Innovative Waste Minimization During PFAS Contaminated Water Remediation

ect2

Montrose Environmental Group

NORTHEAST CONFERENCE

THE SCIENCE OF PFAS:

Public Health & The Environment

Outline

Innovative Waste Minimization During PFAS Contaminated Water Remediation

- **Onsite PFAS destruction technology comparison**
- **What's the key to making them practical?**
- **Options for minimizing PFAS waste generation**
  - Membrane treatment
  - Foam fractionation
  - Regenerable resin
- **Real life examples**
  - Separate
  - Concentrate
  - Destroy
  - Hub & spoke approach

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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 paired with AOP
- Zero-valent iron
- Alkali metal reduction

Lots of progress in last 5 years, as incineration and landfilling are falling out of favor

Technology Comparison

Not included: sonolysis, photocatalytic oxidation

	AOPs (not standalone)	**eBeam**	**Plasma (non-thermal)**	**UV sulfite paired with AOP**	**Hydro thermal Alkaline**	**Electro-chemical Oxidation**	**Supercritical Water Oxidation**
Simplicity of Implementation	High	Low	Moderate	High	Moderate	Moderate/ High	Moderate
Reaction kinetics (reported to date)	Minutes to Hours	Minutes	Hours	Hours	Minutes	Hours	Minutes
Mechanism	Ox	Red/Ox	Red/Ox	Red/ Ox	Nucleophilic substitution	Ox	Ox
High brine performance	Variable	Unknown	Fair – kinetically slower in high TDS	Good	Good	Good	TDS >2% is problematic
Optimal pH	Variable	Basic to Highly basic	Not pH sensitive	Highly Basic (12)	pH >14	Neutral to Basic	Basic
Biggest advantage	Simple	Mechanism, Fast	Somewhat simple	Simple, effective	Fast, effective, commercially available	Somewhat simple	Fast, effective
Biggest limitation	Limited efficacy	System footprint/ shielding	Surface reactions, TDS, speed	Speed, pH alteration	pH alteration, salt addition	Speed, perchlorate formation potential	System design, salting out, co-fuel needs
Mineralization Potential	Low	Moderate/ Unknown	Moderate but slow	High	High	Moderate	High

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
- DMAX/Clarkson University
  - Electrical discharge plasma
  - Max throughput up to 10 gpm
- OnVector
  - Plasma vortex
- Inentec/MIT
  - Plasma melter
- Drexel, U. of Michigan
  - Cold plasma

