Vertex Environmental Inc.

Treating PFAS:
Current In-Situ Remediation Approaches

September 27, 2023

SABCS Workshop

Bruce Tunnicliffe, M.A.Sc., P.Eng.

Outline

- Remediating PFAS
  - Why is PFAS remediation difficult?
  - Review of current State of Affairs
- In-Situ Remediation of PFAS
  - Comparison of 2 Amendments
- Closing

Background

Bruce Tunnicliffe, M.A.Sc., P.Eng.

- Masters – U of Waterloo. Remediation
- Founder – Vertex Environmental Inc.
- Founder – SMART Remediation

Vertex Environmental Inc.

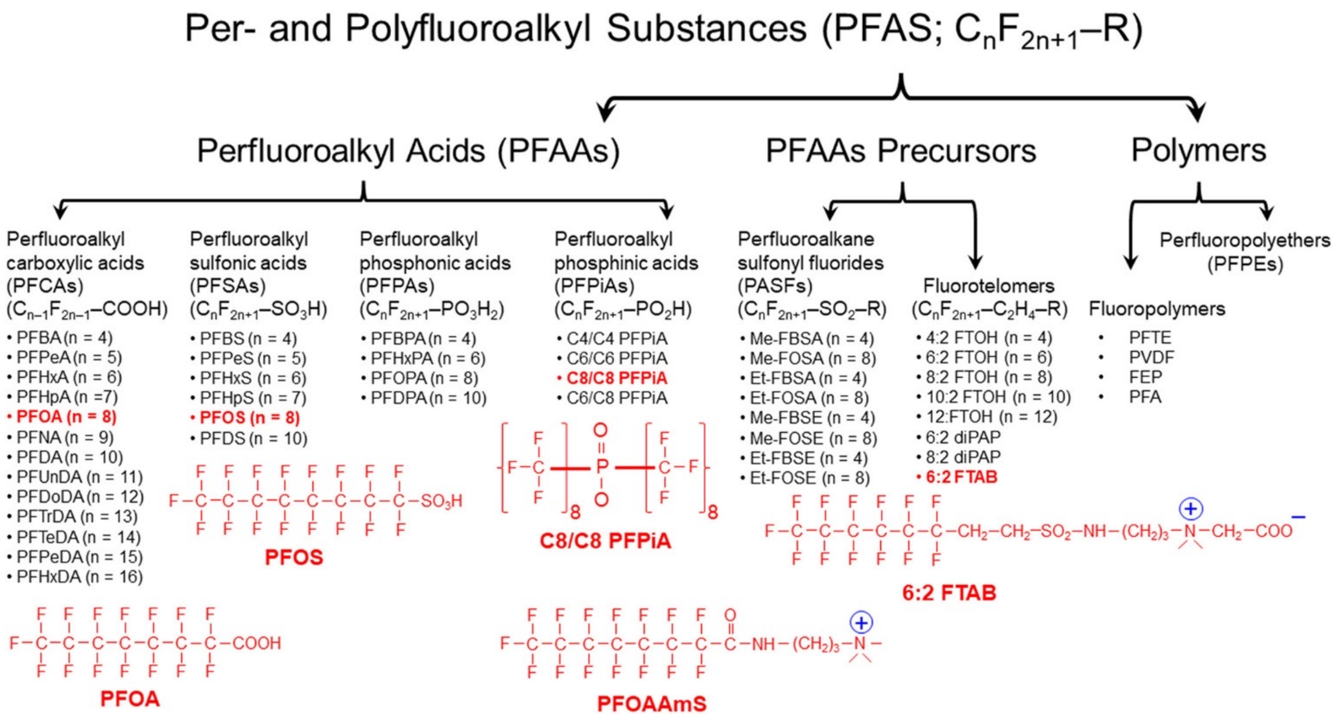
- Started July 2003
- Environmental Contractor

The Characteristics of PFAS, As They Relate to Remediation

PFAS: Why is it hard to Remediate?

PFAS is a Group of Chemicals

- Some say more than 4,500
- Laboratories report ~40 PFAS
- PFAS = Dark Matter?
  - you don't know what you have
- Long chain can degrade to short chain
- Generally short chains are more toxic and mobile than long chains
- Documented water treatment issues
  - e.g. hydrogen peroxide is added during water treatment, the short chained PFAS effluent concentration is higher than influent conc.



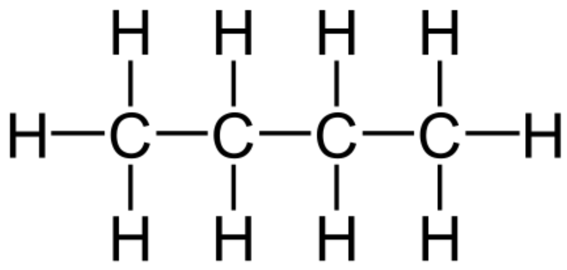
A Take Away
Be careful with PFAS destruction approaches, you have to consider precursors

Xiao, F. "An overview of the Formation of PFOA and PFOS in Drinking-Water and Wastewater Treatment Processes", Journal of Environmental Engineering. April 2022

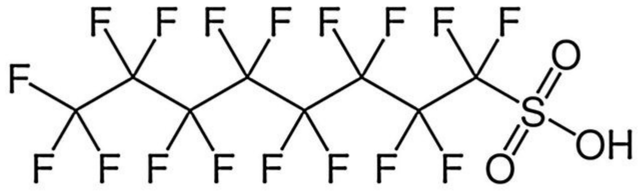
PFAS: Why is it hard to Remediate?

How They Are Made

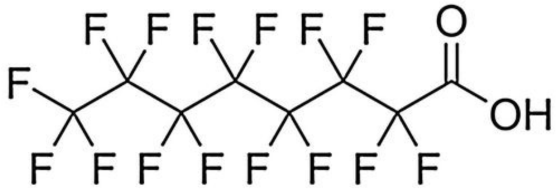
- Human made
- A fossil fuel derivative
- To make PFAS, replace the hydrogen with fluorine
- Carbon-Fluorine (C-F) bond:
  - strongest covalent bond in organic chemistry
- Low to no degradation under natural conditions
- PFAS thermally degrades at $>800^{o}C$



Aliphatic Compound



Perfluorooctane sulfonic acid (PFOS)



Perfluorooctanoic acid (PFOA)

A Take Away

Traditional remediation approaches will be very difficult to apply due to PFAS characteristics

Remediating PFAS
The Current State of Affairs

Remediating PFAS, The Current State of Affairs

ITRC INTERSTATE TECHNOLOGY REGULATORY COUNCIL

Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)

- Treatment technologies for PFAS are the focus of **intense research** and are **evolving**
- The nature of PFAS make many **conventional treatment technologies ineffective**, including those that rely on:
  - contaminant volatilization at ambient temperature (air stripping, soil vapor extraction)
  - bioremediation (biosparging, biostimulation, bioaugmentation)
- Even aggressive technologies require extreme conditions beyond typical practices:
  - thermal treatment and chemical oxidation
- **“…innovative combinations** of…technologies **are required”**

ITRC, July 2022 “Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)”

