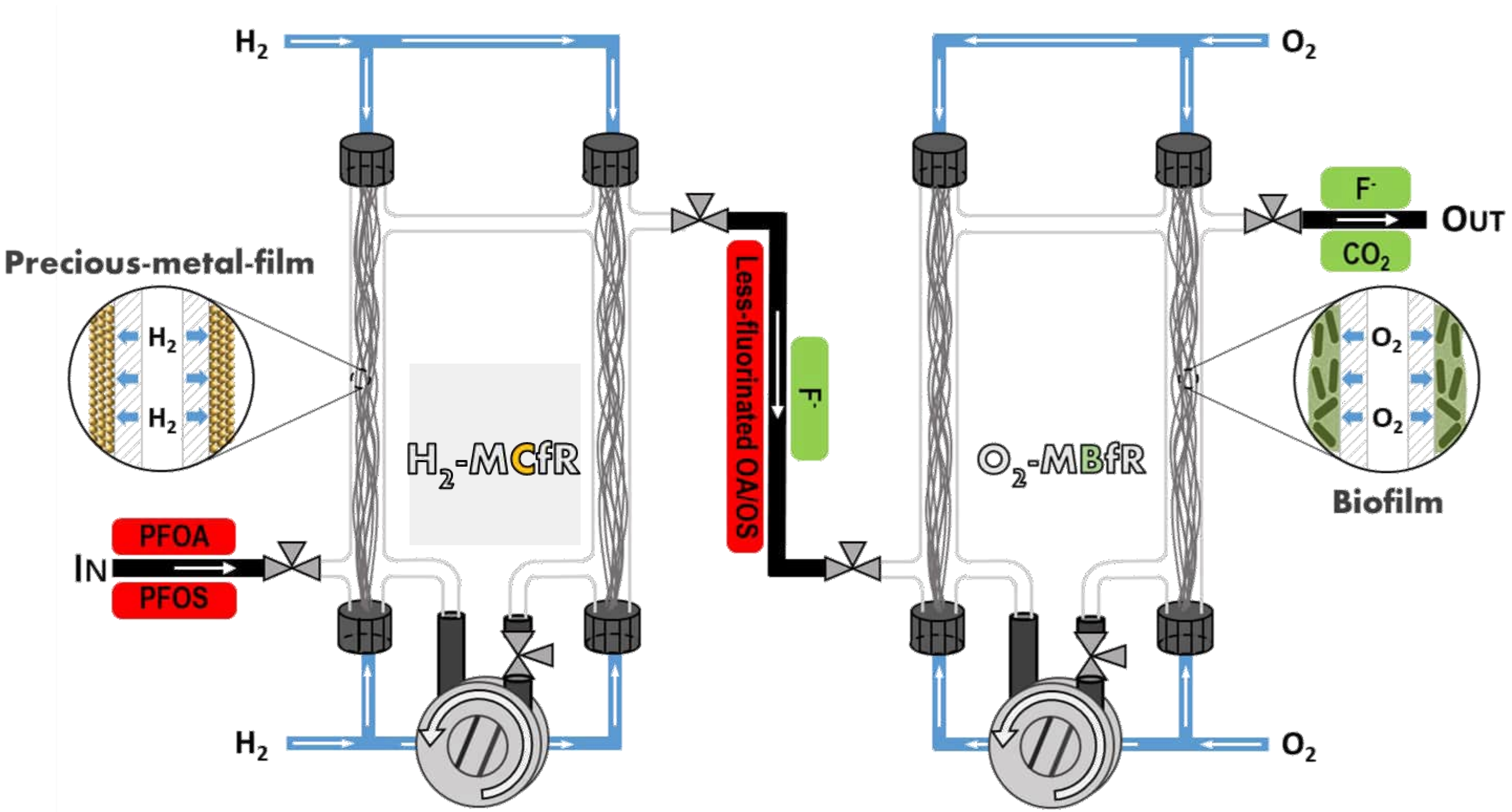
- Promising catalysts so far:

  Pd/Rh (5:0.5 mol/mol decor)

  Pd/Ir (2.5:2.5 mol/mol mixed)

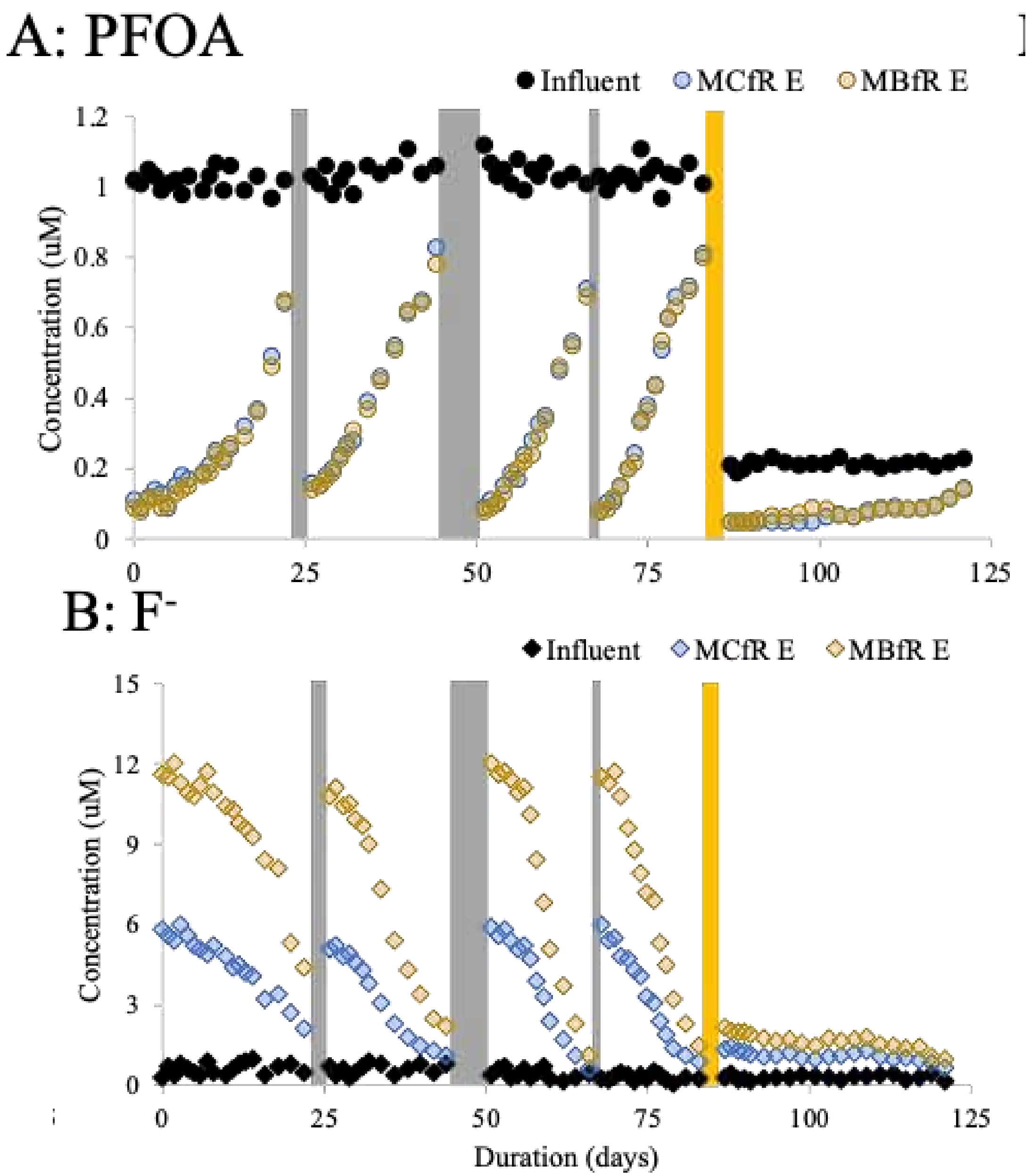


The Synergistic Platform (1)



The Synergistic Platform (2)

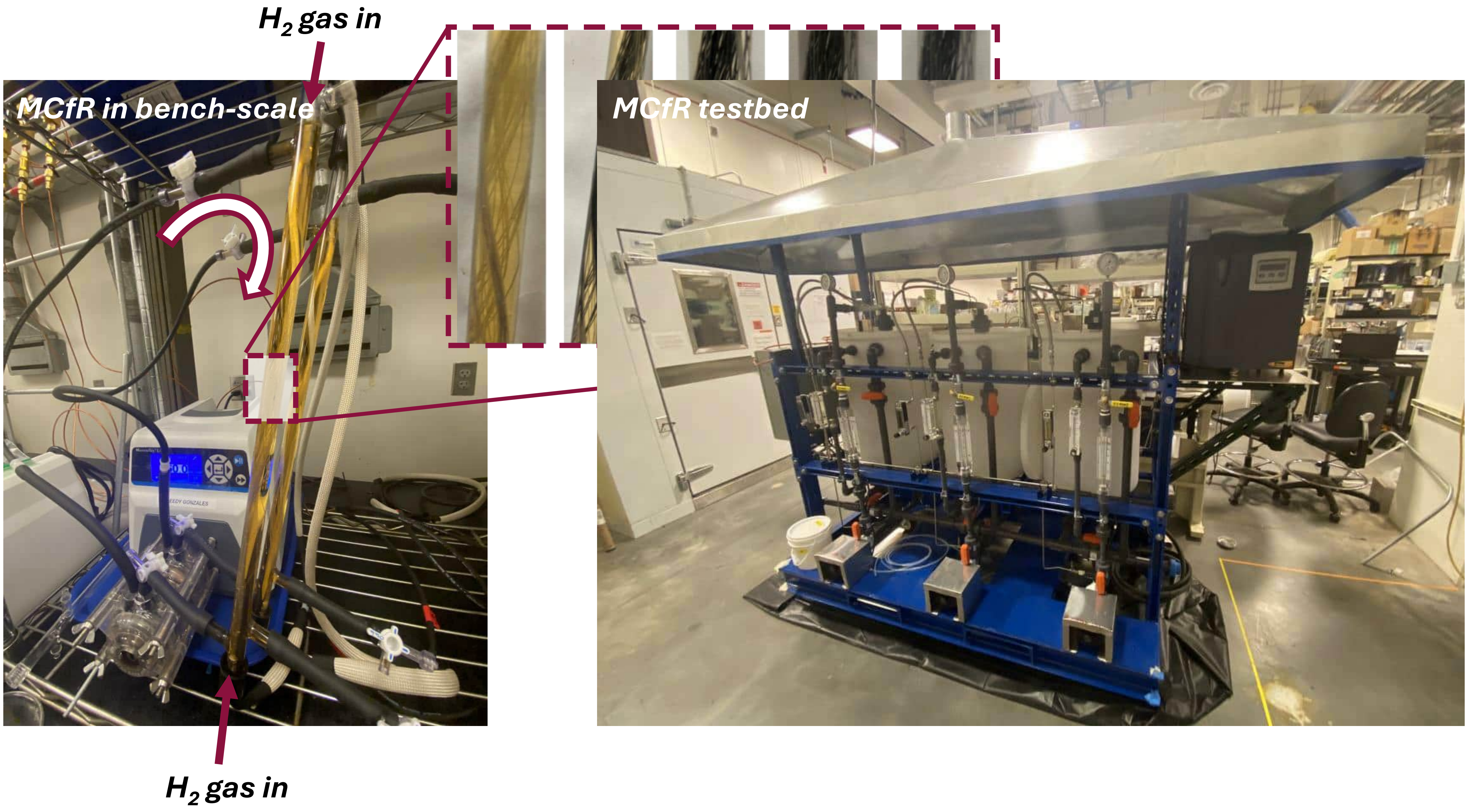
1. PFOA removal in the MCfR, but not in the MBfR – as expected
2. Defluorination in the MCfR and MBfR – roughly equal degrees!
3. Gradual deactivation of the Pd^0 catalysts – due to the high PFOA input concentration (>400 ppb)
4. Reactivation with base treatment (gray bars).
5. Lower influent PFOA concentration (83 ppb) extended the activity -- what we always see.



Take-home Lessons

1. *In-situ* formation of robust Pd^0-based catalytic films on gas-transfer membranes is simple.
2. Ours is first report of Pd^0-catalyzed hydrodefluorination of PFOA (and PFOS and others).
3. Using bi-metallic catalysts extends the pH range of Pd^0 catalysts. Pd/Rh is especially promising.
4. The H_2-based MCfR was able to continuously remove PFOA (and PFOS and others) below the advisory level of 70 ppt.
5. The O_2-based MBfR was able to defluorinate the partially defluorinated reduction products from the MCfR and mineralize fully defluorinated products.

Scaling up MCfR system in progress at ASU



Summary

PFAS are a different class of chemicals than our normal "friends"

PFAS unique surfactant structure balances HYDROPHOBIC and POLAR interactions

Be careful – LC/MS-MS Methods only measure what you are looking for,

Longer chain compounds can "form" regulated PFAS.

Don't forget the little guys (trifluoroacetate (TFA)) but fortunately, shorter chain PFAS are usually less toxic

Consider "total organo-fluorine" surrogate measures

Separation or adsorption are only a FIRST step, you will need "defluorination" at some point (thermal, oxidation, hydrogenation, …)

HETEROgeneous processes have the advantage of "TRAP-AND-ZAP" to preconcentrate PFAS on surfaces prior to defluorination

CalgonCarbon
A Kuraray Company

ADEQ: Arizona PFAS Forum

GAC & IX Pilot Testing Case Studies: *Meeting a new Regulation*

Eli B. Townsend

Applications Engineer

February 1, 2024

Agenda

- Granular Activated Carbon Review
- Ion Exchange Review
- Pilot Test Design
- Pilot-Scale GAC and IX Case Study
- Questions/Discussion

Granular Activated Carbon Technology Review

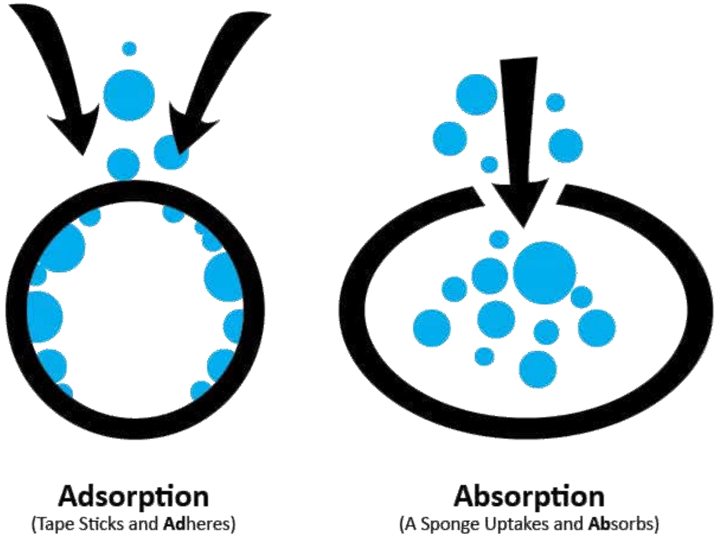
What is Granular Activated Carbon?

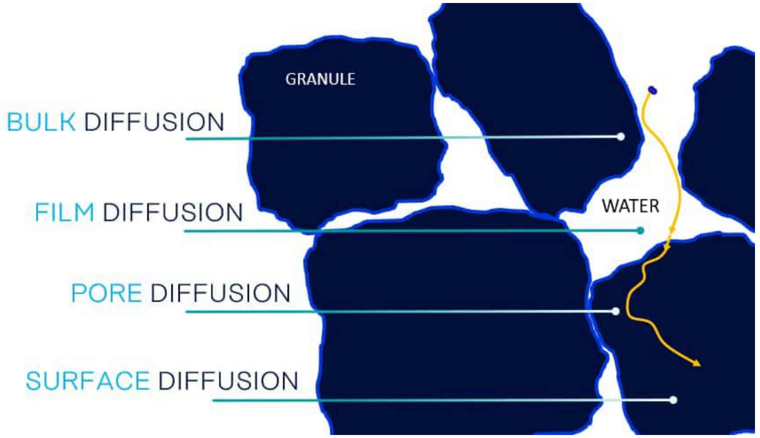
Filter media manufactured from naturally materials

- Coal
- Coconut

Electrochemical forces cause contaminants to adsorb

Best available technology for organics per EPA



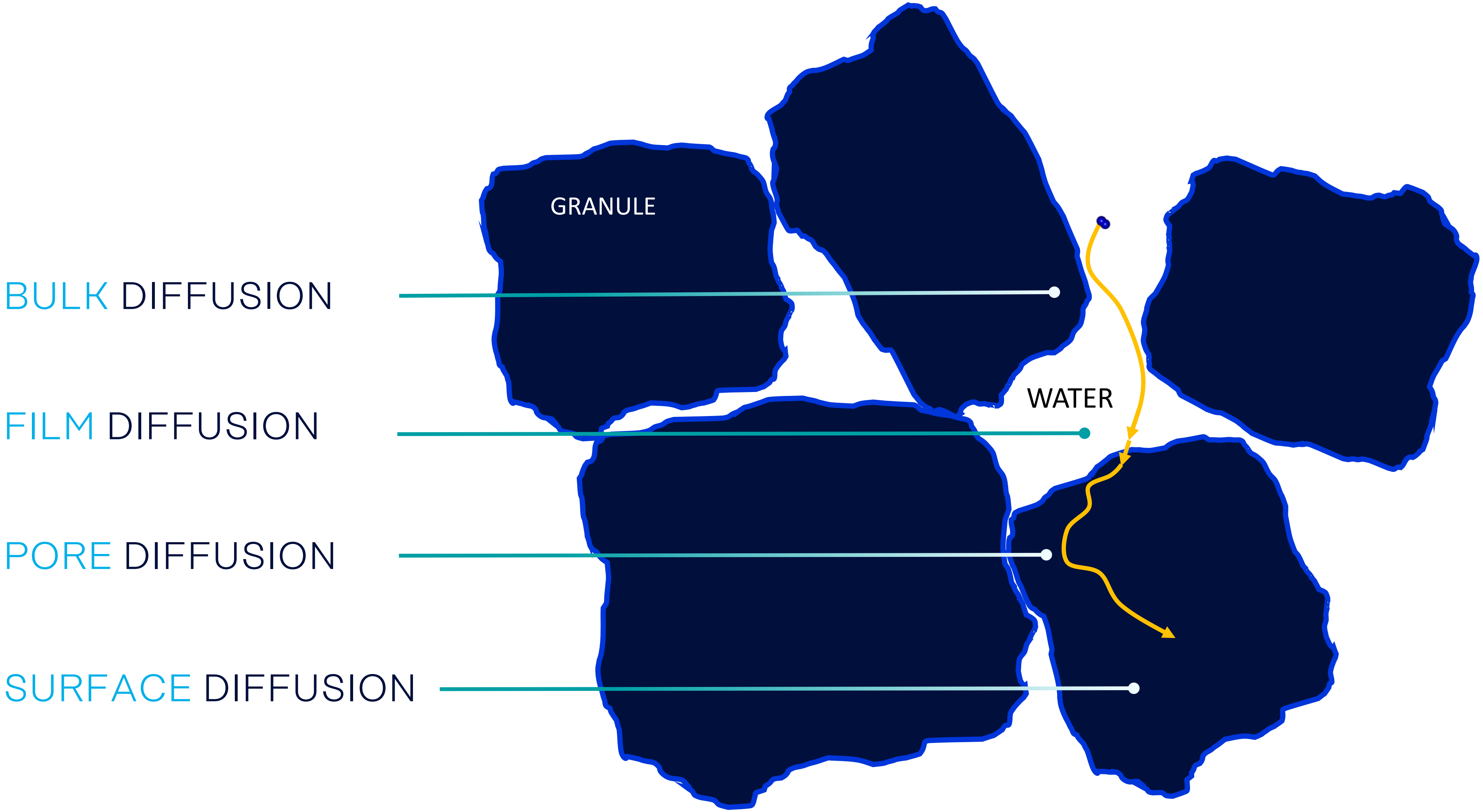


GAC is a **SEMI-RENEWABLE** resource

Contaminants **STICK** to the surface of GAC

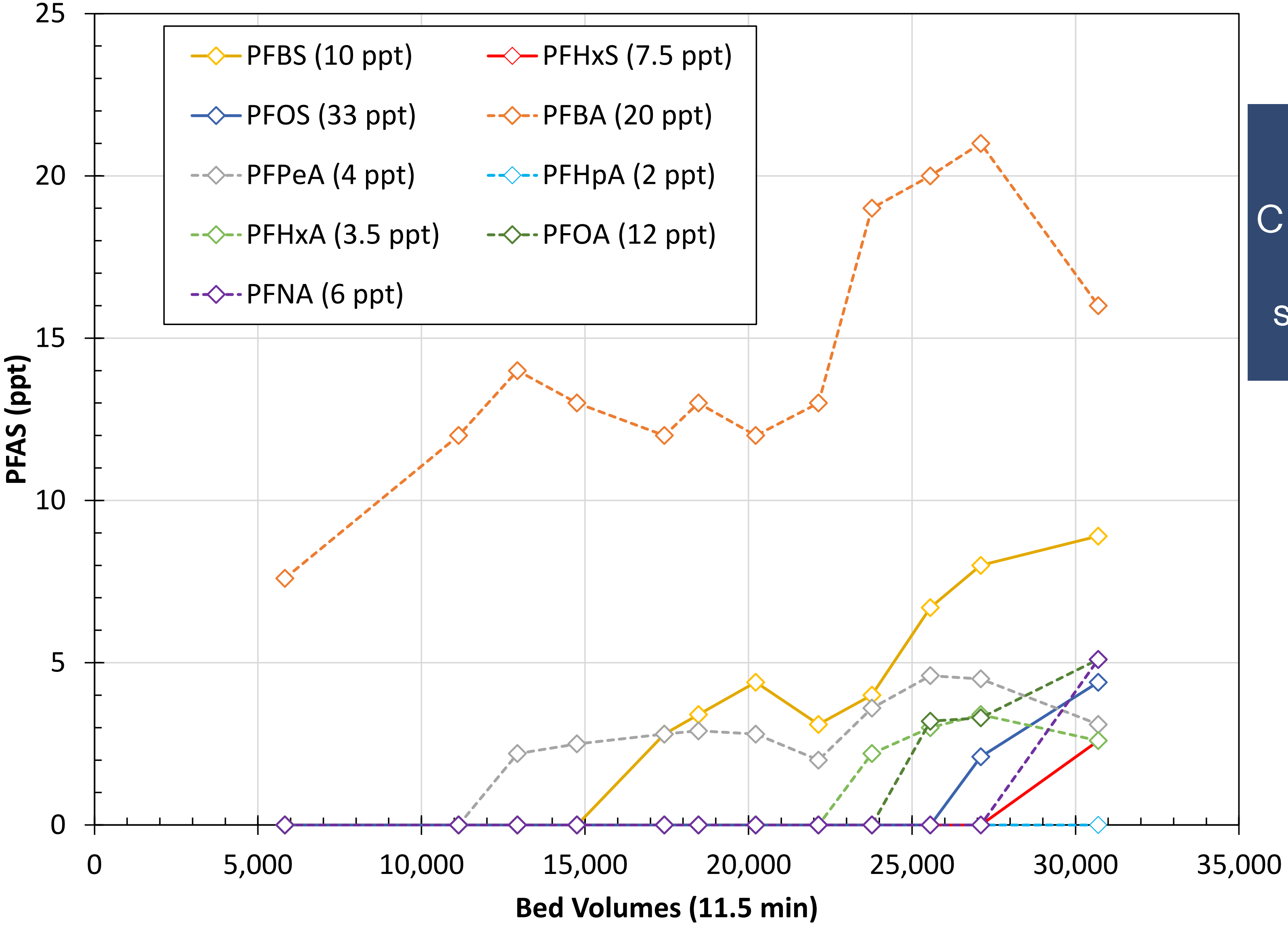
Governed by the kinetics of **DIFFUSION**

Contaminant Diffusion Drives Removal



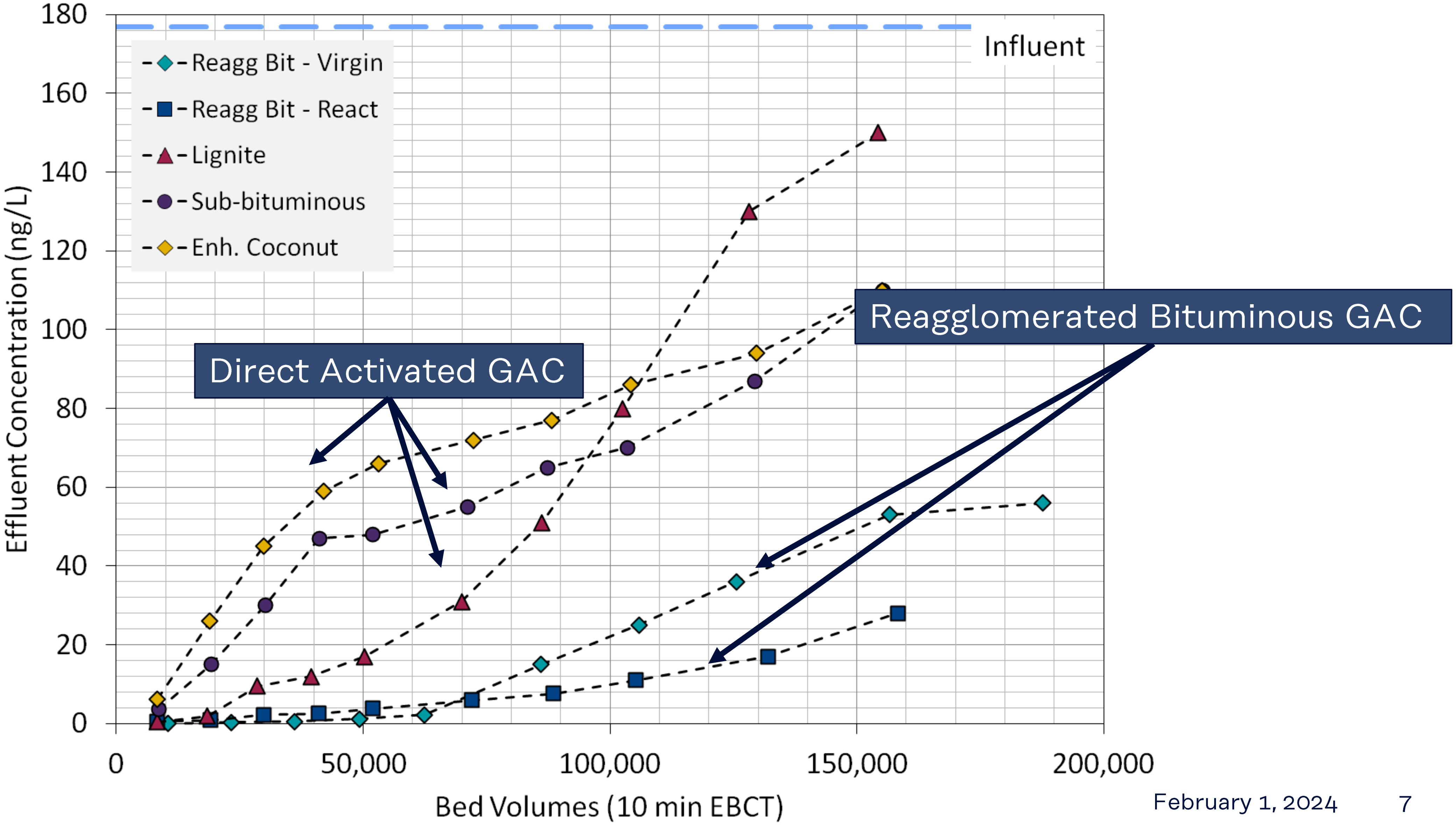
Breakthrough Order of PFAS on GAC

Functional Group is important.

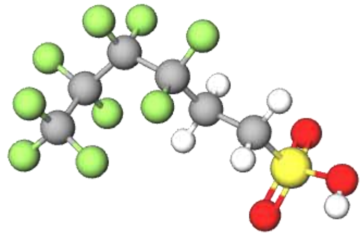


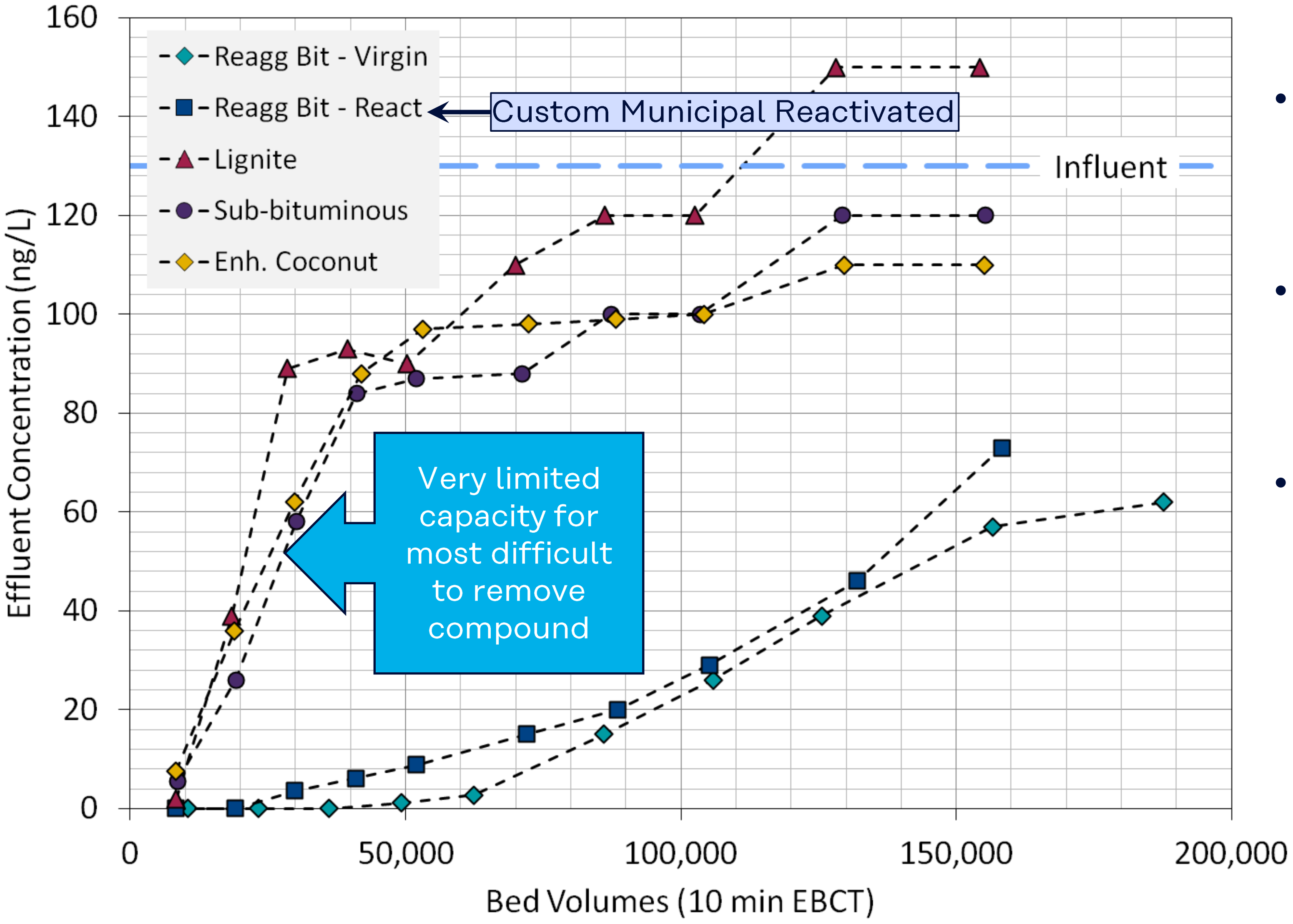
Carboxylates (-COO-) always break through before sulfonates ($-SO_3-$)

PFOA Removal with Different GAC Materials



PFAS Breakthrough: 4:2 FTS





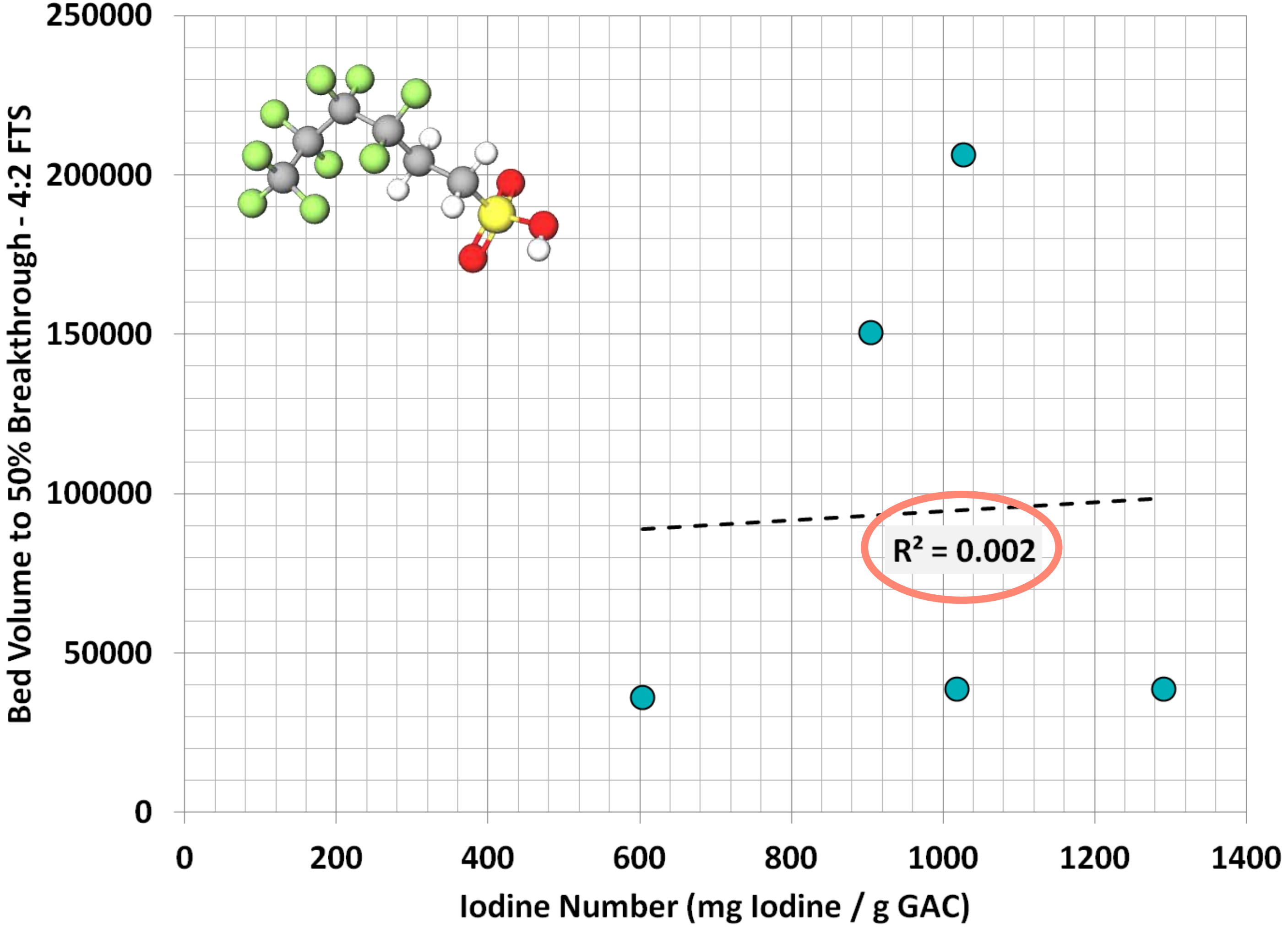
- Similar performance between Virgin and Custom Municipal Reactivated (CMR) Filtrasorb® 400
- Little appreciable capacity for 4:2 FTS in lignite, sub-bituminous, or coconut.
- For PFAS compounds that are especially difficult to remove, GAC selection is most critical.

Can a "simple" test method guide carbon selection for PFAS removal?

Wide variation and seemingly unconnected to results...

GAC Source Material	Full-Scale Mesh Size	Apparent Density (g/cc)	Iodine Number (mg/g)
Reagglomerated Bituminous Coal – Virgin (Domestic)	12 × 40	0.54	1030
Reagglomerated Bituminous Coal – Custom Municipal React. (CMR, Domestic)	12 × 40	0.55	905
Lignite Coal (Domestic)	12 × 40	0.38	605
Sub-Bituminous Coal (Australia)	12 × 40	0.35	1015
Coconut Shell, Enhanced (Southeast Asia)	12 × 30	0.41	1290

Performance vs. Iodine Number (mg Iodine / g GAC)



- Coefficient of Determination (R^2) increases as strength of correlation increases (max. value of 1)
- No relationship seen between mass-based Iodine Number and 4:2 FTS removal.
- 4:2 FTS results used as example since highest levels of breakthrough observed with this PFAS compound.

