Foam Fractionation for PFAS Removal

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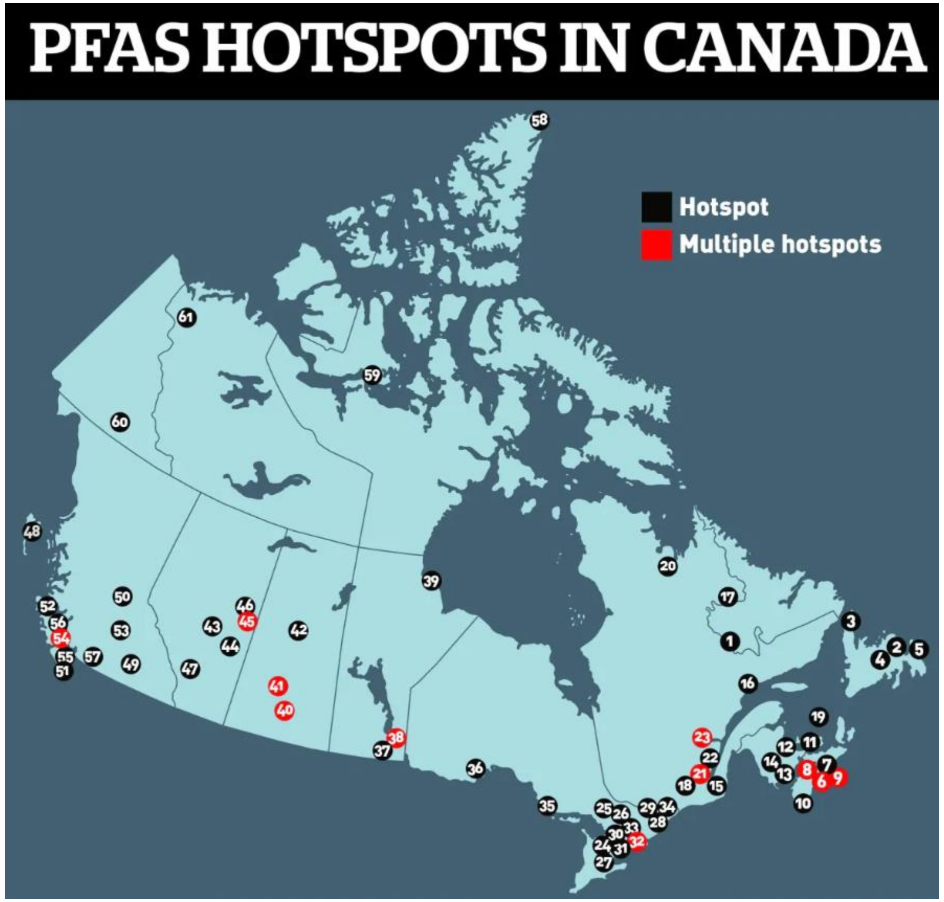
Why Are We Discussing This?

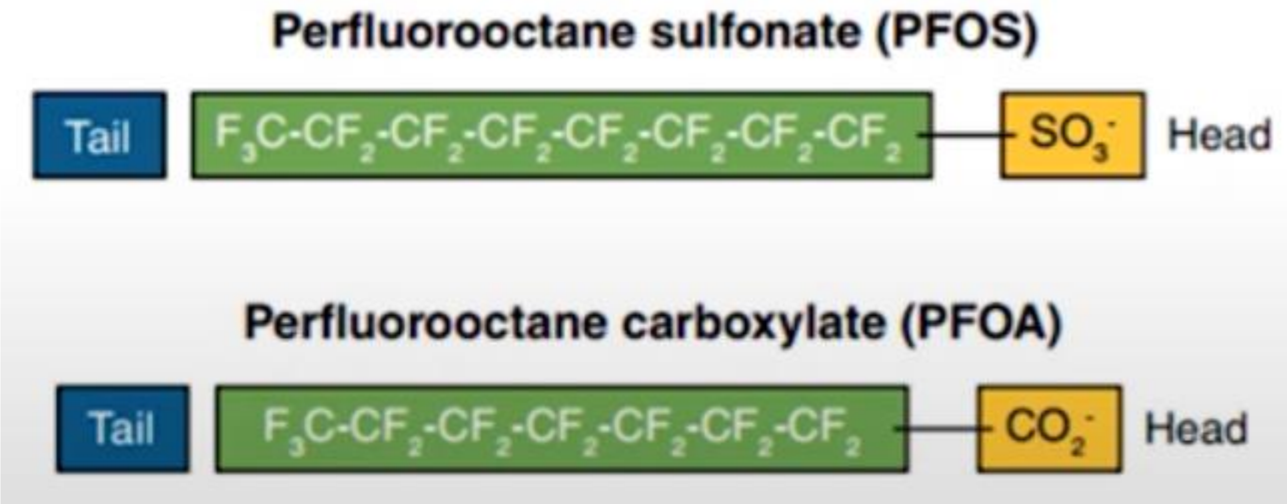
- PFAS substances are a significant problem
- Difficult to remove and/or destroy
- Effective treatment technologies needed
- Foam Fractionation – a new spin on an older technology
  - Variety of liquid waste streams
  - Short- and long-chain PFAS removal
  - Simple
  - Potential for significant waste and liability reduction