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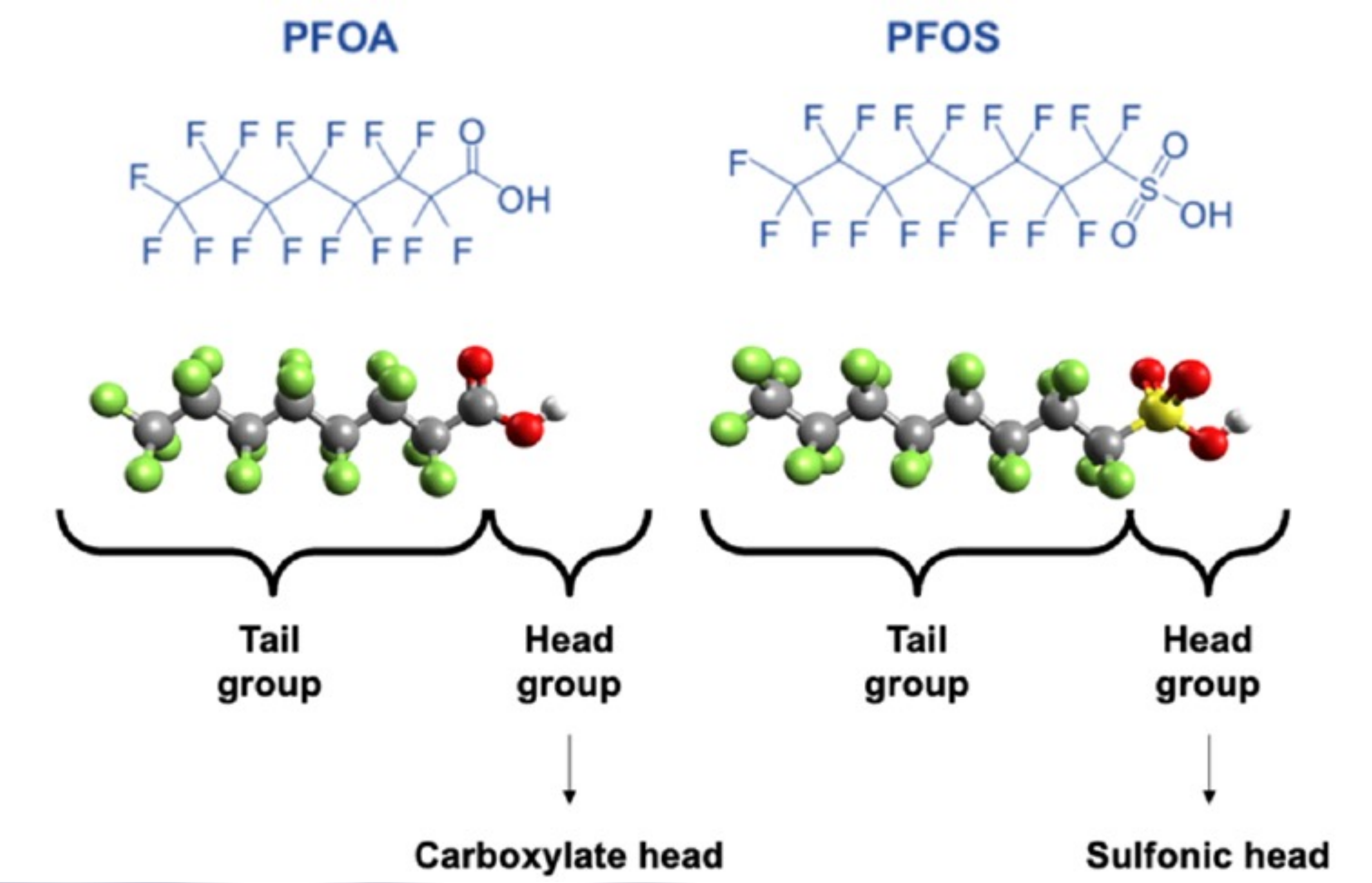
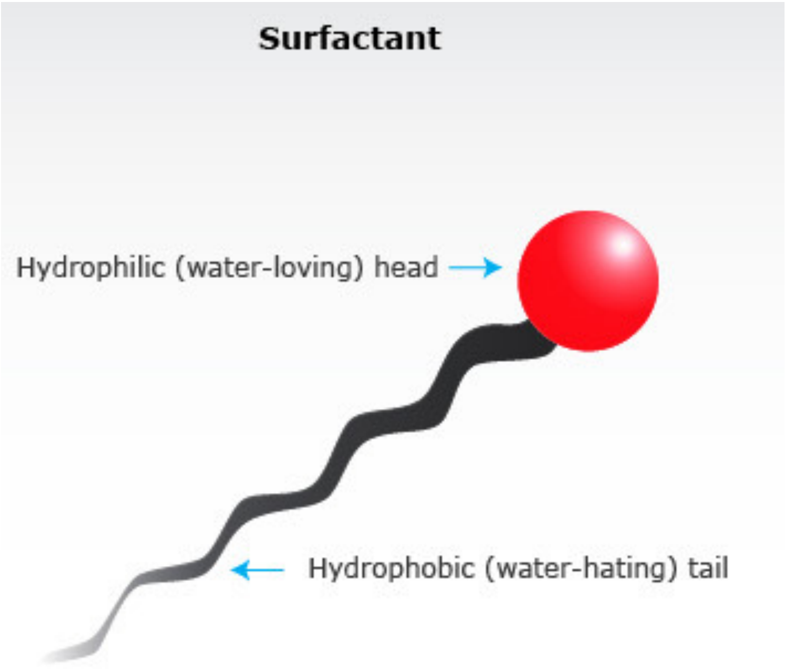
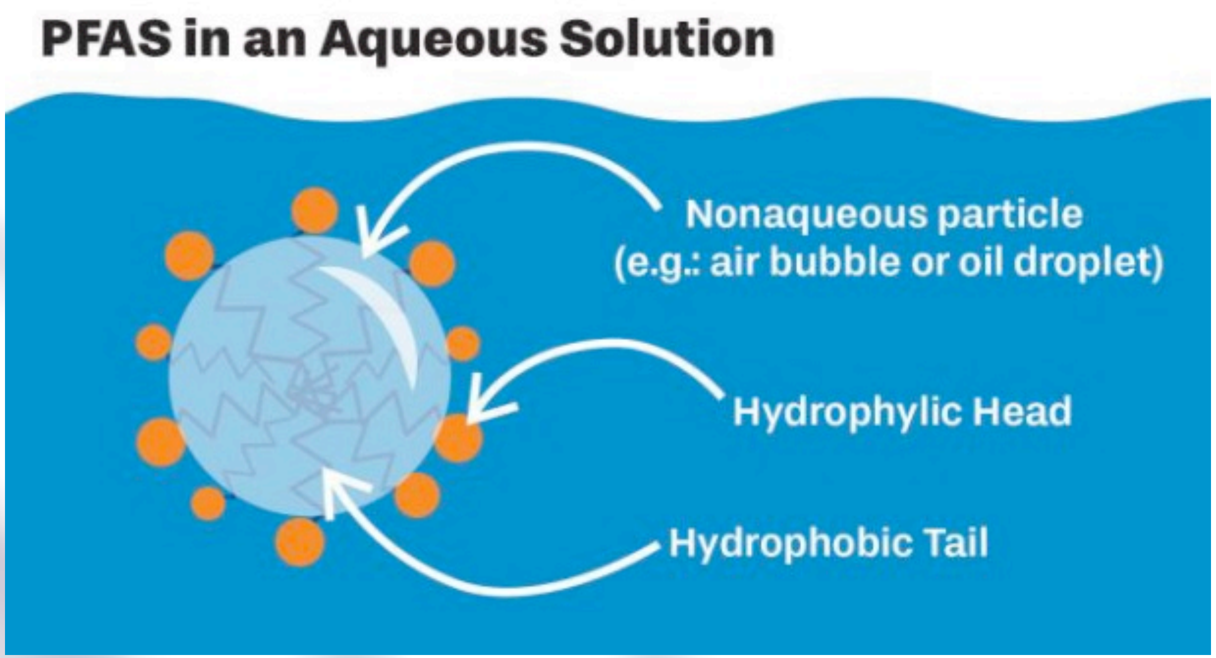
Remediating PFAS
Interesting leading-edge technologies

Remediating PFAS, Foam Fractionation





Remediating PFAS, Foam Fractionation



Credit: CDM Smith

Remediating PFAS, eBeam

ELSEVIER

Radiation Physics and Chemistry

Volume 189, December 2021, 109705

Degradation of PFOS and PFOA in soil and groundwater samples by high dose Electron Beam Technology

John Lassalle [a], Ruilian Gao [a], Robert Rodi [a], Corinne Kowald [b], Mingbao Feng [c], Virender K. Sharma [c], Thomas Hoelen [d], Paul Bireta [d], Erika F. Houtz [e], David Staack [a], Suresh D. Pillai [b]