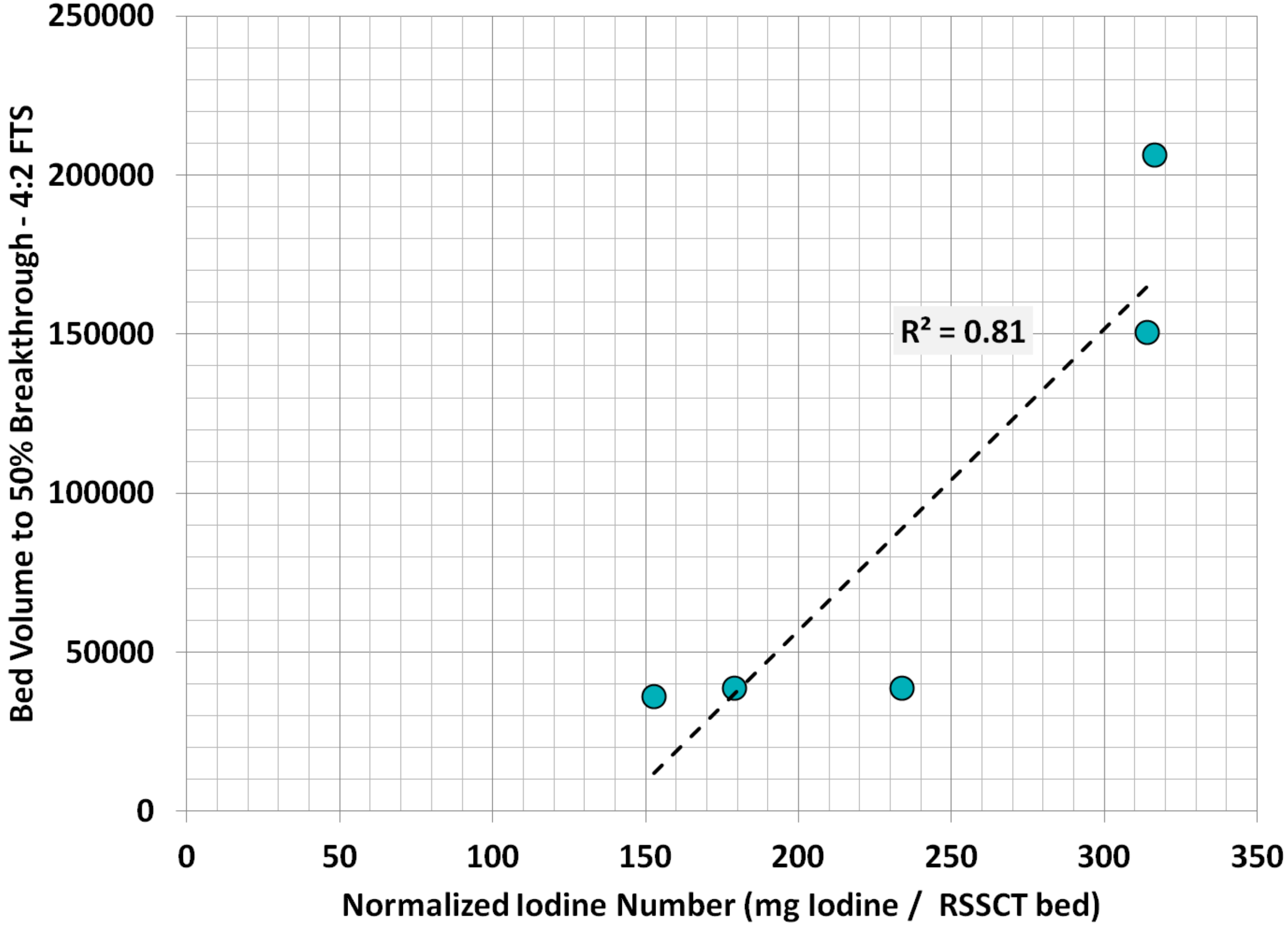
Volume Iodine of Tested GACs

$$Iodine\ Number\ \left(\frac{mg}{g}\right) \times Apparent\ Density\ \left(\frac{g}{cc}\right) = Volume\ Iodine\ \left(\frac{mg}{cc}\right)$$

ASTM D4607 **ASTM D2854**

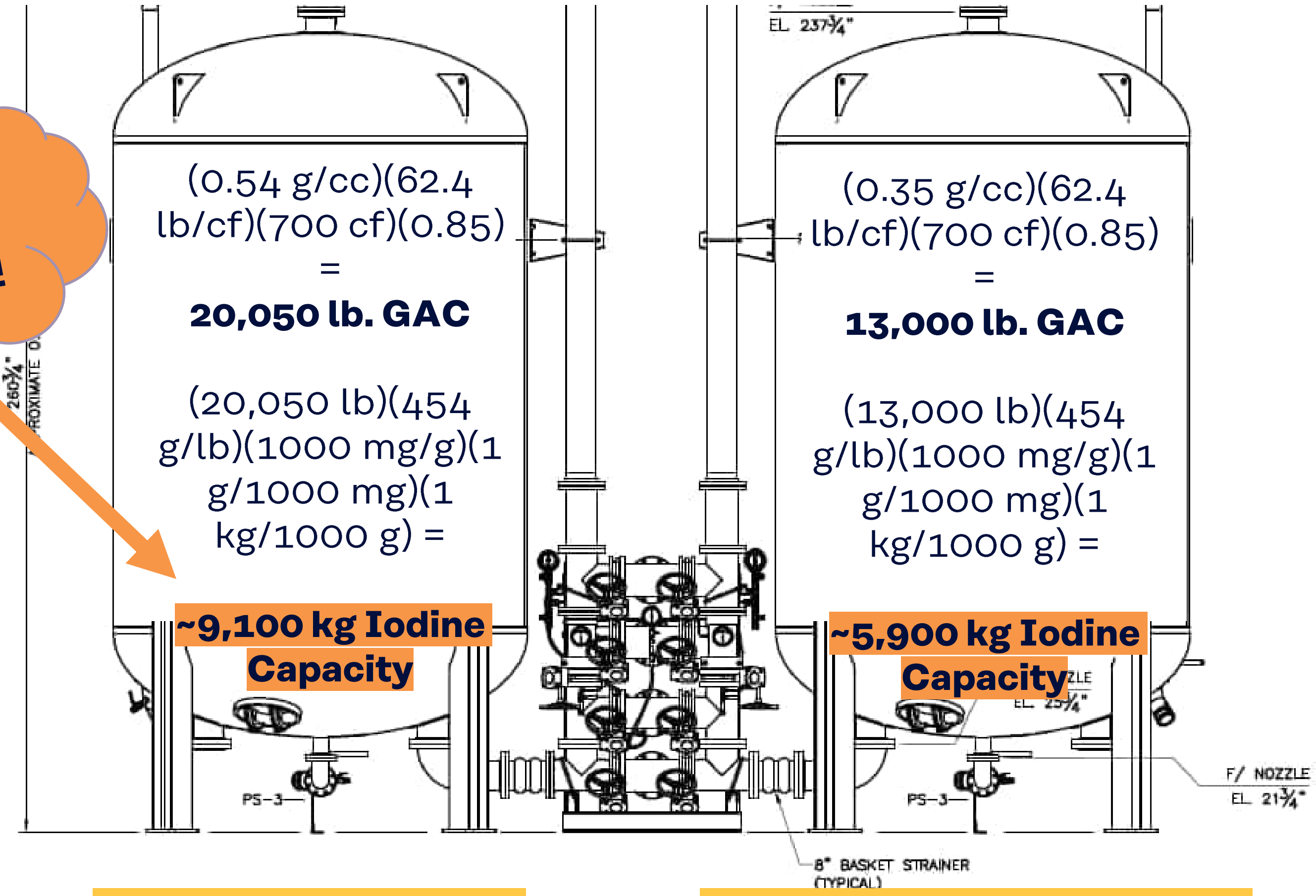
GAC Source Material	Apparent Density (g/cc)	Iodine Number (mg/g)	Volume Iodine (mg/cc)
Reagglomerated Bituminous Coal – Virgin (Domestic)	0.54	1030	556
Reagglomerated Bituminous Coal – Custom Municipal React. (CMR, Domestic)	0.55	905	498
Lignite Coal (Domestic)	0.38	605	230
Sub-Bituminous Coal (Australia)	0.35	1015	355
Coconut Shell, Enhanced (Southeast Asia)	0.41	1290	529

Volume Iodine: A correlation? Yes!



- Not a perfect correlation but markedly better than that with Iodine Number alone
- Customer/Engineer could at least reliably select better performing GACs for further evaluation.

Iodine Number: Not the Complete Picture



Bituminous Fill

Sub-Bituminous Fill

Specification:

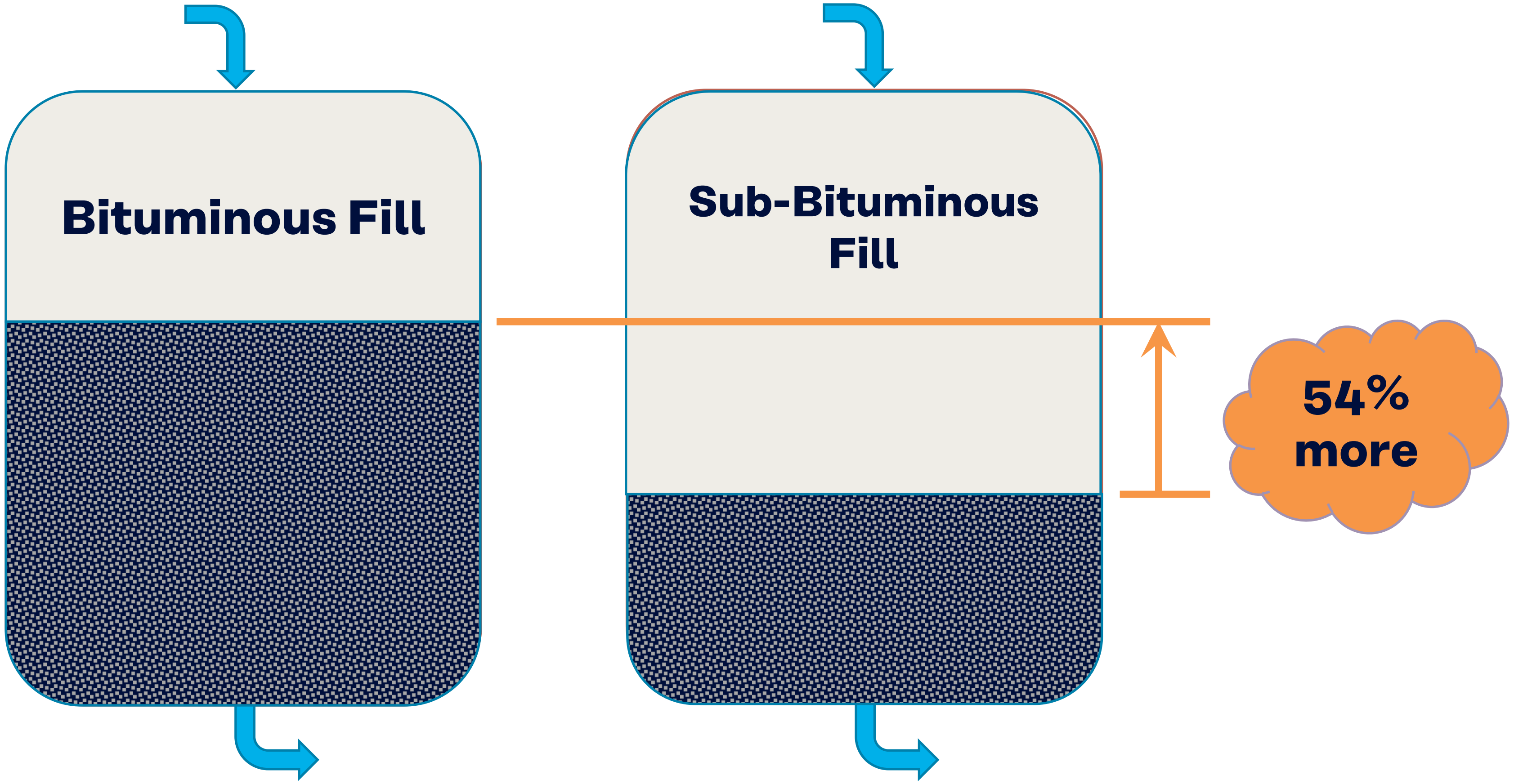
Minimum Iodine Number:
1,000 mg/g

Apparent Density:

0.54 g/cc (bituminous)
0.35 g/cc (sub-bituminous)

Fill Volume:
700 cubic feet
(~20,000 lb. vessel)

Another way to visualize "activity..."



- **Though the fill volume of GAC is the same, the activity of the bed is not.**
- **Equates to "short-filling" of the adsorber.**

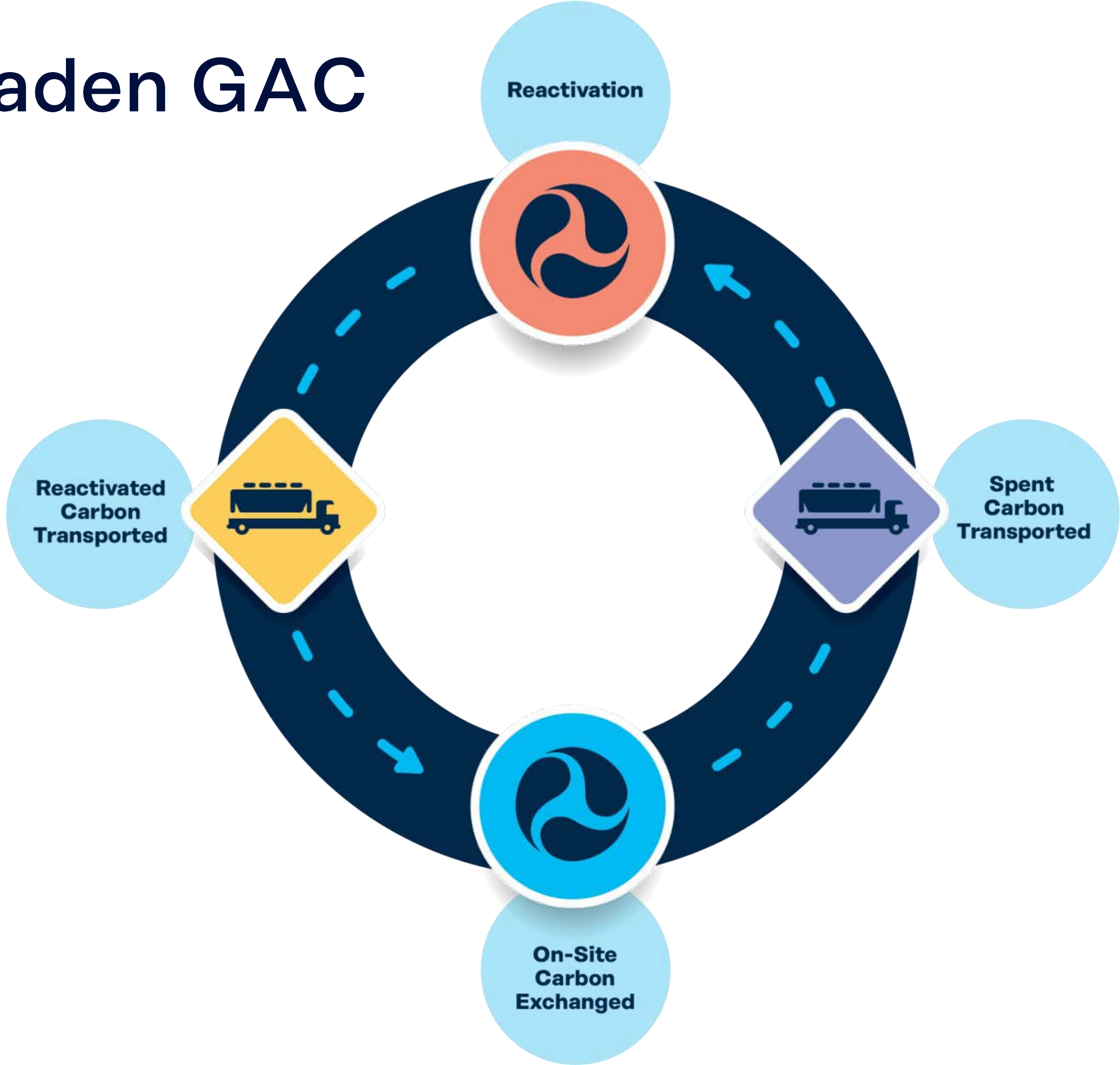
Disposal Options for PFAS Laden GAC

There are two options for GAC

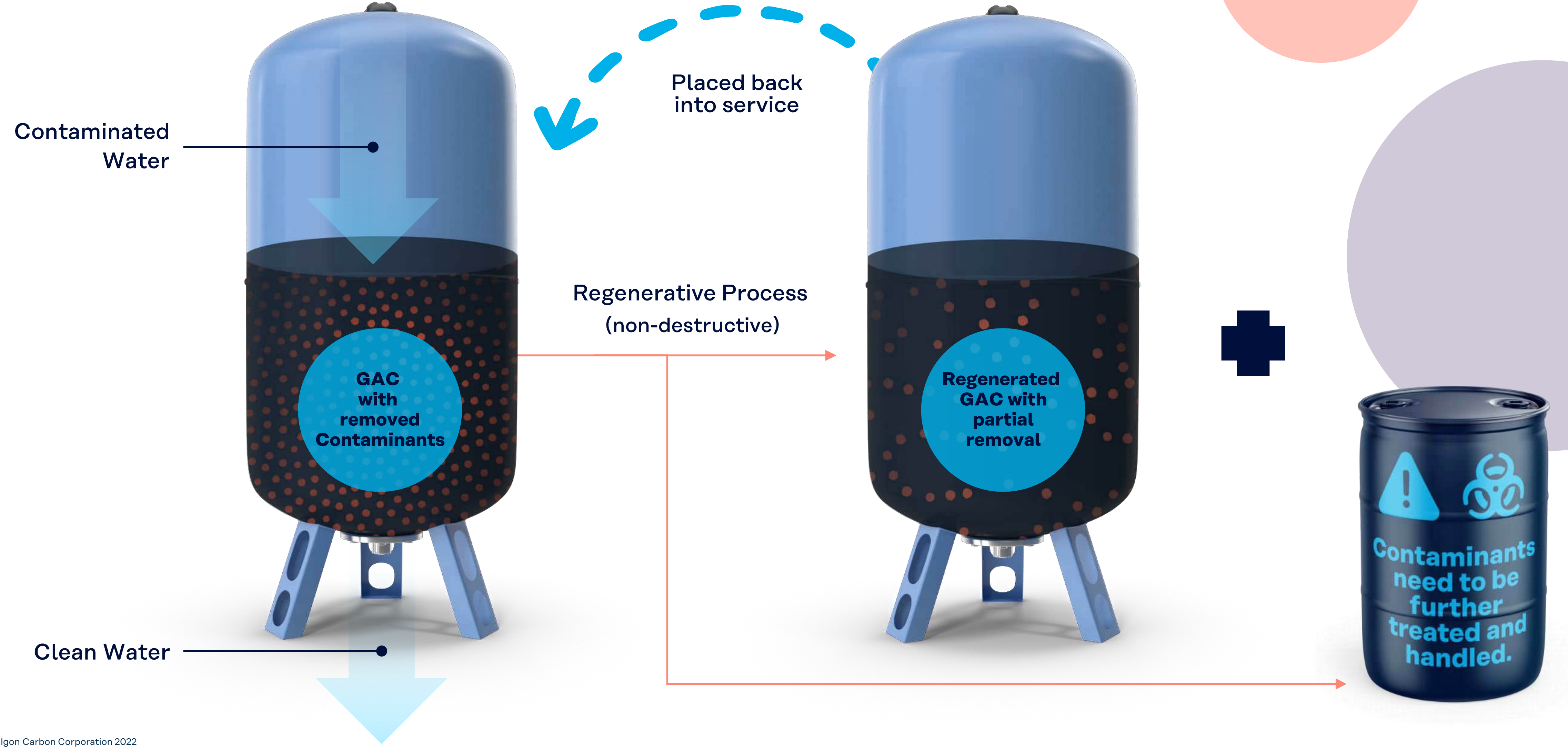
1. GAC can be disposed of through reactivation
2. GAC can be custom reactivated for reuse (CMR).

There is an economy of scale for GAC disposal

- Sites producing < 10,000 lb of GAC/event must pool their media
- 10,000 lb is the smallest volume for CMR (react & return)



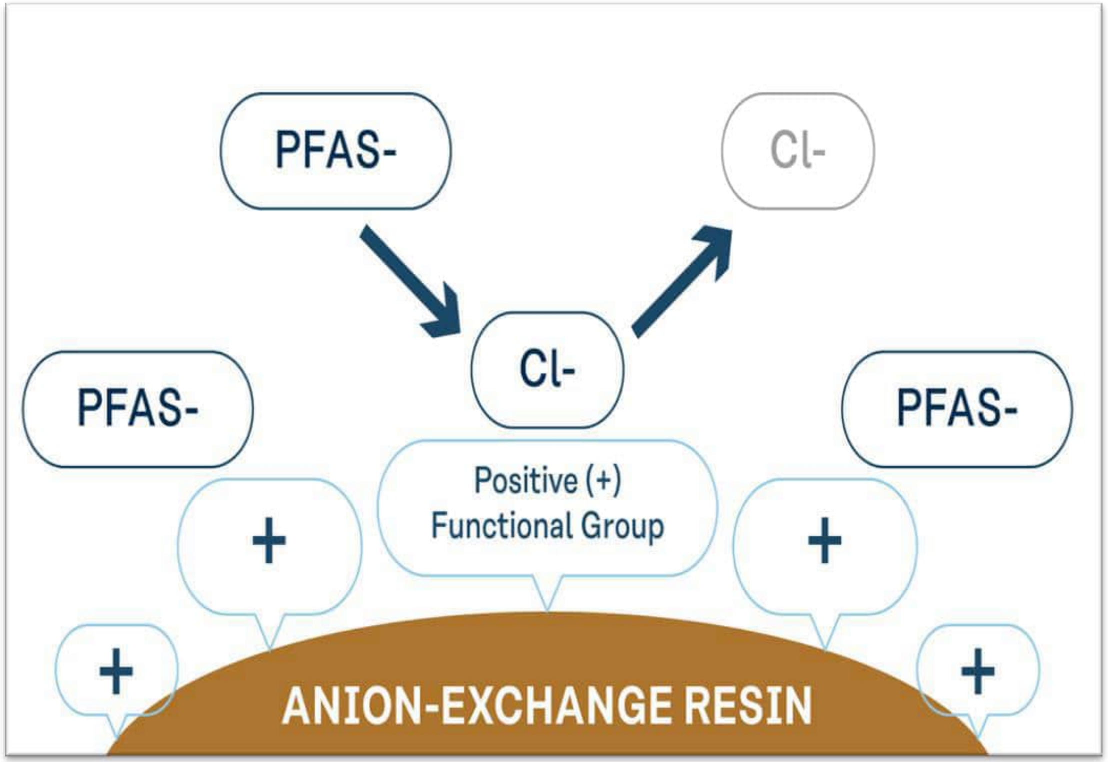
Regeneration process is an *in situ*, non-destructive process

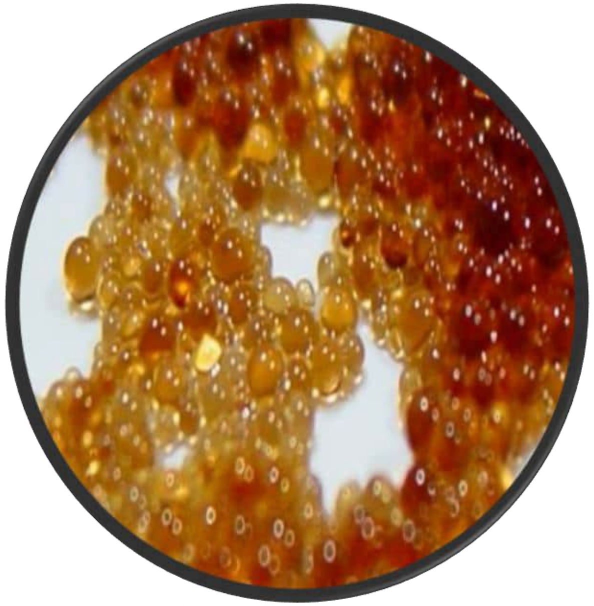


Ion Exchange Technology Review

What is Ion Exchange (IX) Resin?

- Synthetic polymer containing charged (+/-) functional groups (exchange sites)
- Similar to activated carbon in that diffusion is often limiting – not an instantaneous process
- Mechanism is the exchange of ions from the bulk solution with those on the charged functional groups
- Background water quality impacts performance: sulfate, nitrate, TOC, other anions, etc.,





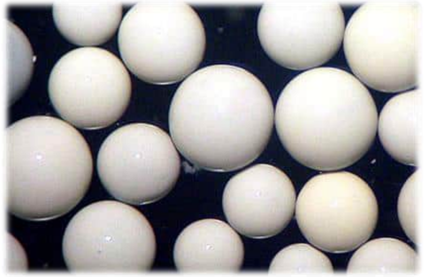
IX Resin Structure

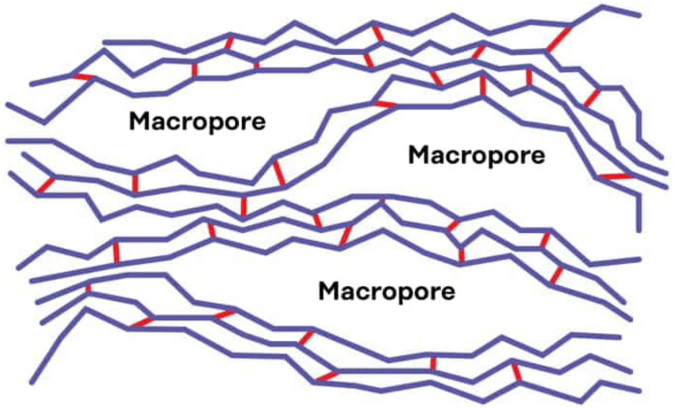
Macroporous (e.g., CalRes 2301)

- Permanent, well-developed porous structure.
- Opaque
- High degree of cross-linking (divinylbenzene (DVB) content >20%
- Resistant to oxidation ← key to future ability to disinfect!

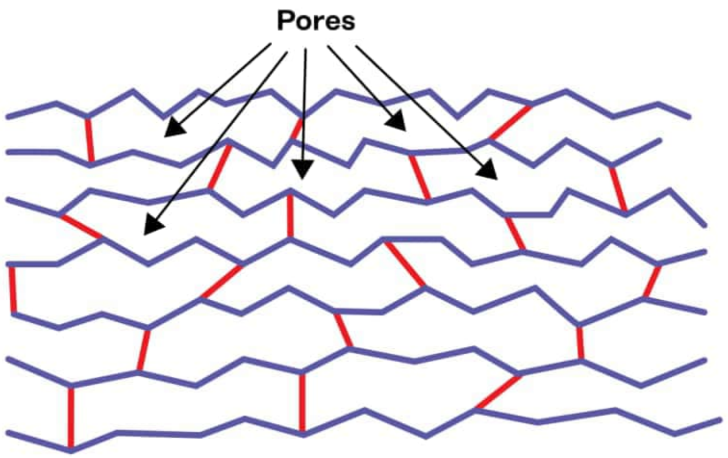
Gel (e.g., CalRes 2304)

- Translucent with a smooth and uniform surface.
- Highly swollen with a large water retention capacity = fast diffusion kinetics
- Low nominal degree of cross-linking (DVB content <12%)
- Relatively soft and compressible





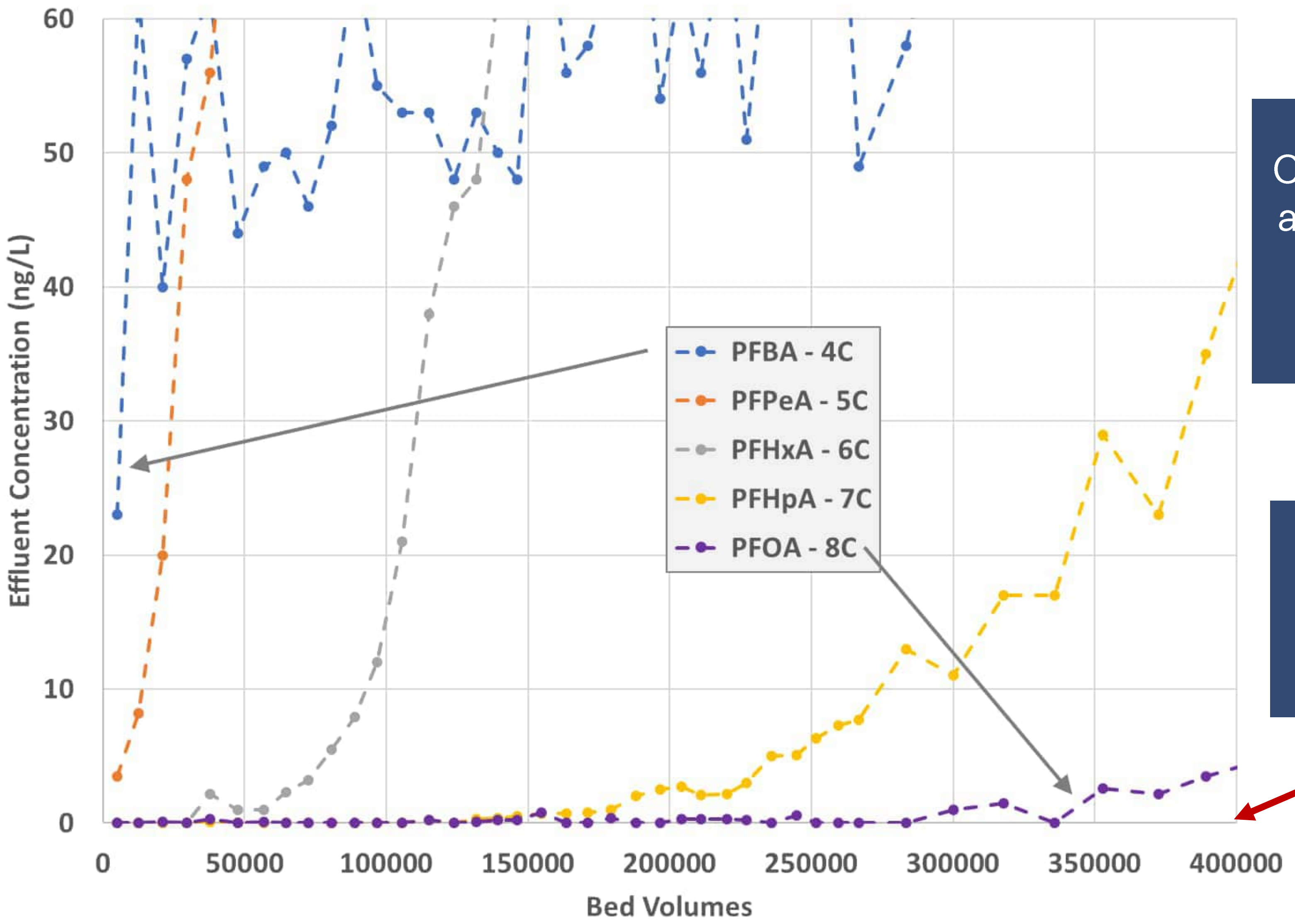
Example of Macroporous Resin Structure



Example of Gel Resin Structure

Breakthrough Order of PFAS on IX

“Short” chain compounds break through before “long” chain



Carboxylates (-COO-) always break through before sulfonates (-SO3-)

No sulfonate breakthrough occurred in this time frame

Disposal Options for PFAS Laden IX

There are two options for GAC

1. IX can be incinerated at a hazardous incinerator
2. IX can be dumped into a leachate lined hazardous waste landfill
   →Additional cost if PFAS>0.5ppm

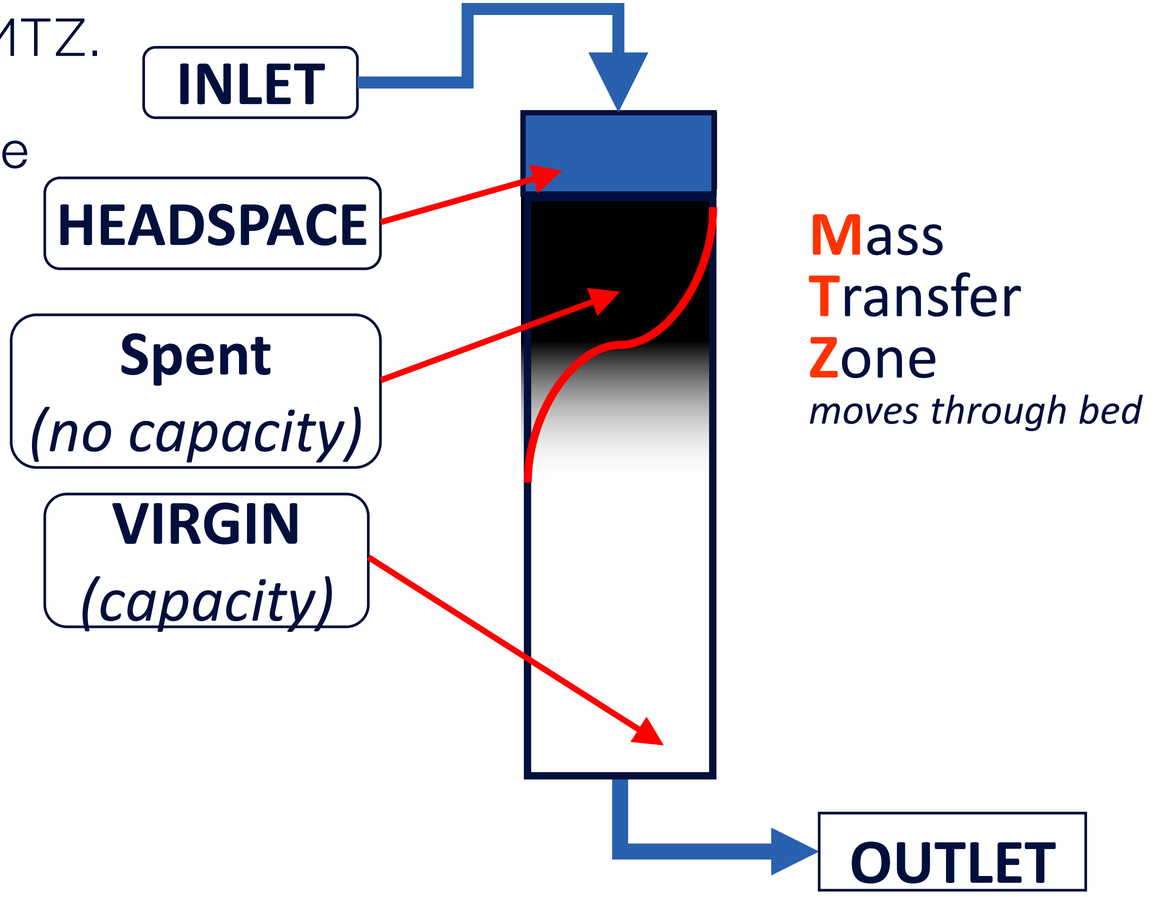
Neither option completely limits all liability

Currently, #2 above is recommended due to technology maturity and liability agreements.

Pilot Test Design

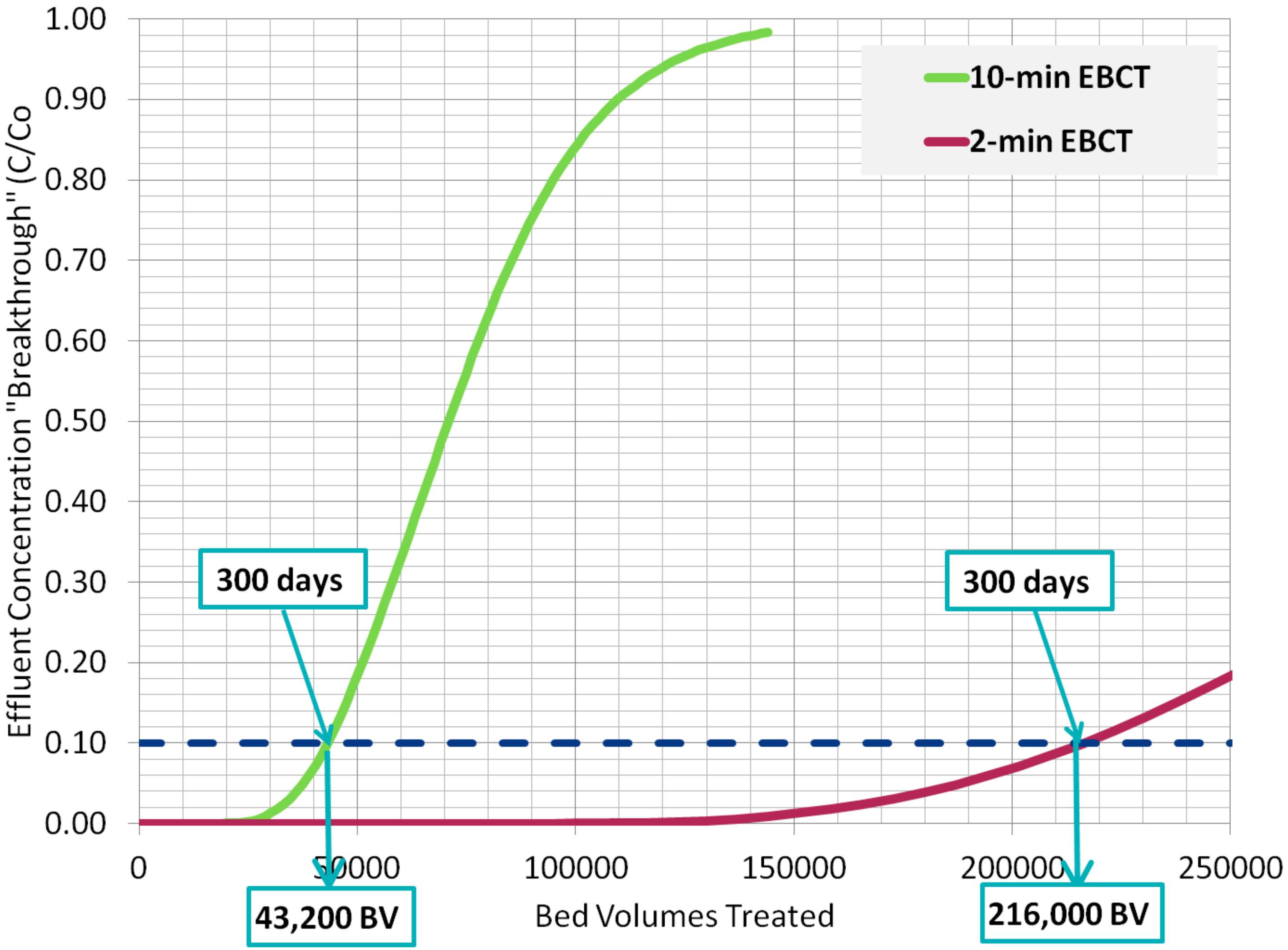
Basis of GAC Application Design - HLR

- Definition: Volumetric flow velocity expressed typically as flow per area (e.g. gpm/ft^2).
- The HLR controls flow distribution and MTZ.
  - Allows for even adsorption/carbon use
  - Typical GAC = 2 – 10 gpm/ft^2
  - Typical IX = 2 – 18 gpm/ft^2
- Potential Issues
  - Too Low → Flow channeling
  - Too Low → Poor media utilization
  - Too High → Excessive head loss
  - Too High → Mechanical failures



ON-SITE PILOT TESTING

EXAMPLE: Reading Breakthrough Curves



Green: GAC System
Bed volume = 10,000 gal

Red: IX System
Bed Volume = 2,000 gal

For a system with 1,000 gpm design flow, GAC and IX each treat the **same volume (432 MG) in 300 days**

→If they have the same interval, which is less expansive?