Presentation Outline

- Foam Fractionation (FF) – how does it remove PFAS?
- Advantages of the technology
- Effects on background chemistry
- Case studies – landfill leachate and industrial wastewater
- Where does FF fit in the treatment train?
- Can FF remove short-chain PFAS?
- Managing the waste foamate: pairing with destruction
- How do they work?
- Real-life examples

Most PFAS are Surfactants



From ITRC

Hydrophobic Tail

Hydrophyllic Head

How FF Works…

PFAS-rich foam (foamate) for further treatment or direct destruction

PFAS-impacted Influent

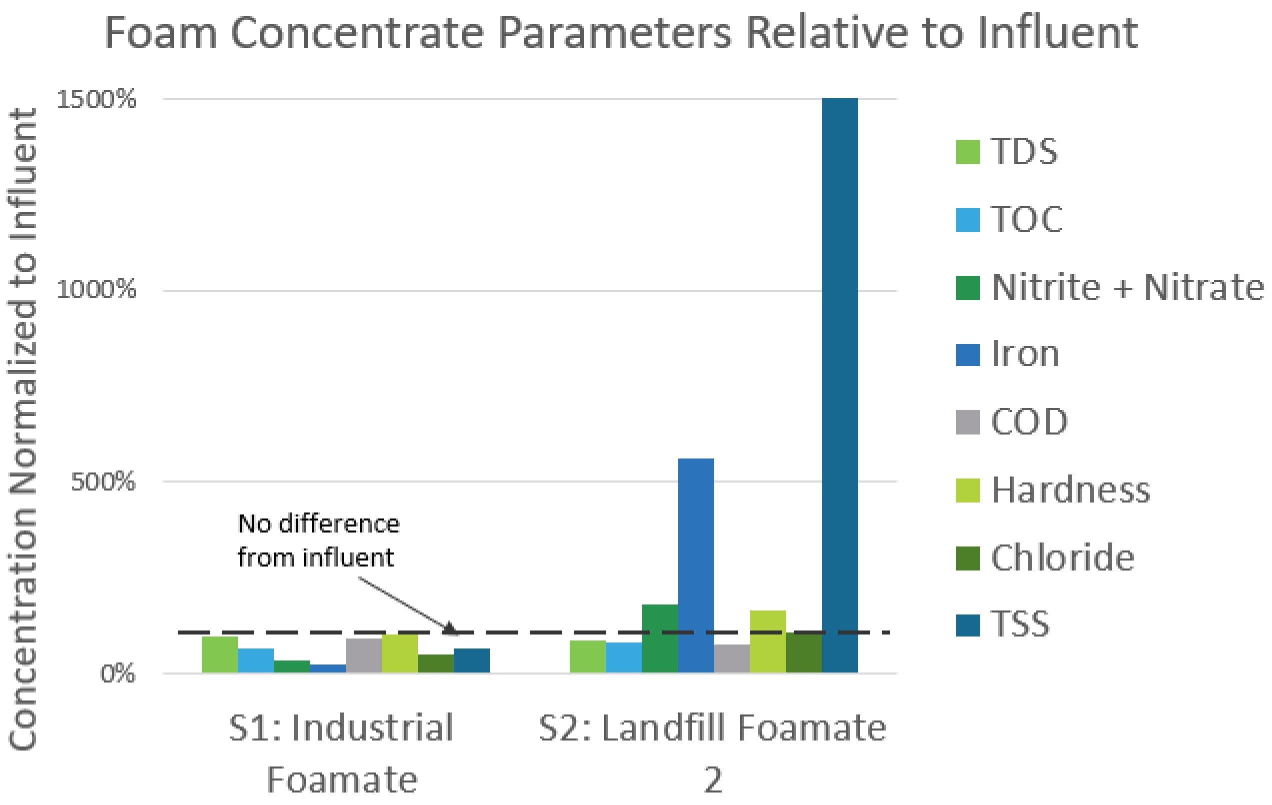
Treated water (raffinate) with majority of PFAS removed

Air Flow

Foam Fractionation Advantages:

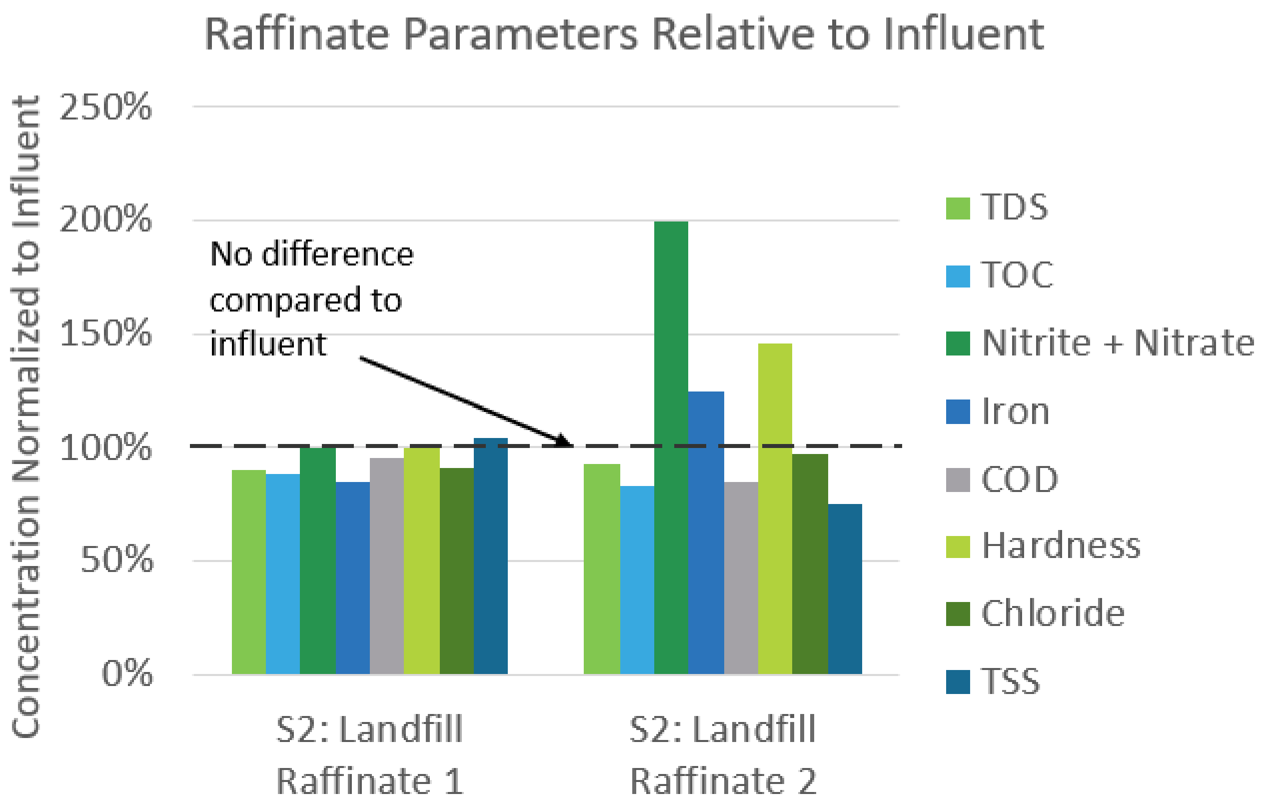
- Agnostic to elevated TDS, NOM, etc.
- Simple operation, few moving parts
- Nothing to clog or build diff. pressure
- Low energy, low pressure
- Low operating expense
- Can be a very effective pretreatment step for difficult-to-treat waters:
  - Landfill leachate
  - Industrial wastewater
  - Groundwater hot spots

Effects on Background Chemistry: Foamate



- Most parameters unchanged
- Industrial source foamate:
  Iron and nitrate/nitrite were depleted >50%
- Landfill source foamate:
  TSS and iron enhanced >500%

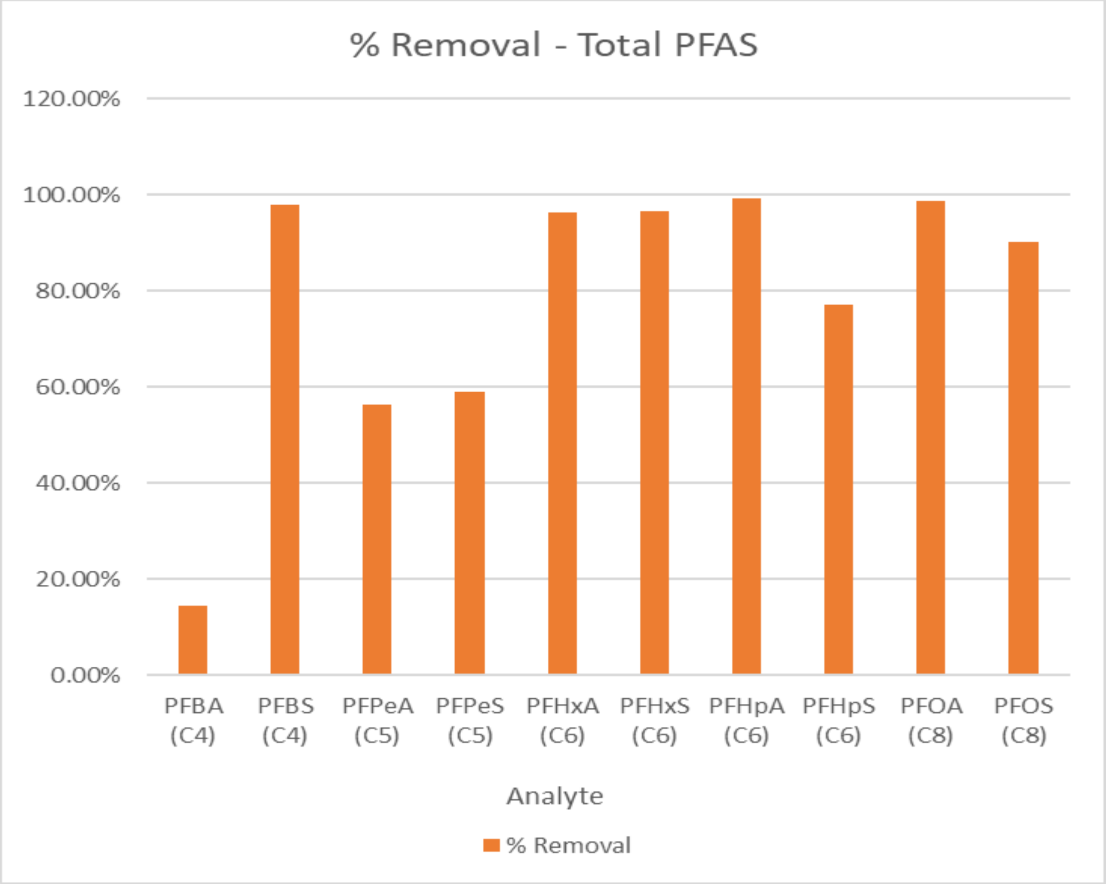
Effects on Background Chemistry: Treated Water