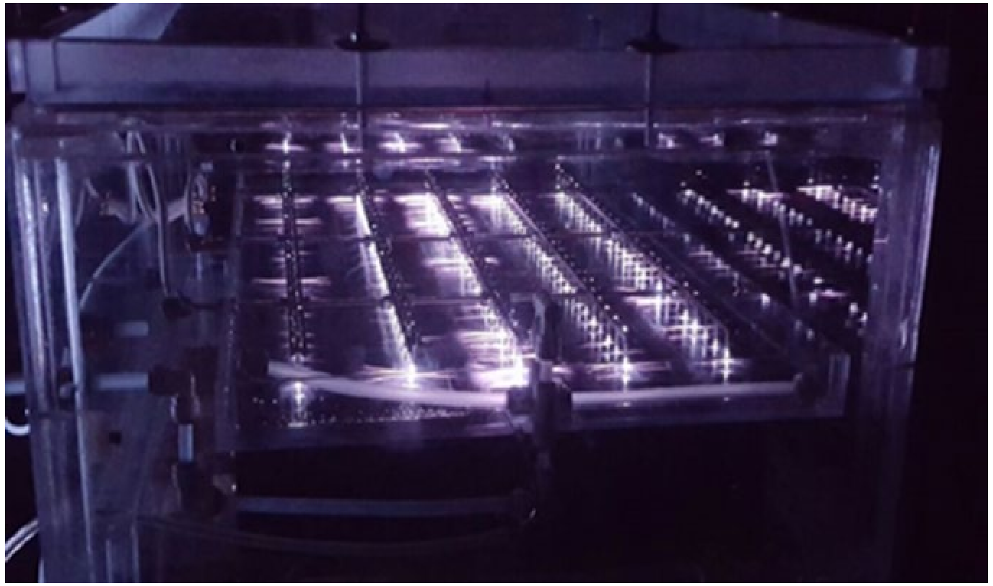


Photo credit: DMAX

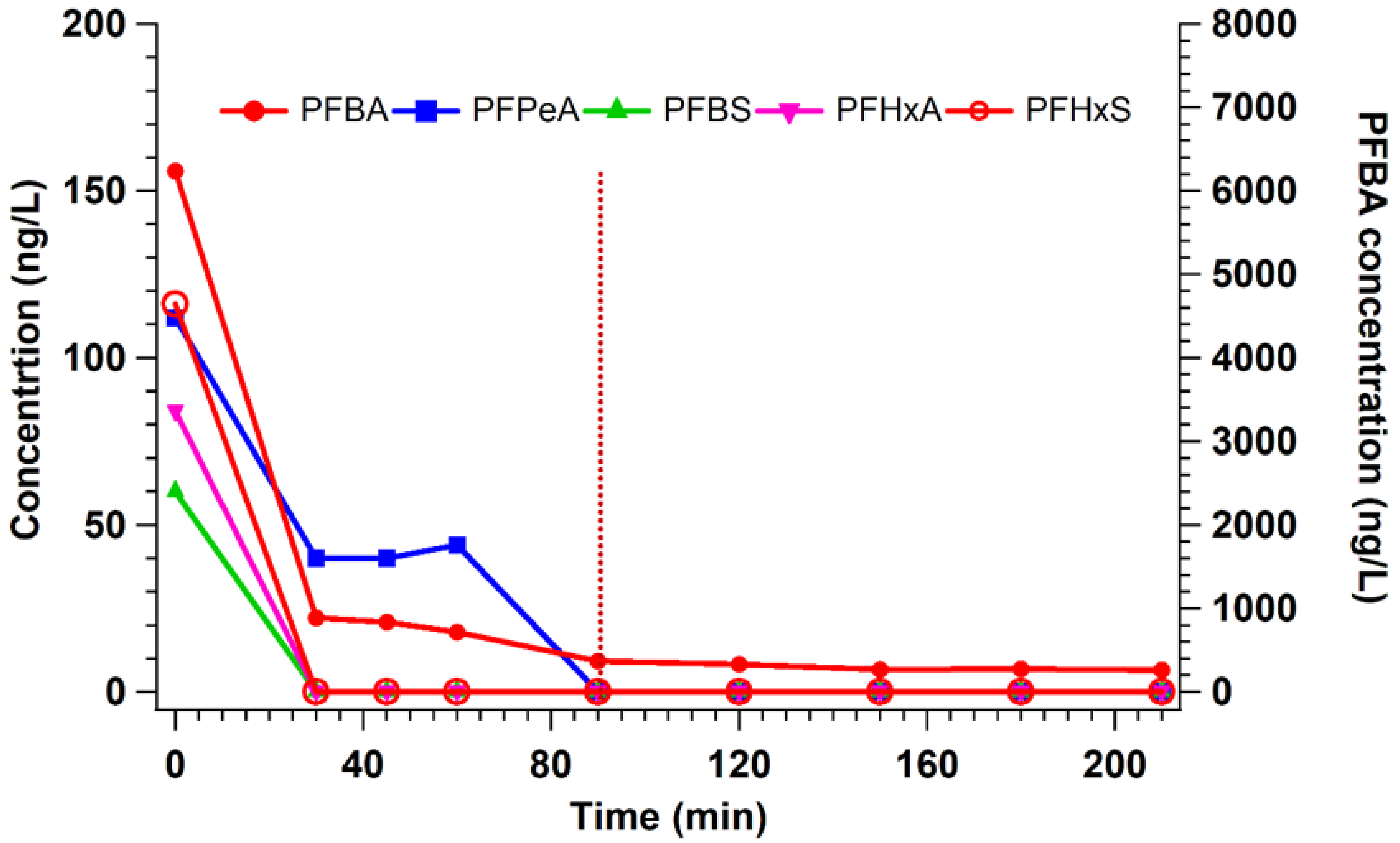


Figure 59 - PFAAs concentrations profiles in the presence of CTAB; CTAB concentration was increase to 0.2 mM after each 30 minutes

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 (onsite USAF pilot)
- Fraunhofer USA
  - Center for Coatings and Diamond Technologies manufactures Boron Doped Diamond (BDD) electrodes
- Aclarity
  - Massachusetts company
  - Demonstrated success on long-chain PFAS