Case Study

CASE STUDY CONTEXT

Ground Water Supply | Rocky Mountain Region | 1 MGD System Flow

Background TOC = < 1.0 mg/L

KEY PFAS Compounds:

- PFOA = 6.7 ng/L or ppt
- PFOS = 18 ng/L or ppt
- PFHxS = 33 ng/L or ppt
- PFPeA = 20 ng/L or ppt

GAC Full-Scale Design

EBCT: ~8 minutes

HLR: 5.7 gpm/ft^2

One M12 system

IX Full-Scle Design

EBCT: ~2.8 minutes

HLR: 8.7 gpm/ft^2

One M10 system

GAC Pilot Design

EBCT: 8 minutes

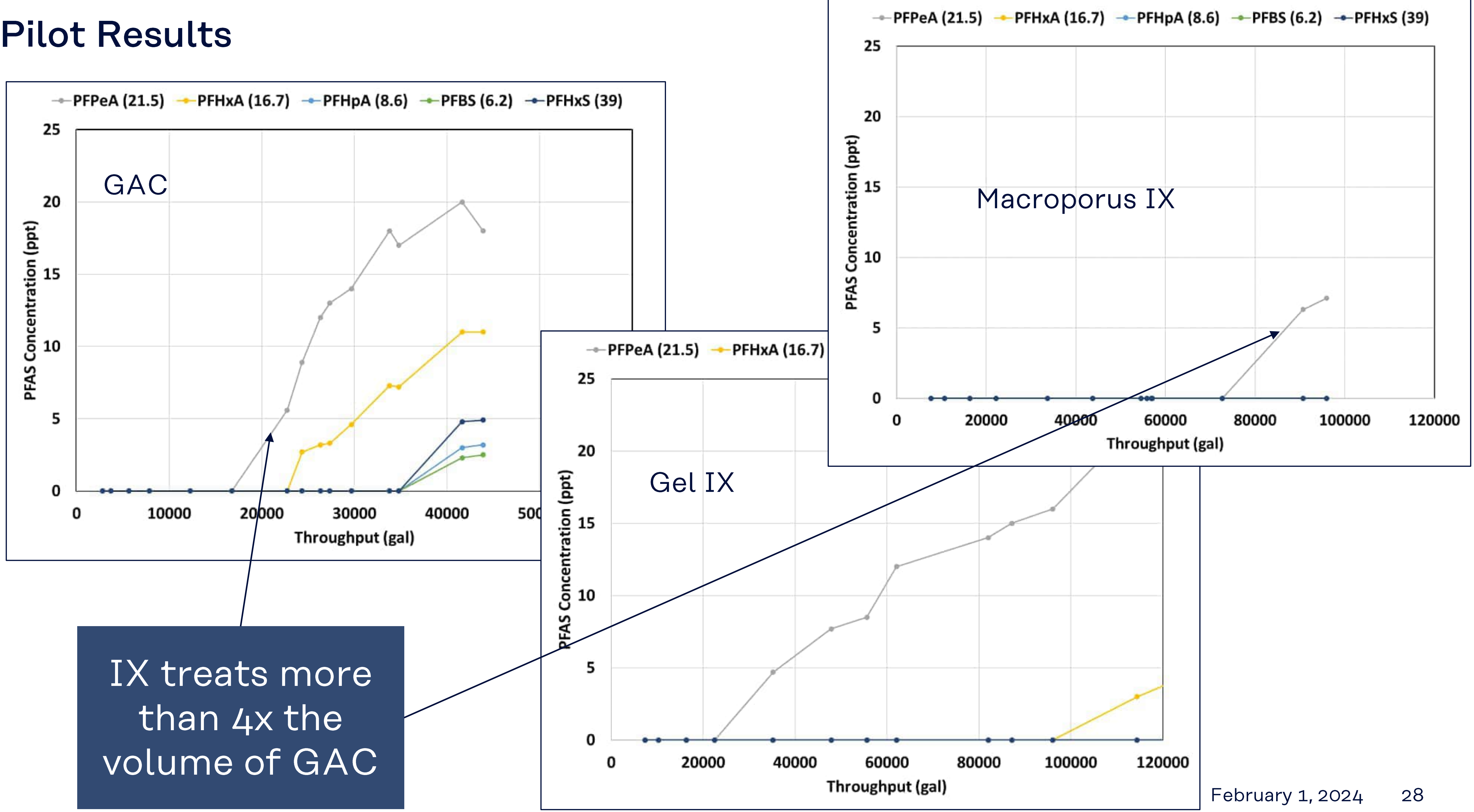
HLR: 5.7 gpm/ft^2

IX Pilot Design

EBCT: 3 minutes

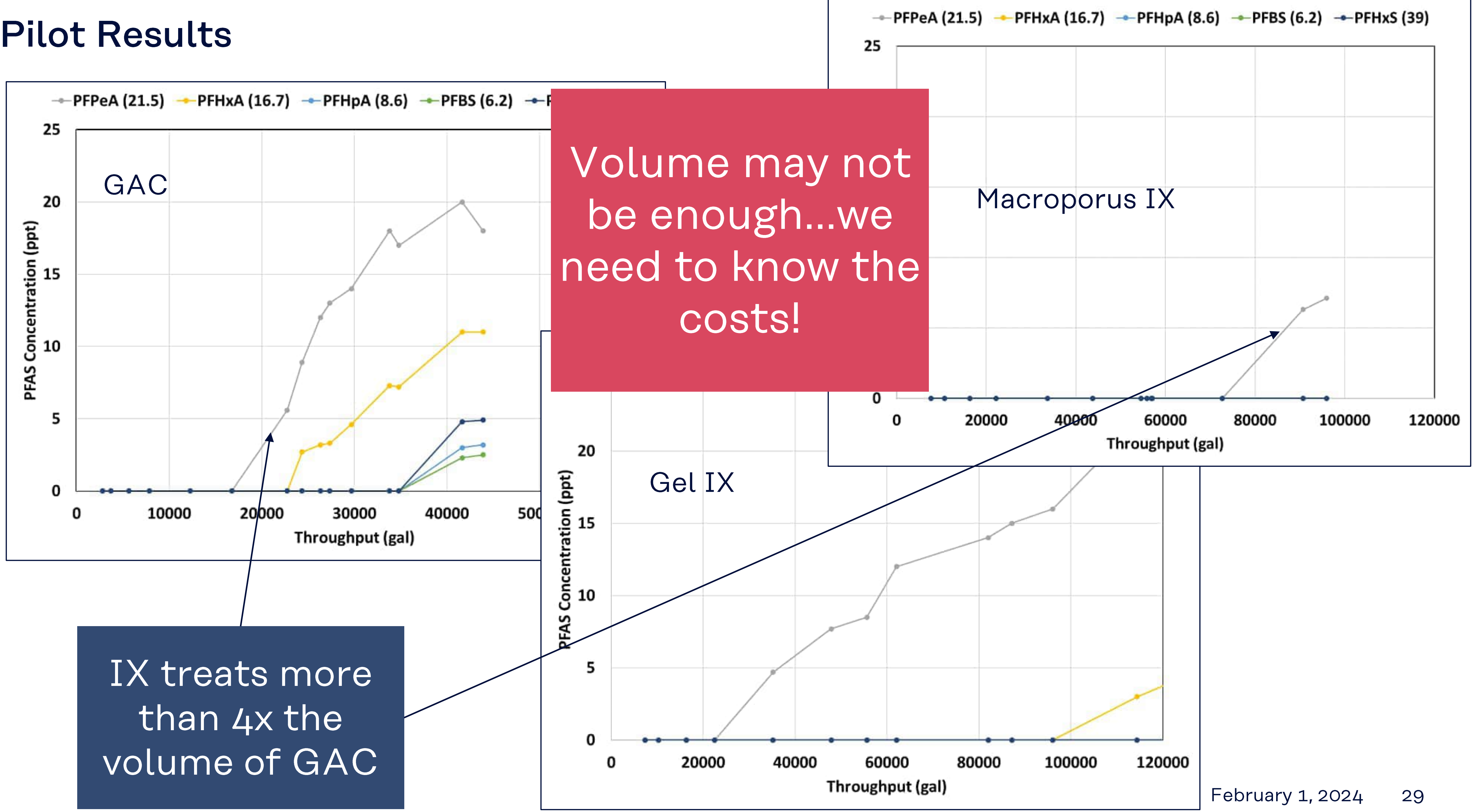
HLR: 8.7 gpm/ft^2

Pilot Results

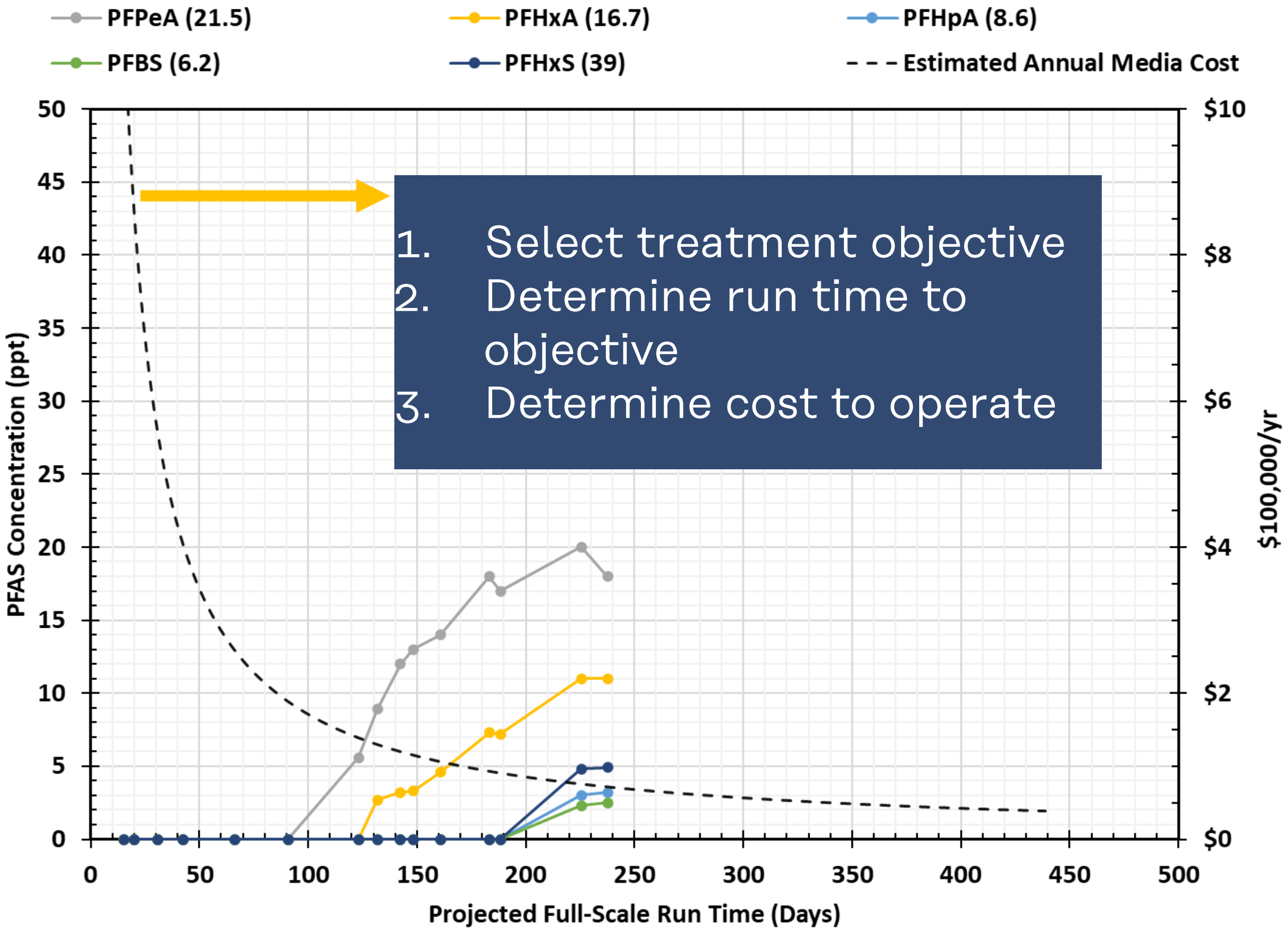


IX treats more than 4x the volume of GAC

Pilot Results

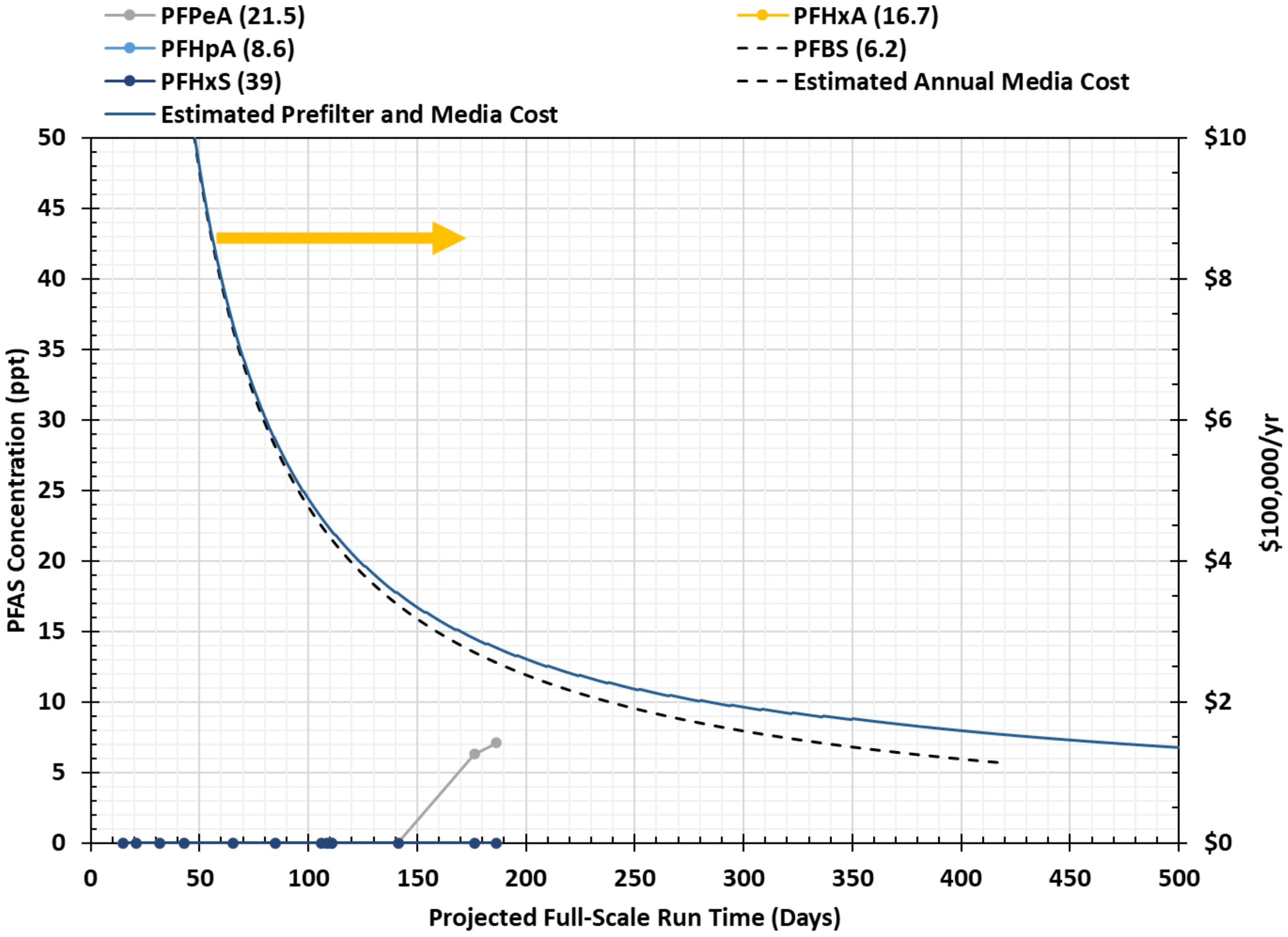


Including Operating Cost – Reagglomerated Bituminous GAC (Pumping Not Shown)



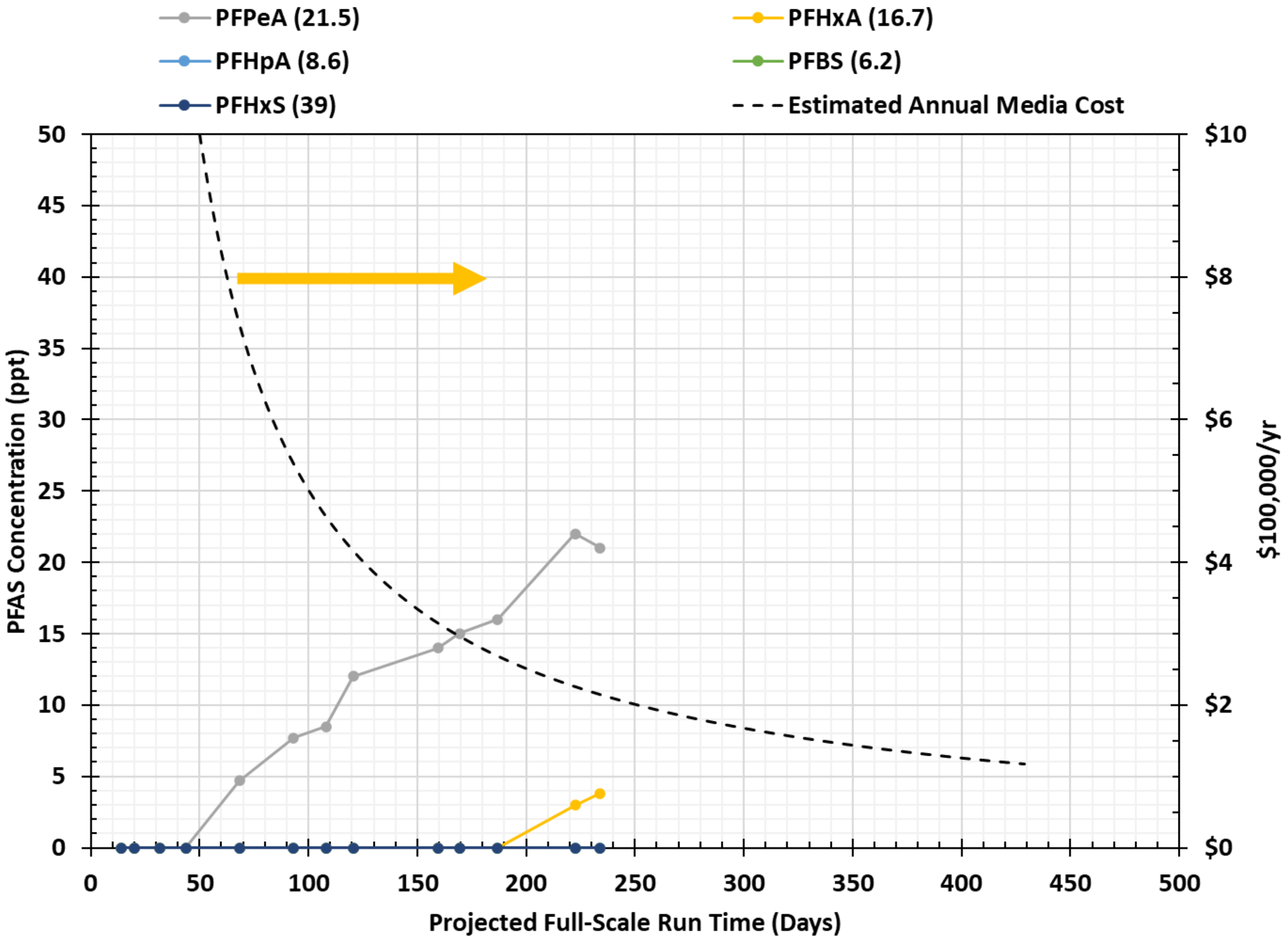
- Unit Media Cost: $2.35/lb
- Annual Media Cost
  - Assumes replacement on the day shown
  - Includes Disposal – Reactivation
- Estimated operation based on initial detect of all PFAS (PFPeA)
  - Resultant Cost: $140k/yr
- Estimated Operation based on 5 ppt PFHxS
  - Resultant Cost: $75k/yr

Including Operating Cost – Macroporus Resin (Pumping Not Shown)



- Unit Media Cost: $385/ft³
- Unit Media Disposal Cost: $145/ft³
- Annual Media Cost
  - Assumes replacement on the day shown
  - Includes Disposal – Incineration
- Estimated operation based on initial detect of all PFAS (PFPeA)
  - Resultant Cost: $280k/yr
- Pre-Filter cost assumes 2-week replacement interval ($40k/yr MAX) – Disposal not included

Including Operating Costs – Gel Resin (Pumping Not Shown)



- Unit Media Cost: $412/ft^3
- Unit Media Disposal Cost: $145/ft^3

- Annual Media Cost
  - Assumes replacement on the day shown
  - Includes Disposal – Incineration

- Estimated operation based on initial detect of all PFAS (PFPeA)
  - Resultant Cost: $700k/yr

- Pre-Filter cost not shown
  →General media costs prohibitive
  →Also $40k/yr – disposal not included

Case Study Discussion

- Annual GAC media costs were half that of IX resin
- There are no compounds other than PFPeA and PFHxA breaking through the IX at this location to date

- Only treating for regulated PFAS
  - GAC costs decrease: $140k/yr to $75k/yr
  - IX costs decrease from $280k/yr to ??
    → would have to run for ~630 days to achieve $75k/yr (media only)
    →prefilter costs are $40k/yr (w/o disposal)

- GAC was the chosen treatment for this utility

Thank you.

February 1, 2024

Novel Media Use for Emergency PFAS Treatment

Case Study – FLUORO-SORB 200 – Media Implementation

Presented By:
Douglas Craver – AdEdge SW Technical Sales Manager

Presentation Topics

- AdEdge Water Technologies/Chart Water Introduction
- Project and Water Quality Overview
- Treatment Options and Media Comparison
- Selection of Equipment
- FLUORO-SORB Treatment Results - 2022
- Questions?

WHO IS CHART?

Chart Industries, Inc. (NYSE: GTLS) is a leading, independent global manufacturer of highly engineered equipment servicing multiple applications in the Energy, Water, and Industrial Gas markets.

Heat Transfer Systems

- Air Cooled Heat Exchangers (ACHX),
- Brazed Aluminum Heat Exchangers (BAHX)
- Cold Boxes
- Nitrogen Rejection Units (NRU)
- Integrated systems
- High Efficiency Flow Fans

Cryo Tank Solutions

- Bulk and Micro Bulk Storage Tanks
- ISO Containers
- Packaged Gas Systems
- Fueling Stations
- Non-specialty mobile equipment
- Vaporizers

Repair, Service & Leasing

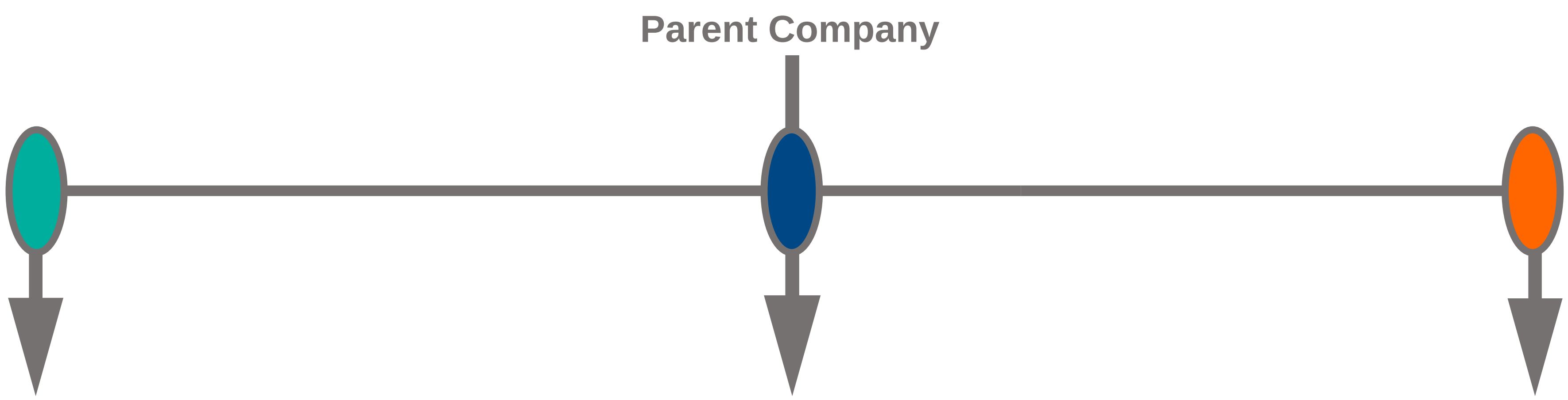
- Repair and service
- Aftermarket parts and maintenance
- Global Leasing
- Installations
- Full lifecycle

Specialty Products

- Aerospace
- Beverage carbonation
- Biogas liquefaction
- Carbon capture
- Fuel systems & stations
- Hydrogen energy
- Liquid air energy systems
- Water treatment

Who is ChartWater™?

ChartWater™, a division and brand of Chart Industries, Inc., is a global manufacturer and service provider of engineered solutions for municipal water treatment and industrial process applications with over 1,100 installations in 22 countries.



BlueInGreen *A Chart Industries Company*	CHART	AdEdge water technologies
Biological wastewater tretament, Odor removal, pH control, Disinfection	Highly engineered cryogenic equipment	Water treatment solution provider, municipal and industrial water and wastewater

AdEdge Water Technologies – A Chart Industries Company

We offer diverse system solutions to best fit the application and enable customers to eliminate a wide variety of contaminants from potable, industrial, wastewater, and reuse streams.

MODULAR TREATMENT SYSTEMS

ADEDGE PACKAGED UNITS (APU)

WATERPOD CONTAINERIZED SYSTEMS

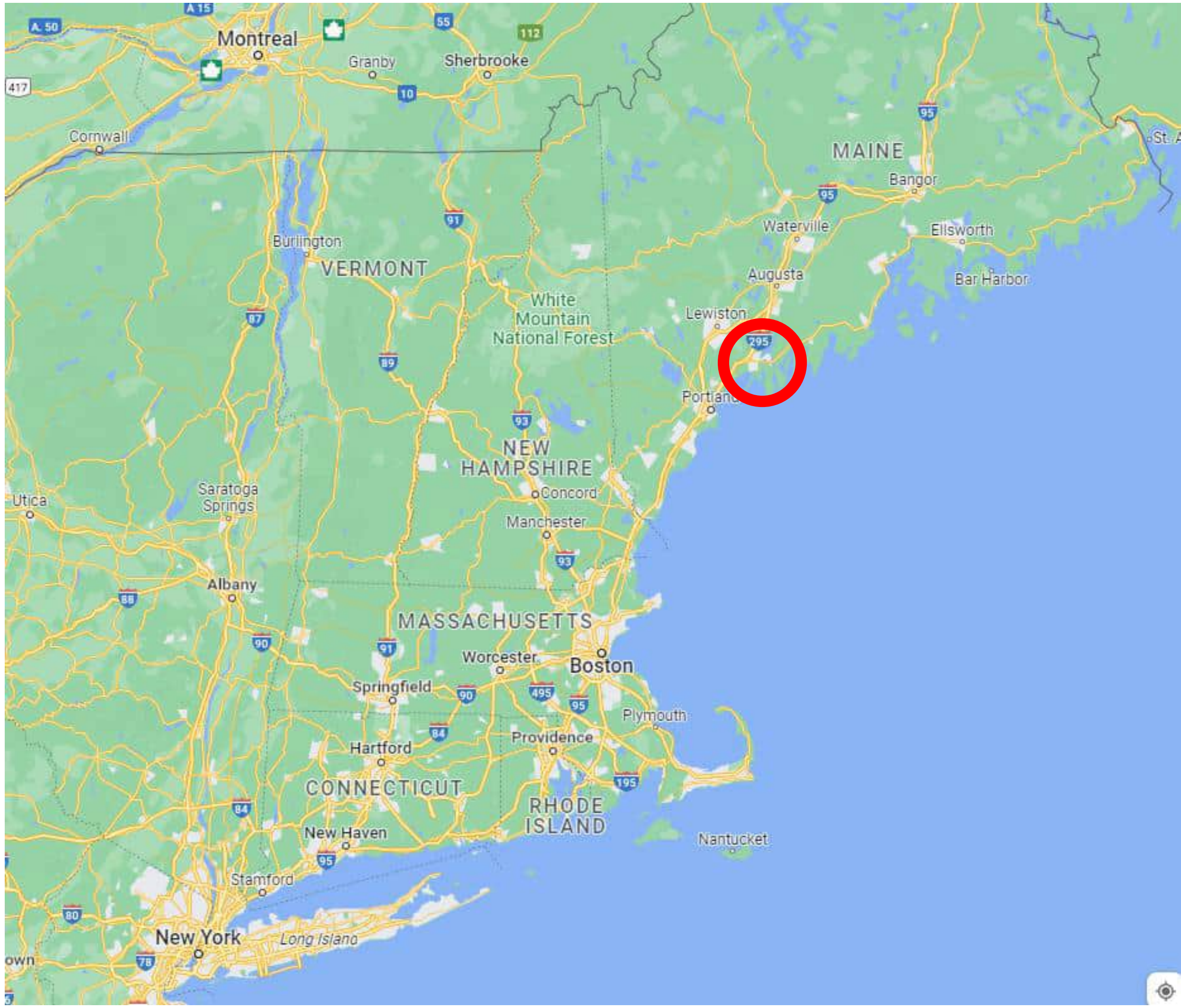
ULTRA-HIGH RECOVERY FLOW REVERSAL RO

biottta® BIOLOGICAL TREATMENT

LARGE MODULAR TREATMENT SYSTEMS

Brunswick & Topsham

- Average Day 1.7 MGD max day 3.4 MGD
- 7,300 Service Connections
- 108 miles of mains
- 2 Storage Tanks (3.0 MG and 4.0 MG)
- 770 hydrants
- 22 employees
- 2 Bowling trophies



Brunswick & Topsham Well Field

Brunswick & Topsham Well Field

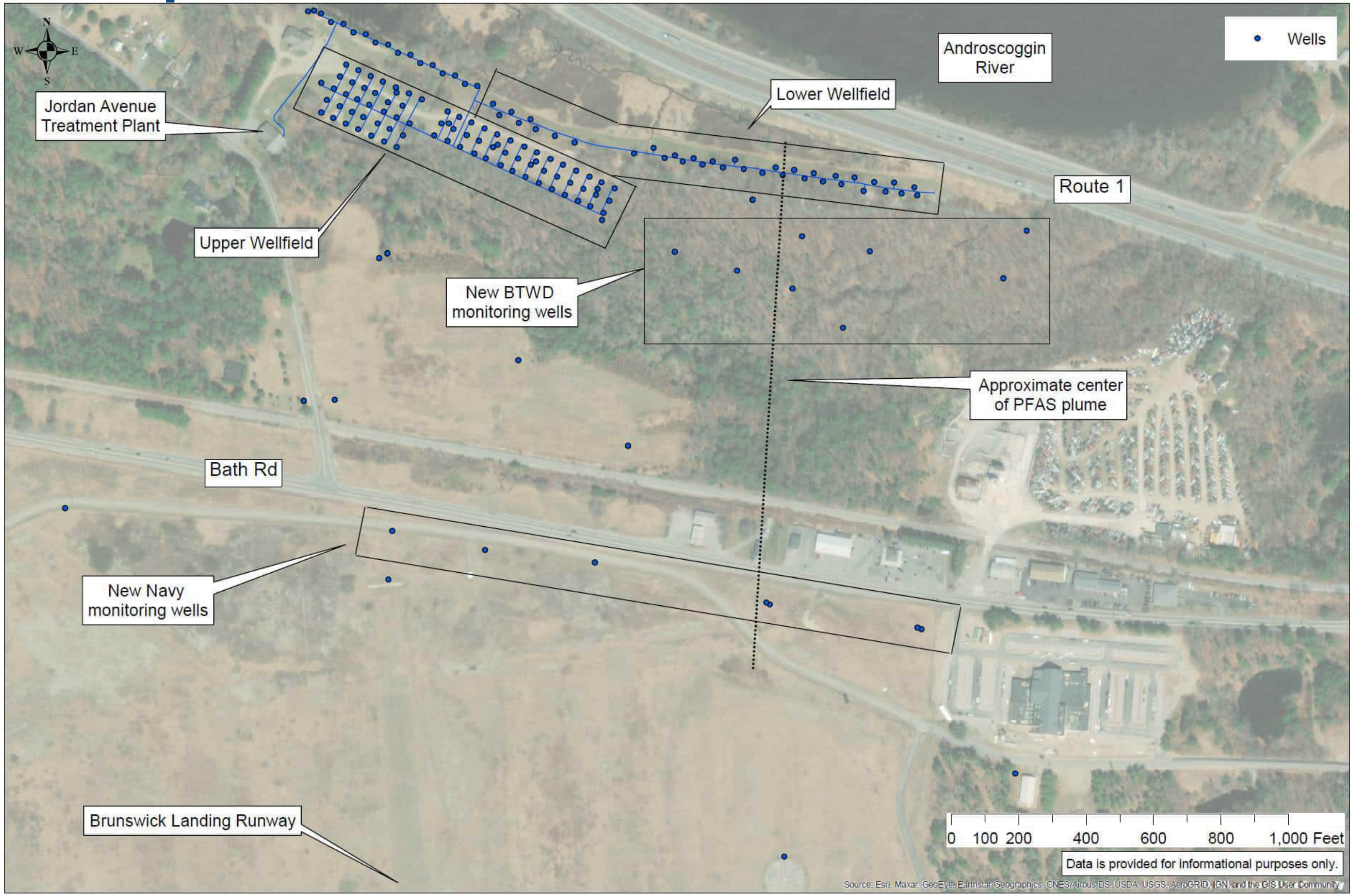


CHART WATER

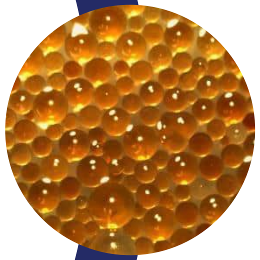
Brunswick & Topsham WD Water Quality 2022

Water Chemistry ** indicates critical data for PFAS resin projection

	Parameters			Parameters			Parameters	
PFBA	2.60	ng/L (ppt)	**pH**	6.10		**Ammonia**		mg/L NH_3-N
PFPeA	7.840	ng/L (ppt)	**Total Arsenic**	0.003	mg/L As	**** Nitrate**	1.030	mg/L NO_3-N
PFHxA	6.310	ng/L (ppt)	**Arsenic (III)**	N/A	mg/L As(III)	**Sodium**	12.900	mg/L Na
PFHpA	<2.0	ng/L (ppt)	**Total Sulfides**		mg/L Total Sulfides	**** Chloride**	13.000	mg/L Cl
PFOA	7.260	ng/L (ppt)	**** Alkalinity**	26.000	mg/L (as $CaCO_3$)	**** Sulfate**	14.000	mg/L as SO_4
PFNA	<2.0	ng/L (ppt)	**Bicarbonate**	26.000	mg/L (as $CaCO_3$)	**Fluoride**	<0.1	mg/L F
PFTeA		ng/L (ppt)	**Hardness**	51.900	mg/L (as $CaCO_3$)	**Total Dissolved Solids**		mg/L TDS
PFBS	4.280	ng/L (ppt)	**Calcium**	17.800	mg/L Ca	**Total Suspended Solids**	<0.1	mg/L TSS
PFHxS	33.200	ng/L (ppt)	**Magnesium**	1.800	mg/L Mg	**Gross Alpha**	<1.79	pCi/L
PFHpS	<2.0	ng/L (ppt)	**Phosphate**	<0.2	mg/L PO_4	**Combined Radium**	<0.7	pCi/L Ra 226/228
PFOS	8.060	ng/L (ppt)	**Silica**		mg/L SiO_2	**Uranium**	<0.001	mg/L U 238
4:2 FTS	<2.0	ng/L (ppt)	**Vanadium**	0.0005	mg/L V	**Turbidity**	<0.5	NTU
6:2 FTS	<2.0	ng/L (ppt)	**Iron**	<0.01	mg/L Fe	**Temperature**	10C	^{o}F
8:2 FTS	<2.0	ng/L (ppt)	**Manganese**	0.01	mg/L Mn	**Dissolved Oxygen**		mg/L DO
GenX		ng/L (ppt)	**** TOC**	1.600	mg/L TOC	**Chromium VI**	0.001	mg/L Cr(VI)

AdEdge Media Solutions

Bituminous Activated Carbon
12x40 Mesh
NSF 61 – Several Suppliers



Anion Exchange Resin (Buffered Option)
PFAS Selective
NSF 61 – Several Suppliers

FS200 Modified Organo-Clay
12x40 Mesh
NSF 61 – Preferred Supplier

Cost Factors for “Apples to Apples” Media Comparisons of Technologies

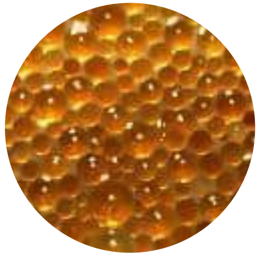
Unit Cost of the Media ($/lb. or $/cuft.)

$\neq$

Total Treatment (Lifecycle) Cost

There are multiple other Factors to Consider

PFAS Removal Solutions - Benefits

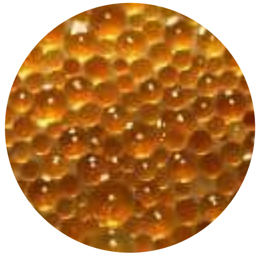


FLUORO-SORB MEDIA	ION EXCHANGE
✓ High capacity for PFAS ✓ Short EBCT of 2-3 min resulting in compact footprint ✓ Excellent performance even in presence of TOC, TDS, and free chlorine	✓ High capacity for PFAS ✓ Short EBCT of 2-3 min resulting in compact footprint ✓ Minimal start-up wastewater volumes and no backwashing
GRANULAR ACTIVATED CARBON	**REVERSE OSMOSIS**
✓ Proven PFAS removal and widely accepted ✓ Addresses other water quality parameters as needed (TOC, T&O, VOC's) ✓ Non-leaching	✓ >99% PFAS rejection ✓ Multiple contaminant removal solution

CHART WATER

PFAS Solutions - Considerations

FLUORO-SORB MEDIA	ION EXCHANGE
✓ Hydraulic loading rate ✓ Media conditioning at start-up ✓ Periodic backwashing infrastructure	✓ Higher cost per cubic foot ✓ Background water quality impacting life (competing ions and organics) ✓ Dechlorination required
GRANULAR ACTIVATED CARBON	**REVERSE OSMOSIS**
✓ Background water quality impacting life (organics) ✓ Backwash infrastructure required ✓ Waste volumes at start-up for pH and Arsenic ✓ Longer EBCT = Larger Footprint	✓ Concentrate management ✓ Operating cost (energy, membrane replacements, CIP)



Media Solutions for PFAS – Comparison Summary



FLUORO-SORB (FS)	ION EXCHANGE (IX) - BUFFERED	GAC - F400-01 VERSION
Surface modified organo-clay	Gel-type, Buffered Product	F400-01 is the same as F400 carbon but with a pre-conditioning step that suppresses the release of metals inherent in activated carbons (see supp. Info sheet) – can use F400 AR+ as well
Proven PFAS removal	Proven PFAS removal	Proven PFAS removal
Shorter EBCT (~3 min) = Compact Footprint	Shorter EBCT (~3 min) = Compact Footprint	Longer EBCT (~10 min) = Larger Footprint
Presence of TOC = Minimal Media Life Impact	Presence of TOC = Greater Impact on Media Life	Presence of TOC = Greater Impact on Media Life
Free Chlorine = Tolerant up to 1 mg/L Continuous (Passes Through) = No Dechlor or Rechlor after Fe/Mn System *low continuous chlorine dose can also mitigate bio-fouling*	Free Chlorine = No Continuous Tolerance = Dechlor and Rechlor with Fe/Mn Treatment at site *macro resin may allow for low continuous chlorine dose*	Free Chlorine = Consumed through GAC = Rechlor with Fe/Mn Treatment at site
Background TDS / Anions = No Media Life Impact	Background TDS / Anions = Possible Reduced Media Life	Background TDS / Anions = No Media Life Impact
VOC / T&O = No Treatment	VOC / T&O = No Treatment	VOC / T&O = Treated by GAC
Bag Filter Pre-Treatment = Required	Bag Filter Pre-Treatment = Required	Bag Filter Pre-Treatment = Not Required
Start-Up = BW Required for Fines Removal, No Required Forward Rinse	Start-Up = No BW Required, 20 BV Forward Rinse for NSF (non-buffered requires 100 – 150 BV)	Start-Up = BW Required for Fines Removal, 20 BV Forward Rinse for NSF
Backwashing (once in service) = Only if Required	Backwashing (once in service) = None	Backwashing (once in service) = Only if Required
Leaching = None	Leaching = None	Leaching = None
Mined and Modified in the USA	Manufactured in Europe, China, or India	Manufactured and Rinsed in USA
Media Unit Cost = Moderate	Media Unit Cost = Higher	Media Unit Cost = Lower

CHART WATER

Media Predictive Testing Comparison

Test Type	Details	GAC	IX	FS
RSSCT	- Bench top testing scaled to simulate full scale - Shorter test time for comparative results - Moderate predictability of full-scale, weeks for results	✓	✗	✓
Field	- 2” or 3” columns, match gpm/sqft or EBCT - Incorporates impact of changing flow and water quality - Best predictability of full-scale, months to years	✓	✓	✓
Life Projection	- Media life estimations based on experience or empirical data	✓	✓	✓
Software Modeling	- Media life projection curves based on software model	✗	✓	✗

Long Chain vs. Short Chain

- Sulfonic acids (PFOS) more easily removed than carboxylic acids (PFOA)
- Longer chains more easily than shorter chains

7

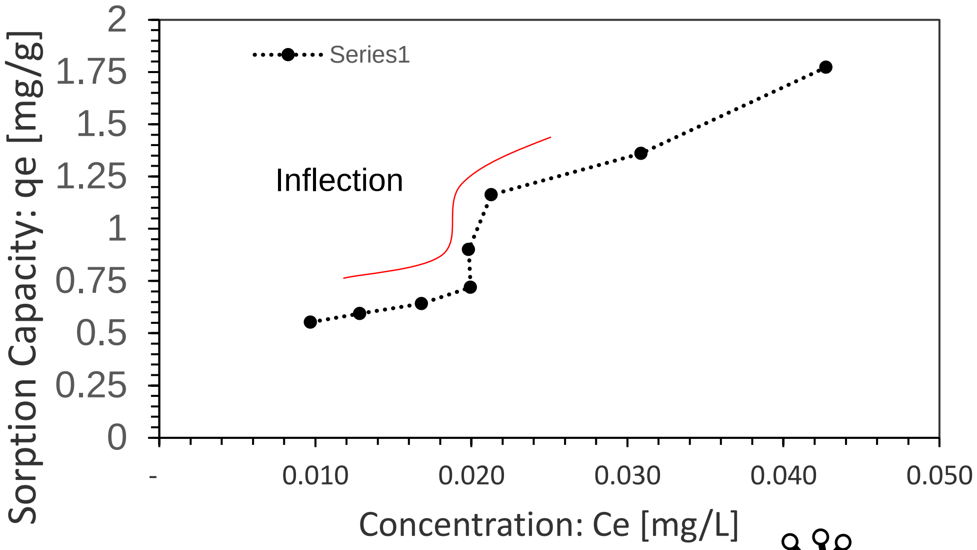
Table 3-2. Short-chain and long-chain PFCAs and PFSAs

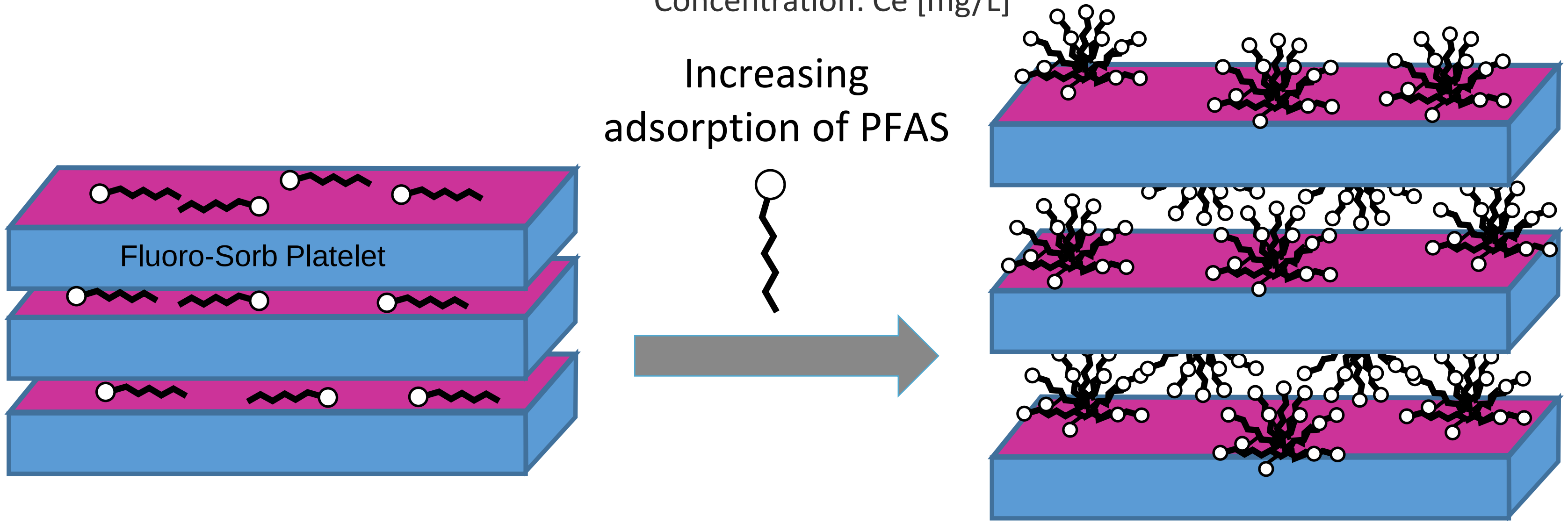
Short-chain PFCAs				Long-chain PFCAs				
PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
Short-chain PFSAs		Long-chain PFSAs						