- Most parameters unchanged
- Modest reductions in TSS translated to large increase in TSS in foamate
- Other apparent increases/ decreases in raffinate were not seen as decreases / increases in foamate

Recent FF Pilot Test - Landfill Leachate

Analyte	Influent (ng/L)	Effluent (ng/L)	Percent Removal
PFBA (C4)	1,503	1,285	14%
PFBS (C4)	1,944	40	98%
PFPeA (C5)	1,507	660	56%
PFPeS (C5)	62	25	59%
PFHxA (C6)	2,735	102	96%
PFHxS (C6)	337	11	97%
PFHpA (C6)	723	4.9	99%
PFHpS (C6)	4	0.8	77%
PFOA (C8)	1,166	16	99%
PFOS (C8)	115	11	90%



Short-chain PFAS removal (<C7) more challenging than long-chain PFAS (>C7)

Boosting Agents Can Enhance PFAS Removal

Analyte	Influent (ng/L)	Without FF-1 Boost	Percent Removal	With FF-1 Boost	Percent Removal
PFHxA	387	271	30%	< 13	97%
PMPA	8,961	3.325	64%	< 63	99%
PolyF - 1	3,037	397	87%	< 65	98%
PolyF - 2	11,296	8,960	21%	< 63	99%
PFOA	828	117	86%	< 63	92%

Without boosting agent 21 – 87% removal

With boosting agent 92 – 99% removal

Short- and long-chain removal enhancement

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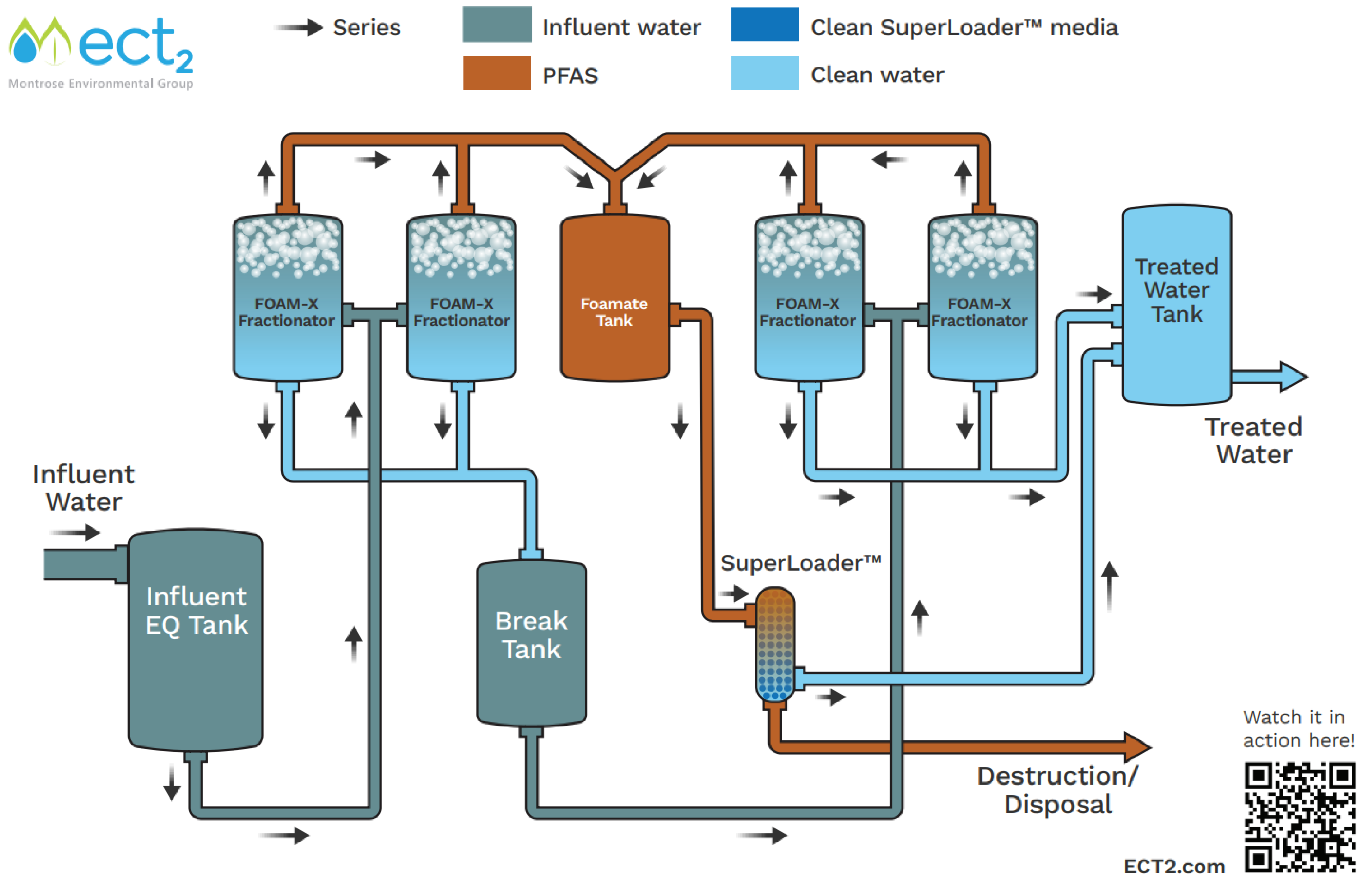
So Where Does Foam Fractionation Fit In?