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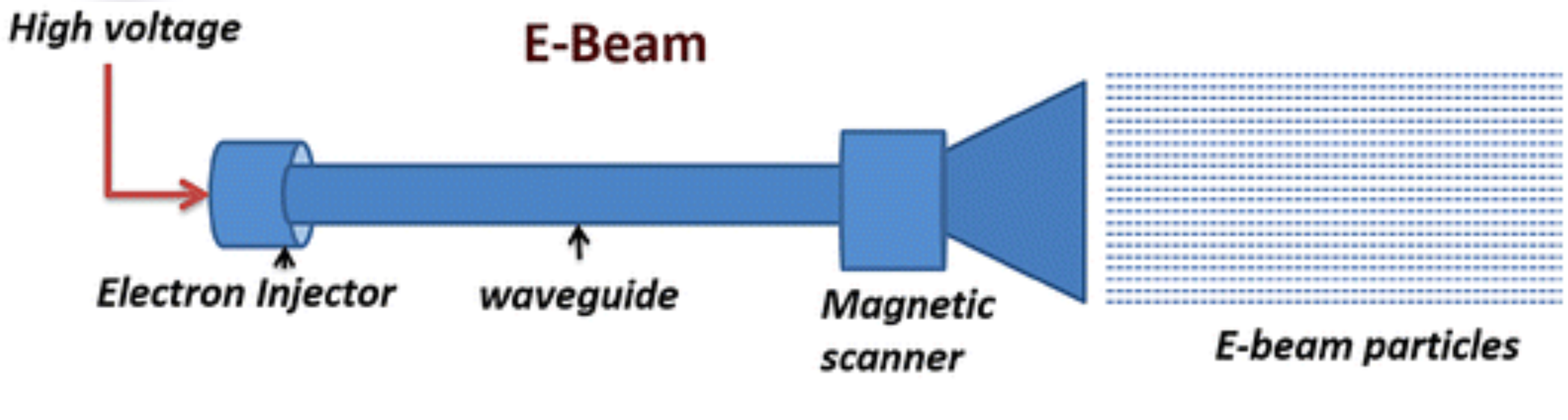
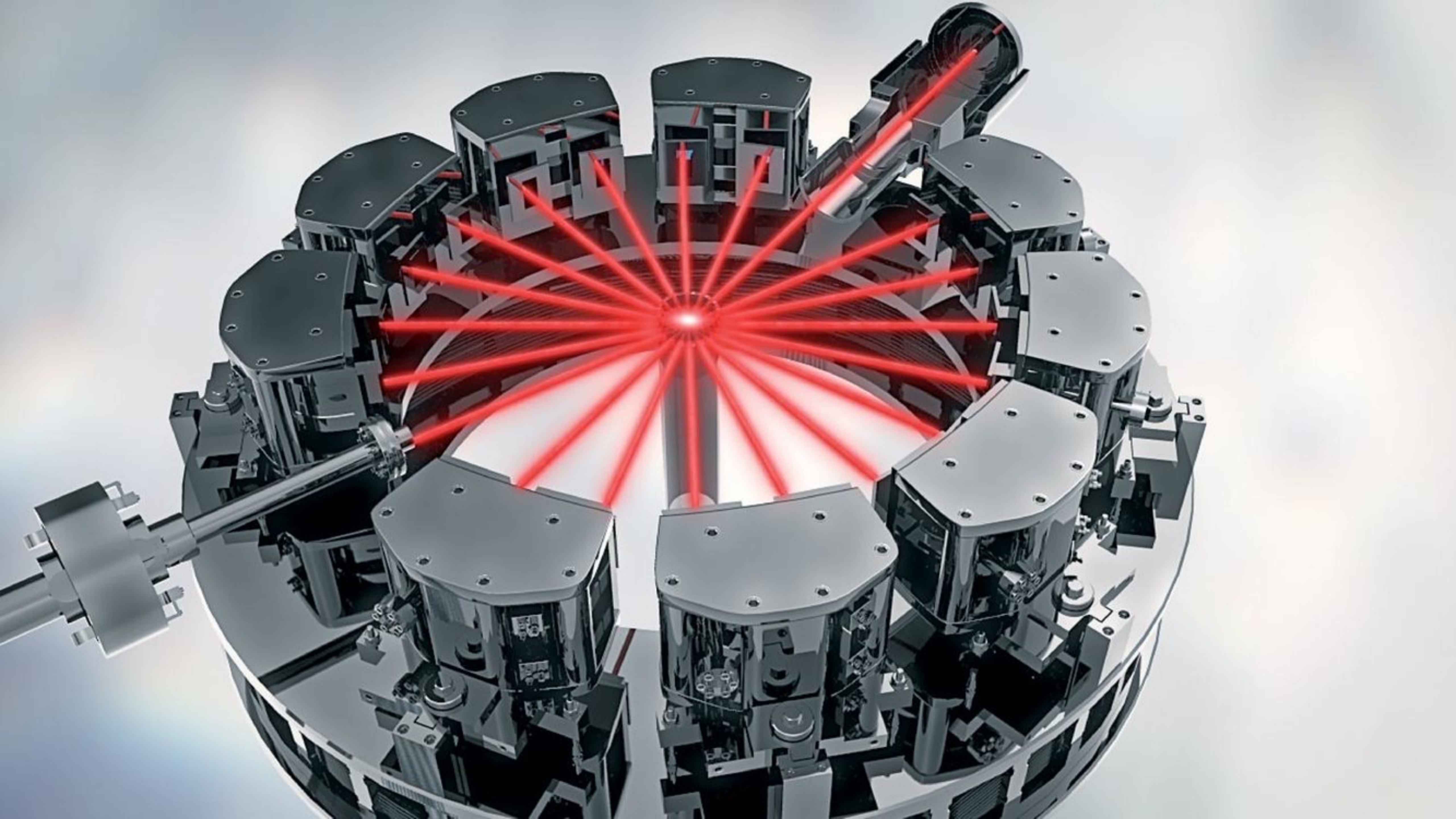
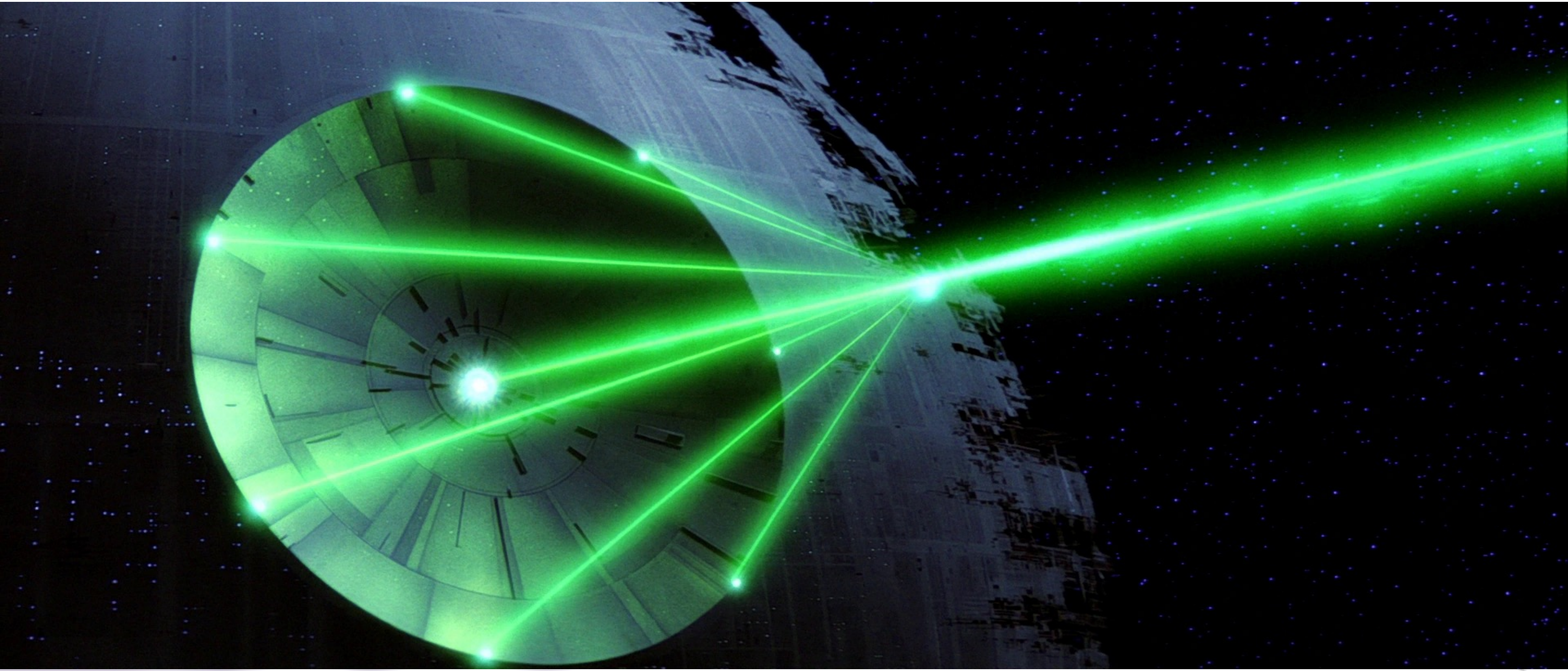
Remediating PFAS, eBeam

- Electron beam (eBeam) technology utilizes compact electron accelerators to generate large numbers of **highly energetic electrons** from electricity. The technology is commonplace in the medical device sterilization industry, wire and cable polymer crosslinking and food pasteurization industries.