5

Source: https://pfas-1.itrcweb.org/wp-content/uploads/2018/03/pfas_fact_sheet_naming_conventions__3_16_18.pdf

FLUORO-SORB Removal Mechanism





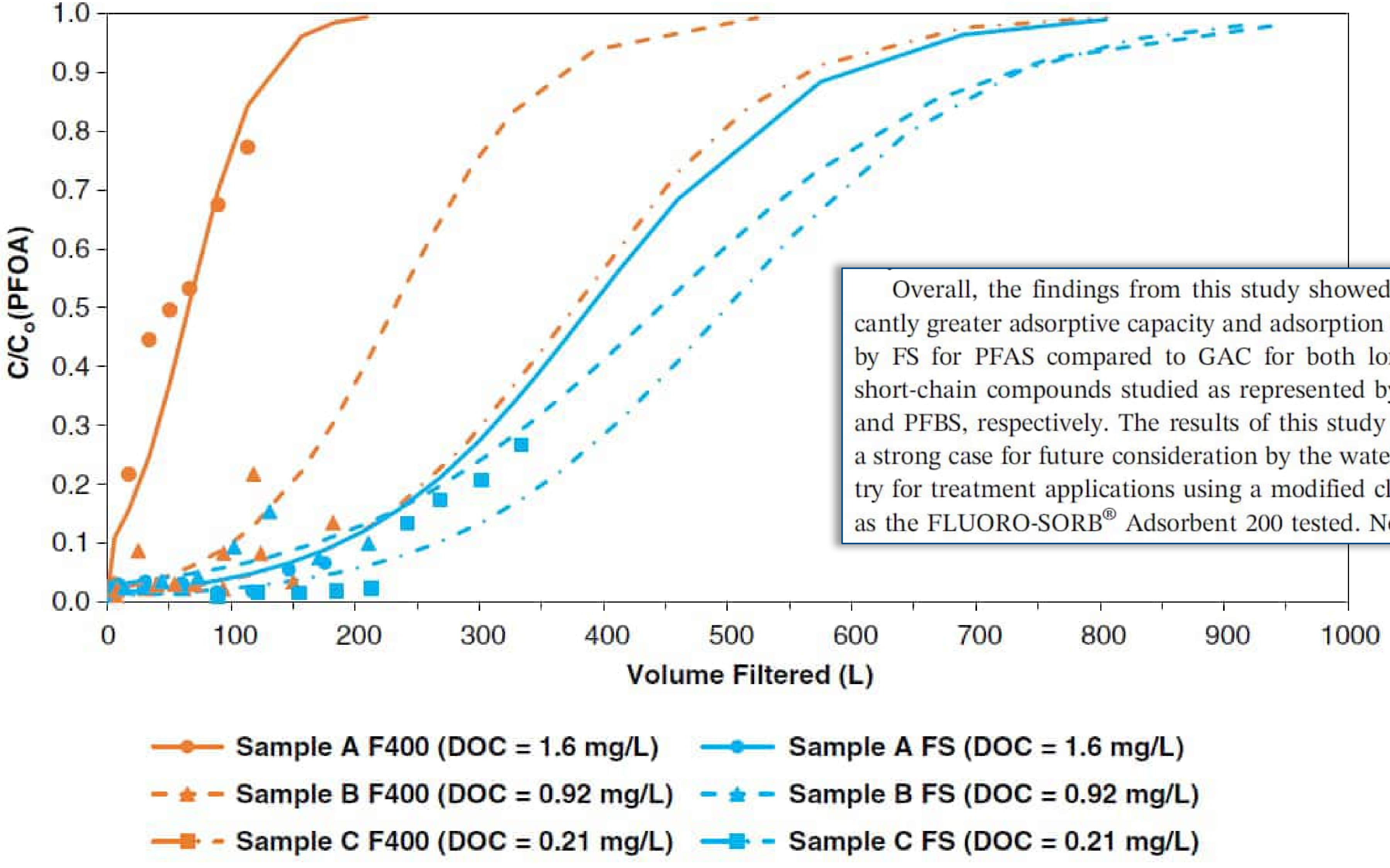
Source: CETCO

Treatment Performance Comparison – FS vs. GAC in the Presence of TOC

FIGURE 6 Thomas model curve comparison between granular activated carbon (GAC) F400 and Fluorosorb (FS) for perfluorooctanoic acid and perfluorobutanesulfonic acid at selected dissolved organic carbon (DOC) values. Method reporting limit (MRL) was <0.5 ng/L. 50% MRL was used for non-detects]

GAC = 10 min EBCT

FS = 2 min EBCT



Overall, the findings from this study showed significantly greater adsorptive capacity and adsorption kinetics by FS for PFAS compared to GAC for both long- and short-chain compounds studied as represented by PFOA and PFBS, respectively. The results of this study provide a strong case for future consideration by the water industry for treatment applications using a modified clay such as the FLUORO-SORB® Adsorbent 200 tested. Neverthe-

Source: Comparing conventional and emerging adsorbents for per- and polyfluoroalkyl substances: Kinetic, equilibrium, and column experiments, Greico et al., AWWA Water Sci. 2021;e1256

LifeCycle Cost Comparison – 250 gpm w/ Disposal

	IX (Buffered Product)	FLUORO-SORB (200)	GAC (F400-01)
ESTIMATED CAPITAL COSTS (CAPEX)			
Flow (gpm)		**250**	
Vessel Diameter (in)	72	72	120
Qty of Vessels	1	1	1
EBCT (min, per vessel)	3.0	3.0	10.0
Active Media Volume (total cuft/vessel)	100	100	335
Total Active Media Volume (cuft)	100	100	335
Total Capital Cost (Equipment, Media, Start-Up)	**$170,000**	**$150,000**	**$360,000**
Estimated Footprint of System (sqft)	36	36	100
Estimated Footprint of Building (sqft - Assumes 3' clearance in each direction)	144	144	256
Estimated $/sqft of building	$400	$400	$400
Estimated Building Cost *(if needed)	$57,600	$57,600	$102,400
Engineering Costs	$30,000	$30,000	$30,000
Estimated CAPEX (System + Building + Eng)	**$227,600**	**$207,600**	**$462,400**

LifeCycle Cost Comparison – 250 gpm w/ Disposal

	IX (Buffered Product)	FLUORO-SORB (200)	GAC (F400-01)
ESTIMATED OPERATING COSTS (OPEX)			
Media Capacity Projection (Bed Volumes)	305,000	274,000	85,000
Media Capacity Projection (Gallons)	228,140,000	204,952,000	212,993,000
Utilization (%)	100%	100%	100%
Utilization (Gallons per Day)	360,000	360,000	360,000
Media Capacity Projections (Years)	1.7	1.6	1.6
Media Replaced at Change Out (cuft))	100	100	335
Media Cost ($/cuft)	$395	$220	$118
Media Cost Only ($/event)	$39,500	$22,000	$39,530
Turnkey Media Services - Removal, Disposal, Replacement, Re-Commissioning ($/event)	$27,992	$27,992	$54,165
Total Event ($)	$67,492	$49,992	$93,695
Annualized OPEX Based on Gallons Capacity and Utilization ($/year)	**$38,873**	**$32,051**	**$57,802**
Op Cost per Thousand Gal	**$0.79**	**$0.59**	**$1.10**
10 YR LIFE CYCLE COST (CAPEX and OPEX)	**$616,327**	**$528,110**	**$1,040,424**

Equipment Selection

<u>Design selected for the process was a single vessel approach using FS200 media.</u>

- Due to well conditions, prefiltration with 5 micron bag filters was recommended.
  - Proved very useful during start up.
- Vessel sizing was 72” diameter with a 3 minute EBCT for the FS200 media
  - Approximately 100 ft3 installed in the vessel
  - Well water flow rate could accommodate the initial backwash requirements of up to 250 gpm
  - GAC would have required 750-800 gpm, which was not available
- Seasonal operation of the plant made the need for disinfection a greater concern, as the plant was off line for the winter months
  - Concern for bio-growth with stagnant water

CHART WATER

Equipment Selection

<u>Design selected for the process was a single vessel approach using FS200 media.</u>

- Ability to locate the equipment in an existing building
- Work with AdEdge on a standardized design for rapid delivery
  - Order placed first week in April 2022
  - System delivered and on line by mid-June 2022

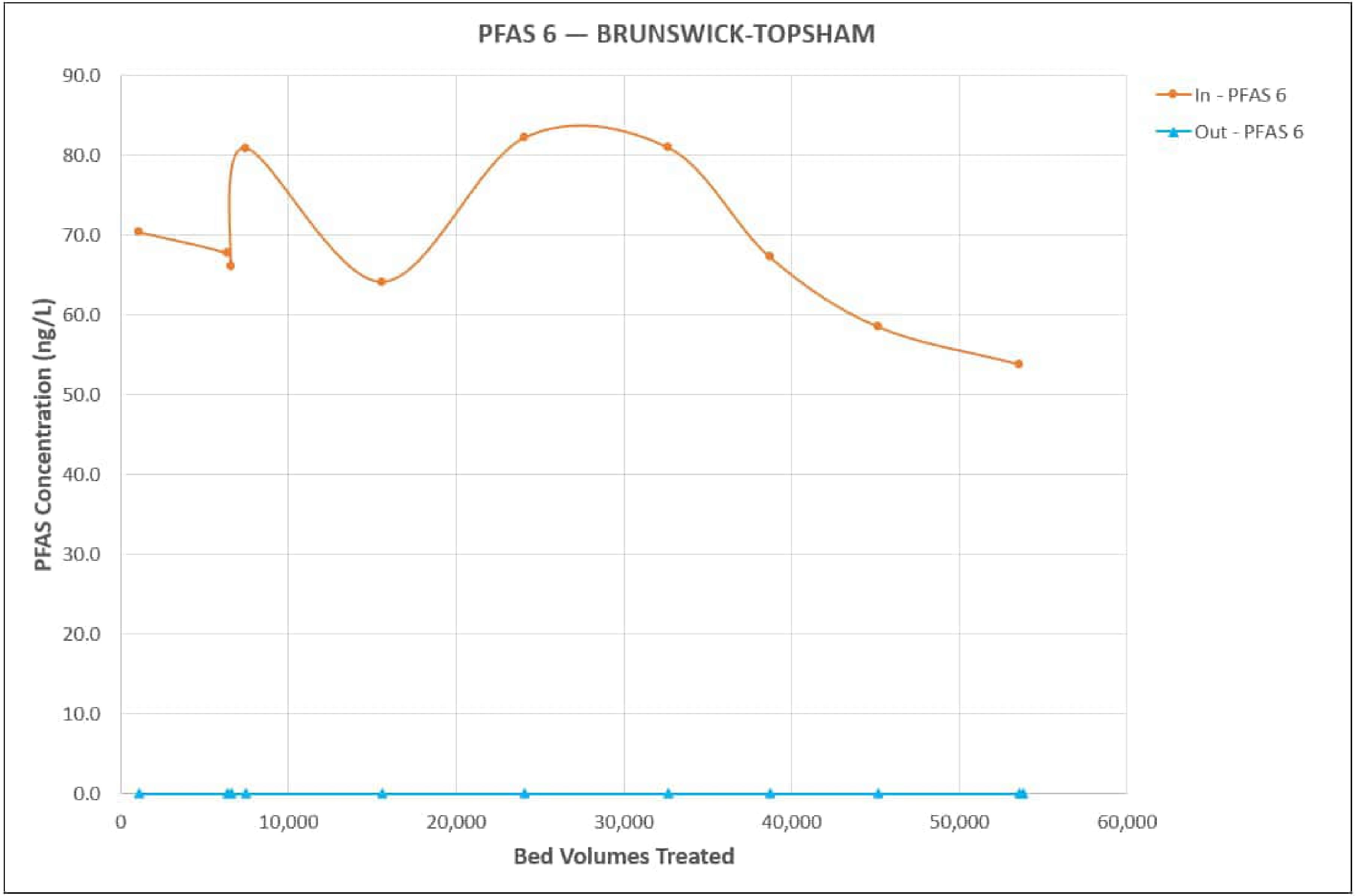
Equipment Selection

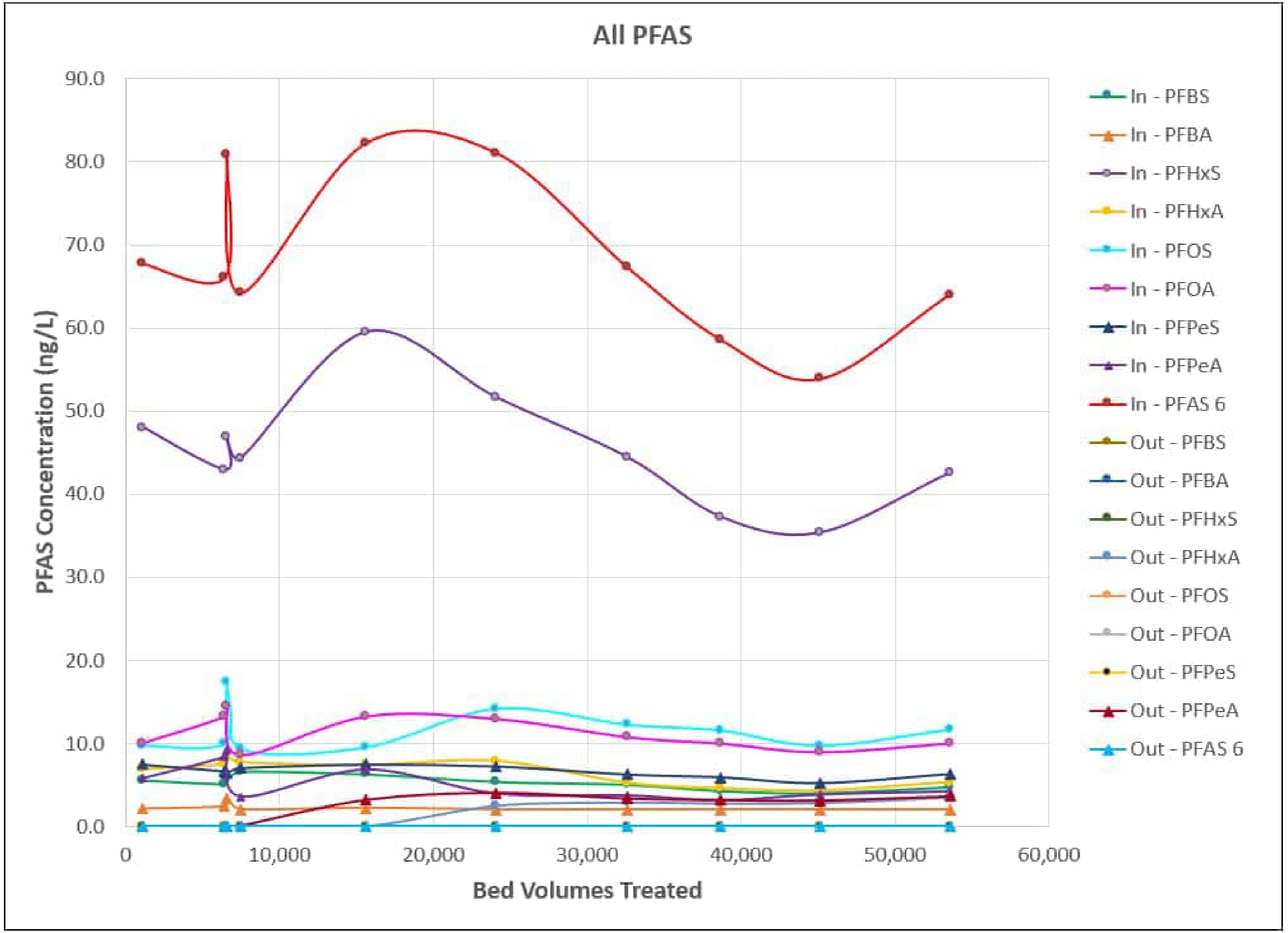
Site Installation

Brunswick Topsham WD Results

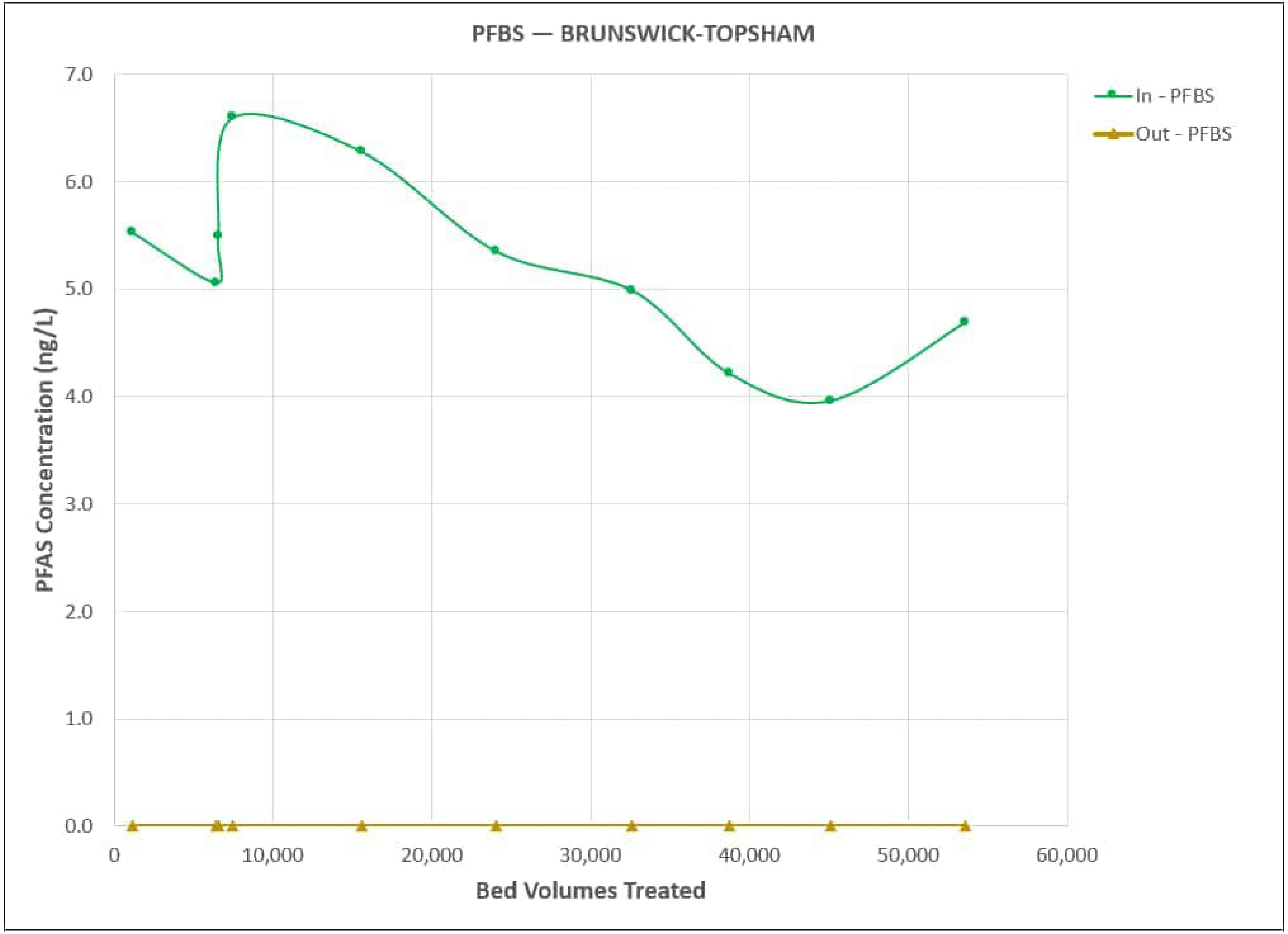
Treat Volume to date 14.6 million gallons = 19,500 Bed Volumes

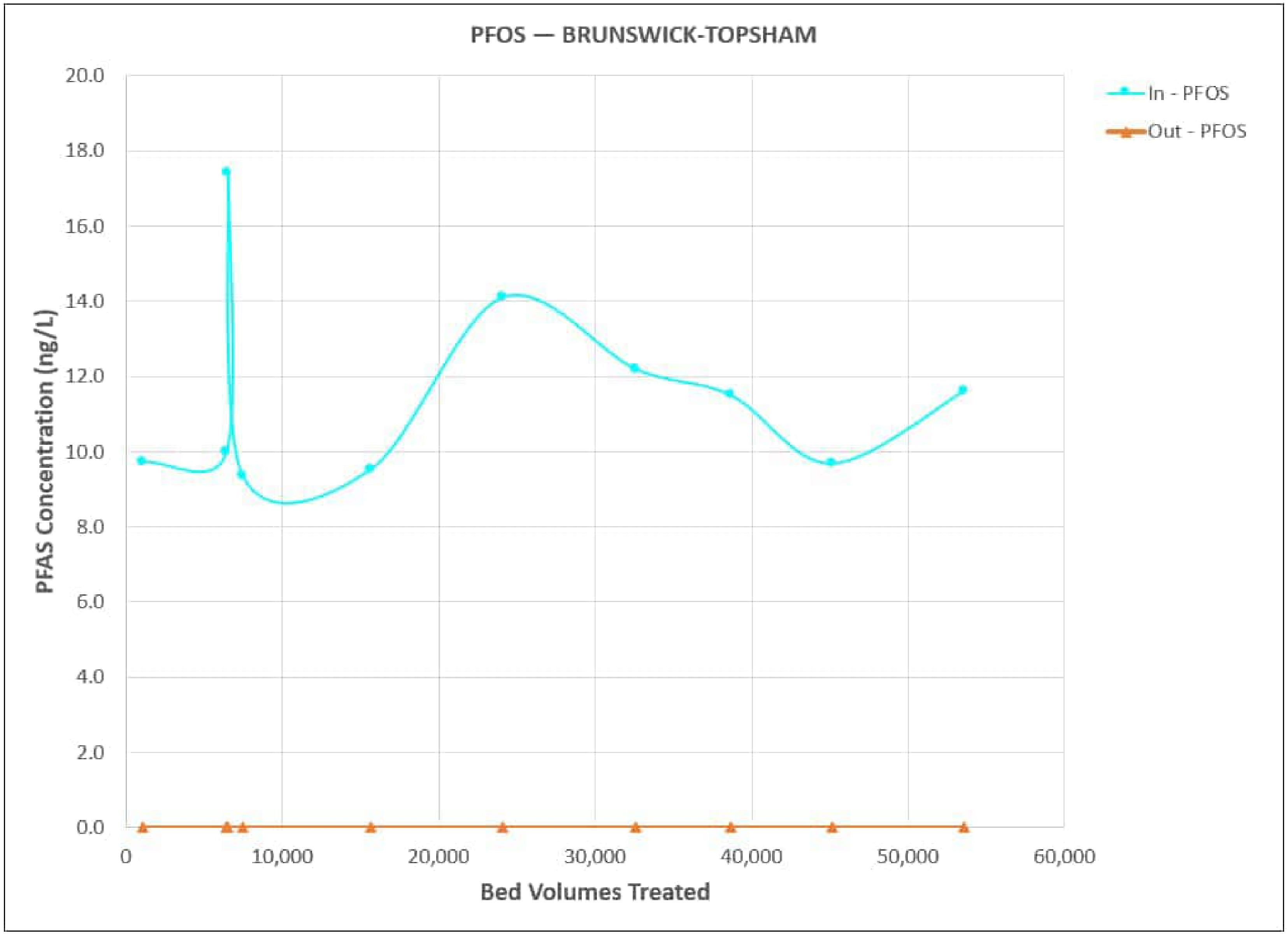
	March 2022 Inlet Data	September 2022 Inlet Data	April 2023 Inlet Data	September 2022 Results	April 2023 Treated after Restart	
PFBA	2.60	2.04	2.18	< 2.00	< 2.00	ng/L (ppt)
PFPeA	7.840	3.54	6.8	< 2.00	3.18	ng/L (ppt)
PFHxA	6.310	7.69	7.37	< 2.00	< 2.00	ng/L (ppt)
PFHpA	<2.0	2.04	<2	< 2.00	< 2.00	ng/L (ppt)
PFOA	7.260	8.53	13.2	2.39	< 2.00	ng/L (ppt)
PFNA	<2.0	< 2.00	<2	< 2.00	< 2.00	ng/L (ppt)
PFPeS		7.00	7.44	< 2.00	< 2.00	
PFBS	4.280	6.6	6.28	2.58	< 2.00	ng/L (ppt)
PFHxS	33.200	44.3	59.5	6.17	< 2.00	ng/L (ppt)
PFHpS	<2.0	< 2.00	<2	< 2.00	< 2.00	ng/L (ppt)
PFOS	8.060	9.37	9.51	3.21	< 2.00	ng/L (ppt)


PFAS 6 — BRUNSWICK-TOPSHAM
In - PFAS 6
Out - PFAS 6
PFAS Concentration (ng/L)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated



All PFAS
PFAS Concentration (ng/L)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated
In - PFBS
In - PFBA
In - PFHxS
In - PFHxA
In - PFOS
In - PFOA
In - PFPeS
In - PFPeA
In - PFAS 6
Out - PFBS
Out - PFBA
Out - PFHxS
Out - PFHxA
Out - PFOS
Out - PFOA
Out - PFPeS
Out - PFPeA
Out - PFAS 6


PFBS — BRUNSWICK-TOPSHAM
PFAS Concentration (ng/L)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated
In - PFBS
Out - PFBS


PFOS — BRUNSWICK-TOPSHAM
In - PFOS
Out - PFOS
PFAS Concentration (ng/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated

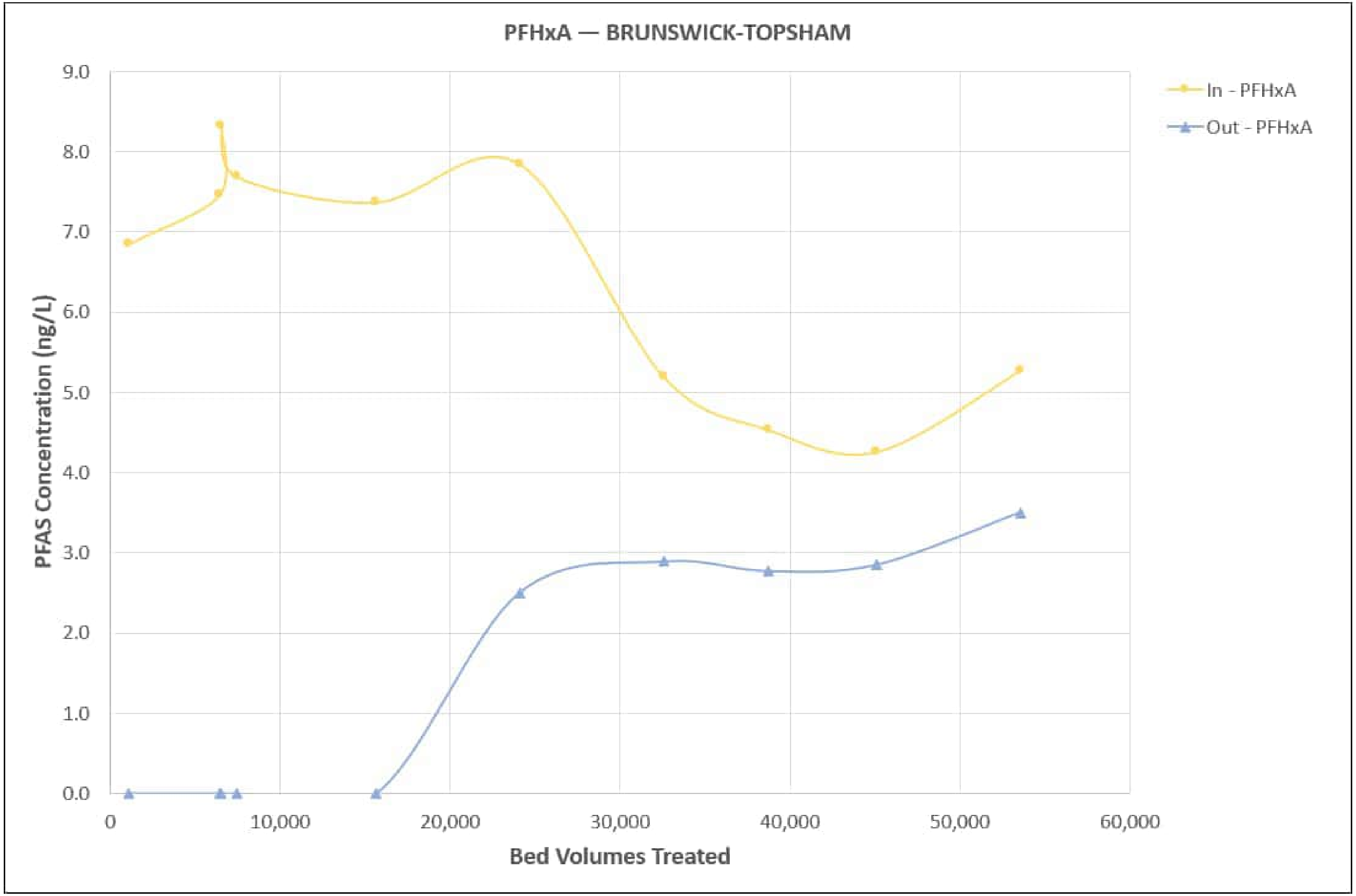
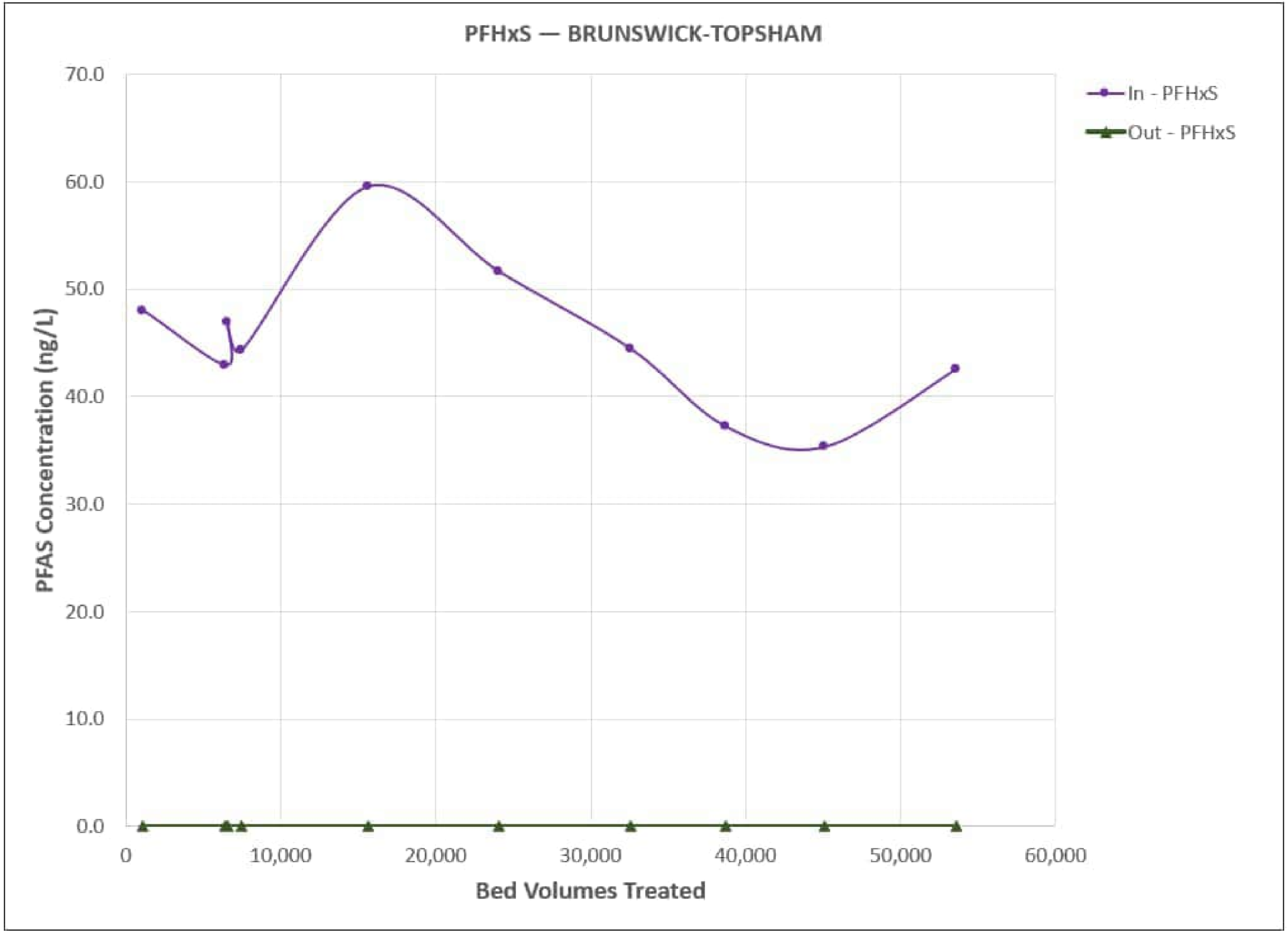

PFHxA — BRUNSWICK-TOPSHAM
In - PFHxA
Out - PFHxA
PFAS Concentration (ng/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated

CHART WATER


PFHxS — BRUNSWICK-TOPSHAM
PFAS Concentration (ng/L)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated
In - PFHxS
Out - PFHxS

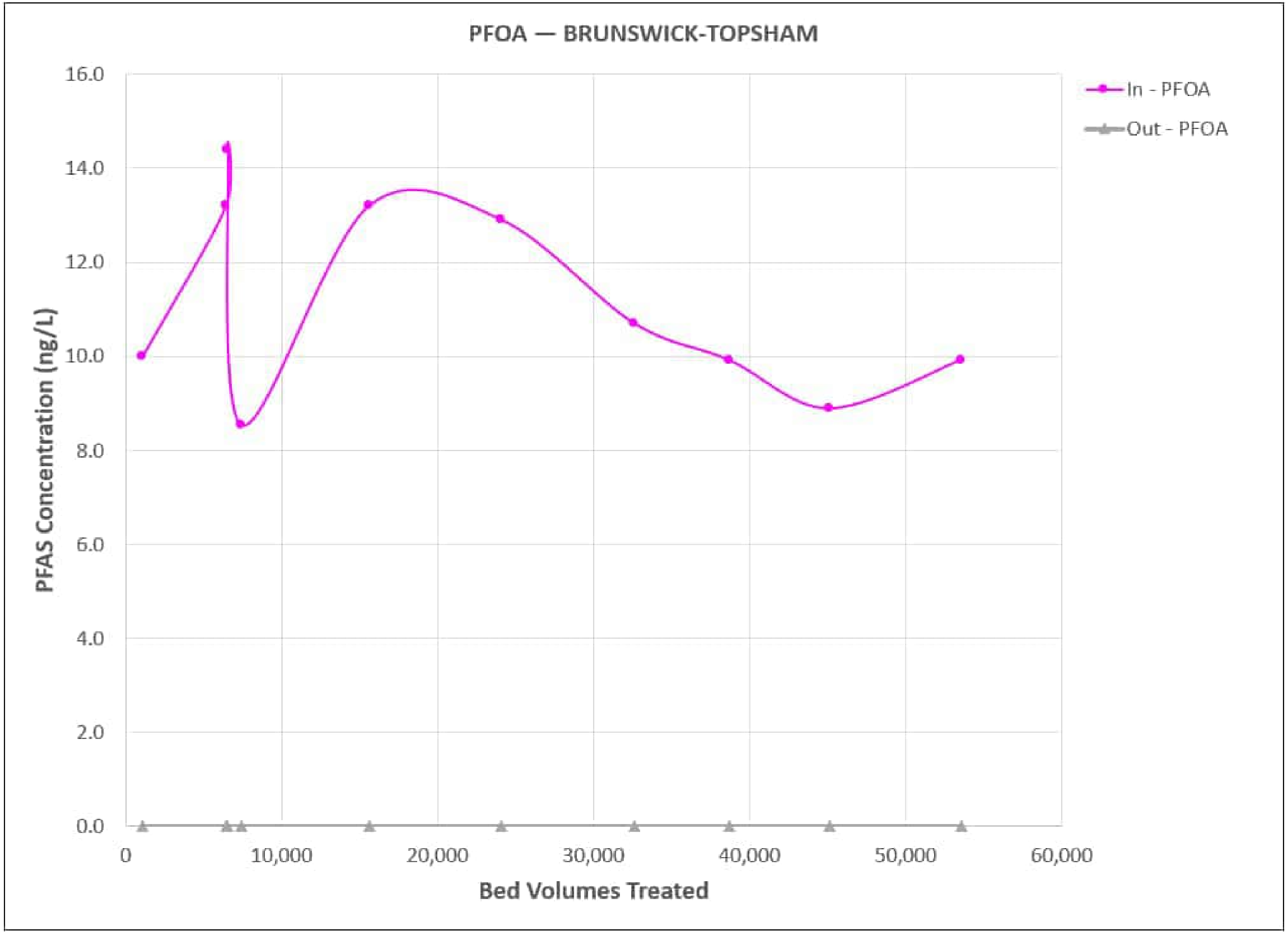

PFOA — BRUNSWICK-TOPSHAM
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
PFAS Concentration (ng/L)
0
10,000
20,000
30,000
40,000
50,000
60,000
Bed Volumes Treated
In - PFOA
Out - PFOA

CHART WATER

Brunswick, ME	
Contaminant	PFAS 6
Process	Adsorption
Solution	FLUORO-SORB
Flow Rate	250 gpm
PFOS, Raw	7.26 ng/L
PFOA, Raw	8.06 ng/L
Installation	Spring 2022

CHART WATER

Long Term Solution – Permanent Facility

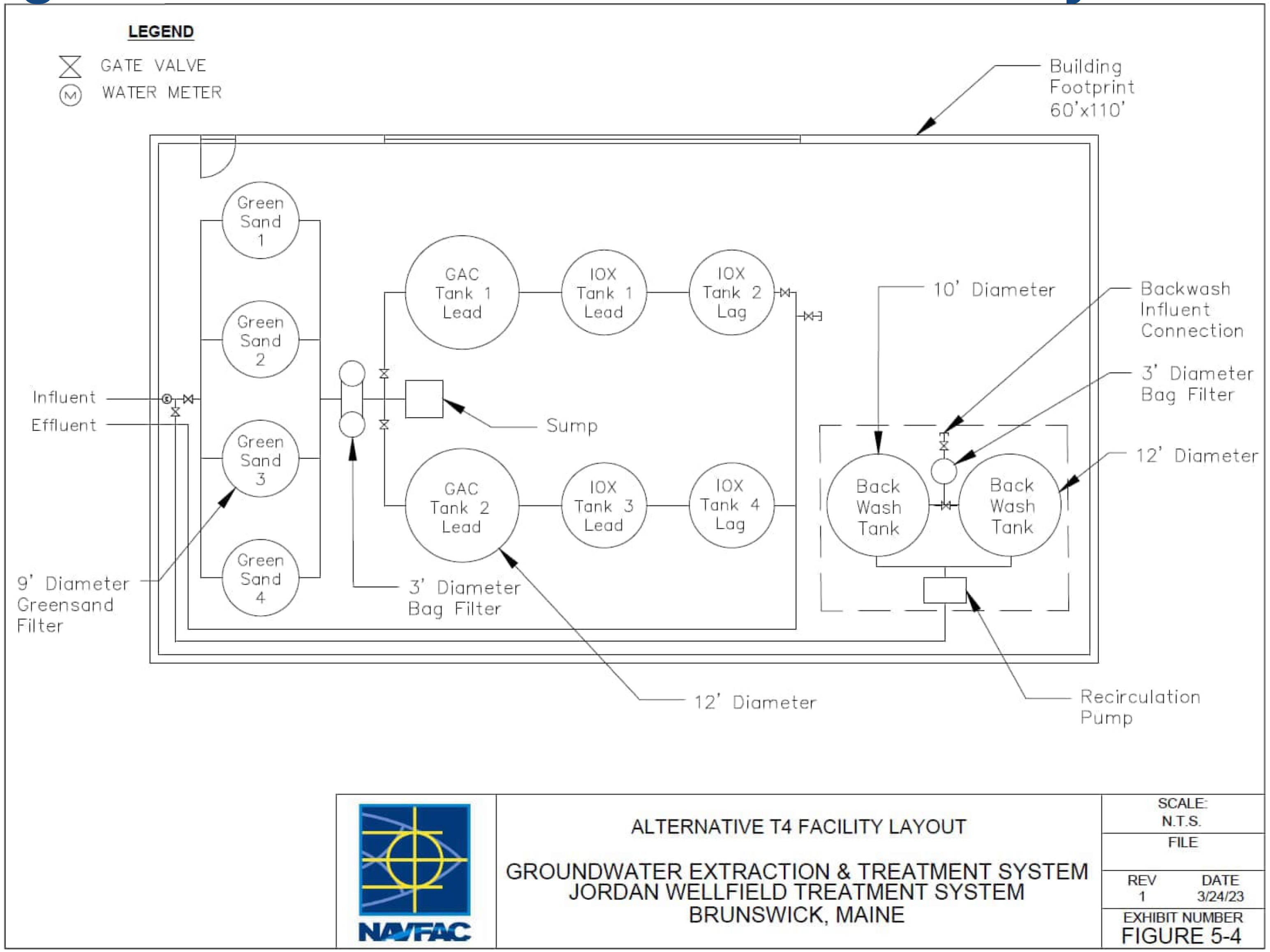


CHART WATER

Summary – Take Aways

PFAS are here to stay…...