It Depends……..

- Influent PFAS concentrations
- Short-chain vs. long-chain PFAS present
- Background chemistry
- Purpose: pretreatment vs. treatment
- Final remedy vs. interim action
- Cost
- **Regulatory criteria**

Field pilot testing can inform suitability of technology…….

Mobile Pilot System



Mobile Pilot System in Action

Example of Full-Scale System

Onsite PFAS Destruction Technologies

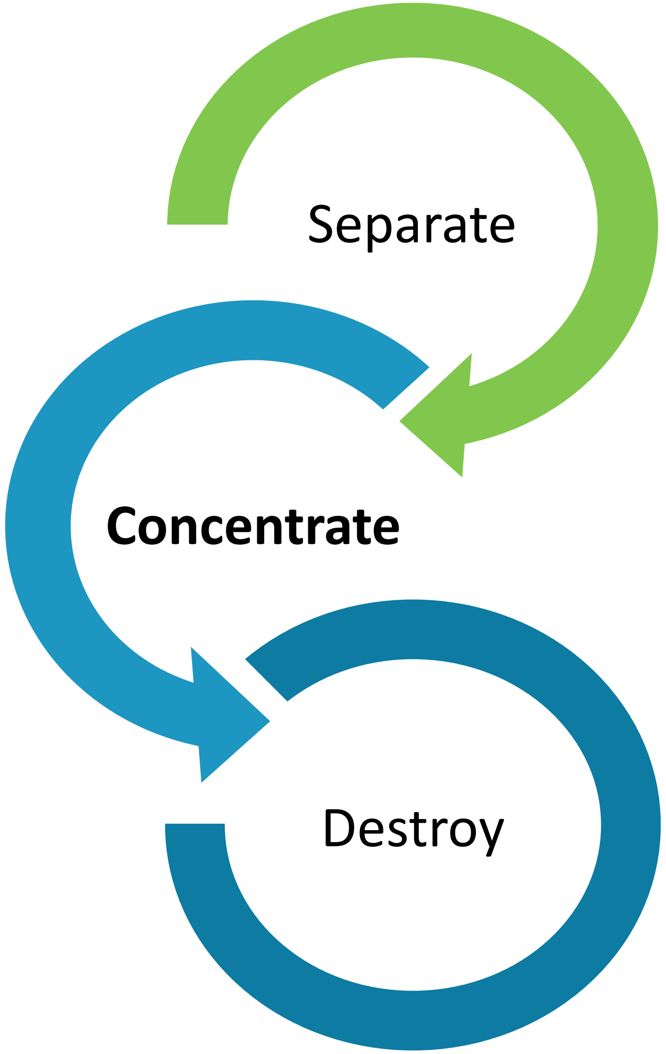
- Plasma
- Electrochemical oxidation
- Supercritical water oxidation
- Hydrothermal alkaline treatment
- Micelle-assisted photocatalytic reduction
- Electron beam
- Advanced oxidation processes
- Sonolysis
- UV-sulfite
- Zero-valent iron
- Alkali metal reduction
- Biodegradation

Lots of progress in last 5 years, as incineration is falling out of favor

What’s the Key to Making them Practical?

- Reduce liquid volume to be treated
- Increase concentration of PFAS
- PFAS concentration options:
  - Membrane treatment
  - Regenerable Ion Exchange (IX) Resin
  - Foam Fractionation

Complete PFAS Treatment



Plasma

- Ionized gas destroys PFAS by promoting powerful reduction and oxidation reactions
- Emerging as a promising technology for PFAS destruction
- DMAX has demonstrated greater than 99% destruction of PFAS at multiple sites in combination with ECT2’s regenerable IX resin technology
- Developers:
    - DMAX/Clarkson University
    - OnVector
    - Inentec/MIT
    - Drexel, U. of Michigan

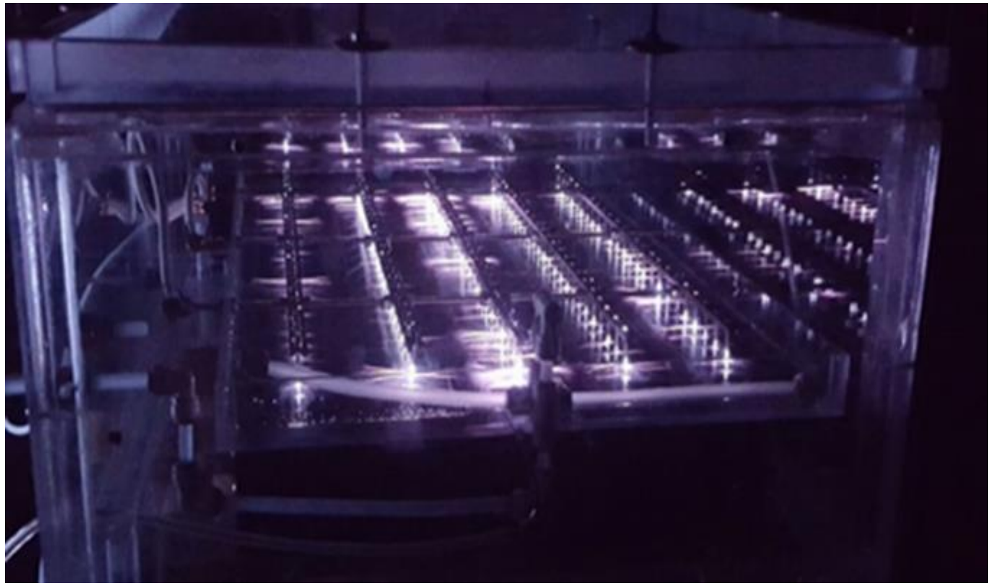


Photo credit: DMAX

Electrochemical Oxidation (EO)