Remediating PFAS, eBeam



Remediating PFAS, some Innovative Destruction Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
ELECTROCHEMICAL OXIDATION	• Effective for long-chain PFASs. • Efficient for highly concentrated PFASs. • Effective for low-volume PFASs. • Low environmental impact. • Does not require pretreatment.	• Widescale application. • Inefficient for short-chain PFASs. • Electrodes are expensive. • Reduced electrode lifetime. • High energy consumption. • Toxic by-products. • Forms short-chain PFAS
PLASMA	• Effective for long-chain PFASs. • Effective for short-chain PFASs. • Low energy consumption. • No chemical additives are needed. • Short treatment time. • Effective for highly concentrated PFASs. • Effective against Co-contaminants.	• Affects water's pH, making it acidic. • Forms short-chain PFASs. • Its mechanism is not well understood. • Longer time for short-chain treatment. • The addition of chemicals is required. • Nontargeted reactions can result in longer treatment time
PHOTOCATALYSIS	• Low energy consumption. • Performed at ambient temperatures. • Sustainable technology. • It can be recycled.	• Low degradation efficiency. • Inefficient for sulfonic groups. • Toxic intermediate products. • Additional treatment is needed. • Affected by co-contaminants.
SONOLYSIS	• Effective for long-chain PFASs. • Effective for short-chain PFASs. • Effective in soils and liquids. • Effective for highly concentrated PFASs. • Effective against co-contaminants. • No chemical additives are needed. • Does not require pretreatment. • Efficient for highly concentrated PFASs.	• Widescale application. • High energy consumption. • Its mechanism is not well understood. • Optimization of ultrasonic and geometric parameters are needed to scaling up of technology
SUPERCRITICAL WATER OXIDATION	• Effective for long-chain PFASs. • Effective for short-chain PFASs • Low environmental impact. • Relatively quick treatment time	• Not economically viable for large volumes. • Affects water's pH, making it acidic. • Corrosion of the reactor. • Precipitation of salts. • Toxic intermediate products.
THERMAL DEGRADATION/ INCINERATION	• Widescale application. • Reduced capital cost. • Effective for long-chain PFASs.	• Toxic intermediate and final products. • High environmental impact. • Air and soil contamination. • Toxic emission. • Toxic by-products.

"A Review of PFAS Destruction Technologies", Dec 2022, International Journal of Environmental Research and Public Health

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Remediating PFAS
In-situ

What Can We Do Right Now?

Remediating PFAS, in-situ

- In-situ PFAS destruction
  - In general, **not feasible** for full-scale application at this time
- In-situ: adsorption and stabilization
  - It is **feasible** to immobilize PFAS in-situ at this time

INTERSTATE ITRC TECHNOLOGY REGULATORY COUNCIL

Treatment Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)

- “It might be reasonable and necessary to implement **interim remedial actions**…
  …to mitigate completed exposure pathways…
  …with the intent of applying more robust and **permanent solutions as they are developed**.”
- Now: Adsorption in-situ approaches
- Years, decades later: Apply new technology to **destroy** PFAS

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Remediating PFAS, in-situ

Adsorption / Stabilization:

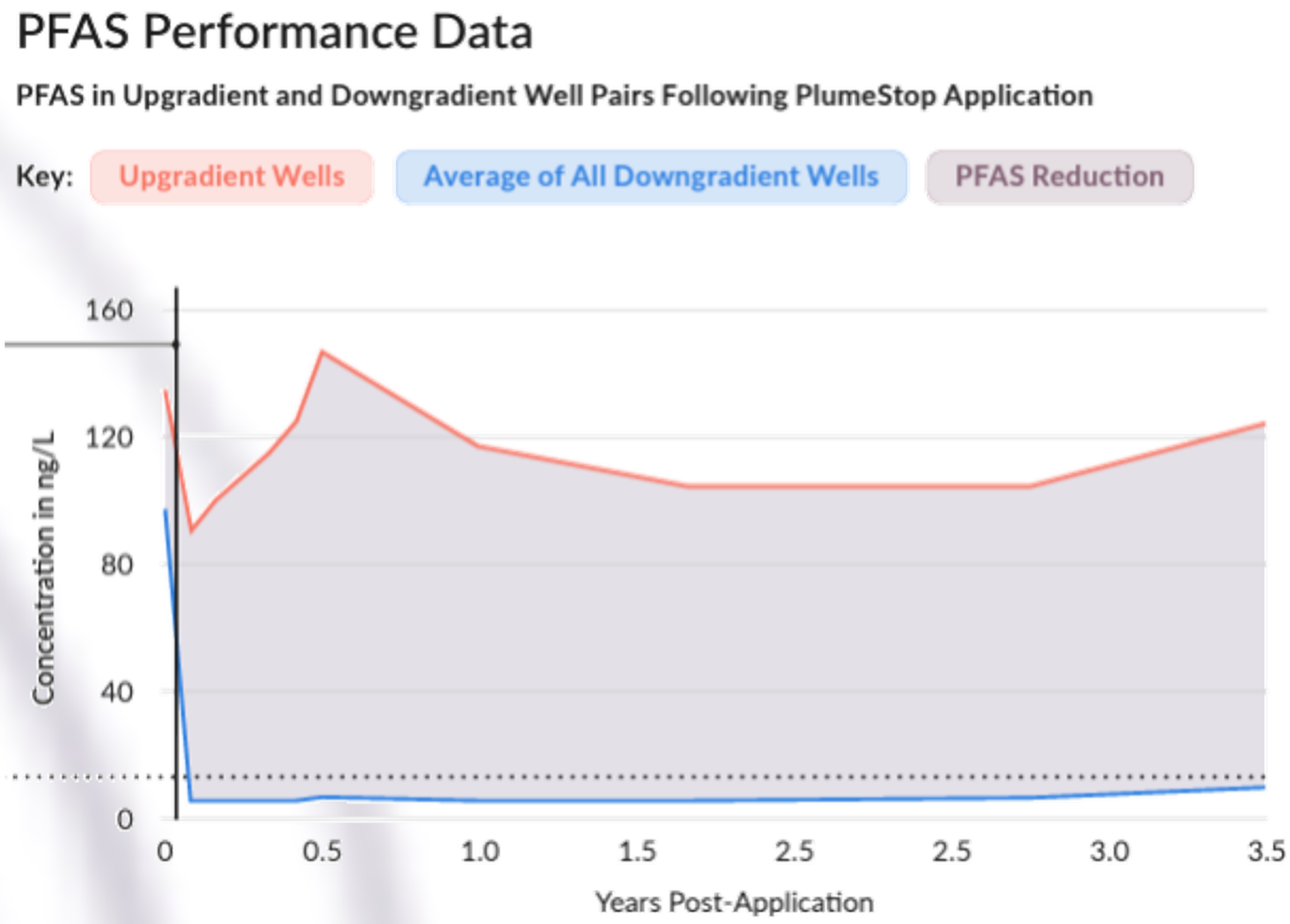
Amendments exist that can be injected into the subsurface:

- Activated Carbon
  - PlumeStop
- Modified Clay
  - Fluoro-Sorb®

These amendments are proven to effectively adsorb PFAS

Remediating PFAS, in-situ using Activated Carbon

- Regarding Activated Carbon, one product has been applied numerous times for PFAS
- Colloidal Activated Carbon (PlumeStop)