One of the biggest water issues of the last 30 years

Regulations will continue increase particularly at the State level

Treatment needs will grow exponentially over the foreseeable future

IX Resins, GAC, Alternative adsorbents and RO /high recovery FR-RO are all viable commercial options for PFAS removal

Each technology has advantages and limitations with no “one size fits all” approach

Flurry of activity on many fronts occurring from Consultants, Engineers, Media suppliers, and Solution Providers from piloting to full-scale installations to meet growing demand to meet the latest regulations

Summary – Take Aways

- Consider all aspects of the design and site limitations before choosing an option
- Work with a solutions provider and consultant to evaluate and determine which option may be best whereby the correct system configuration and design to meet your requirement.
- Water quality is key.
- Life cycle costs will help decide which technology is best for a particular site
- AdEdge offers the flexibility, experience, and applications knowledge to assist you in finding and delivering a solution by providing:
  - Applications and design support
  - Manufacturing / system supply (modular, skid Mounted, and rental systems)
  - We will work closely together with your consulting Engineer
  - Close collaboration with media manufacturers to size / apply the best solution with the lowest costs

Thank you

CHART WATER

PFAS Treatment with Ion Exchange: Meeting the EPA Proposed MCL

Cathy Swanson

February 2, 2024

Purolite®
An Ecolab Company

Agenda

- IX Basics
- System Design
- Modeling / Piloting
- Choosing your Treatment Technology
- Startup Considerations and Corrosion Control

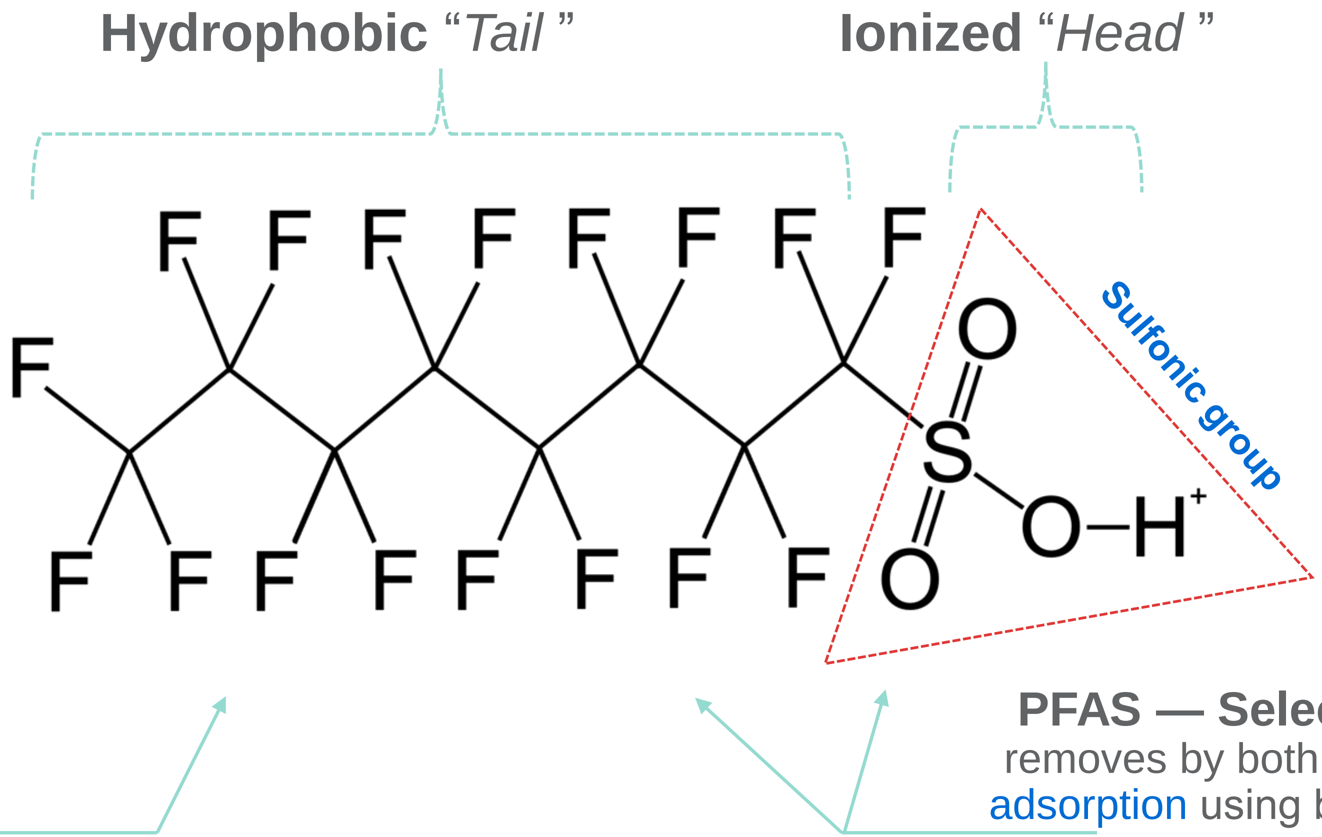
Future-Proof Your PFAS Technology Choice

PFAS-Selective IX Resin Provides the Following Advantages:

- Fast kinetics → Smaller footprint → Lower Capital Costs
- Higher selectivity → Long bed life → Lower Operational Costs
- Higher selectivity → better long-term performance than GAC with PFAS of concern → Future-Proof
- Higher selectivity → no sloughing of shorter chain PFAS or nitrate → Future-Proof
- Less Waste Generation → Lower Operational Costs

PFAS Example

Perfluorooctane sulfonic acid

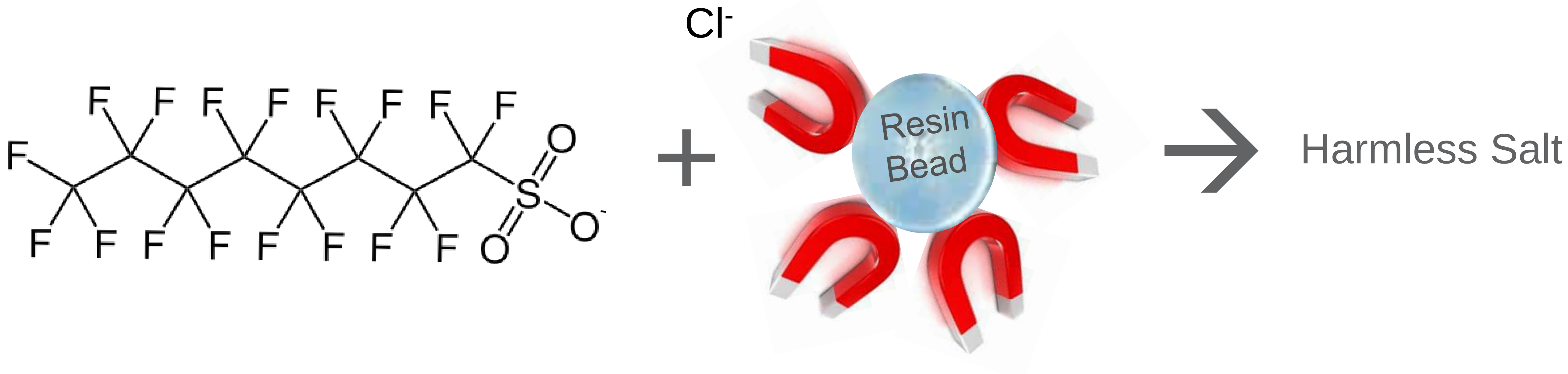


GAC
removes by adsorption
using hydrophobic "Tail"

PFAS — Selective IX Resins
removes by both ion exchange and
adsorption using both "Head" & "Tail"

Ion Exchange

Fast attraction reaction



PFAS-Selective Resin Selectivity

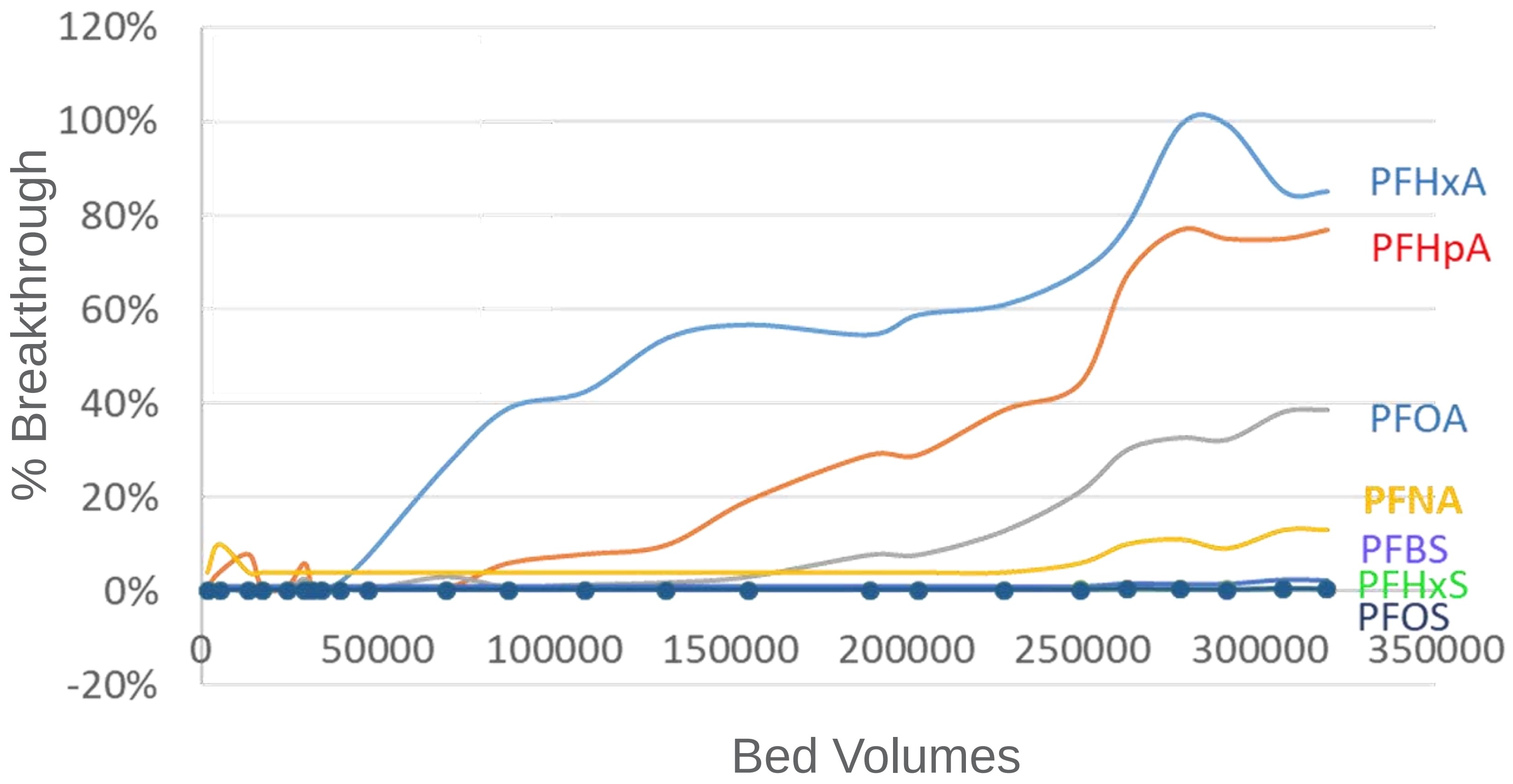
- Sulfonic acids are removed more easily than carboxylic acids
- Longer chains are removed more easily than shorter chains
- On the right is an approximation of selectivity

PFOS
PFHxS
PFBS
PFTrDA
PFTA
PFDoA
PFUnA
PFDA
PFNA
PFOA
ADONA
GenX
PFHpA
ClO4
PFHxA
PFPeA
PFBA
NO3
SO4
Cl
HCO3
F

Order of PFAS Breakthrough

Field Pilot running over 2 years

PFHxA < PFHpA < PFOA < PFNA < PFBS < PFHxS < PFOS

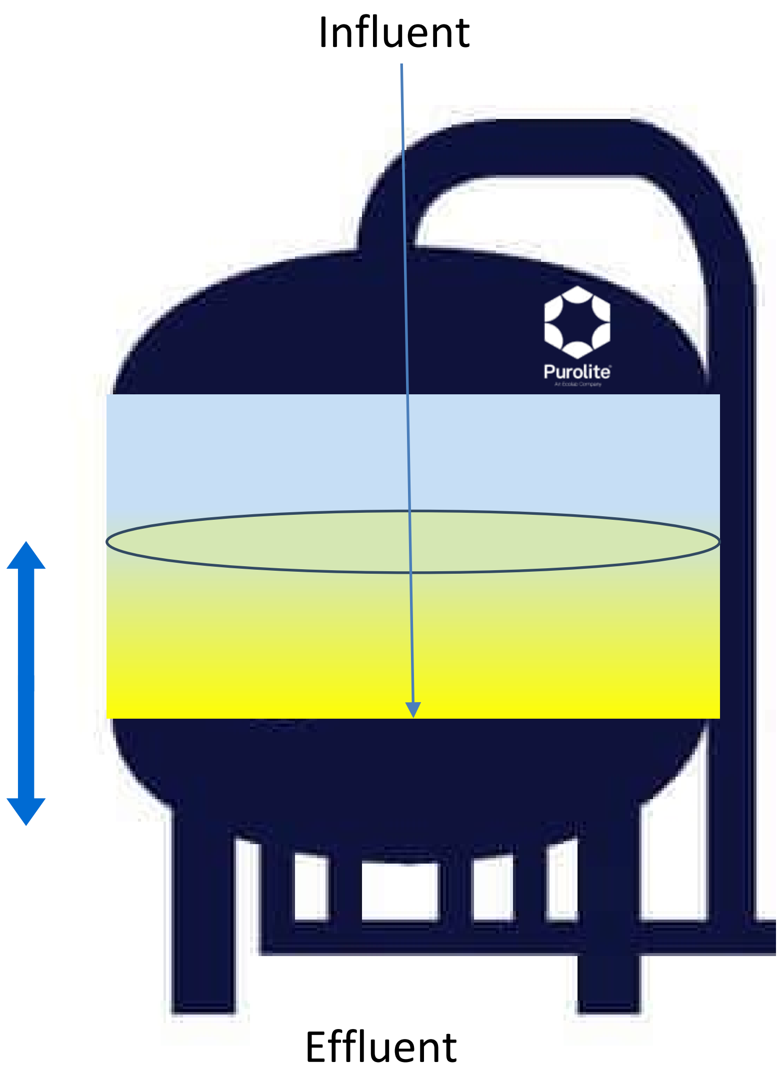


Influent	ng/L
PFHxA	105–177
PFHpA	39–61
PFOA	186–290
PFNA	7–14
PFBS	27–45
PFHxS	275–429
PFOS	504–910

Bed Volume

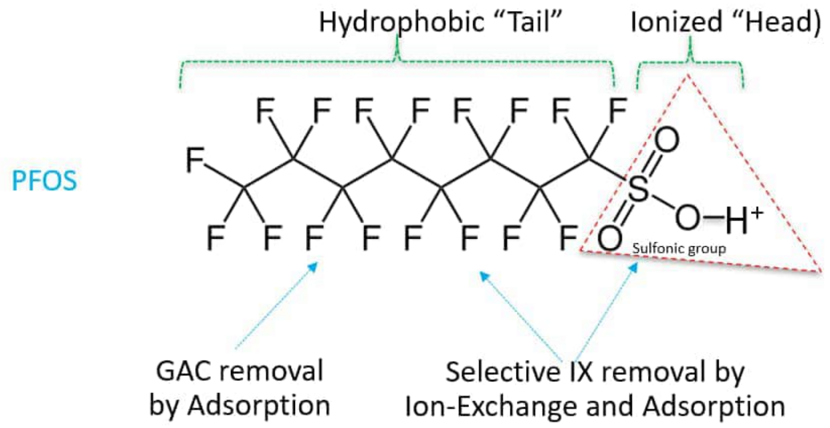
Volume of media in vessel

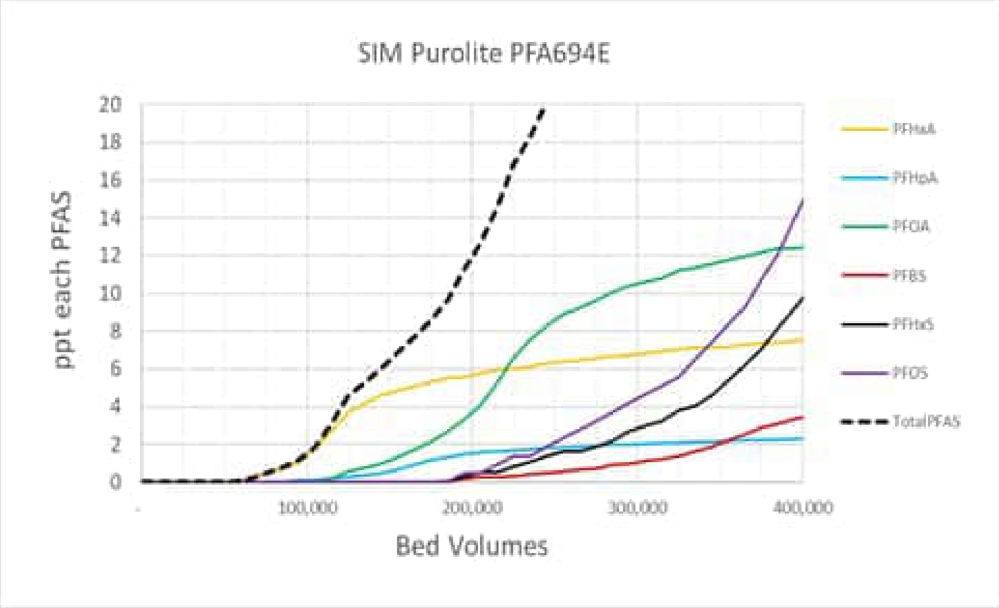
Bed Depth x Area = Bed Volume



Process of Modeling - Chemistry

- Impact of major ions
- Resin selectivity coefficients for contaminants - highly confidential
- Predict effluent breakthrough curves
- We cannot model every one of the thousands of PFAS that exist, but we can model the main ones in drinking water





System Design

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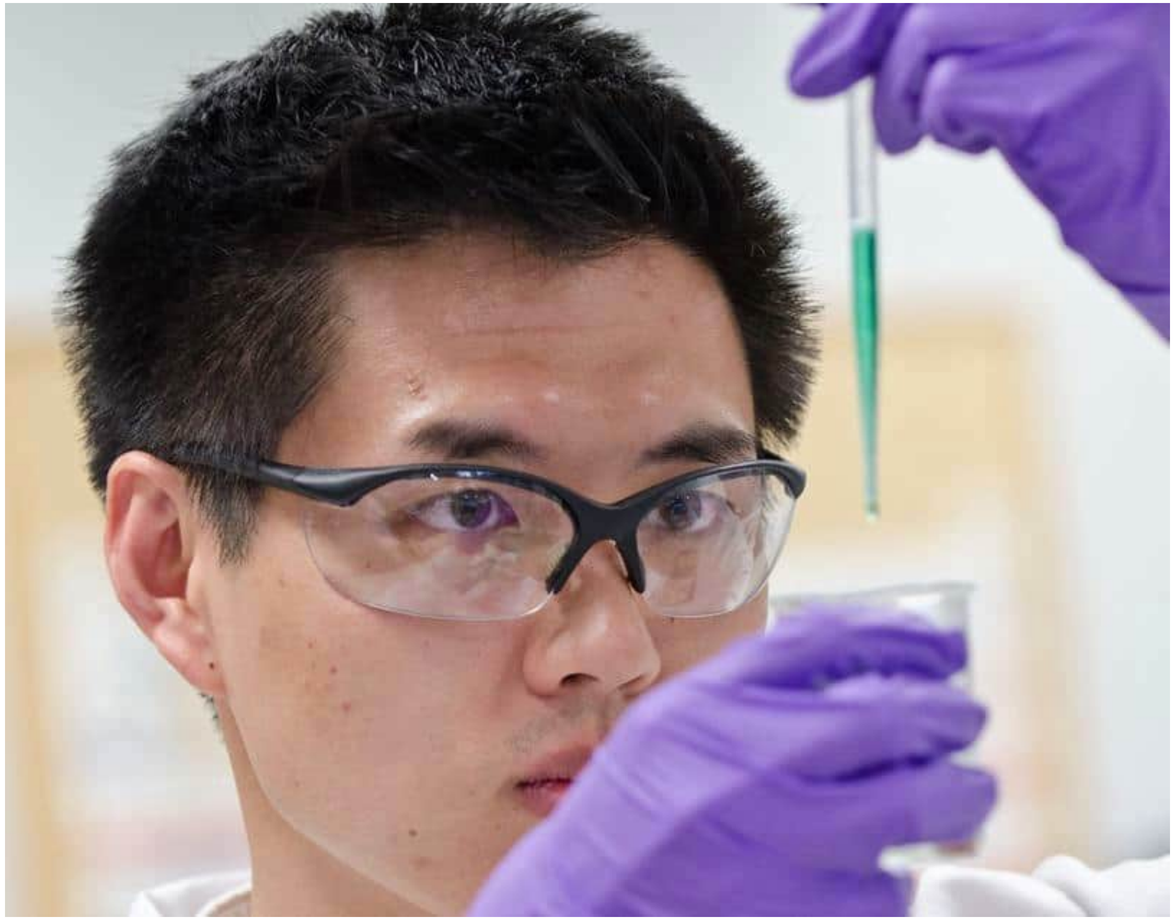
Water Chemistry

- Need a complete and balanced water chemistry to figure out beforehand what the issues will be.
- Changes in water chemistry will affect the resin longevity.



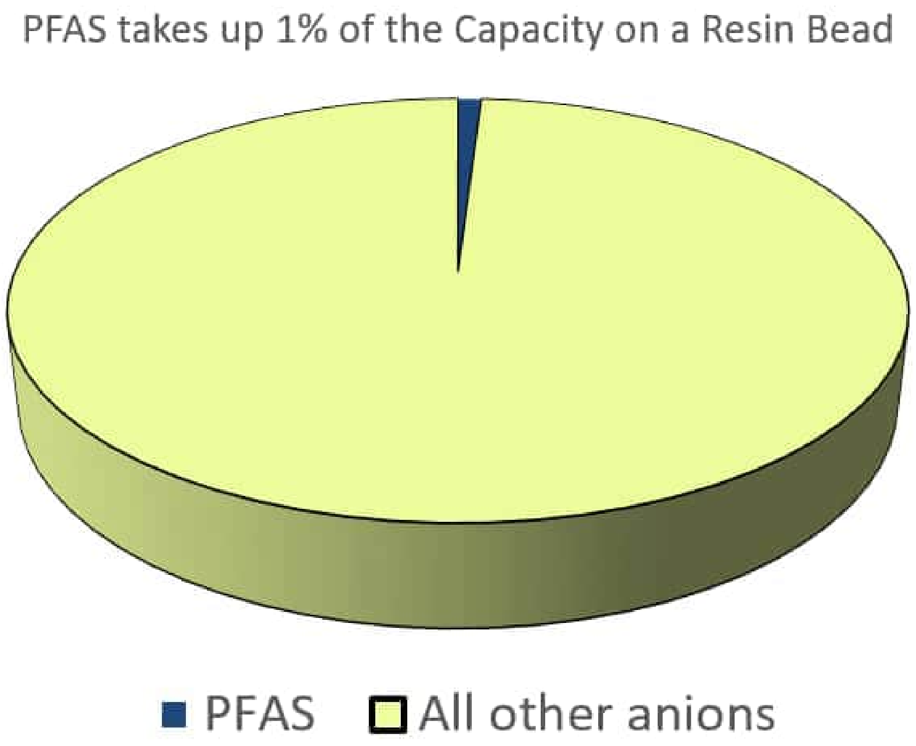
Start with Water Quality

- Background WQ will help determine operational treatment costs
- Modeling, piloting will confirm

Description	Units
Operational Flow Rate	gpm
Operational Schedule	hour/day
Daily Volume (average)	Gallons
Sulfate	mg/L
Nitrate (as N)	mg/L as N
Nitrate (as NO3)	mg/L as NO3
Alkalinity (as $CaCO_3$)	mg/L
Chloride	mg/L
Fluoride	mg/L
Perchlorate	ppb
Arsenic	ppb
Hexavalent chromium	ppb
Uranium	ppb
Calcium (as $CaCO_3$)	mg/L
Magnesium (as $CaCO_3$)	mg/L
Sodium	mg/L
Potassium	mg/L
Iron	mg/L
Manganese	mg/L

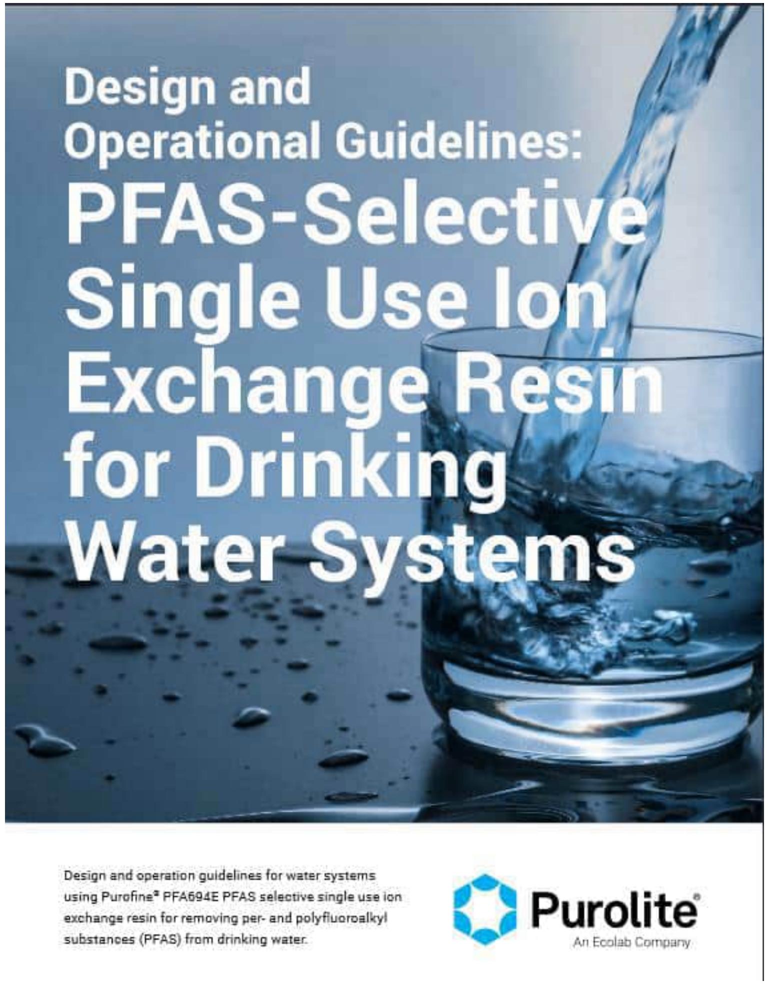
pH		
ORP		
TDS		mg/L
Suspended Solids		mg/L
Oil & Grease		mg/L
Total Organic Carbon	TOC	mg/L
Perfluorobutanoic acid	PFBA	ng/L (ppt)
Perfluoropentanoic acid	PFPeA	ng/L (ppt)
Perfluorohexanoic acid	PFHxA	ng/L (ppt)
Perfluoroheptanoic acid	PFHpA	ng/L (ppt)
Perfluorooctanoic acid	PFOA	ng/L (ppt)
Perfluorononanoic acid	PFNA	ng/L (ppt)
Perfluorododecanoic acid	PFDoDA	ng/L (ppt)
Perfluorotetradecanoic acid	PFTeA	ng/L (ppt)
Perfluorobutanesulfonic acid	PFBS	ng/L (ppt)
Perfluorohexanesulfonic acid	PFHxS	ng/L (ppt)
Perfluoroheptanesulfonic acid	PFHpS	ng/L (ppt)
Perfluorooctanesulfonic acid	PFOS	ng/L (ppt)
4:2 FTS (fluorotelomer sulfonate)	4:2 FTS	ng/L (ppt)
6:2 FTS (fluorotelomer sulfonate)	6:2 FTS	ng/L (ppt)
8:2 FTS (fluorotelomer sulfonate)	8:2 FTS	ng/L (ppt)
GenX	GenX	ng/L (ppt)
VOC	VOC	ppb

How selective is Resin for PFAS?



Design Guidelines

Vessel Parameter	Design Goal
Linear Velocity (LV)	6 to 18 gpm/ft^2 (15 to 45 m/h)
Bed Depth for LV <= 12 gpm/ft^2 (30 m/h)	3 ft (0.91m) minimum
Bed Depth for LV > 12 gpm/ft^2 (30 m/h)	3.7 ft (1.1 m) minimum
Specific Flowrate	1 to 5 gpm/ft^3 (8 to 40 BV/h)
Empty Bed Contact Time (EBCT)	2 min for drinking water 3 min for higher concentrations



Linear Velocity

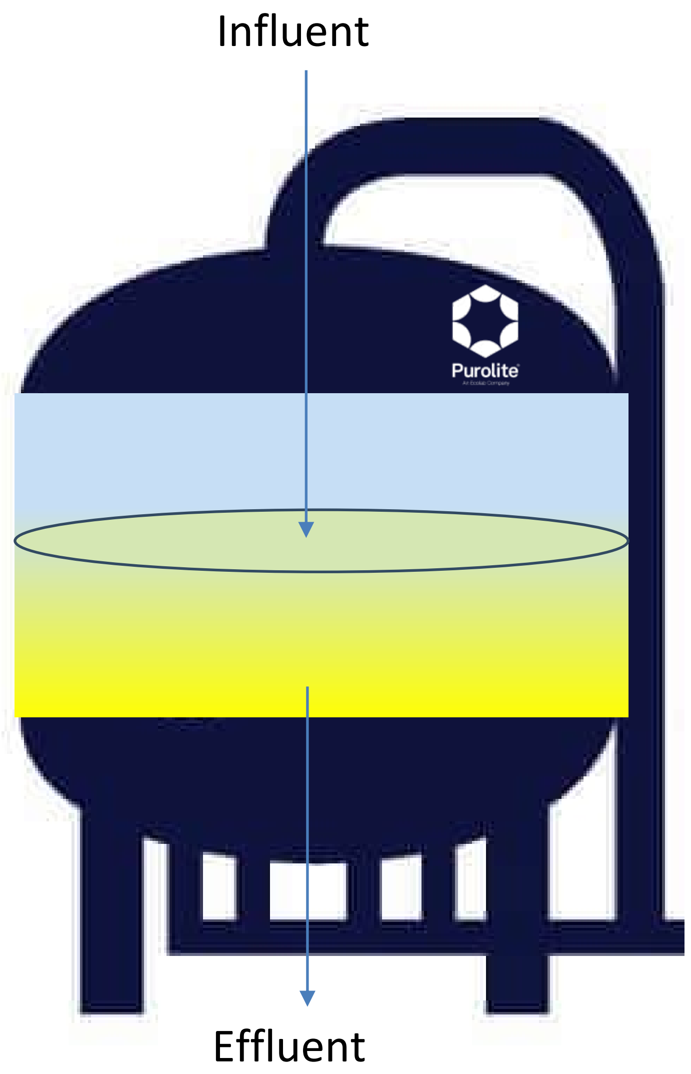
What it is:

- Rate at which water passes over an area
- Expressed as **flow per area** or gpm/ft^2

Why it's important:

- Looking for even flow across the whole vessel; plug flow
- Too low a linear velocity can cause channeling
- Too high a linear velocity can cause resin movement

- **Beware minimum flow rates!** Too low a flow will cause the linear velocity to drop below the minimum of 6 gpm/ft2 and cause channeling.



Bed Depth and Mass Transfer Zone

Bed Depth

- Minimum 3’ to develop the mass transfer zone
- Do not backwash

Modeling vs Piloting

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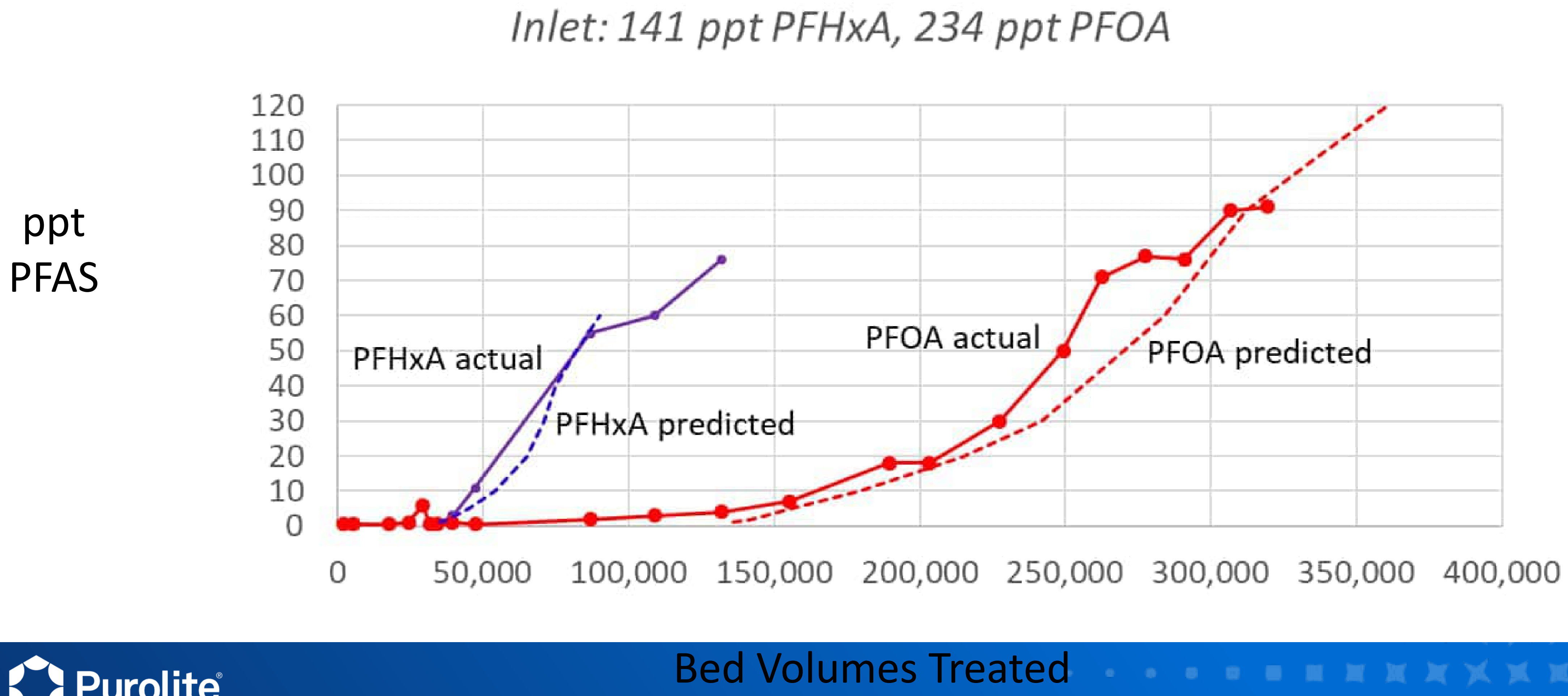
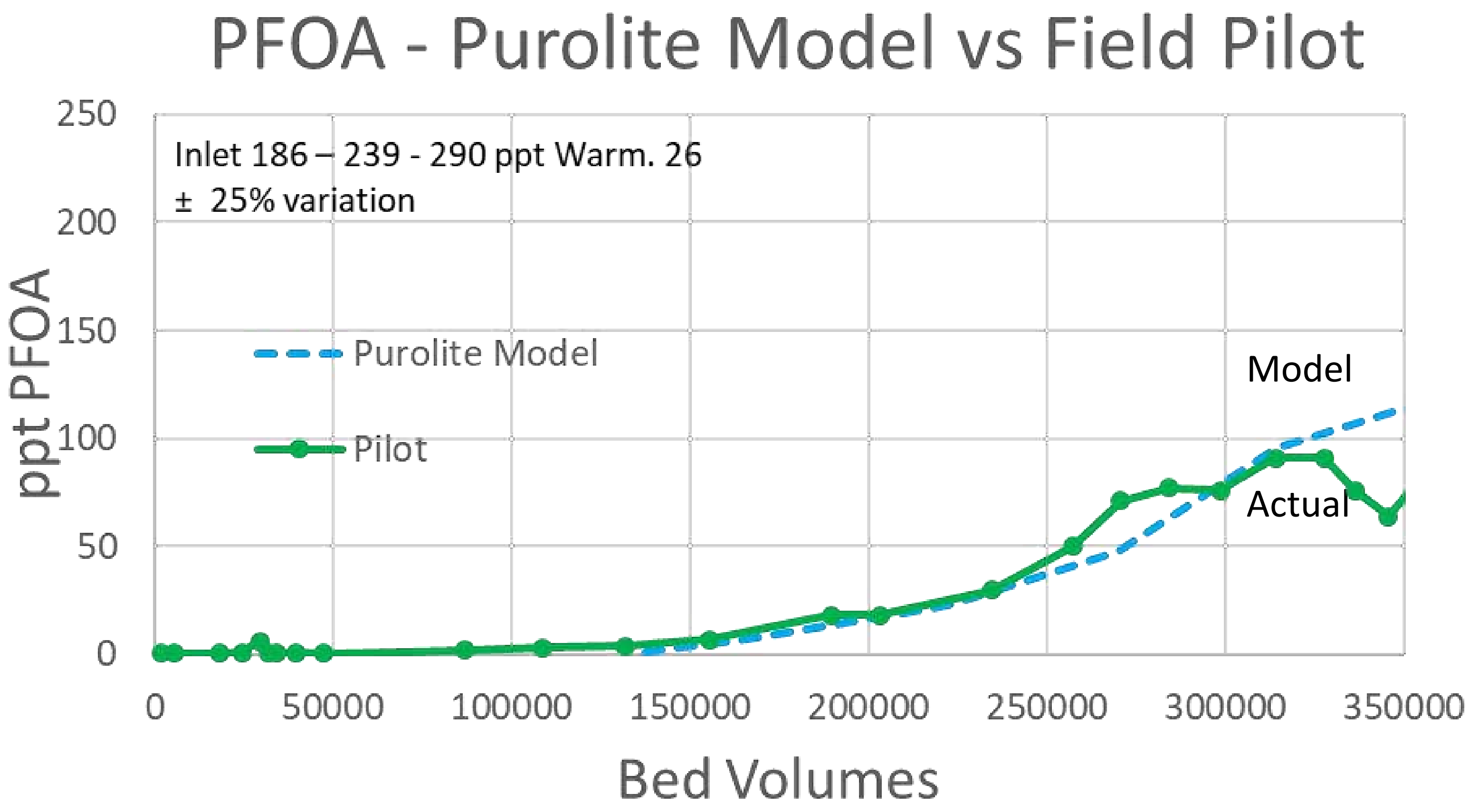
Predicted & Actual Result Match Closely