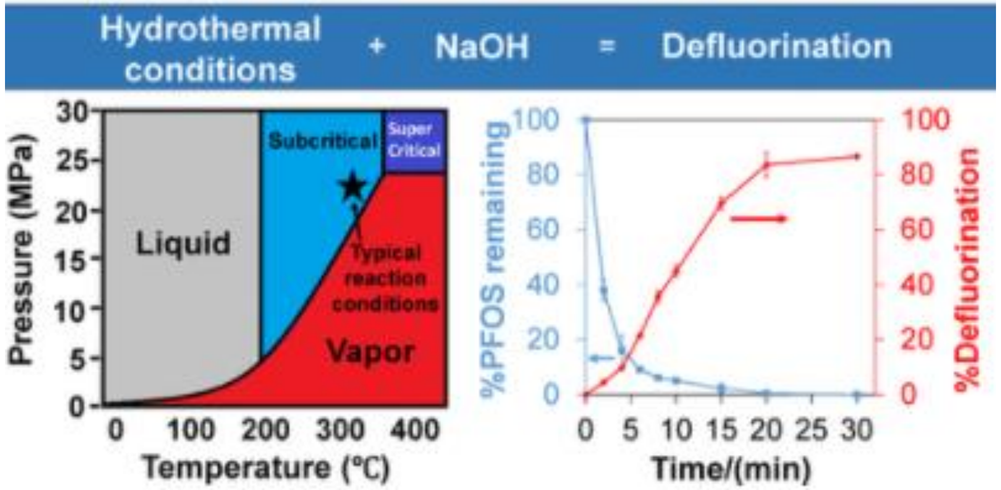
- Direct electron transfer at anode, indirect oxidative species generation
- EO is emerging as a successfully demonstrated technology for PFAS destruction
- AECOM/ U. Georgia
  - DE-FLUORO™ Process
  - Successfully demonstrated in combination with ECT2's regenerable resin technology (on-site pilot project at Wright-Patterson Air Force Base)

Photo credit: AECOM

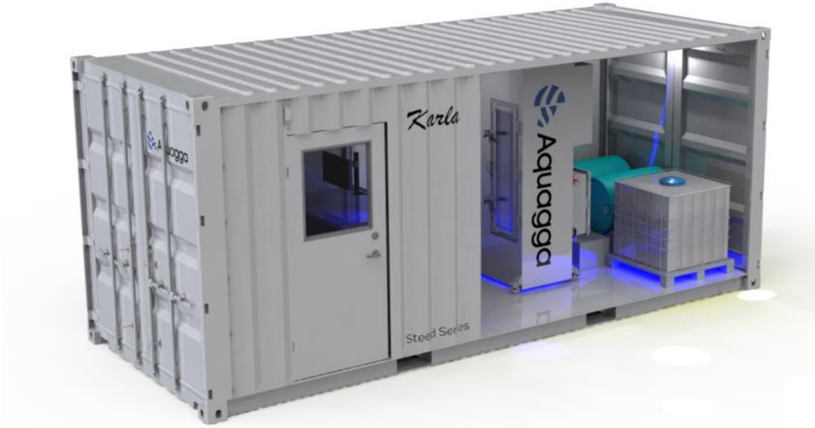
Hydrothermal Alkaline Treatment (HALT)

- Sub-critical water oxidation process at high pH
- Have demonstrated complete mineralization, including short chains
- Simpler than supercritical water oxidation; operated at lower temperature and pressure; can be chemical intensive