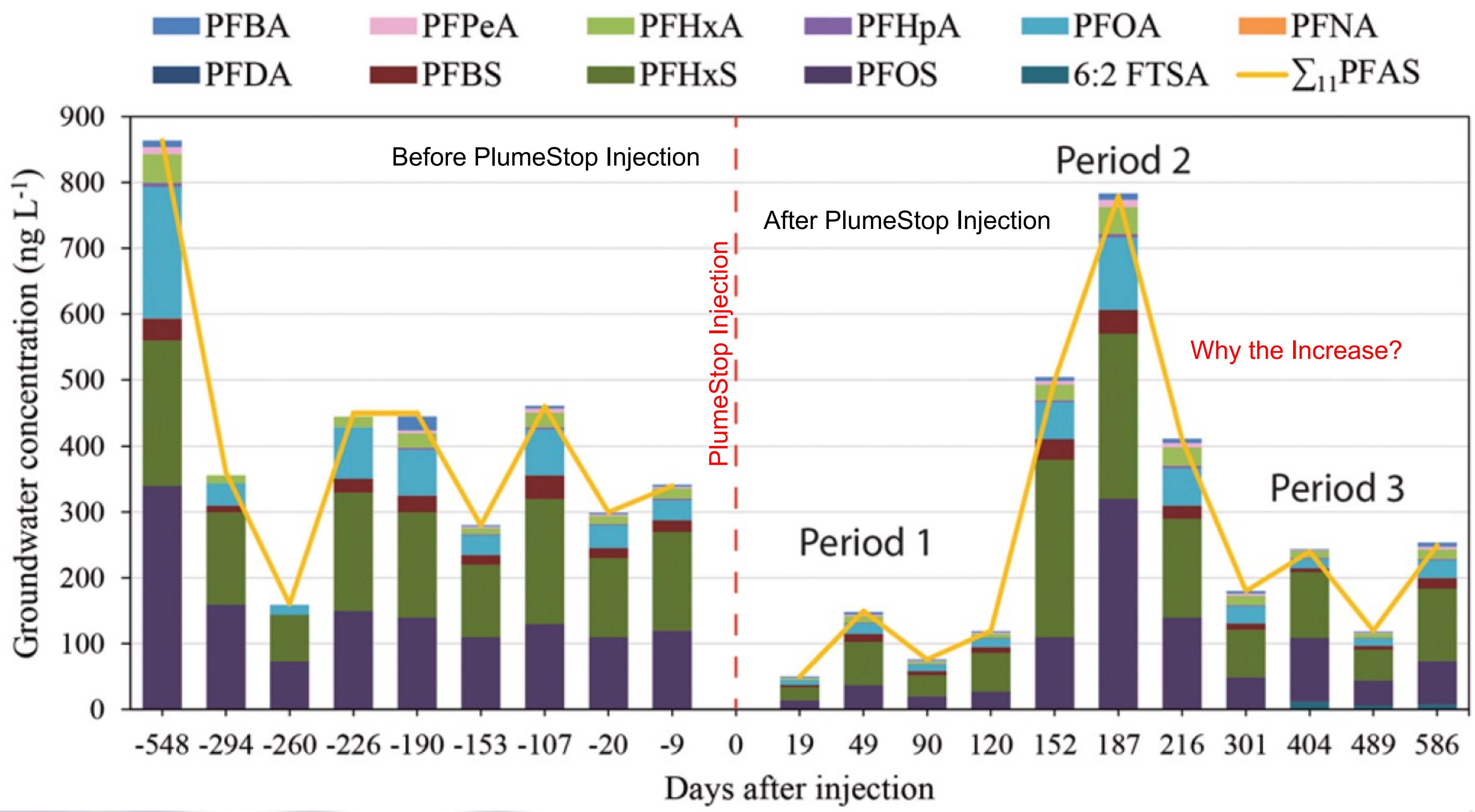


Plumestop Data
from the Manufacturer

Credit: Regenesis

Remediating PFAS, in-situ with AC

Colloidal Activated Carbon (PlumeStop) Published Case Study



G.Niarchos *et al.*, 2023 – "In-situ application of colloidal activated carbon for PFAS-contaminated soil and groundwater: A Swedish case study"

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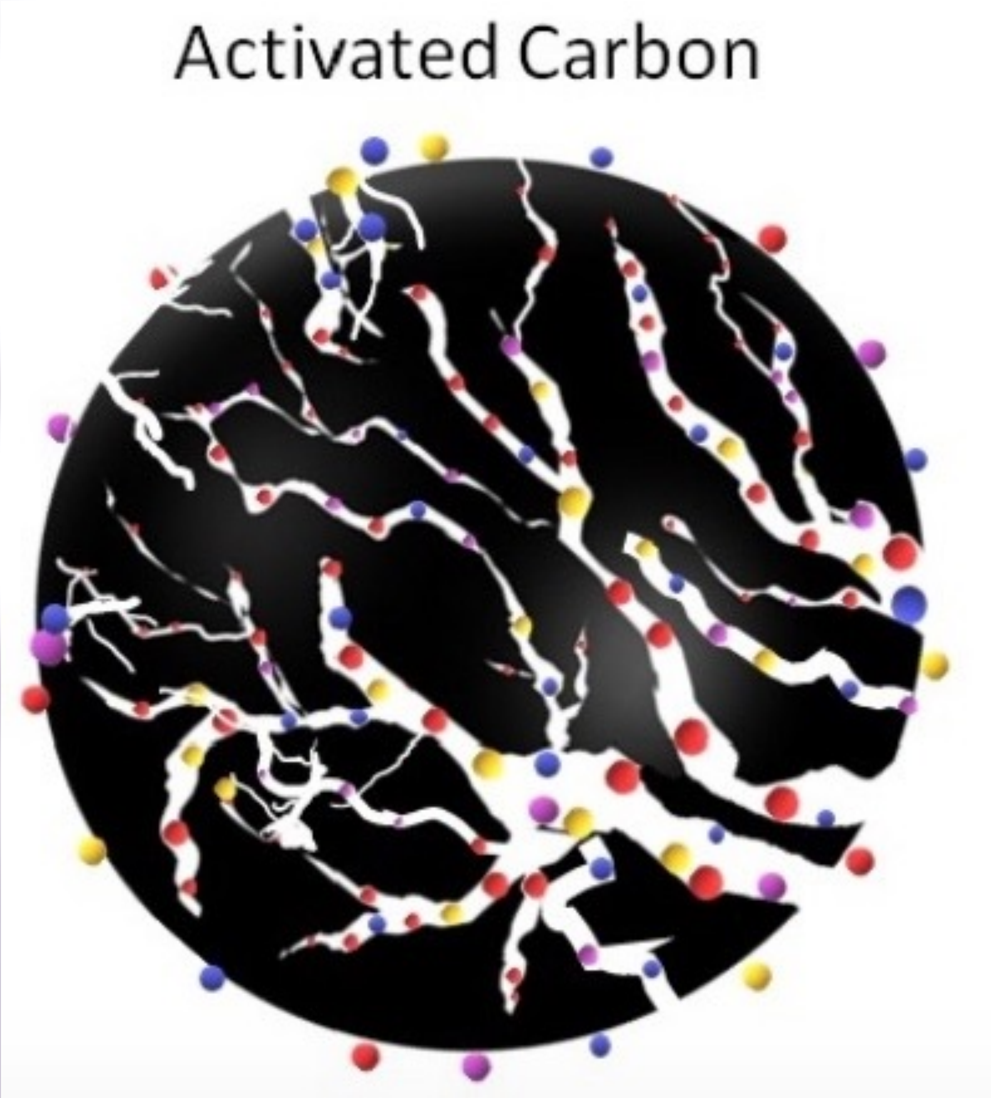
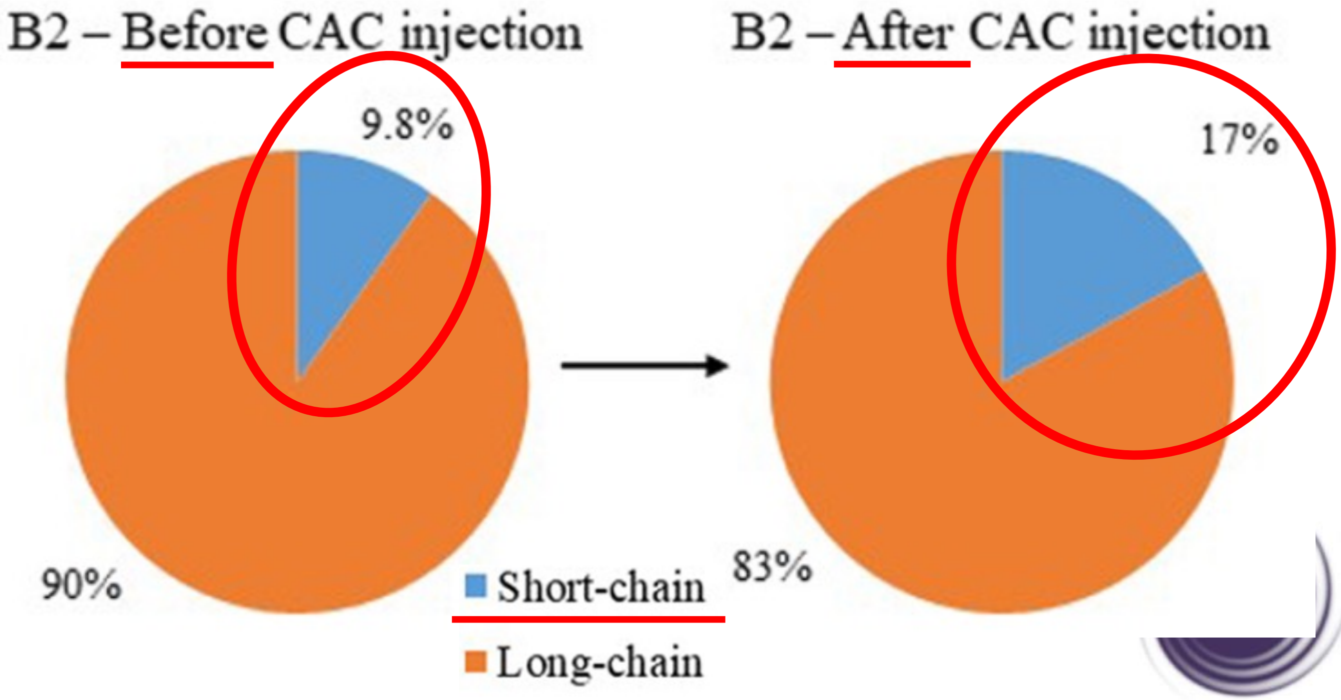
Remediating PFAS, in-situ with AC