with Purolite Proprietary Simulator

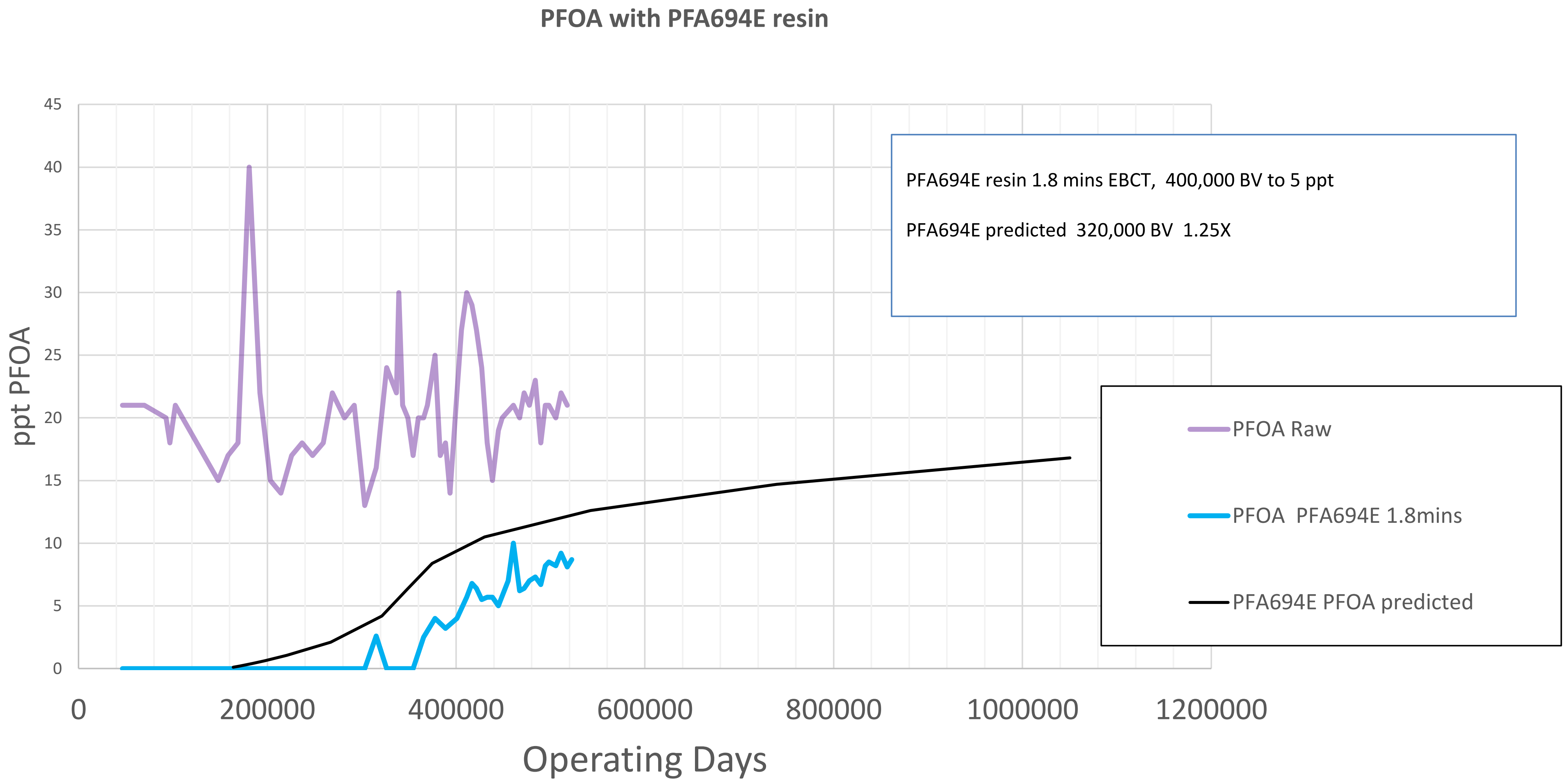


Modeling vs Field IX Pilot for PFOA

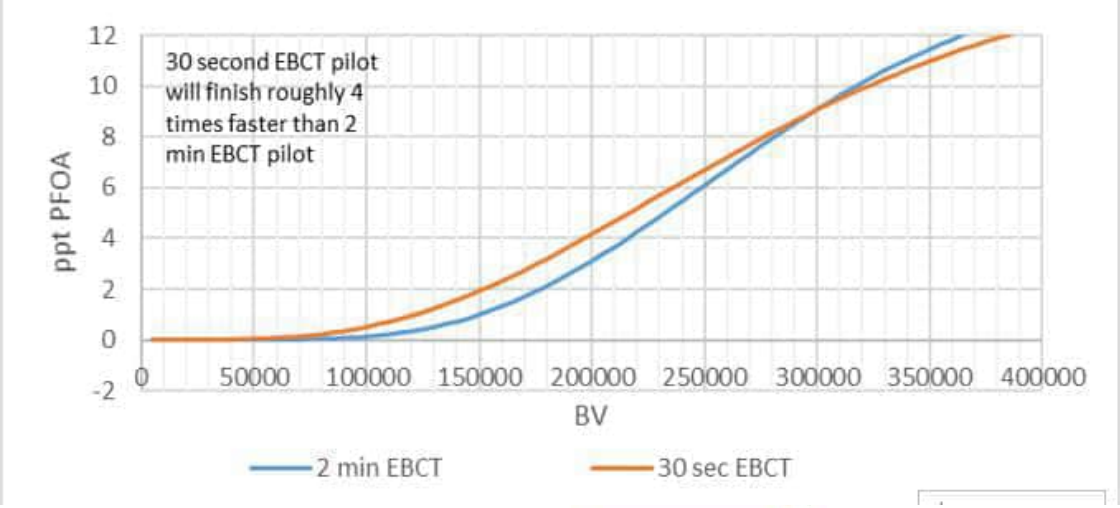
Close Tracking

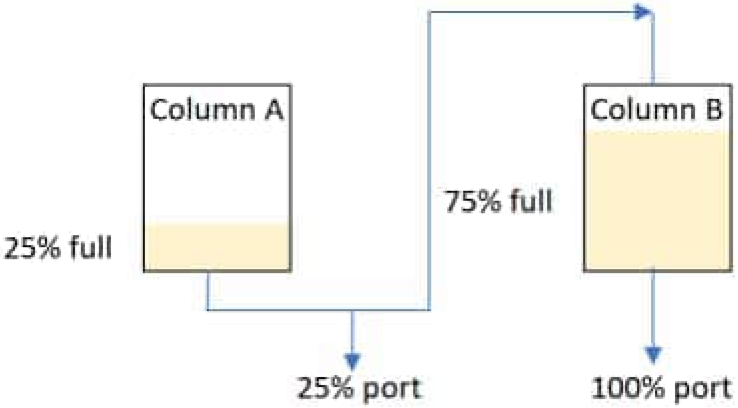


Modeling vs Actual for Horsham Well 10



Accelerated Piloting

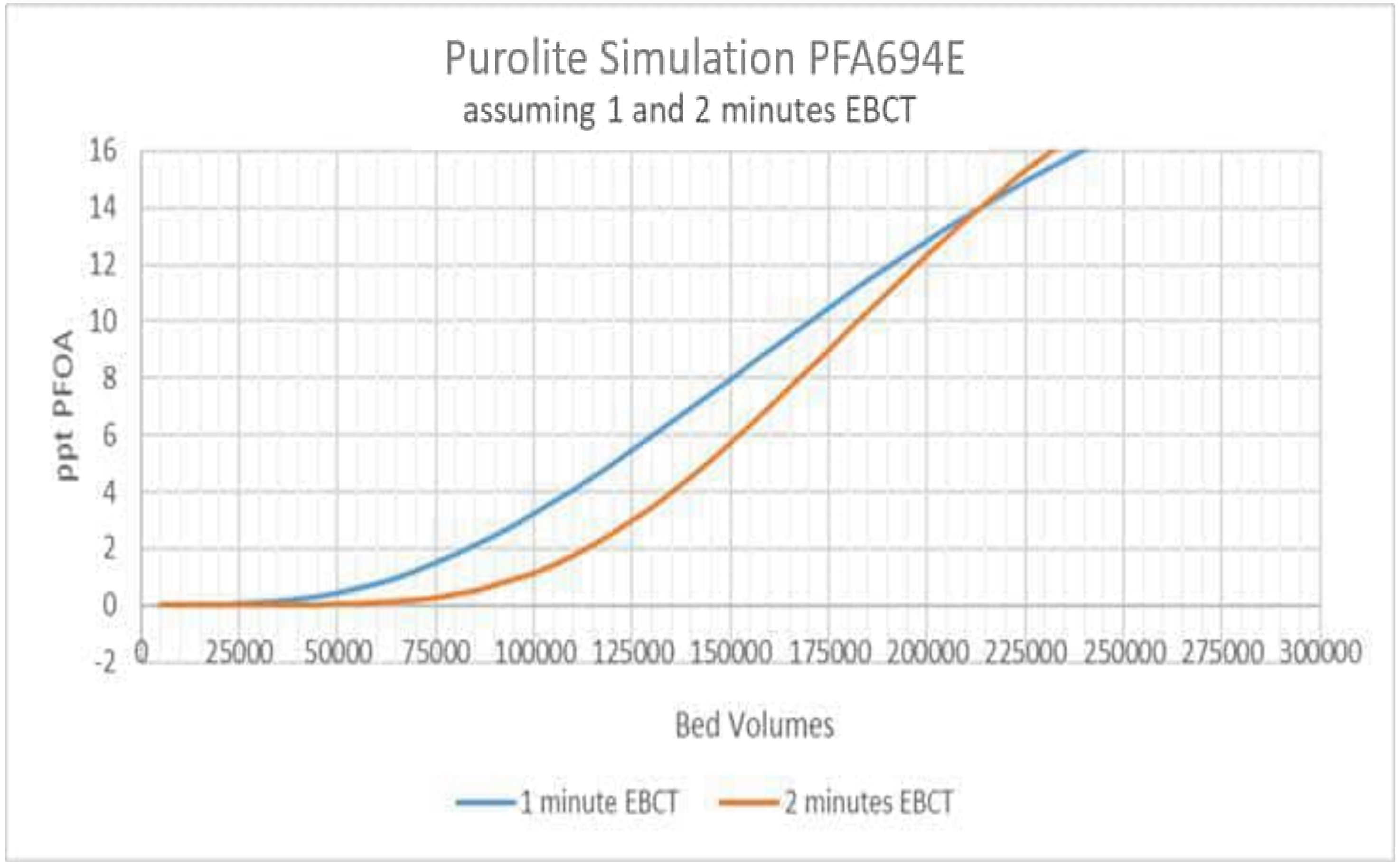




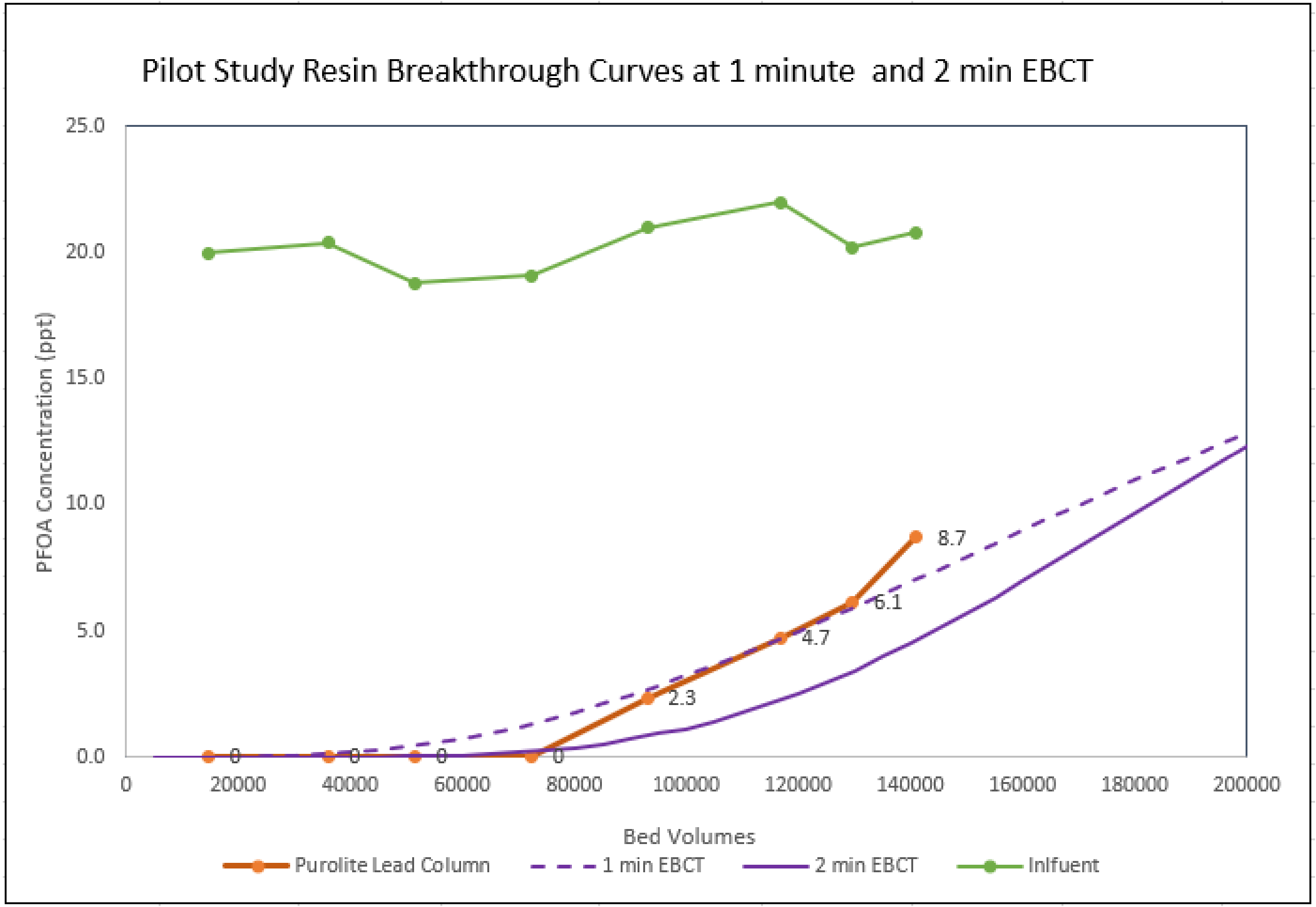
Simulation can anticipate shorter bed depth

- Shorter bed depth and EBCT slightly reduce performance

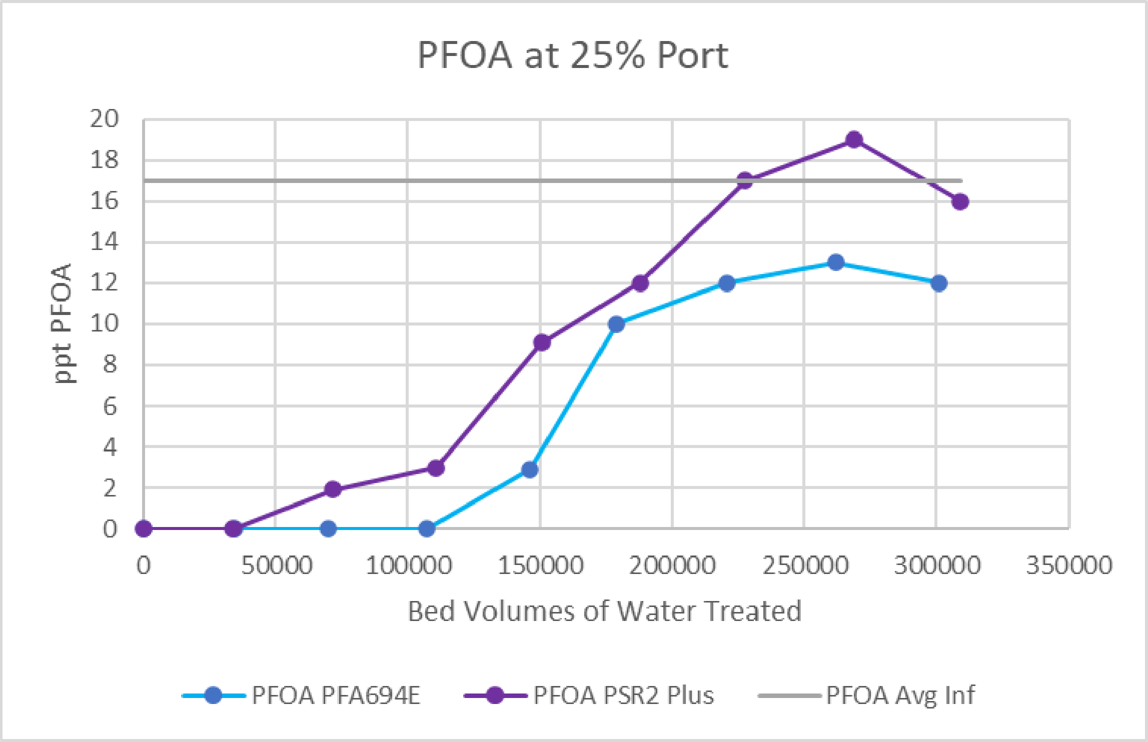
- Accounted for in modeling

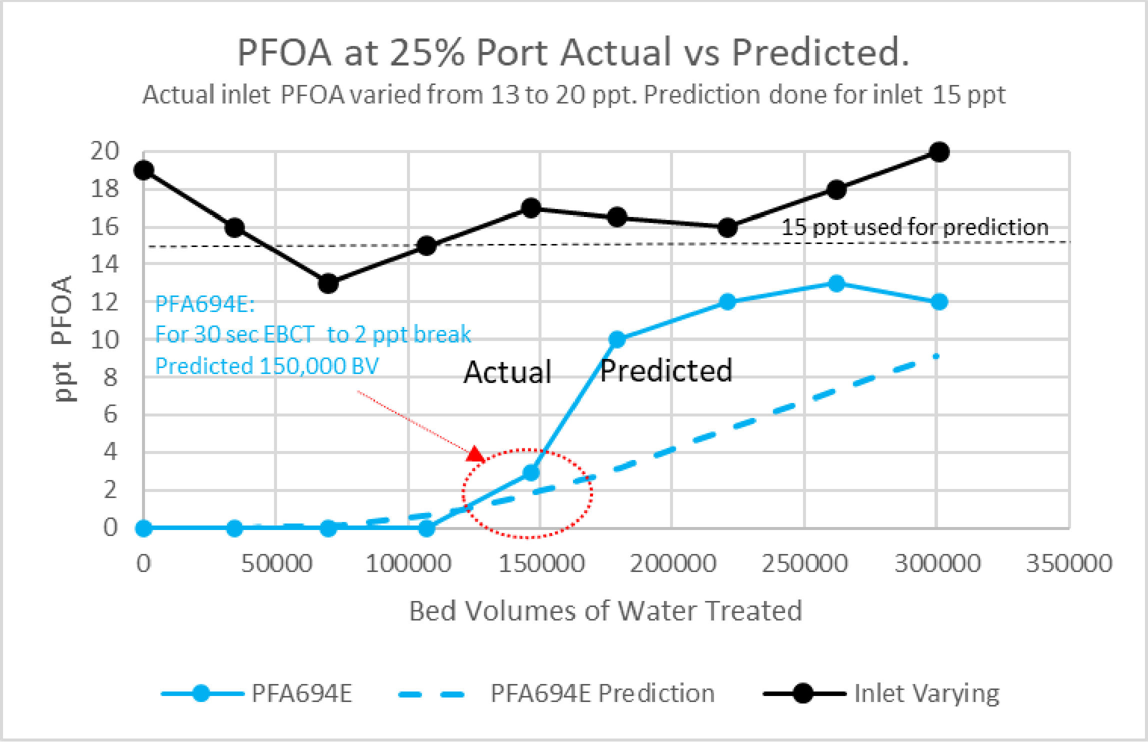


Simulation and Data



Accelerated Pilot results





Choosing your PFAS Technology

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How do you pick your technology?

Life Cycle Costs

- Capital/ Footprint

Operational

- Water Quality
- Removal Efficiency
- Bed Life
- Waste Generation

Capital Cost

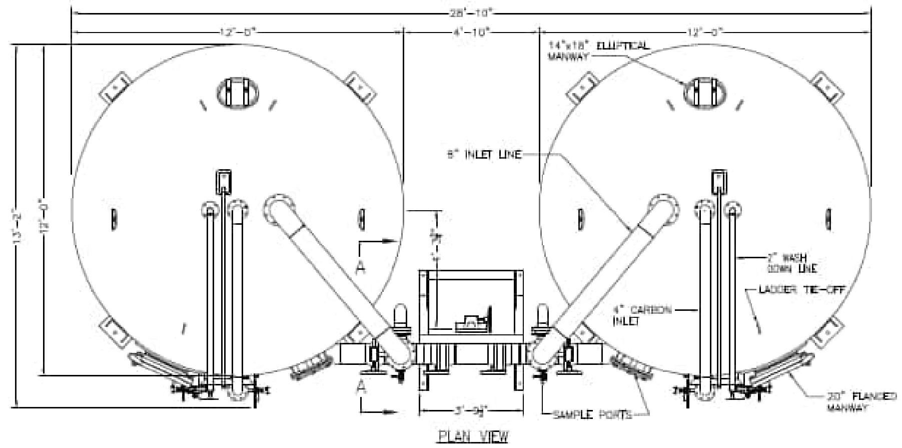
How do you choose your technology?

IX vs. GAC Systems

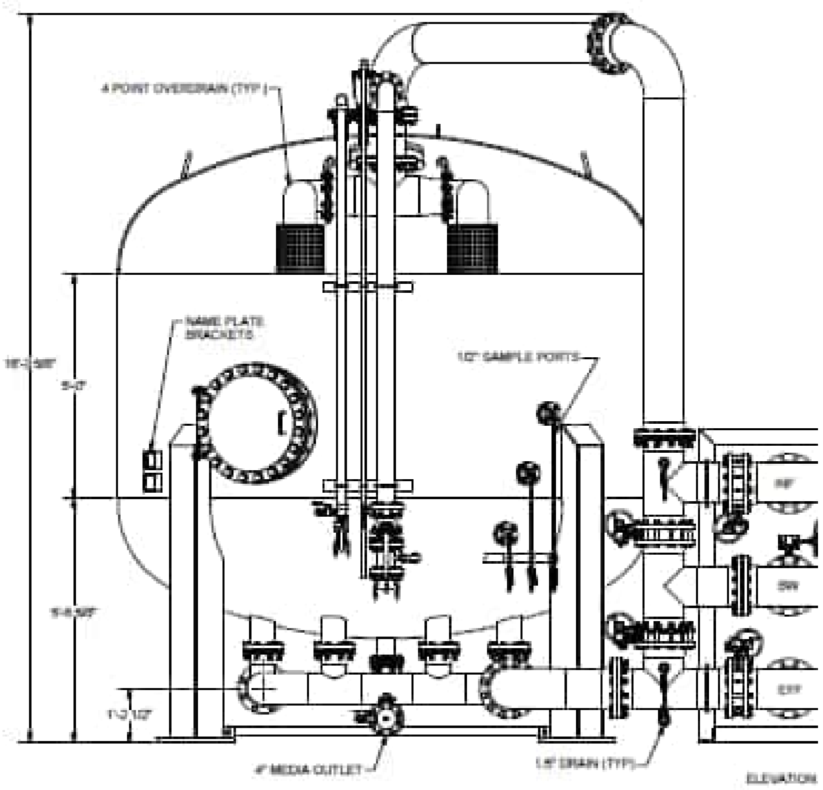
- Because of empty bed contact time (IX = 2 minutes and GAC = 10 minutes) IX can treat up to 5 times the flow in the same footprint as GAC
  - Example: 2000 gpm system
    - IX = 2 x 12’ vessels
    - GAC = 8 x 12’ vessels
- → IX equipment capital is 25% to 50% less than GAC capital

2000 gpm Footprint

Resin with high flow vessels



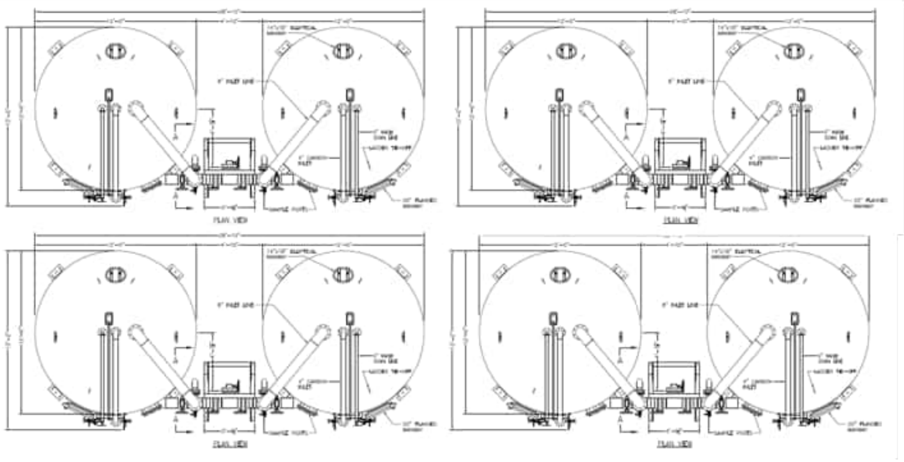
1 System	
Diameter	12'
Height	16' 4"
Cu ft per Vessel	504
EBCT	2 min.



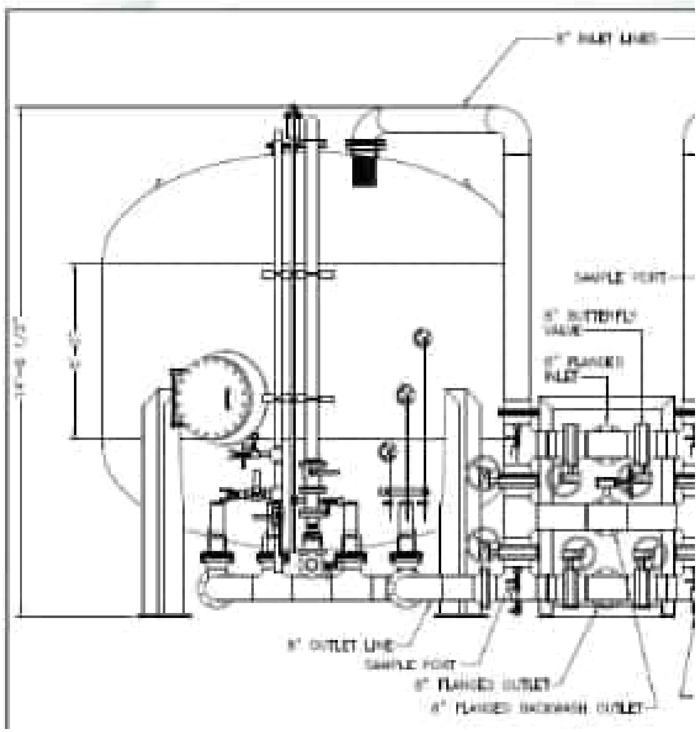
Drawings complements of Aqueous Vets

2000 gpm Footprint: GAC 20,000 lbs

Option 1



4 Systems	
Diameter	12’
Height	14’ 6”
Cu ft per Vessel	595
EBCT	8.9 min.

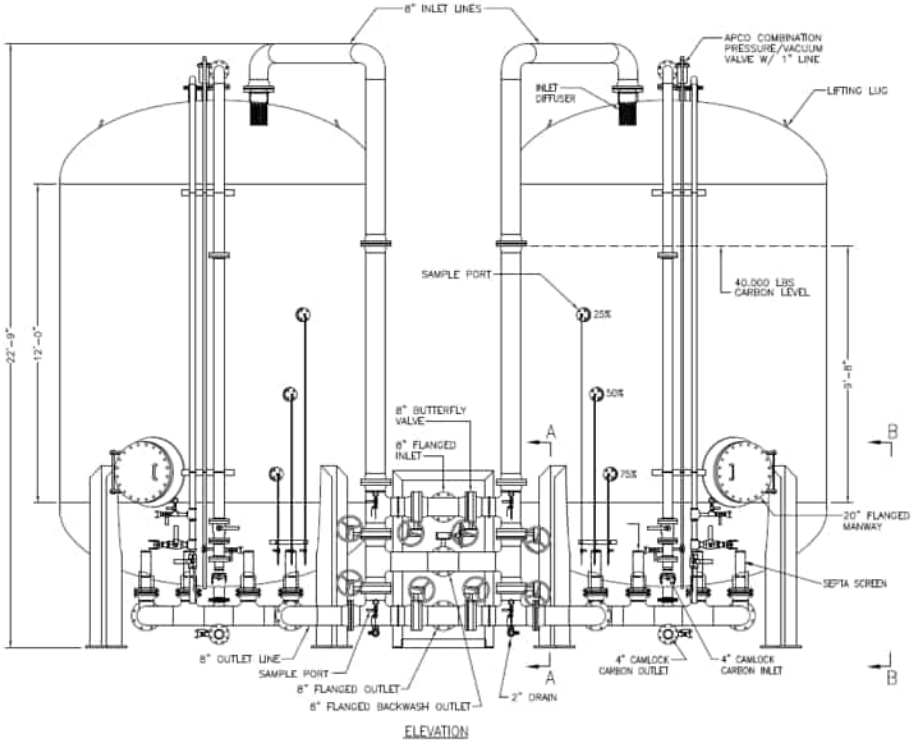


GAC Equipment Capital is ~ Four Times IX

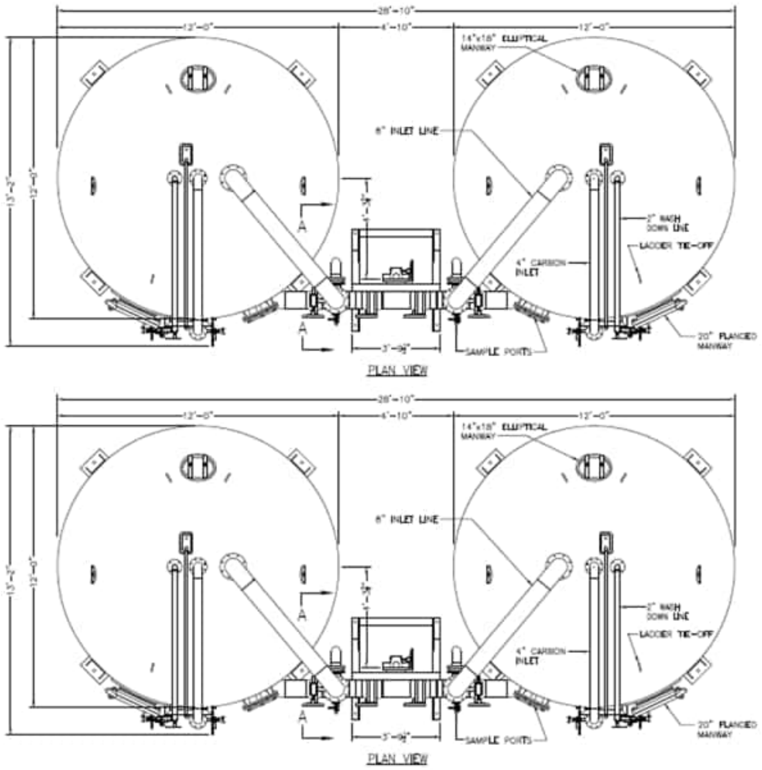
Drawings complements of Aqueous Vets

2000 gpm Footprint: GAC 40,000 lbs

Option 2



2 Systems	
Diameter	12’
Height	22’ 9”
Cu ft per Vessel	1190
EBCT	8.9 min.



GAC Equipment Capital is > 2 Times IX

Drawings complements of Aqueous Vets

Los Angeles County Site

Design Comparison	Resin	GAC	
Total System flow - gpm	3000	3000	
Vessel Diameter - ft	12	12	
Number of trains	2	4	
Flow per train - gpm	1500	1500	
Total number of vessels for all trains (lead + lag)	4	8	
Pounds of GAC	[redacted]	40,000	33.6 lb/cu ft density
Media volume per vessel - ft3	420	1190	
EBCT Contact time per vessel - minutes	2.1	11.9	
Linear Velocity	13.3	6.6	
Estimated BV for lead vessel change out trigger	**273,550**	**27,300**	
Total Water Treated per Year - MMgals/year	1,577	1,577	
Days Between Lead Vessel Change-outs	398	225	
Volume of Media Consumed per Year - CF	771	7721	

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Los Angeles County Site

Design Comparison	Resin	GAC	
Total System flow - gpm	3000	3000	
Vessel Diameter - ft	12	12	
Number of trains	2	4	
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Total Water Treated per Year - MMgals/year	1,577	1,577	
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Volume of Media Consumed per Year - CF	771	7721	

Capital footprint for IX half of GAC with vessels half the height for IX

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Los Angeles County Site

Design Comparison	Resin	GAC	
Total System flow - gpm	3000	3000	
Vessel Diameter - ft	12	12	
Number of trains	2	4	
Flow per train - gpm	1500	1500	
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Estimated BV for lead vessel change out trigger	**273,550**	**27,300**	
Total Water Treated per Year - MMgals/year	1,577	1,577	
Days Between Lead Vessel Change-outs	398	225	
Volume of Media Consumed per Year - CF	771	7721	**10 x more media consumed** **10 x more waste generated**

Drinking Water Design Example

Operational Costs Based on 2023 Data

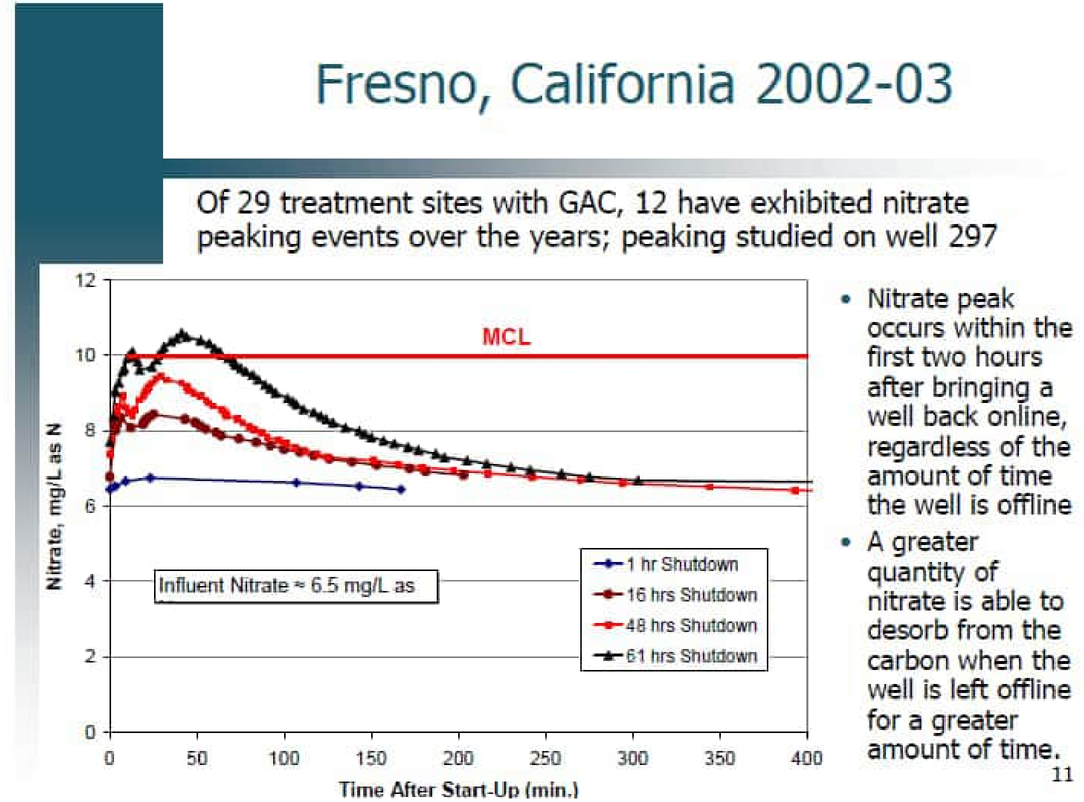
	IX	GAC
Media consumed per year	771	7721
Media Cost per pound		$ 2.00
Media Cost per cubic foot	$ 350	$ 67.20
Media Cost per year	**$ 269,680**	**$ 518,829**
Operating Cost - $/Kgal	**$ 0.17**	**$ 0.33**
OPEX per year $/AF	**$ 55.73**	**$ 107.22**

IX was ~ half the OPEX

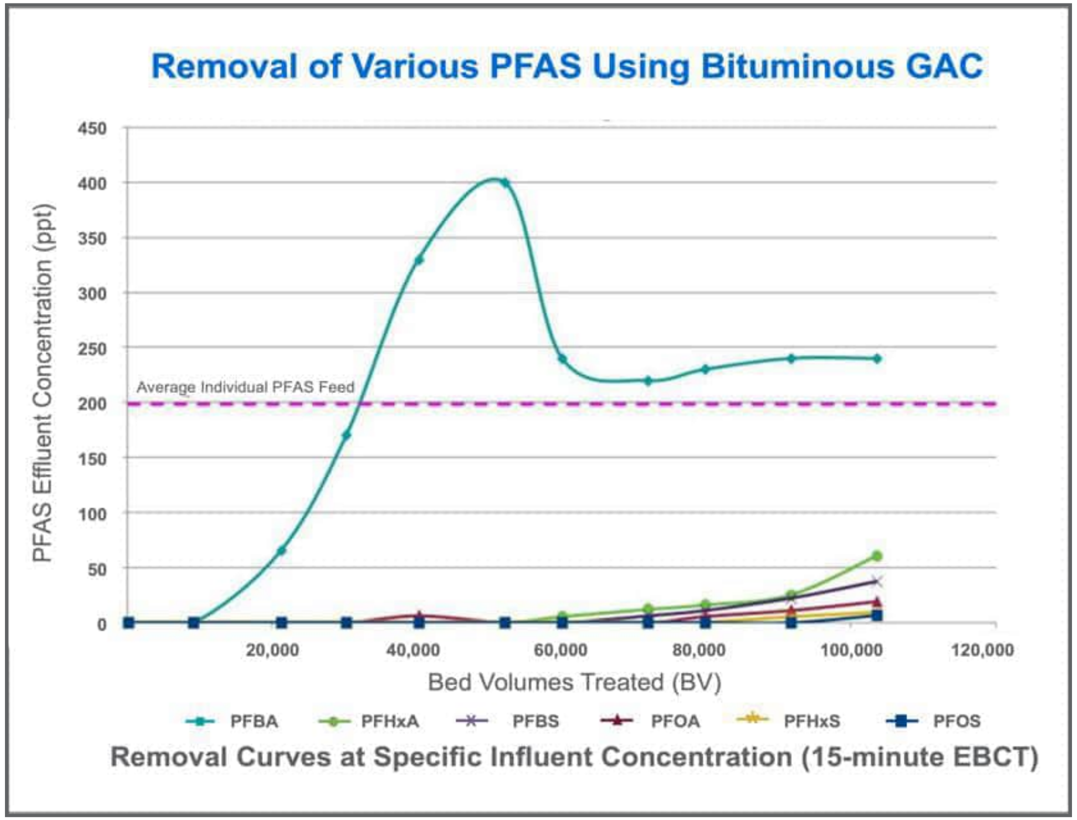
Water quality

How do you choose your technology?

GAC can slough contaminants: Nitrate, PFAS, and other TOC



Source: Little and Herd 2007



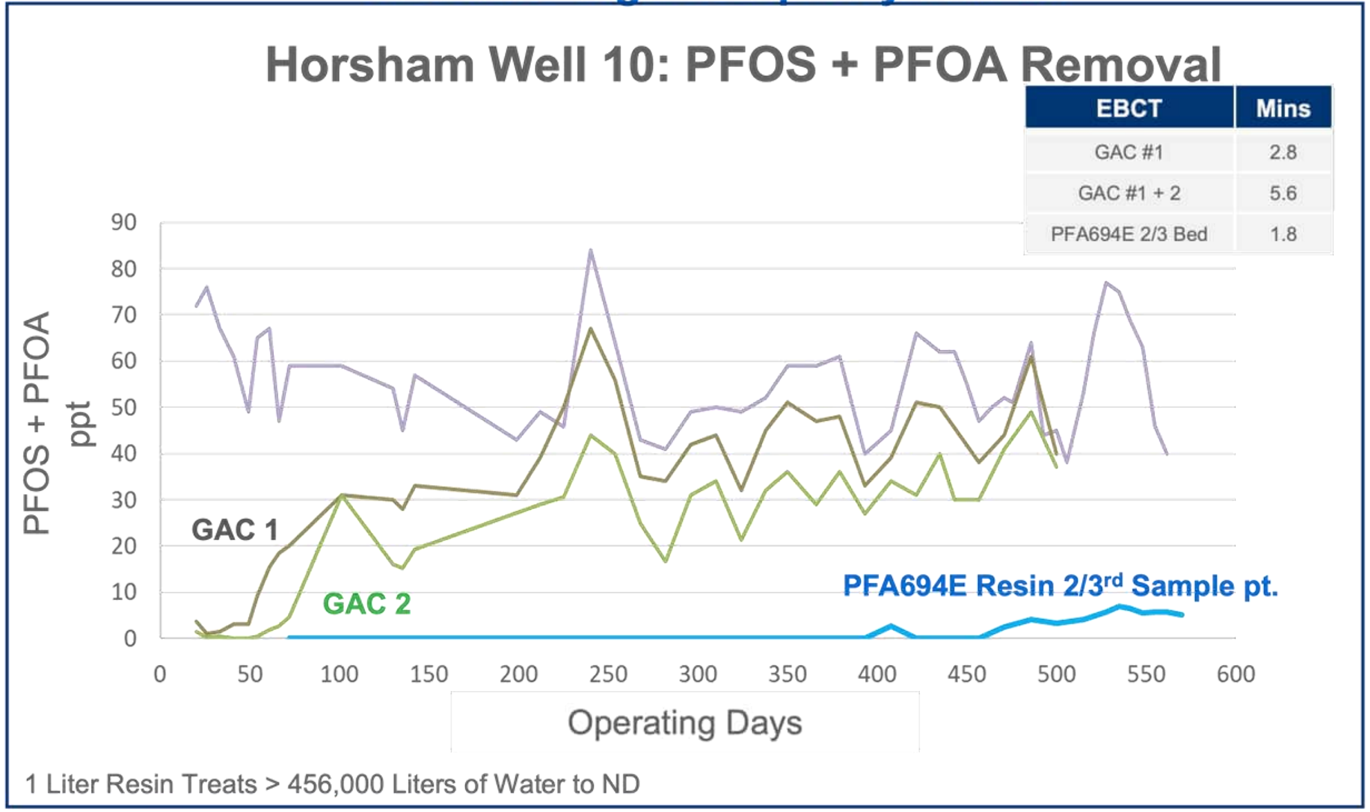
Source: ITRC PFAS Manual

Bed Life

How do you choose your technology?