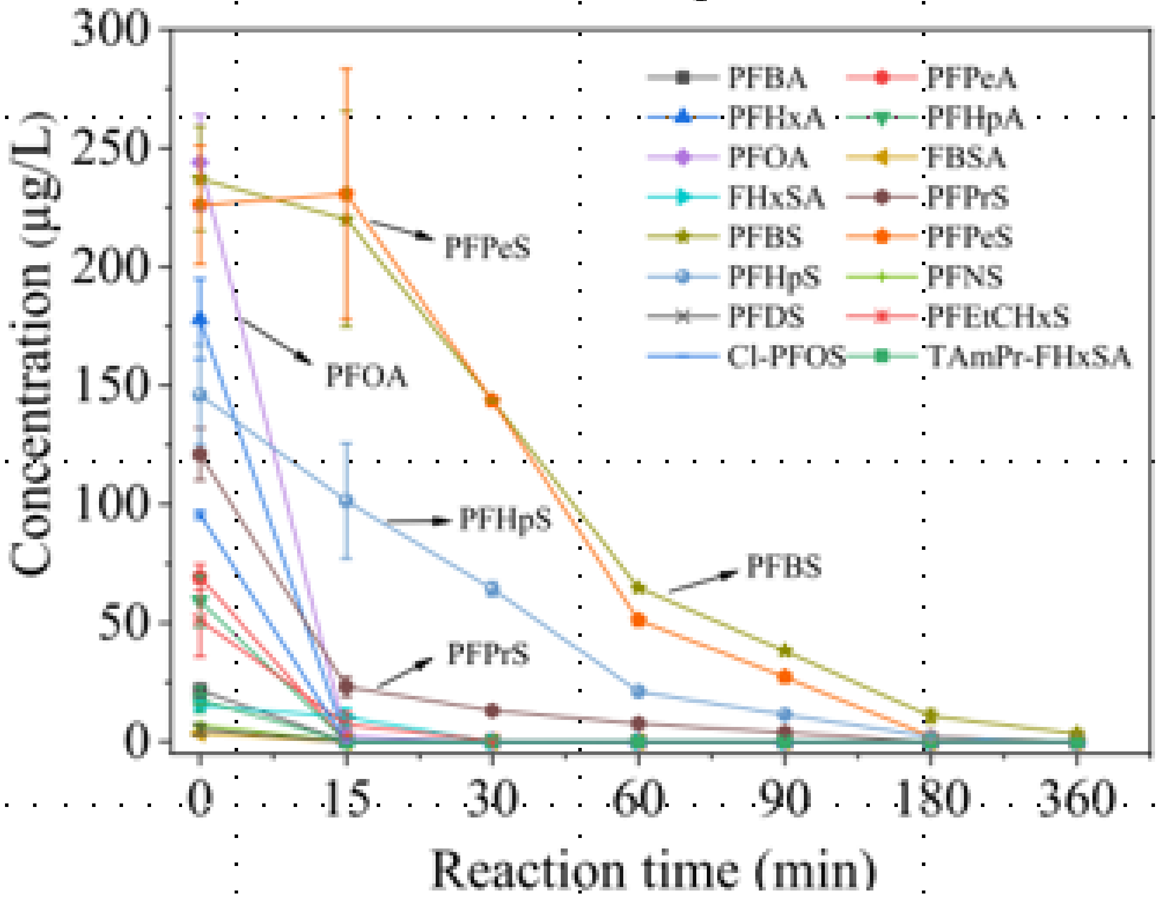
Developer: Colorado School of Mines and Aquagga



Environ. Sci. Technol. Lett. 2019, 6, 10, 630–636



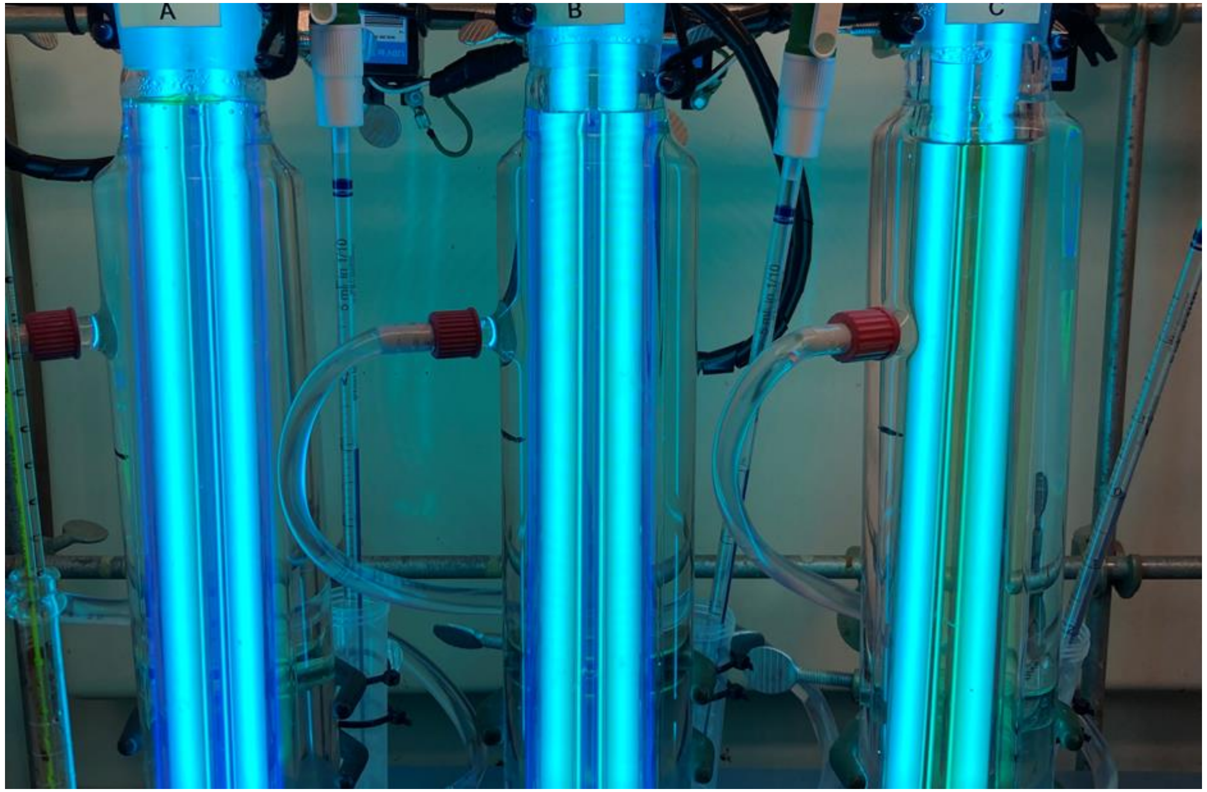
HALT Applied to AFFF – Disappearance of all Short Compounds