Activated Carbon – Roll Over, or Competitive Adsorption

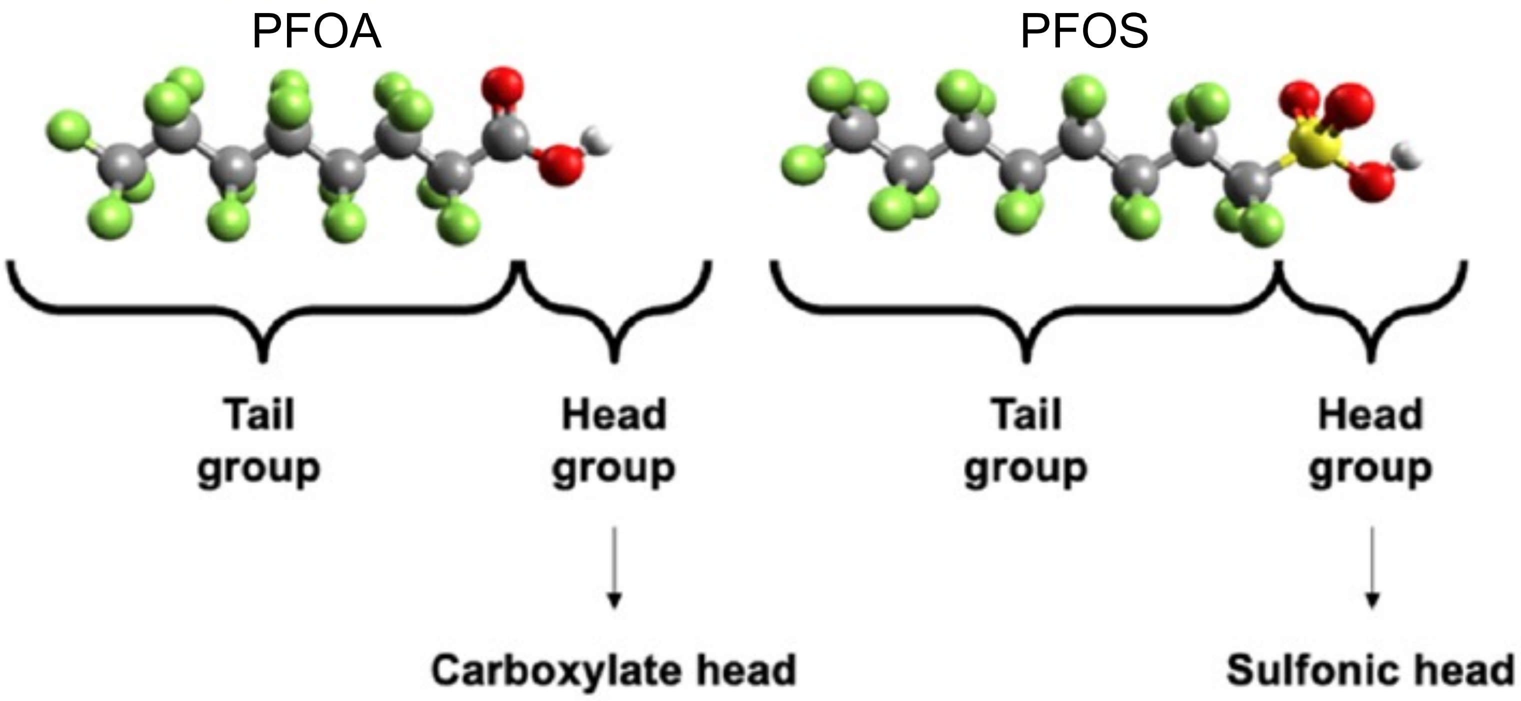
- PFAS >4,500 compounds
- Long Chain PFAS
  - Preferentially adsorbed
- Short Chain PFAS
  - Get "kicked off" the carbon

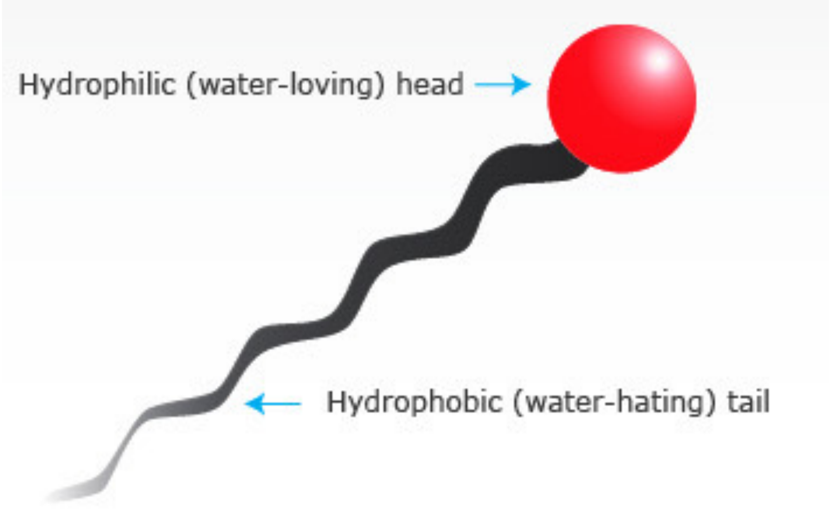


Remediating PFAS, in-situ with Modified Clay

- Activated carbon has a Competitive Adsorption mechanism
- Modified clay (FluoroSorb®) does not

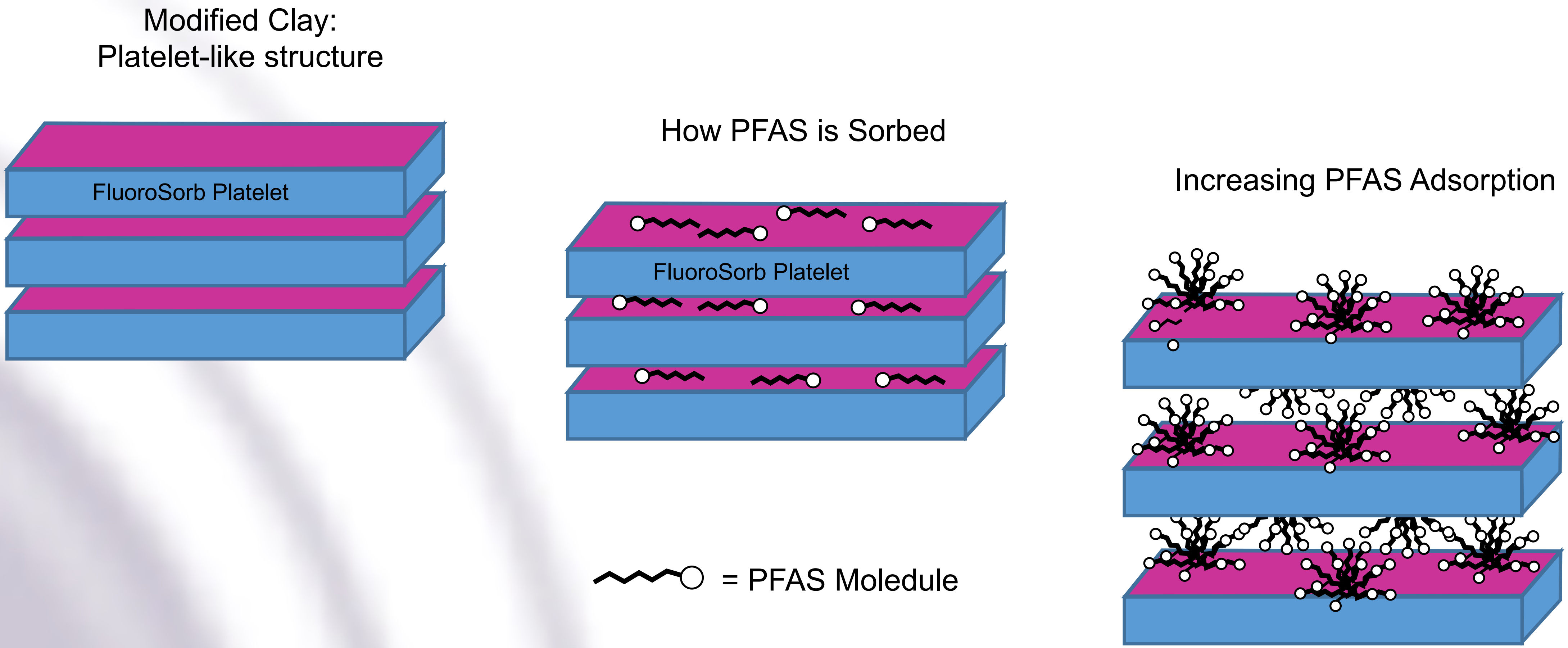
- The modified clay adsorption is ion exchange as well as hydrophobic attraction
- PFAS is surfactant-like, thus partially hydrophobic