- Water Quality will drive bed life
- IX can be 5 to 20 times higher throughput than GAC

20 Times Higher Capacity with IX



EBCT	Mins
GAC #1	2.8
GAC #1 + 2	5.6
PFA694E 2/3 Bed	1.8

Data collected at a pilot run at Horsham, PA by Purolite

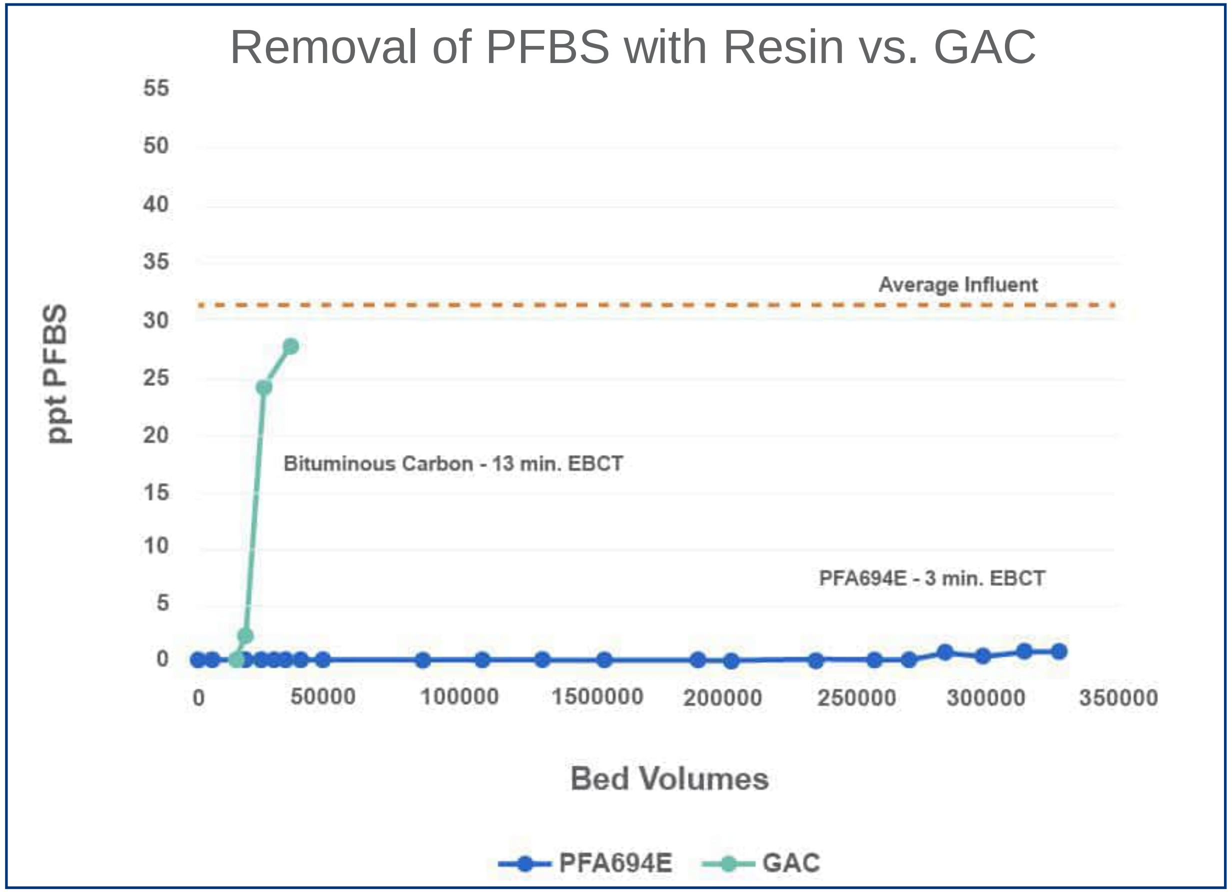
Removal efficiency

How do you choose your technology?

EPA has proposed MCLs and Hazard Index for:

- PFOA*
- PFOS*
- PFBS**
- GenX or HFPO-DA**
- PFHxS
- PFNA

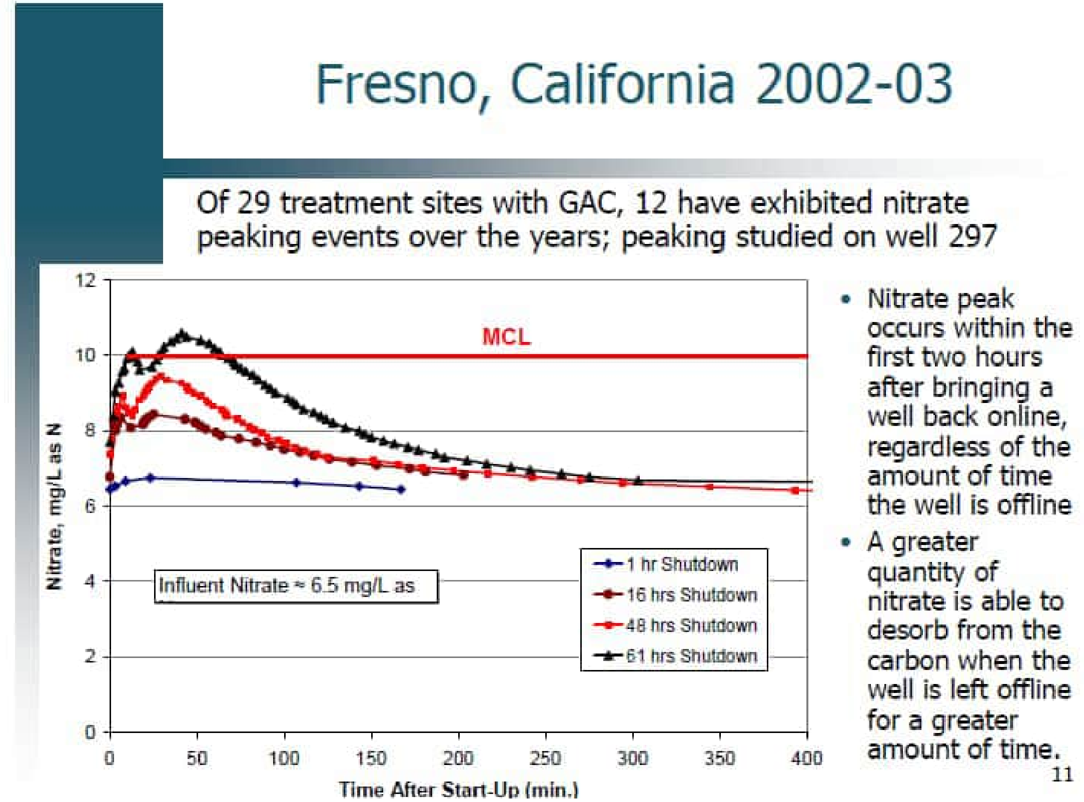
Ion Exchange does a better job at removing these compounds than GAC.



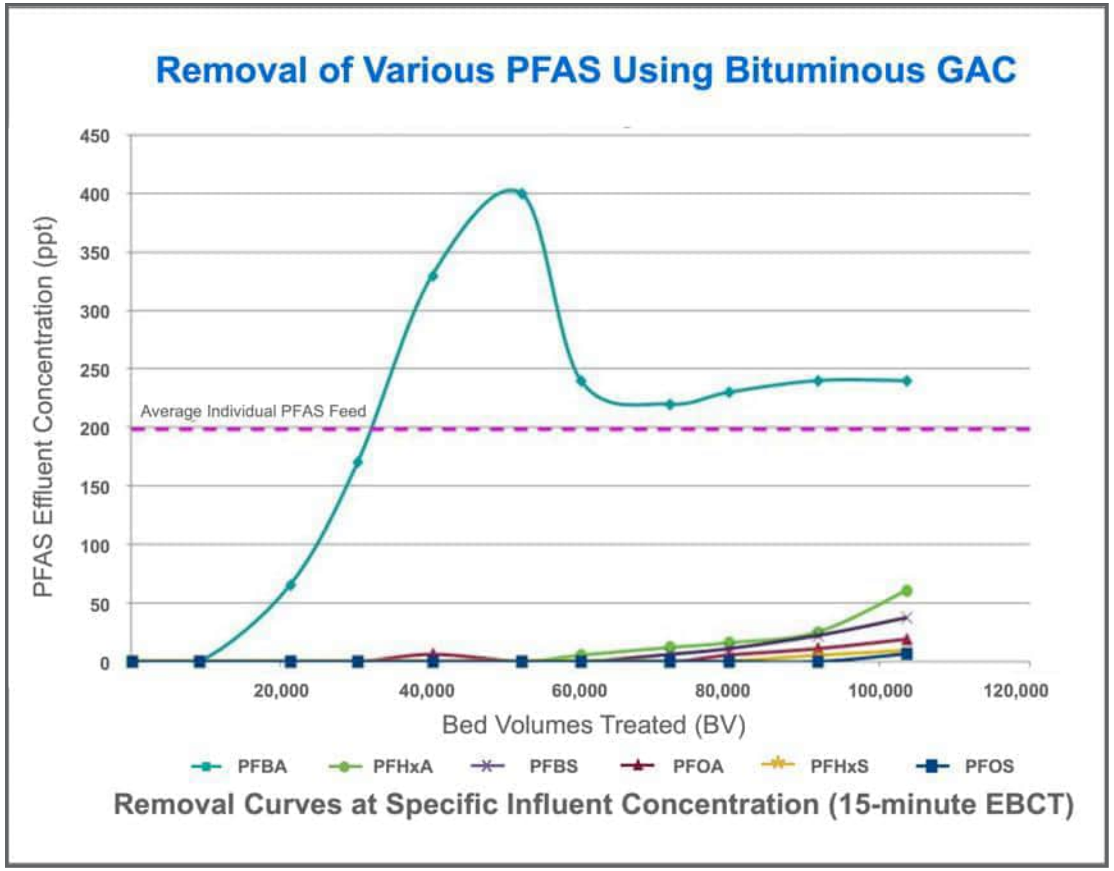
Data collected at a pilot run at Warminster, PA by Purolite

Water quality considerations

GAC can slough contaminants: Nitrate, PFAS, and other TOC



Source: Little and Herd 2007



Source: ITRC PFAS Manual, data provided by Calgon

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PFAS Waste Management

Landfill Incineration Reactivation (GAC)	**Currently Commercial**
Mechanochemical Supercritical Water Oxidation Electrochemical	**Promising Technologies**
Chemical Biological Plasma Sonolysis Ebeam UV	**Technologies Also Being Developed**
Deep Well injection Sorption / stabilization Land application	**Less Desirable**

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Startup Considerations and Corrosivity

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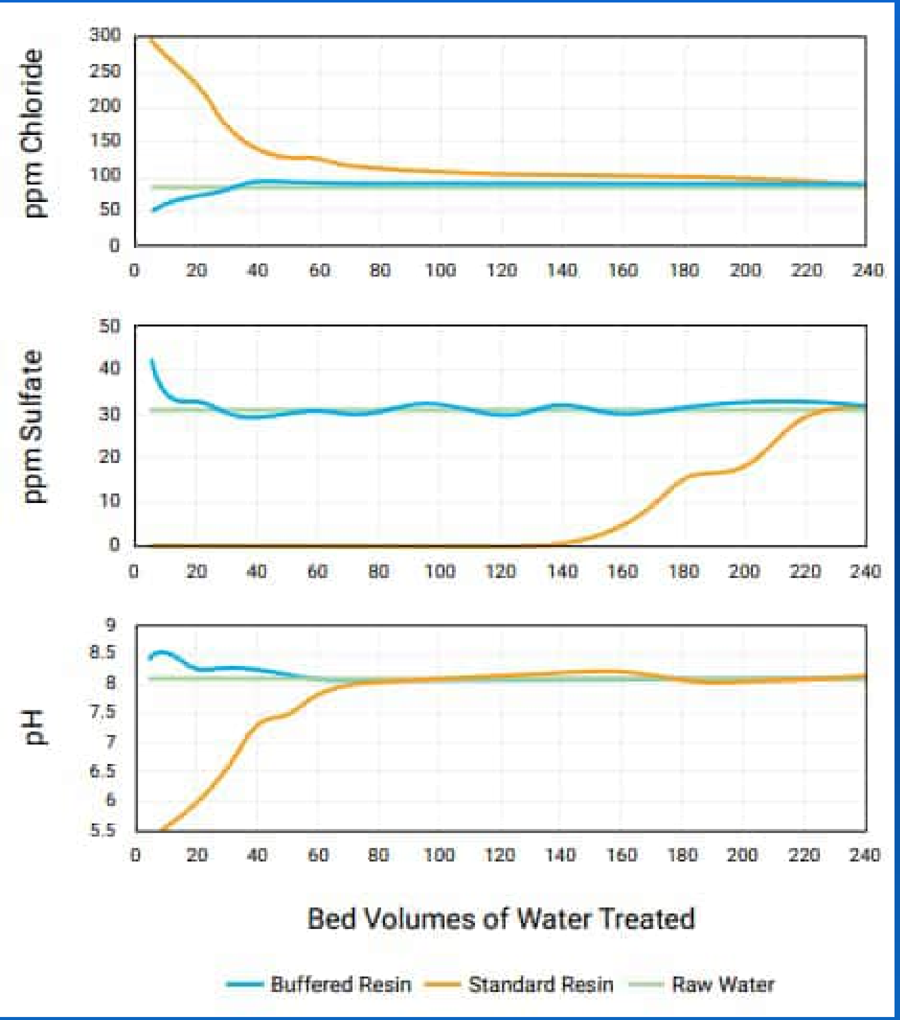
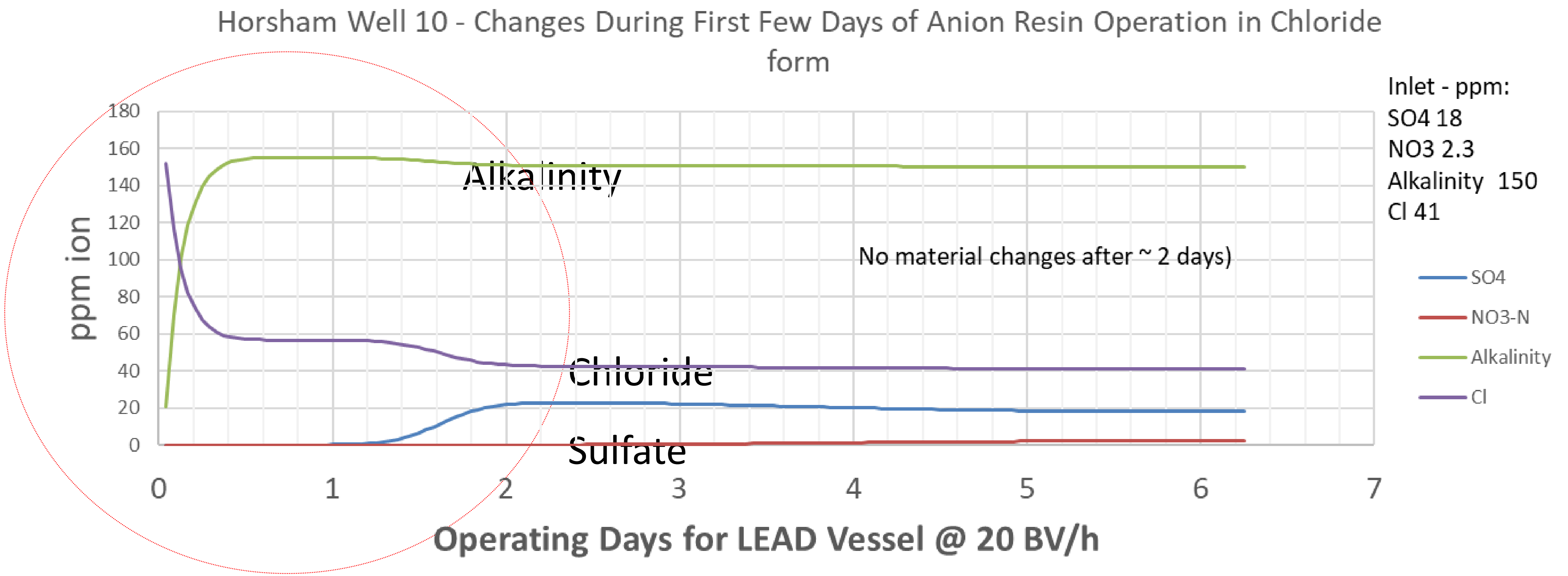
Startup

- Look at orange line for standard resin
- Chloride is released at startup
- Sulfate is taken up at startup
- pH starts out low

Typical Elution Profile of Anion Resins



Equilibrium Reached Quickly after Startup

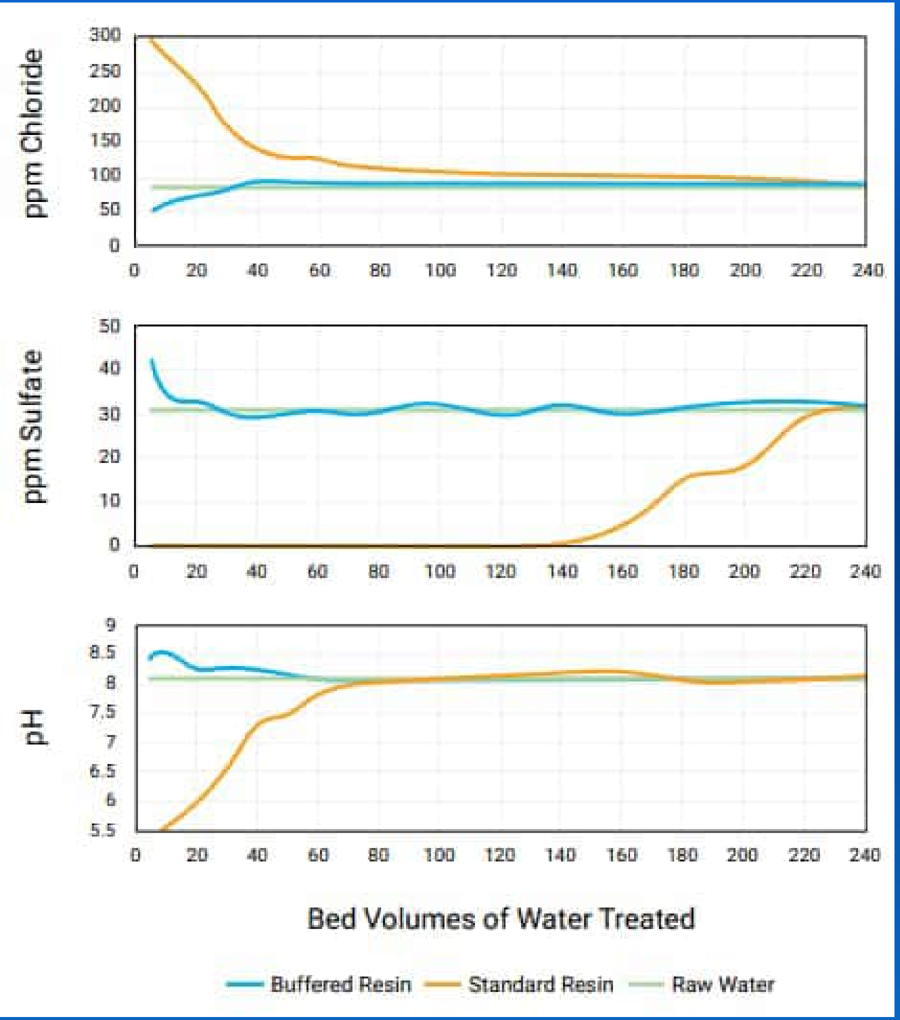


After Simple Initial Rinsing to Drain – No Material Changes Occur as long as the resin is not changed out – usually in 2 to 3 years

Corrosion Control: Buffered Resin

- Resins in buffered forms to facilitate neutral discharge at startup.
- Anion resins altered to maintain beneficial chloride to sulfate mass ratio (CMSR)
- Cation resins partially hydrolyzed to help achieve neutral discharge
- Prevents chloride discharge
- Prevents chromatographic peaking

Typical Elution Profile of Anion Resins



Purolite®
An Ecolab Company

Aug. 2021: The Air Force Civil Engineer Center has completed installation and testing of a water filtration system that reduces **Perfluorooctanoic Acid** and **Perfluorooctane Sulfonate** from drinking water near **Luke Air Force Base**, Arizona, to levels below the Environmental Protection Agency's lifetime health advisories.

The ion-exchange water filtration system installed at the **Valley Utilities Water Company**'s Bethany Hills West location will remove PFOS and PFOA from drinking water going to homes next to the installation.

Air Force installs system to protect drinking water near Luke AFB

Source: https://www.wpafb.af.mil/News/Article-Display/Article/2730251/air-force-ins... afb/

ADEQ Central Tucson PFAS Pilot Project

- Removes PFAS pollution from groundwater north of Davis-Monthan Air Force Base
- Started Dec 2021

Source: https://archive.org/details/cotaz-Central_Tucson_PFAS_P

Conclusions

- Ion Exchange resin treats PFAS
  - With a smaller footprint
  - Lower capital costs
  - Longer bed life
  - Lower operational costs
  - Better efficiency
- Modeling of PFAS uptake on PFAS selective resin is accurate and conservative
- Corrosion control is attainable with buffered resins

AzWater PFAS Forum

The PFAS Residuals Dilemma

February 1, 2024| Mary Lou Romero, PE| 925.210.2485 | MLRomero@BrwnCald.com

Overview

1. PFAS treatment technologies:
   State of the Industry
2. Destructive PFAS treatment technologies
   1. Hydrothermal processes
   2. Thermal processes
3. Q&A

Drinking Water | Municipal Wastewater | Industrial Wastewater Landfill Leachate | Groundwater

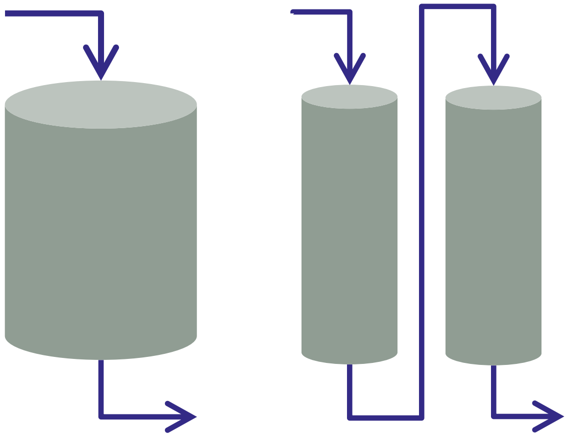
Why residuals matter

- Focus is on MCLs, but CERCLA and RCRA designation may be more problematic
- Managing residuals is critical to minimizing future liabilities
- Currently, individual states are approaching PFAS disposal from different angles
  - Bans on land application
  - Bans on incineration
  - Bans on landfilling
- Federal requirements likely in the near future

PFAS treatment technologies: State of the Industry

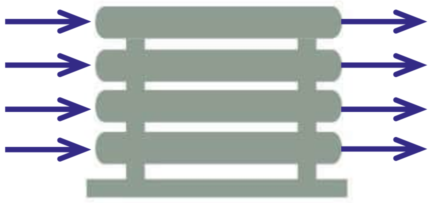
Current best available treatment technologies

Separation and concentration



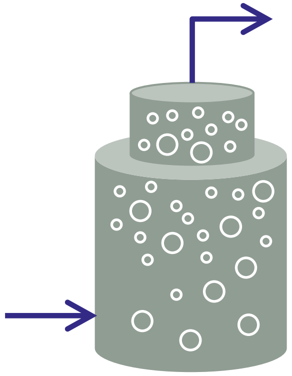
Media adsorption

- Granular Activated Carbon (GAC)
- Anion Exchange Resins (AER)
- Novel Adsorbents



Membrane separation

- Nanofiltration (NF)
- Reverse Osmosis (RO)

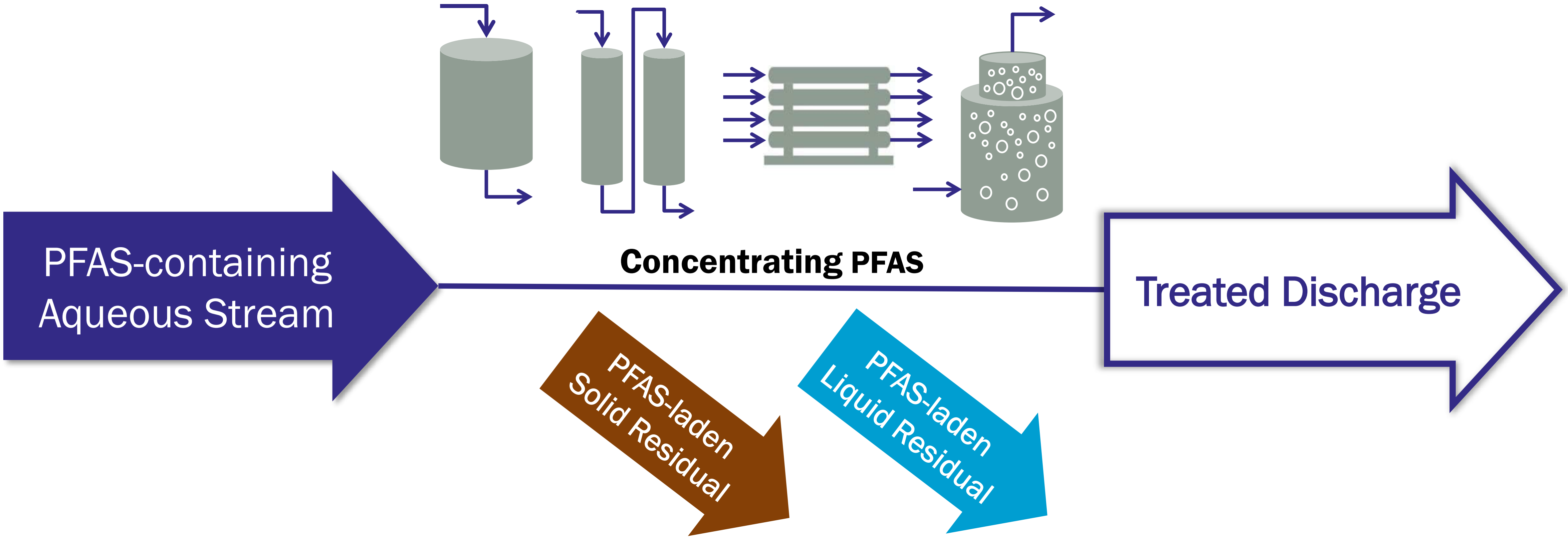


Foam fractionation

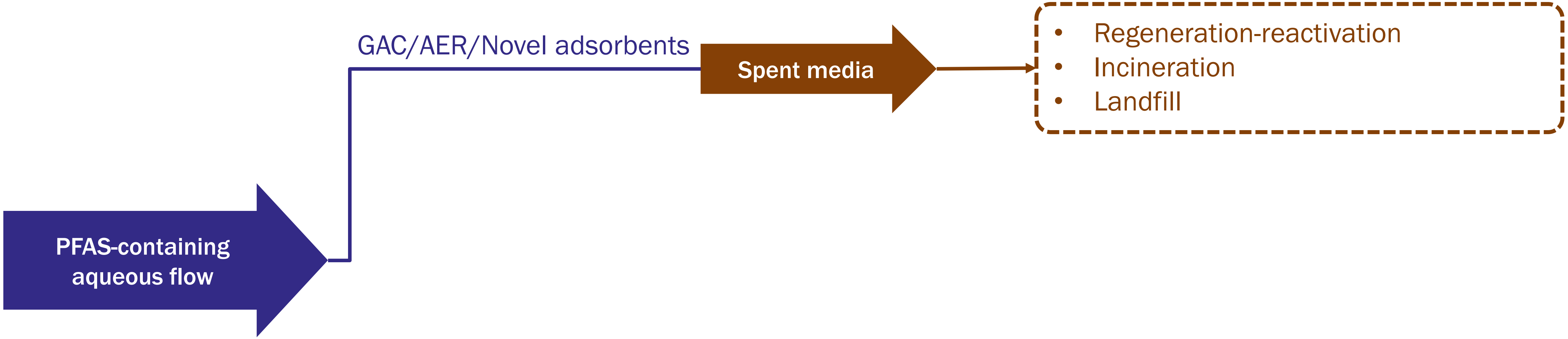
- Air
- Ozone

Current best available treatment technologies

Separation and concentration



Residual management from typical treatment



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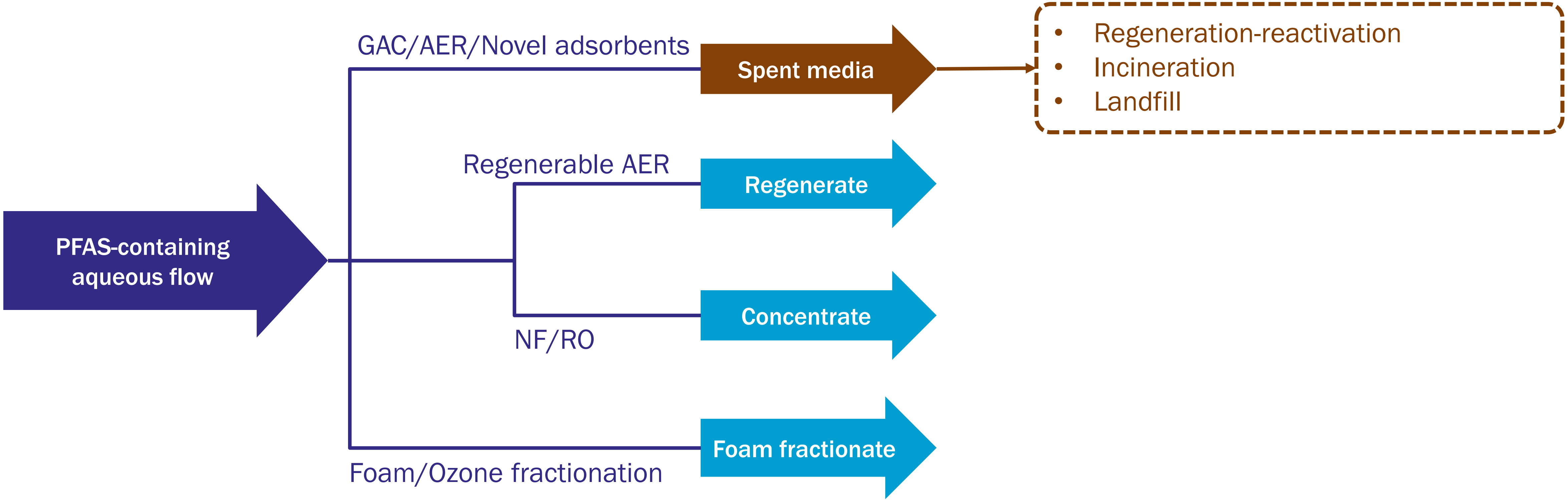
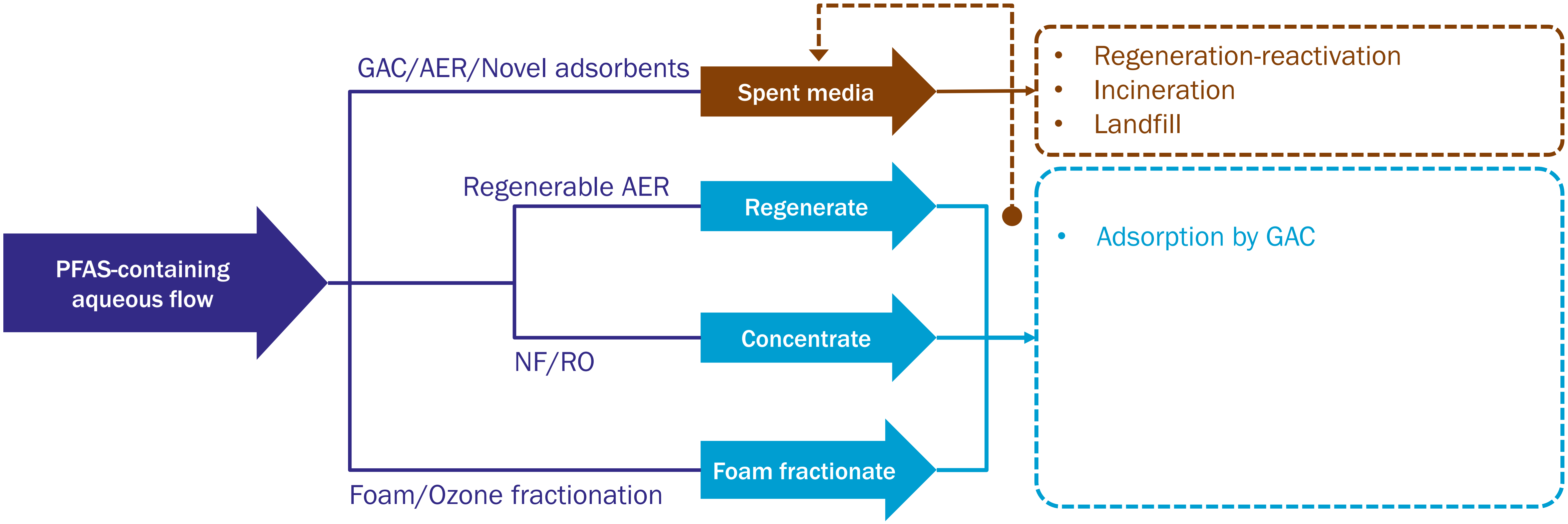
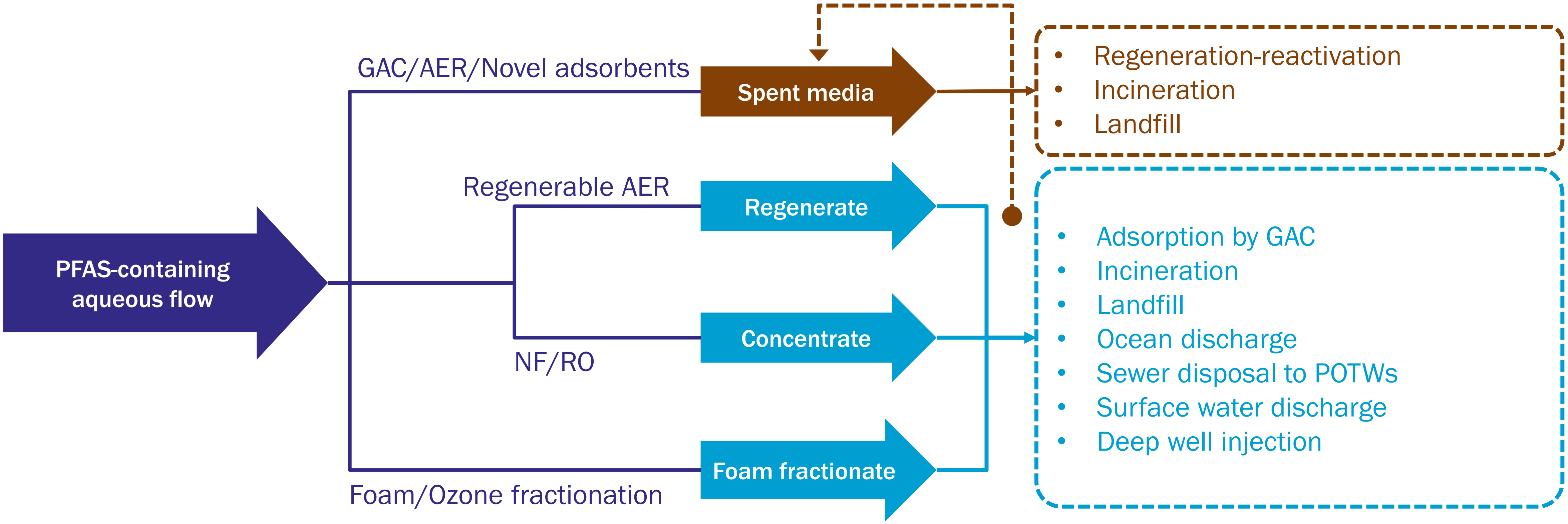


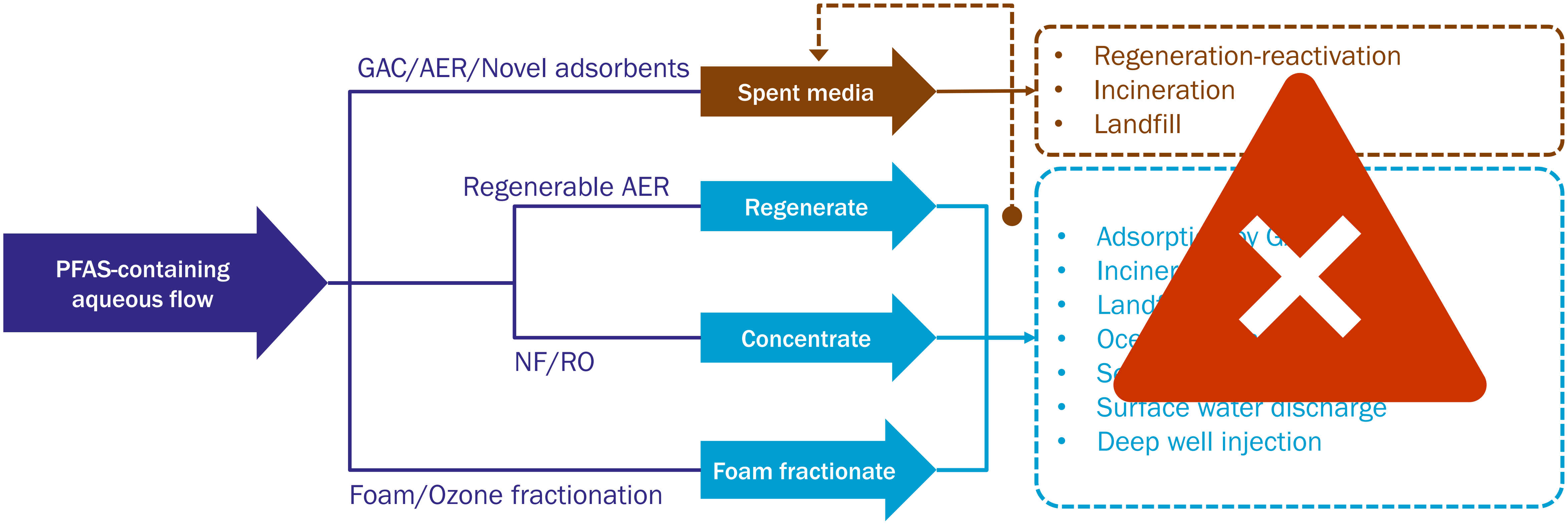
Residual management from typical treatment



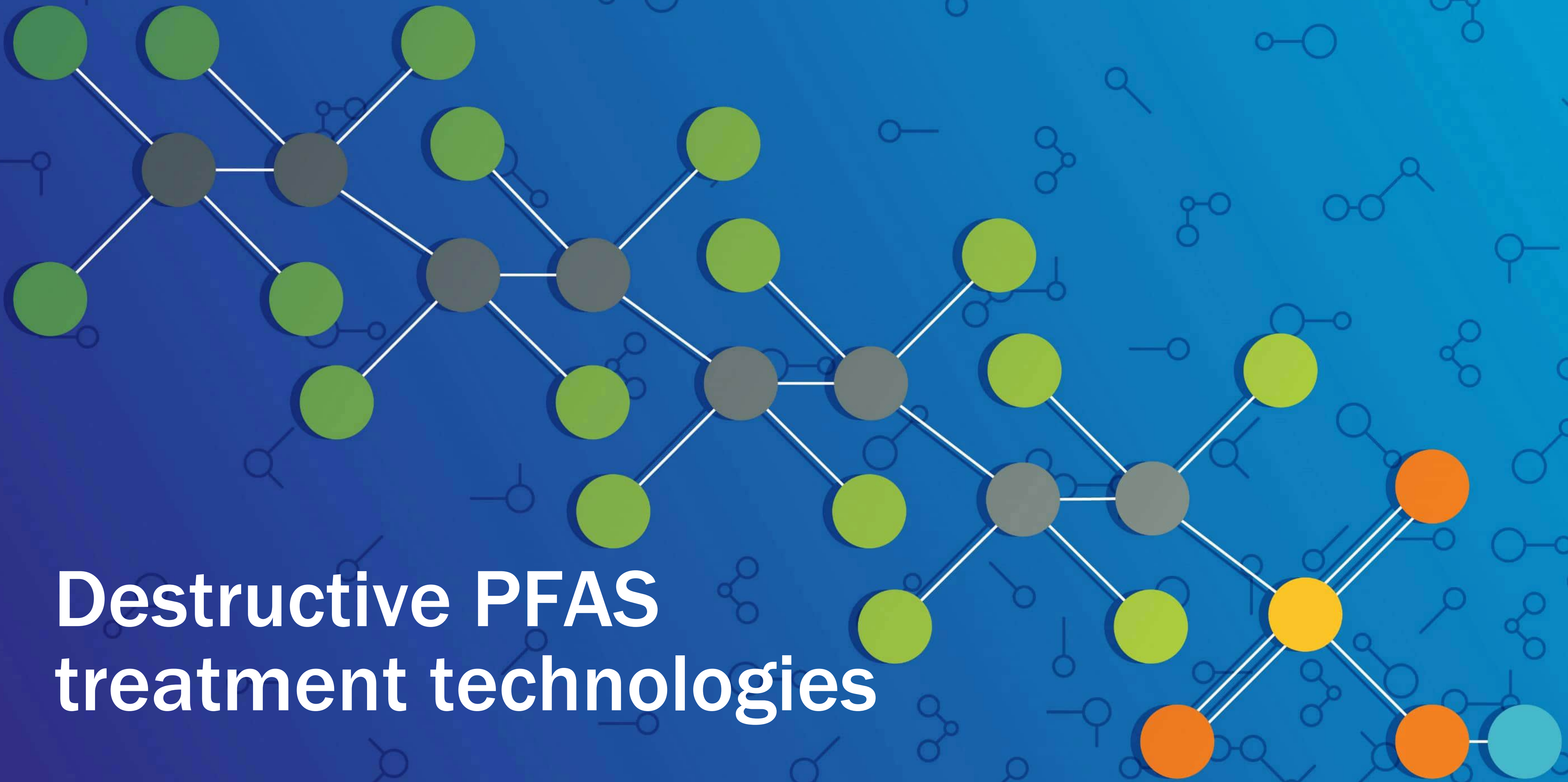
Residual management from typical treatment



Limitations on residual disposal will require PFAS destruction in the future



Destructive PFAS treatment technologies

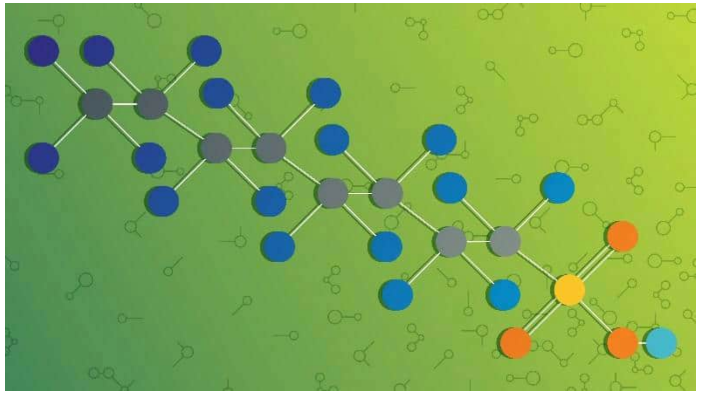


PFAS Properties

The carbon structure of PFOS makes it very difficult to break down.