Effective and rapid treatment of short and long chain PFAS

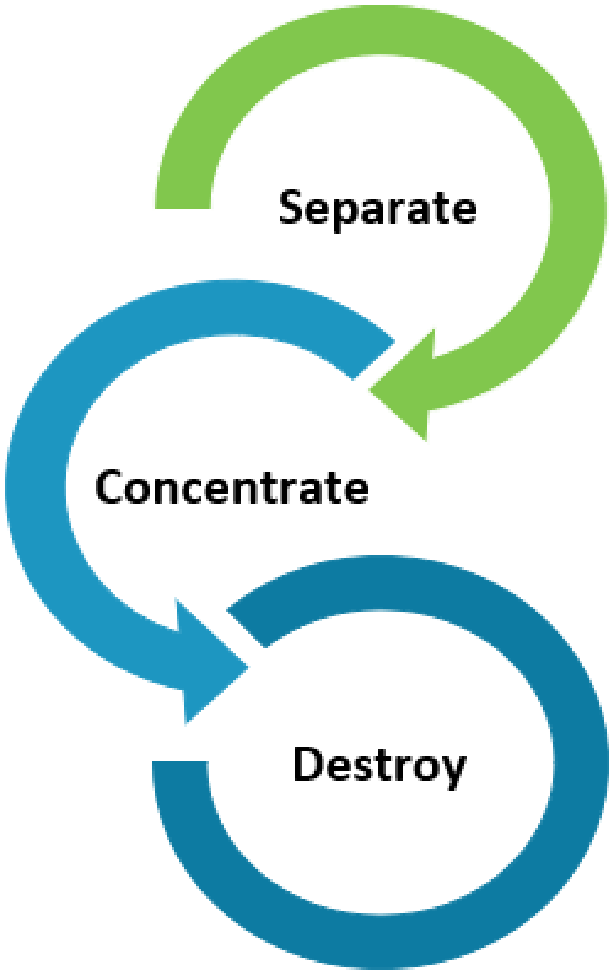
Micelle-Assisted Photoactivated Reductive Defluorination

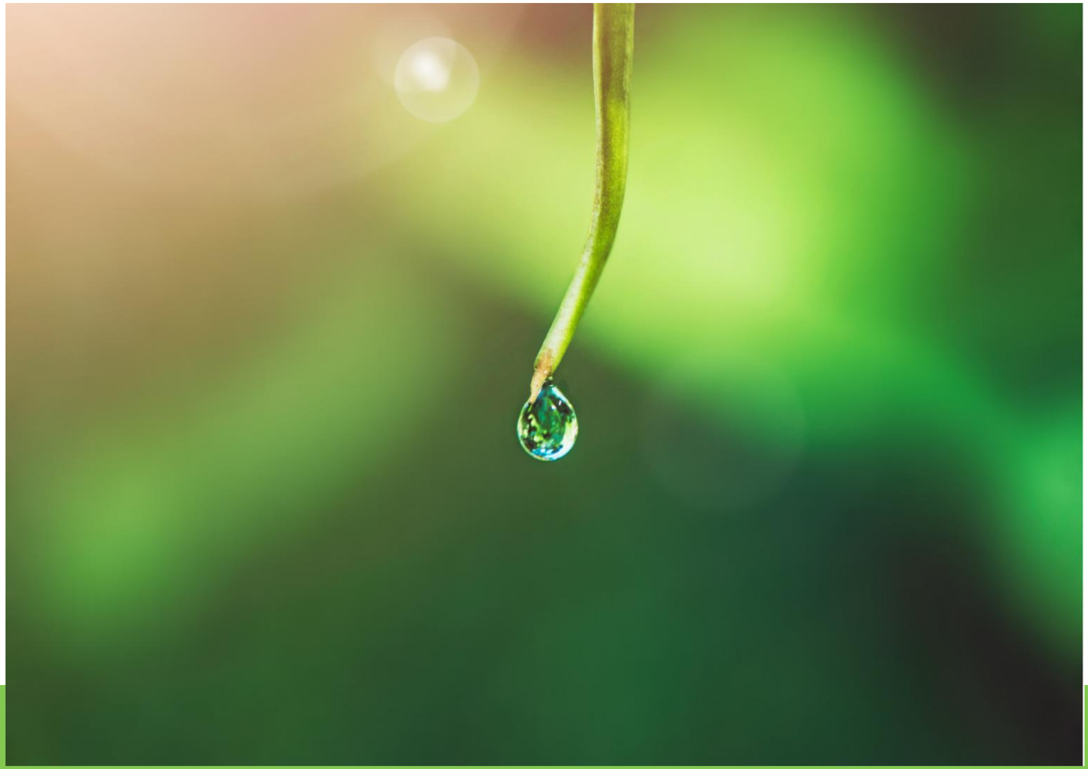
- New technology, showing promise
- Formation of the micelle reactive cage accelerates the reaction rate
- Reaction rate claimed to be approximately 40 times faster than competing technologies
- Low energy use
- **Enspired Solutions** is commercializing the technology



Summary

- You can't destroy PFAS without concentrating it
- Foam fractionation can be a cost-effective means to remove and concentrate PFAS waste
- Not a silver bullet – depends upon objectives and water characteristics
- Significant work underway to refine process and meet stringent cleanup goals
- Q&A





Questions?

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