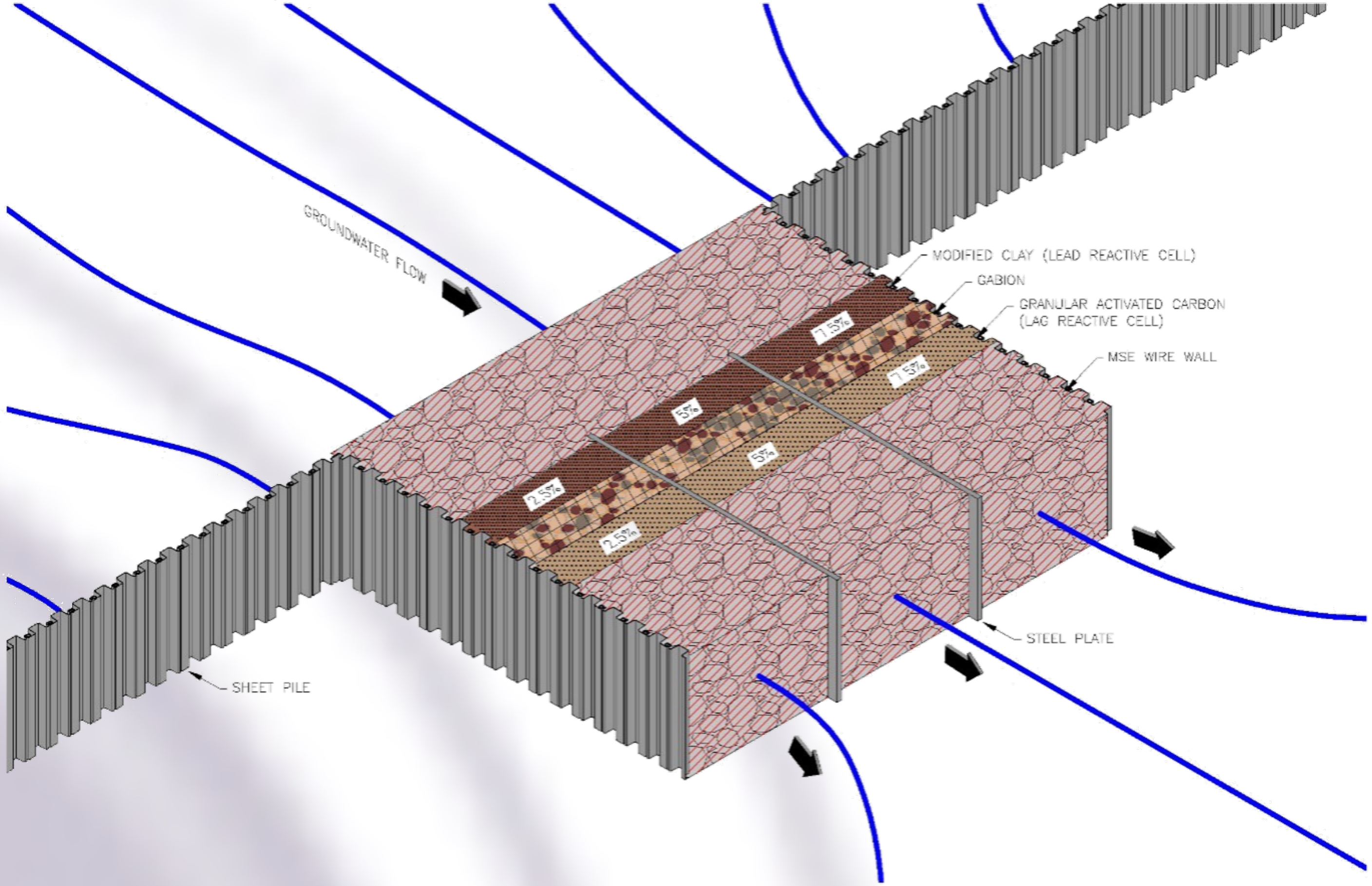
Remediating PFAS, in-situ with Modified Clay

- Modified Clay Sorption Mechanism



Credit: CETCO

Remediating PFAS, in-situ with Modified Clay



Lead Reactive Cells

(First 90 days)

	2.5% MC	5% MC	7.5% MC
Vol. of Treated Water (L)	~9,700 L	~9,200 L	~9,050 L
Flux ∑PFAS (µg)	~160,300	~152,900	~149,700
Adsorbed ∑PFAS (µg)	~90,800	~148,200	~149,400
Removal Efficiency (%)	**57%**	**97%**	**99.8%**

(Second 90 days)

	2.5% MC	5% MC	7.5% MC
Vol. of Treated Water (L)	~9,100 L	~8,250 L	~8,500 L
Flux ∑PFAS (µg)	~236,600	~215,250	~220,040
Adsorbed ∑PFAS (µg)	~235,600	~215,070	~220,020
Removal Efficiency (%)	**99.6%**	**99.9%**	**100%**

Credit: SNC-Lavalin

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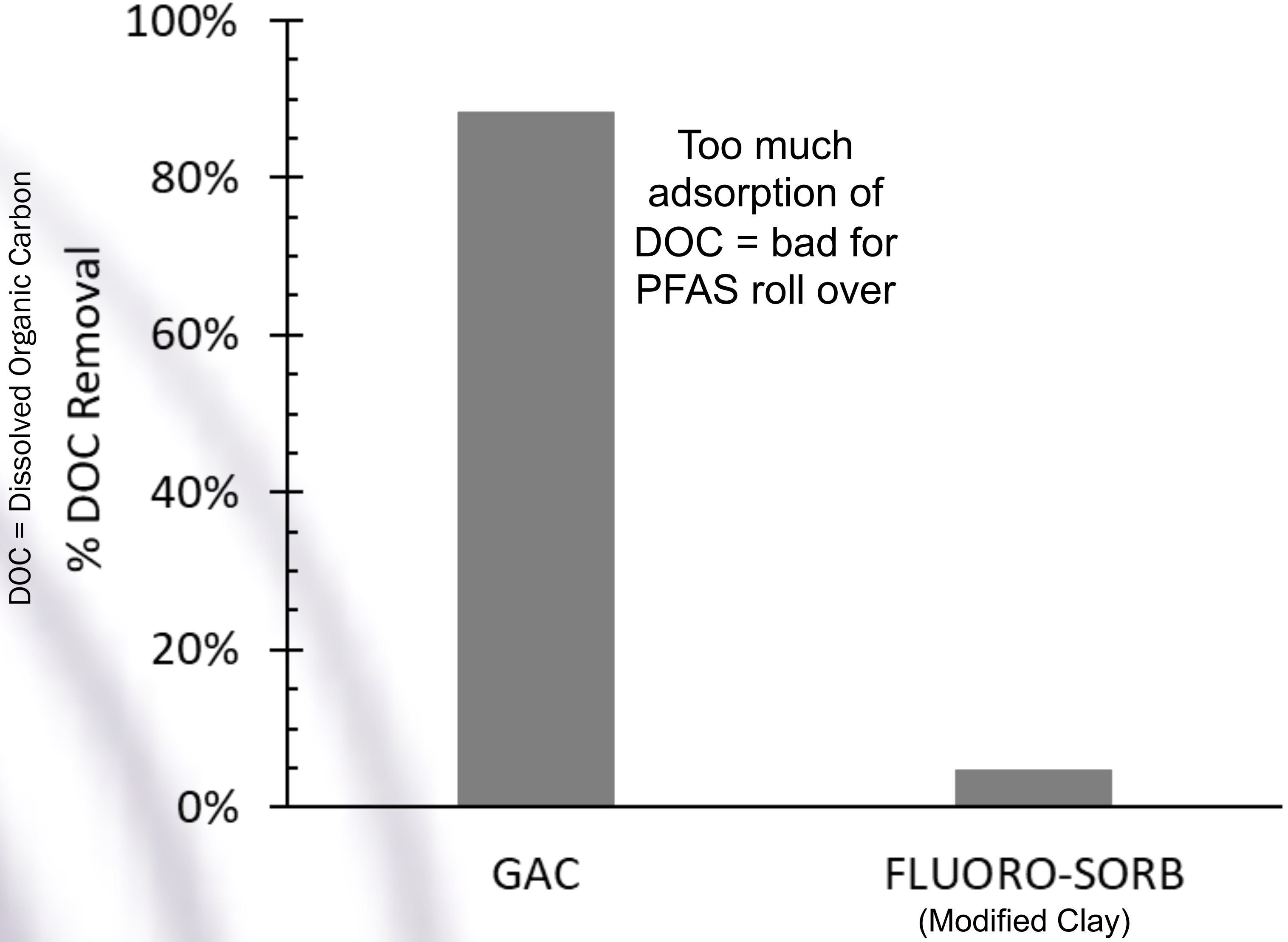
Remediating PFAS, in-situ – Activated Carbon vs Modified Clay