The C-F bond is the strongest bond in chemistry. Because of this, it has been challenging to find effective treatment options to address this contaminant.

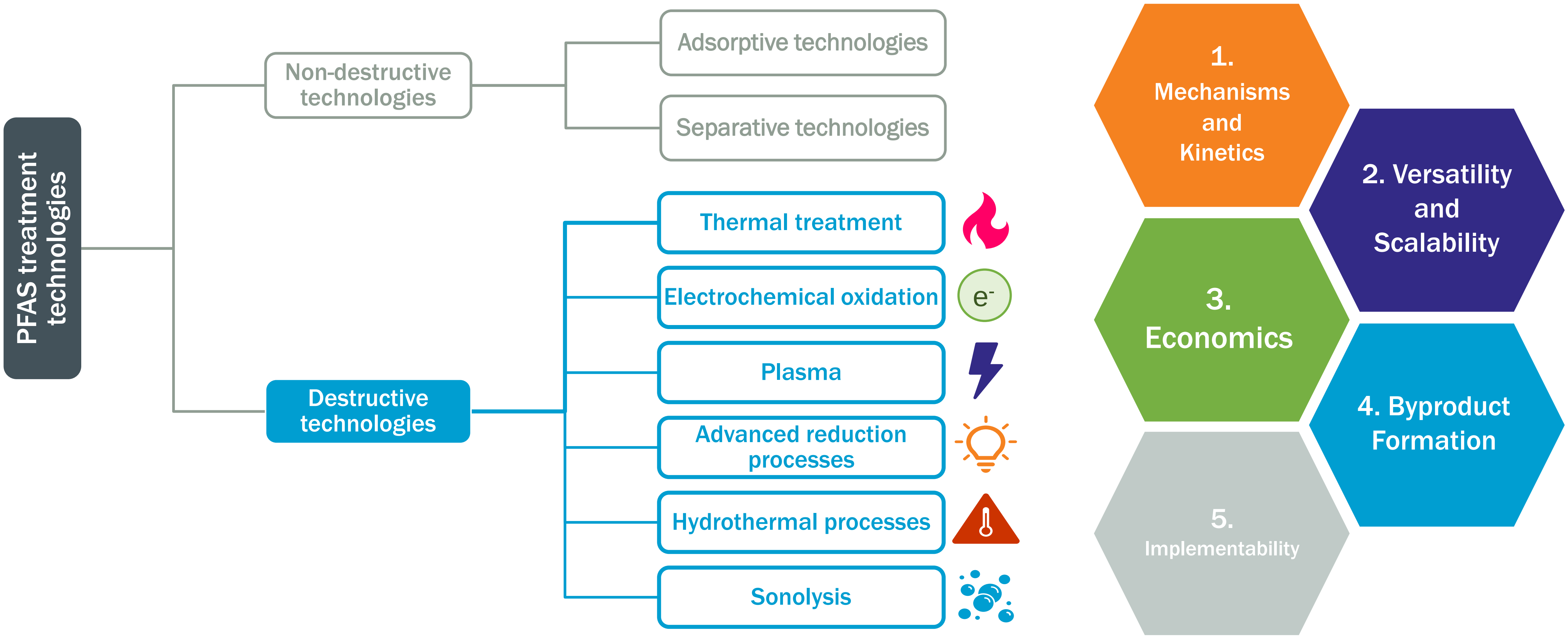
Molecular structure



Strongest bond

	kJ/mol of bonds	
C-F	485	**High C-F Bond Energy**
C-H	436	
C-C	346	
C-Cl	339	
C-N	305	
C-Br	285	
C-S	272	

Key considerations during tech evaluation

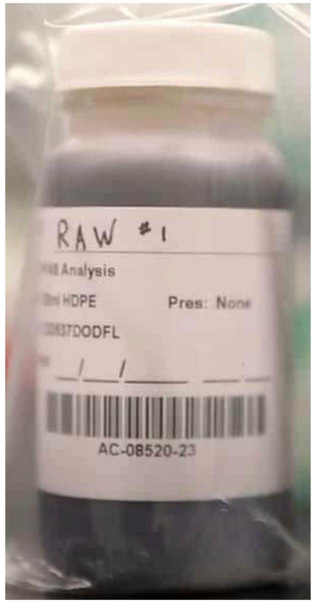


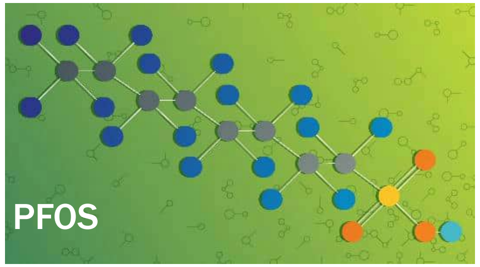
Hydrothermal processes

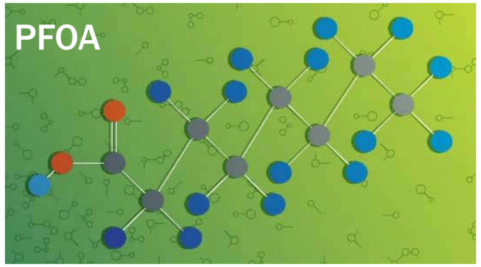
How does it work?

Process involves hot water steam:

1. Supercritical water oxidation (SCWO)
2. Hydrothermal Liquefaction (HTL)





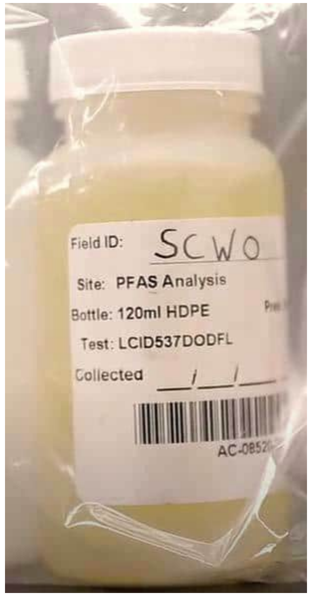


High temperature
High pressure

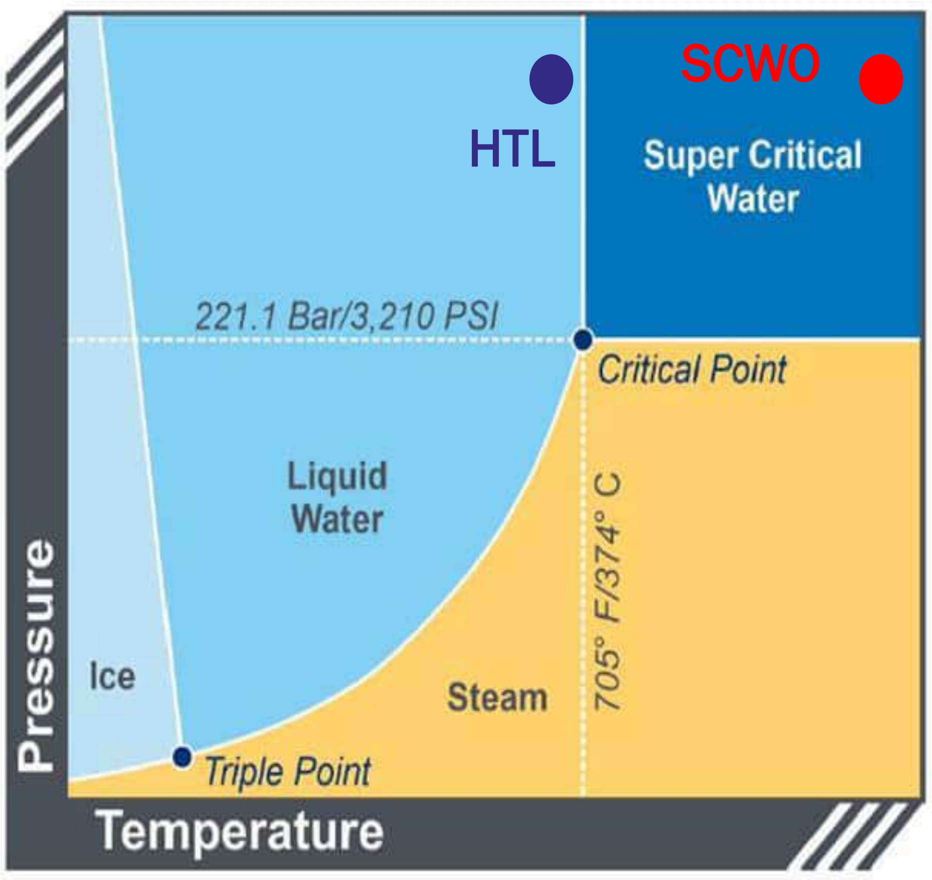
+oxygen source

+neutralizer

CO_2, H_2O NaF, etc.



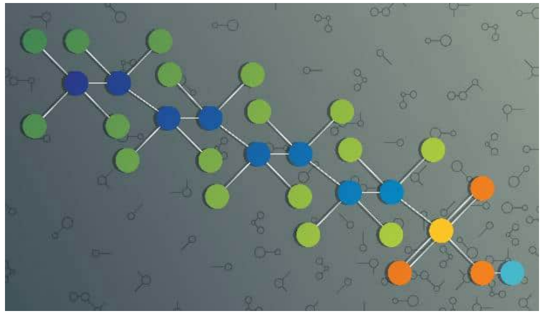
SCWO vs. HTL

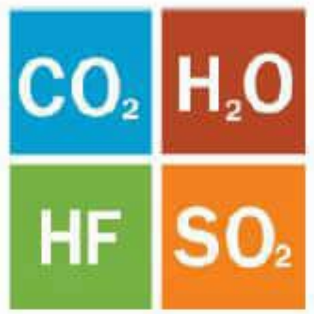


	Supercritical Water Oxidation (SCWO)	Hydrothermal Liquefaction (HTL)
Temperature	600-650 °C	300-350 °C
Pressure	3,600-4,300 psi	3,600-4,300 psi
Reaction time	10-60 seconds	30-120 minutes
Treatment condition	Need oxygen source	Need NaOH as catalyst
Fuel source	Liquid residual + solids (?)	Wet sewage sludge
Fuel chemistry	High in C, H, N, O	
	Low in salinity	

Thermal treatment

Incineration/Pyrolysis/Gasification





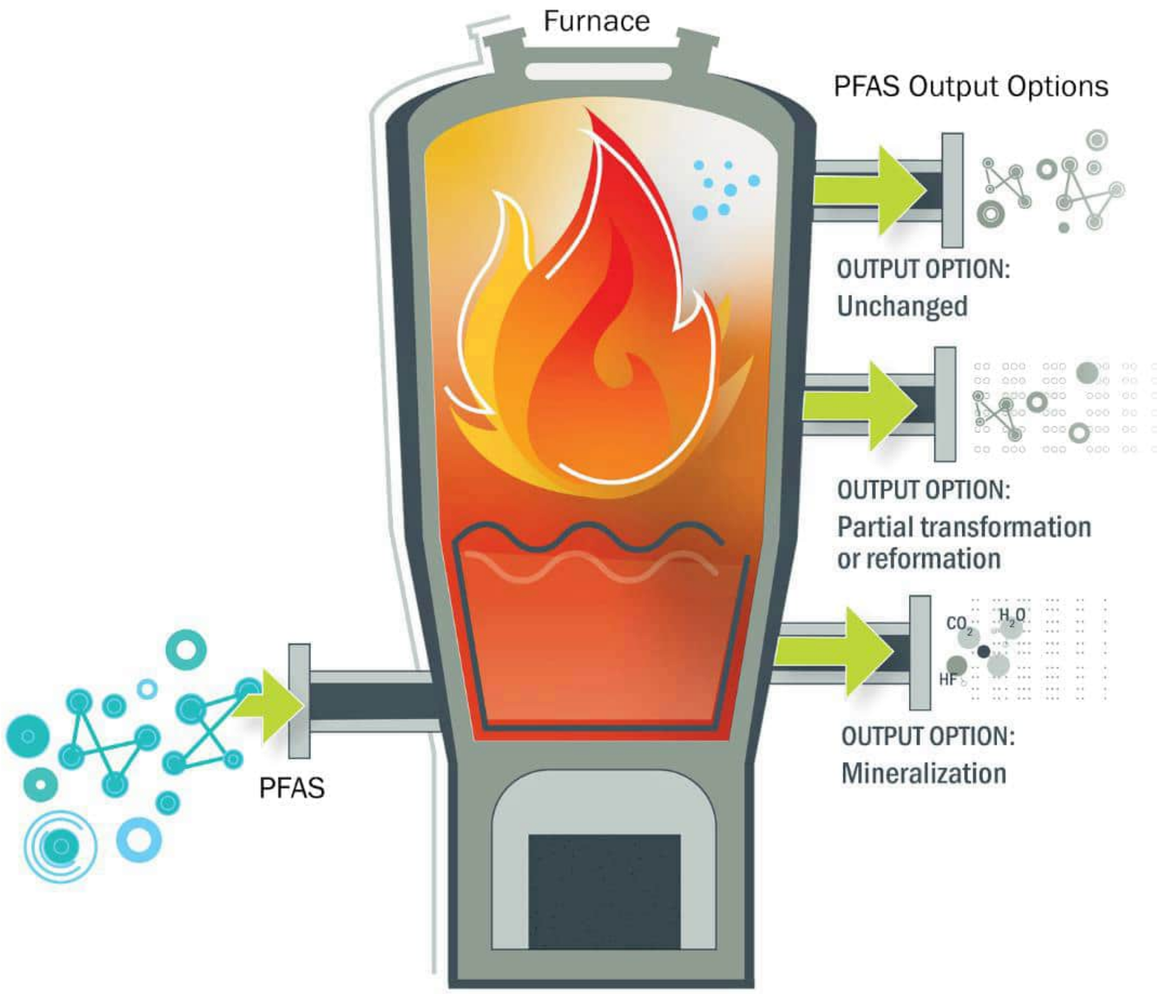
Ultimate goal

Complete PFAS mineralization

	Incineration	Pyrolysis	Gasification
Air/Oxygen Requirement	> Stoichiometric amount	None	< Stoichiometric amount
Temperature	800°C - 900°C	300°C - 750°C	800°C – 1,000°C
Products	Heat, ash, carbon dioxide, and water	Heat, char, and hydrogen rich synthetic gas (syngas)	Heat and syngas, sometimes char

Thermal treatment

Incineration/Pyrolysis/Gasification



How does it work?

- 3 T's:
  - Time
  - Temperature
  - Turbulence
- **Chemistry** of fuel source is critical to PFAS destruction
- **Products** of incomplete combustion?

BC Thermal Treatment Research

Incineration

The Water Research Foundation

Project #5111

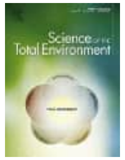
Studying the Fate of PFAS through Sewage Sludge Incinerators

water ENVIRONMENT RESEARCH

Per- and polyfluoroalkyl substances thermal destruction at water resource recovery facilities: A state of the science review

Lloyd J. Winchell, John J. Ross, Martha J. M. Wells, Xavier Fonoll, John W. Norton Jr, Katherine Y. Bell

First published: 15 November 2020 | https://doi.org/10.1002/wer.1483 | Citations: 4



Analyses of *per*- and polyfluoroalkyl substances (PFAS) through the urban water cycle: Toward achieving an integrated analytical workflow across aqueous, solid, and gaseous matrices in water and wastewater treatment

Lloyd J. Winchell [a], Martha J.M. Wells [b], John J. Ross [c], Xavier Fonoll [d], John W. Norton Jr. [d], Stephen Kuplicki [d], Majid Khan [d], Katherine Y. Bell [e]

Pyrolysis/Gasification

Water Environment Federation — the water quality people

Developing a PFAS Destruction Protocol Through Pyrolysis and Thermal Oxidation (In Contracting, Opportunities for Additional Partners)

water ENVIRONMENT RESEARCH

Pyrolysis and gasification at water resource recovery facilities: Status of the industry

Lloyd J. Winchell, John J. Ross, Dominic A. Brose, Thaís B. Pluth, Xavier Fonoll, John W. Norton Jr, Katherine Y. Bell

First published: 04 March 2022 | https://doi.org/10.1002/wer.10701

water ENVIRONMENT RESEARCH

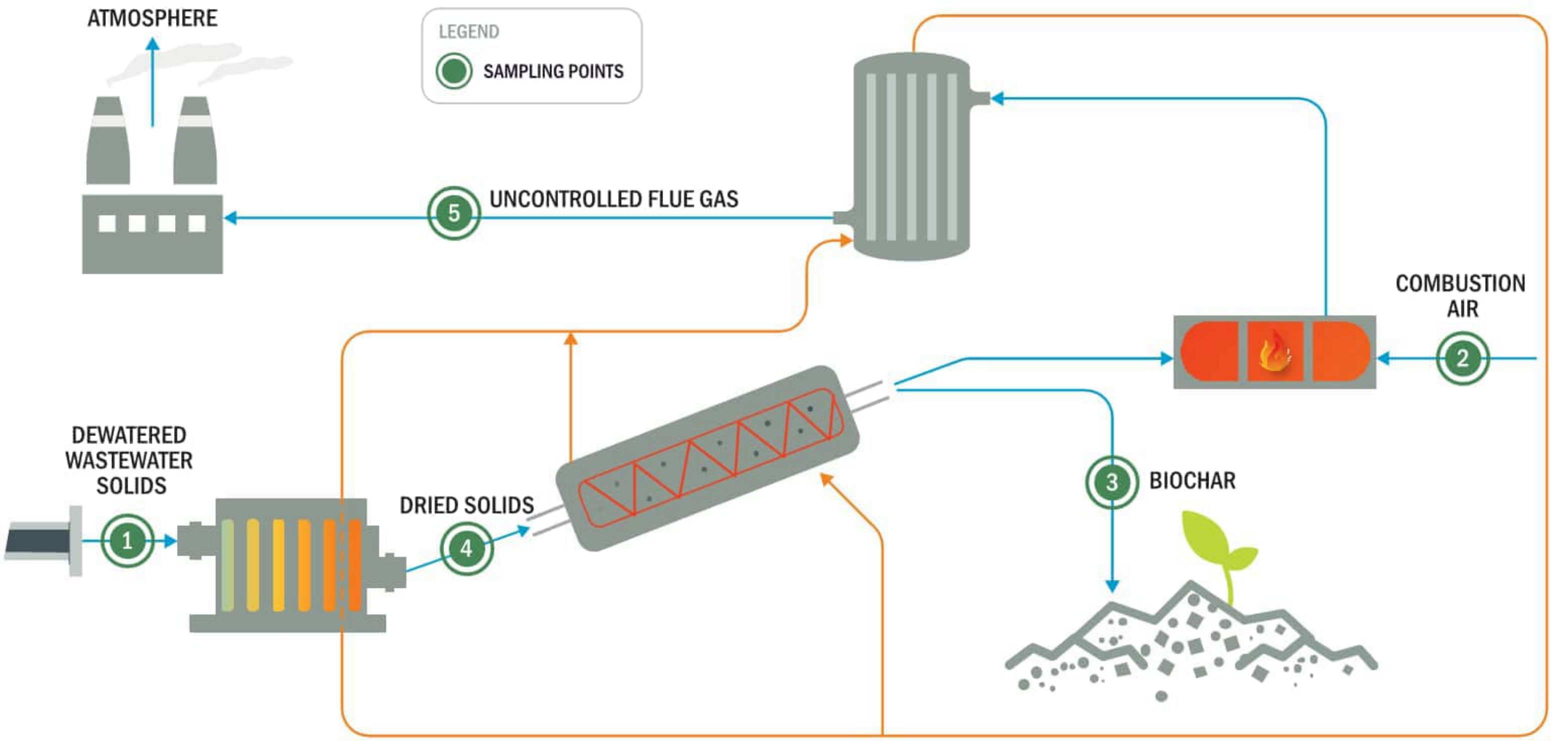
High-temperature Technology Survey and Comparison among Incineration, Pyrolysis, and Gasification Systems for Water Resource Recovery Facilities (Manuscript in Publication)

Ongoing Research

Studies	Status	Key Features
SVCW Field Testing (USEPA)	Field Work: Aug 2020 Publication: Feb 2022	• PFAS below MDLs in biochar • Limited/inconclusive emissions testing
WRF 5111: SSI PFAS Fate Study (BC)	Awarded: 2021 Full-scale testing completed in 2023 and final report expected Spring 2024	• Full-scale PFAS fate study through (2) SSIs
WRF 5107: Understanding Pyrolysis for PFAS Removal (Hazen and MC)	Awarded: 2021 Full scale system in commissioning	• Full-scale PFAS fate study through pyrolysis
WEF Pyrolysis Study (BC)	Bench scale unit commissioned, awaiting full-scale system upgrades	• Full- and lab-scale testing of pyrolysis + thermal oxidation
WRF 5211: Understanding Value Proposition of Thermal Processes to Mitigate PFAS in Biosolids (B&V)	Awarded 2022, final report expected 2025	• Lab-scale PFAS fate study through pyrolysis and gasification

Pyrolysis Study with Silicon Valley Clean Water (Redwood City, CA)

- Dewatered biosolids provided by SVCW will be dried and processed through a lab scale pyrolysis reactor with operating conditions similar to SVCW's current process
- Parallel bench scale and full-scale study



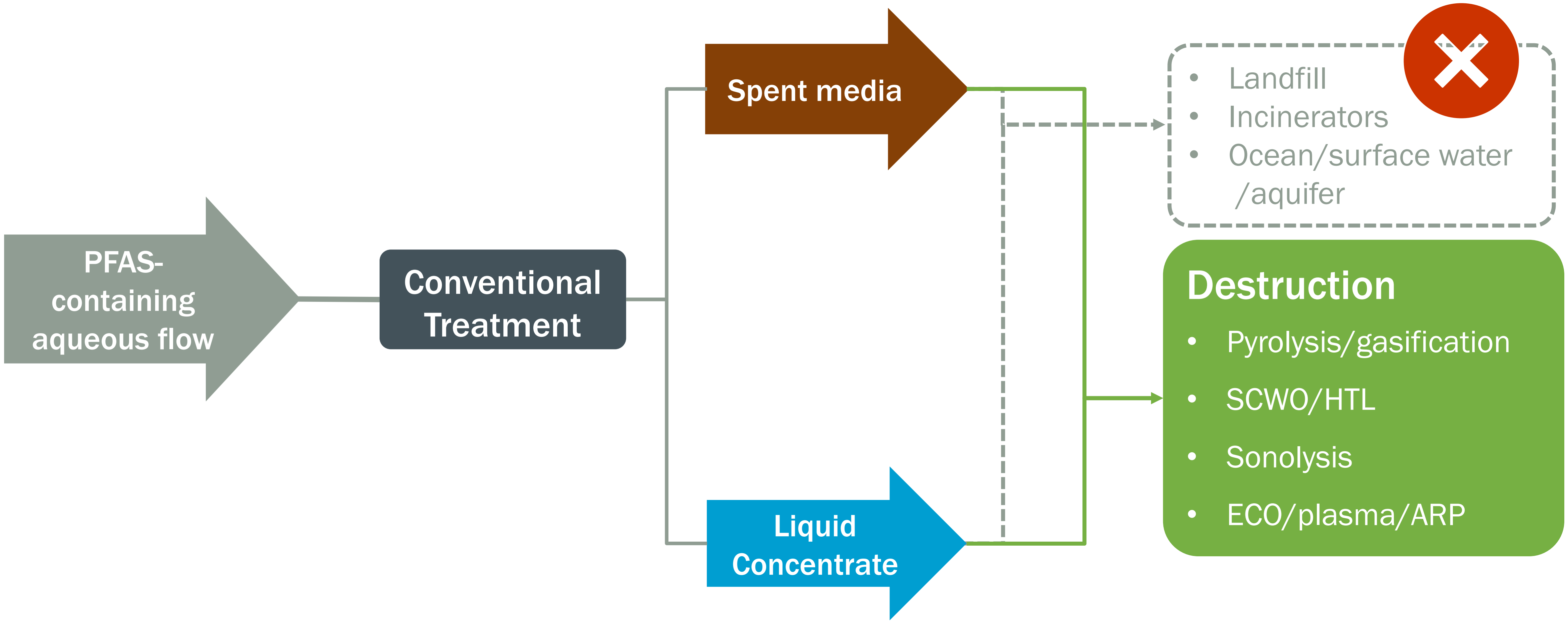
Winchell, L.J., Ross, J.J., Brose, D. A., Pluth, T. B., Fonoll, X., Norton Jr., J.W., Bell, K.Y. High-temperature Technology Survey and Comparison among Incineration, Pyrolysis, and Gasification Systems for Water Resource Recovery Facilities *Water Environ. Res.* http://dx.doi.org/10.1002/wer.10715

Destructive treatment technologies comparison

Technology	Versatility	Scalability: Current State	Scalability: Future State	Economics	Challenges
Incineration	Liquid & Solids	Full-scale	★★★		Permitting challenges
Pyrolysis/Gasification	Solids	Full-scale			Optimizing operation conditions
SCWO	Liquid & Solids	Pilot-scale	★★☆	$$$	Fuel source chemistry
HTL	Liquid & Solids	Pilot-scale			Highly alkaline conditions
Electrochemical Oxidation	Liquid	Pilot-scale	★☆☆		Anode material and size
Plasma	Liquid	Bench-scale			Power supply and inert gas circulation
Advanced Reduction Process	Liquid	Bench-scale			Customized lamps and quantity of lamps
Sonolysis	Liquid	Pilot-scale	★☆☆		Slow reaction kinetics

The future of aqueous PFAS treatment is to **concentrate** large volumes of impacted waters to **improve the economics** of energy-intensive destructive technologies.

Treatment train approach in addressing PFAS challenges



Questions?

Mary Lou Romero
MLRomero@brwncald.com

Brown AND Caldwell

Bull pen

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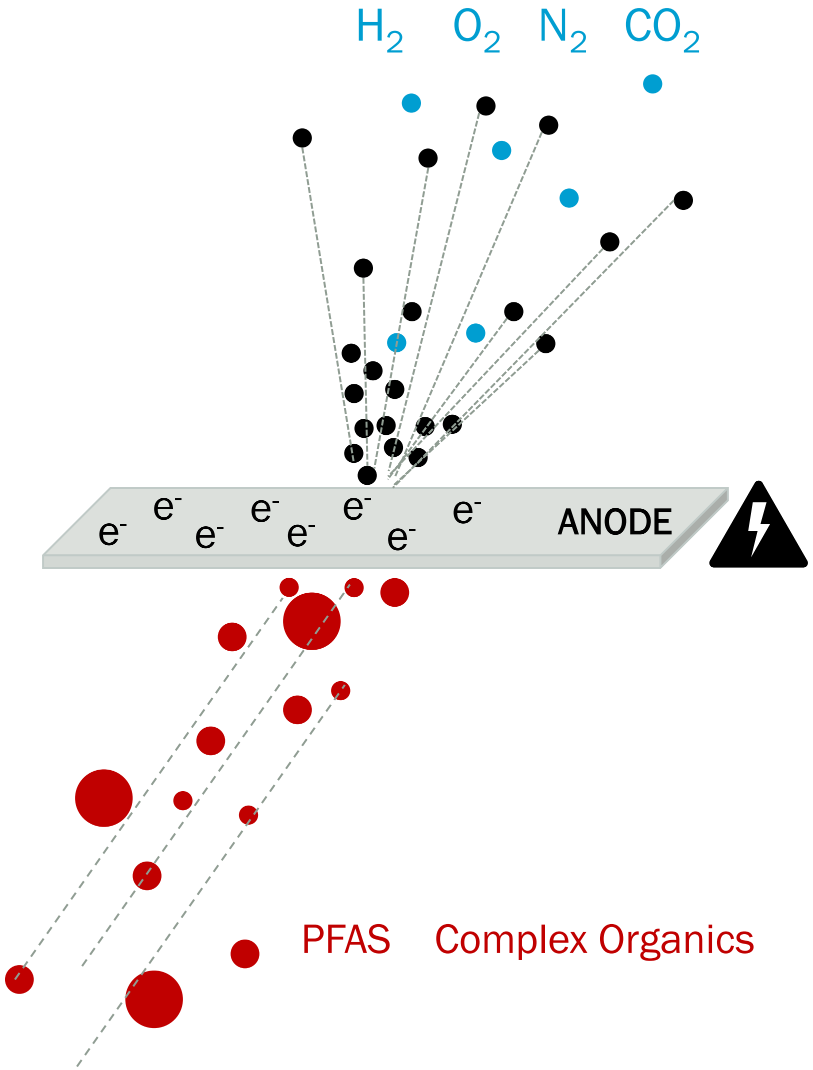
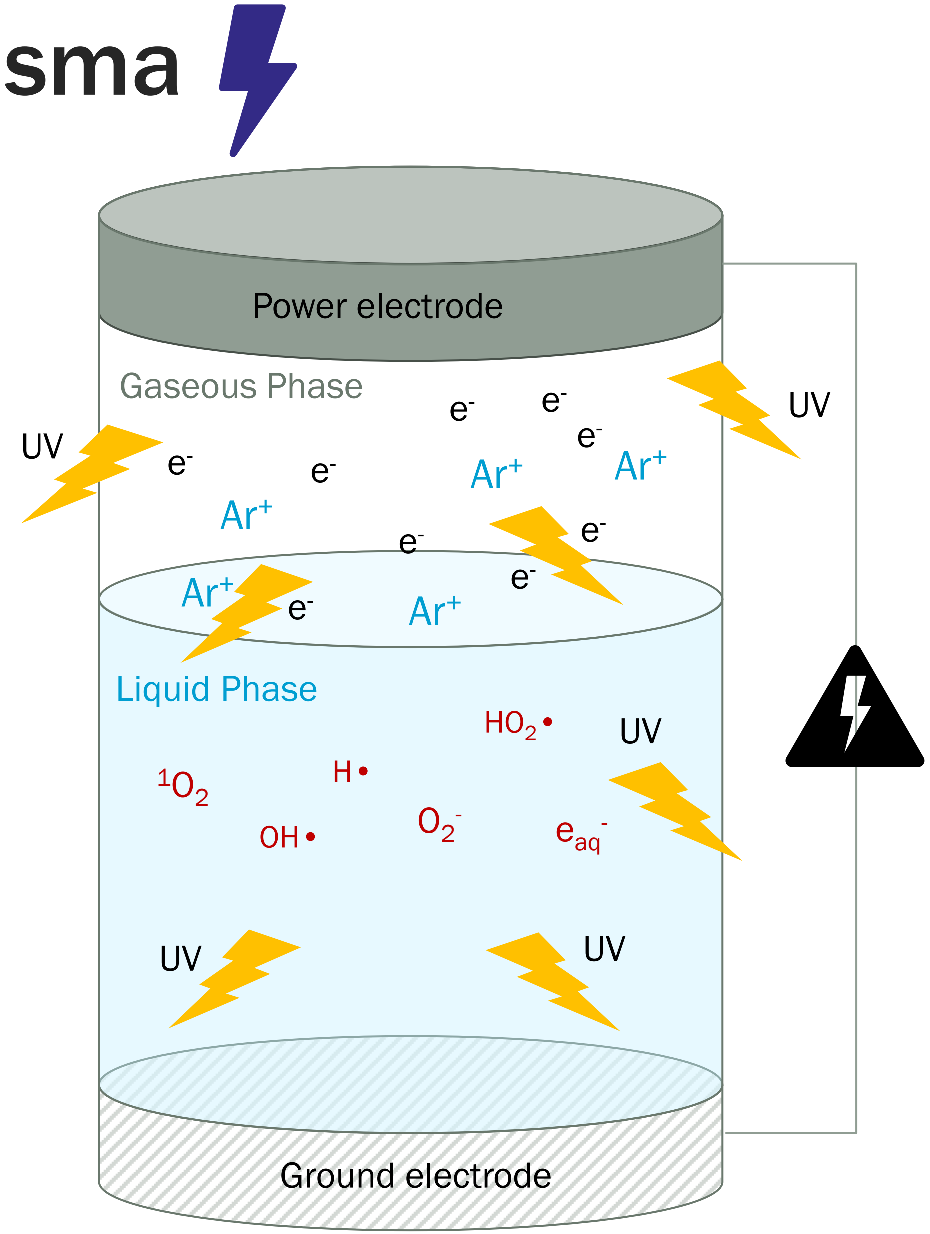
Electrochemical oxidation e⁻

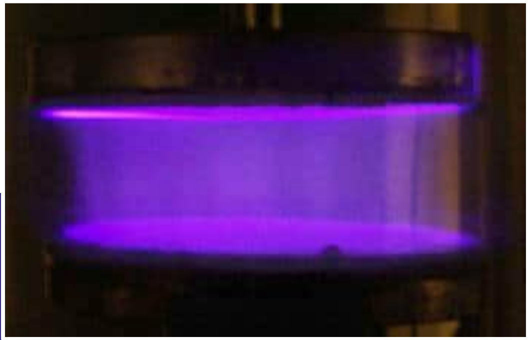


How does it work?

- Electrical currents passed through a solution to oxidize PFAS
- Direct and indirect oxidation mineralize PFAS into CO_2 and other trace gases
  - At the anode surface
  - In bulk solution
- Anode material plays a key role in PFAS destruction.

Plasma

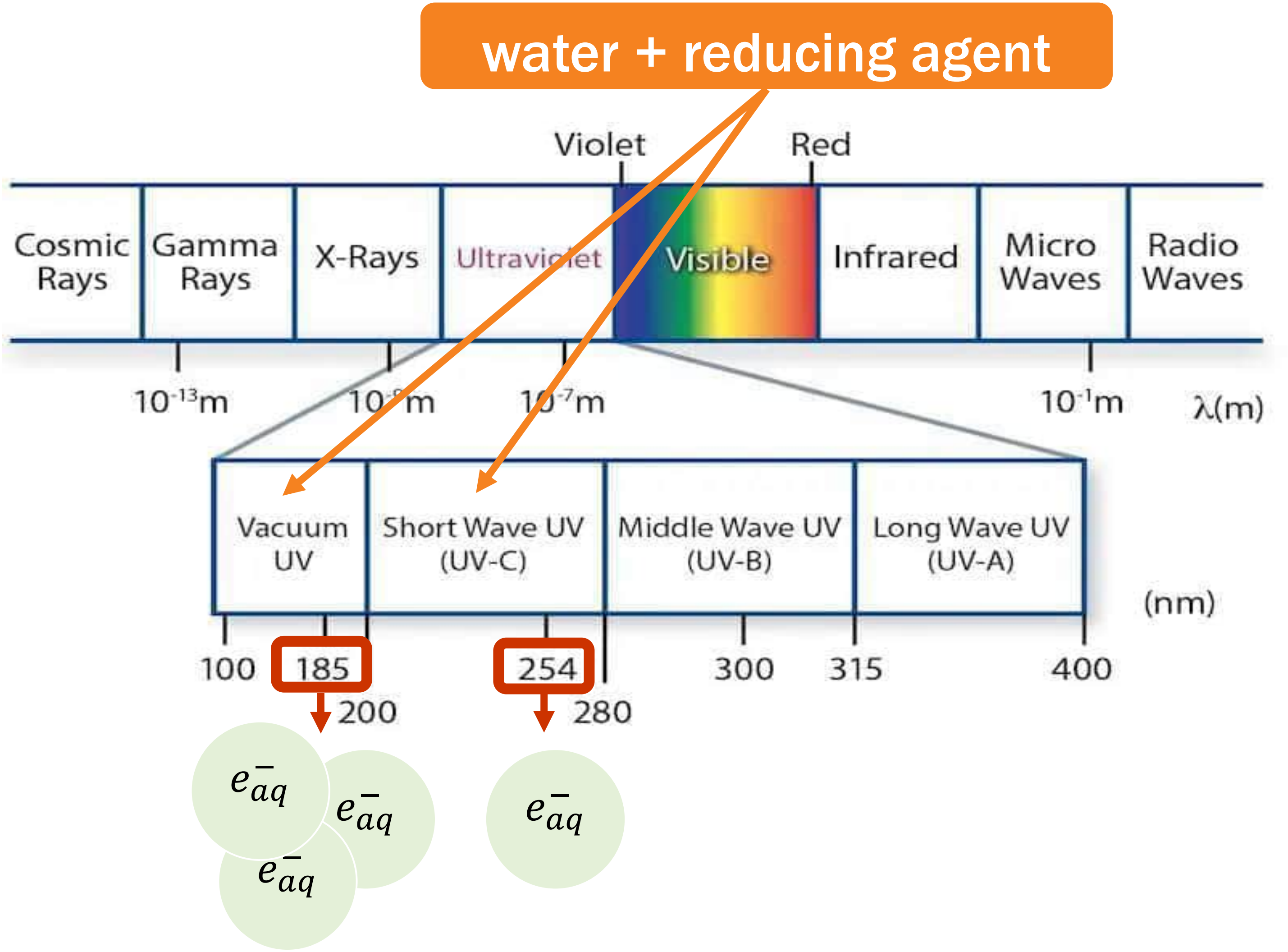




How does it work?

- Plasma is ionized gas:
  - free electrons
  - positively charged gas ions
- Electrons collide with gas molecules to generate a wide array of radicals.
- Radicals diffuse into the liquid phase and react with PFAS.
- PFAS degraded by e_{aq}^{-}.

Advanced reduction process (ARP)



Reducing agents:
- Sulfite
- Iodide
- Ferrocyanide
- Aminopolycarboxylic acids
- Indole derivatives

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