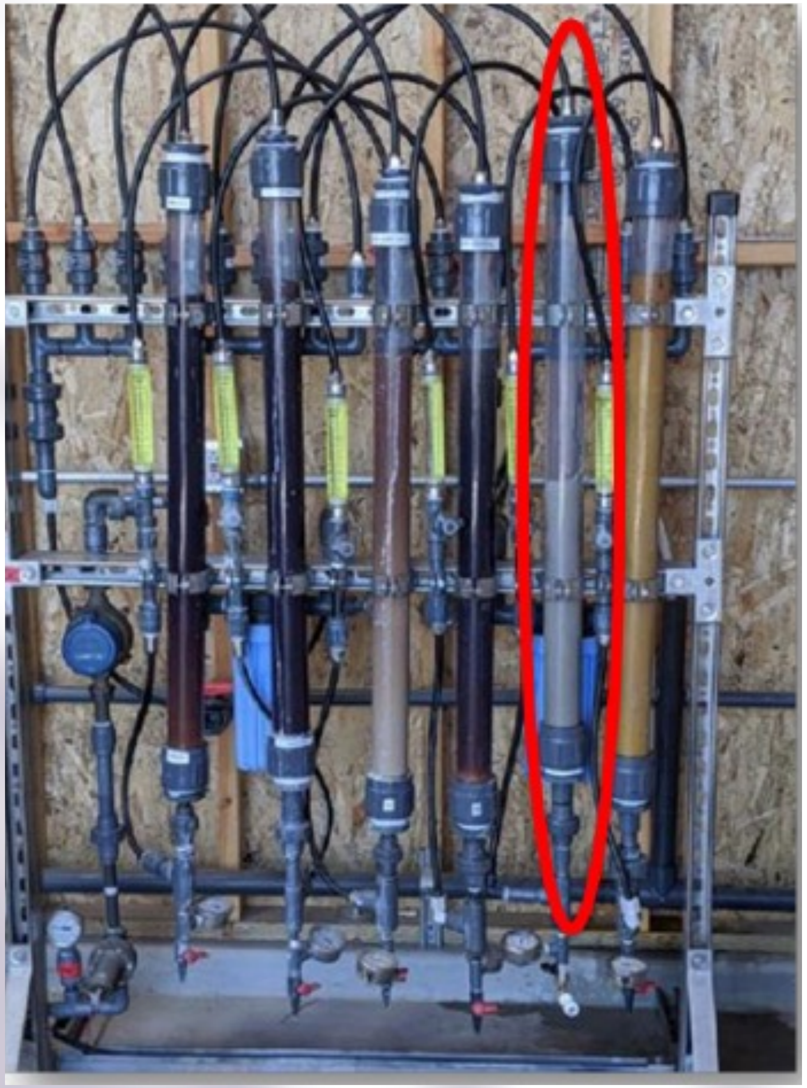
- Groundwater has Dissolved Organic Carbon (DOC) naturally present

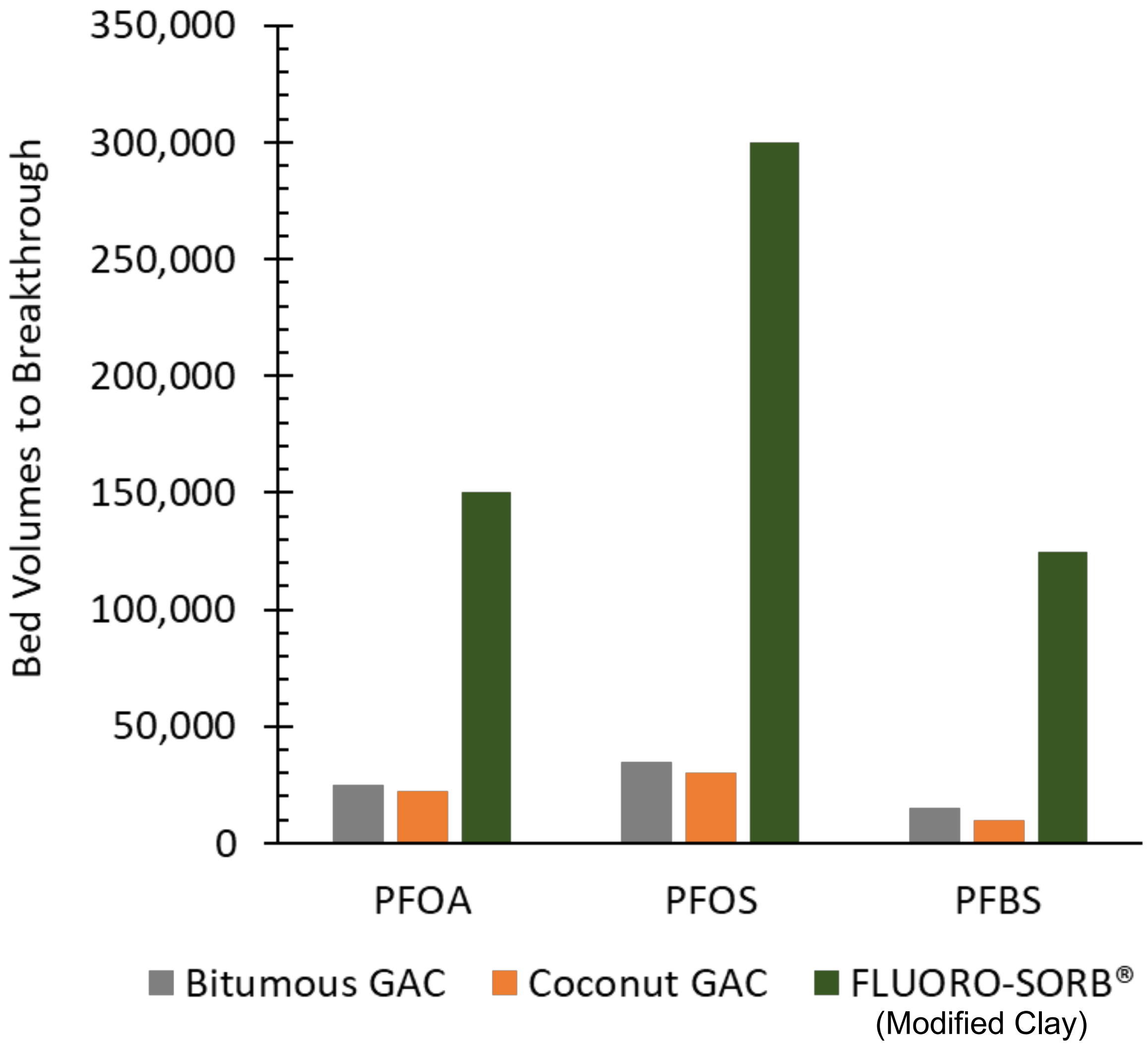


Jacobs "PFAS Treatment Testing Study Final Report" June 2, 2021

Remediating PFAS, in-situ – Activated Carbon vs Modified Clay

- Capacity of PFAS adsorption (How long will it hold onto the PFAS?)





Orange County Water District (2021). PFAS Phase 1 Pilot Scale Treatment Study Final Report. March 24, 2021.

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Remediating PFAS, in-situ – Using Injectable Modified Clay (Fluoro-Sorb®)

- Modified Clay, specifically Fluoro-Sorb®, has some advantages
- Create a suspension with potable water and inject into all geologies
- Will not swell or block formation
- Stays put where placed (non-soluble, non-mobile)
- QA/QC testing

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Closing Thoughts

In-Situ Remediation of PFAS

- PFAS remediation is in a development stage
  - Research, experimentation, pilot tests
  - Very exciting times
- PFAS Destruction is difficult
  - We have to be careful with precursors
- Interim remedial measures are necessary right now
- Two proven in-situ injectable approaches, using:
  - Activated Carbon (specifically, colloidal activated carbon)
  - Modified Clay (specifically, Fluoro-Sorb®)
- Current Assessment:
  - Activated Carbon – In-Situ PFAS Remediation Approach 1.0
  - Modified Clay – In-Situ PFAS Remediation Approach 2.0

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Questions?

Thank You for
Your Time

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