Photo credit: AECOM

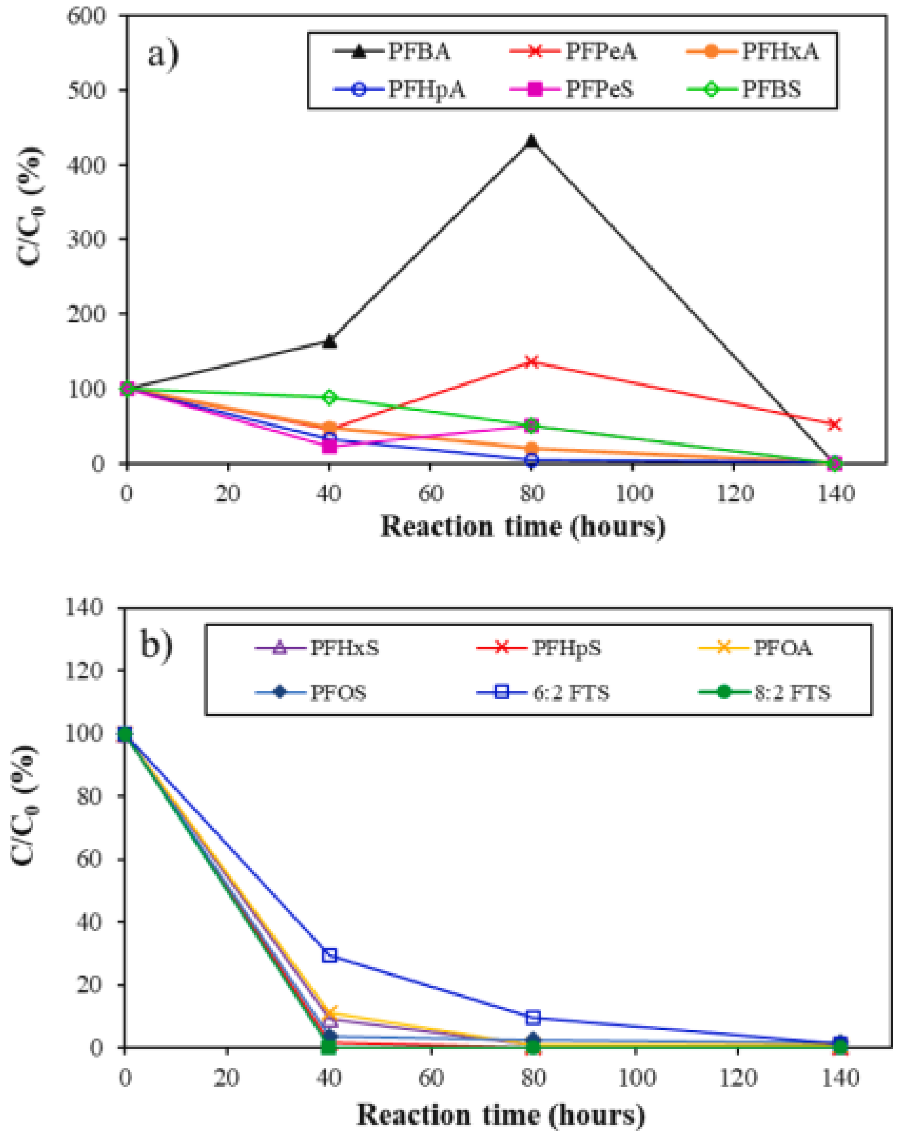


Fig. 6. Degradation profiles of (a) short-chain PFAAs and (b) long-chain PFAAs and precursors in SB1 treated using bench scale EO reactor at the University of Georgia.

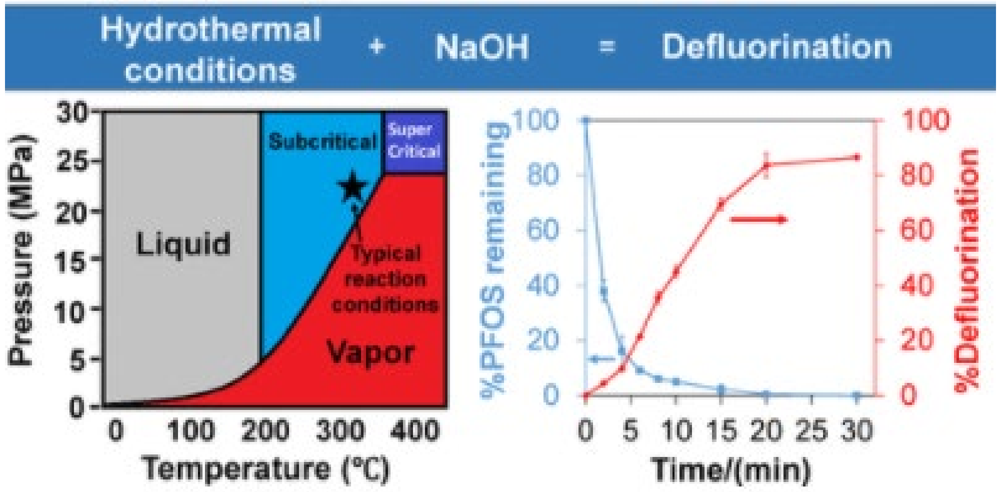
From Liang et al., 2022

Hydrothermal Alkaline Treatment (HALT)

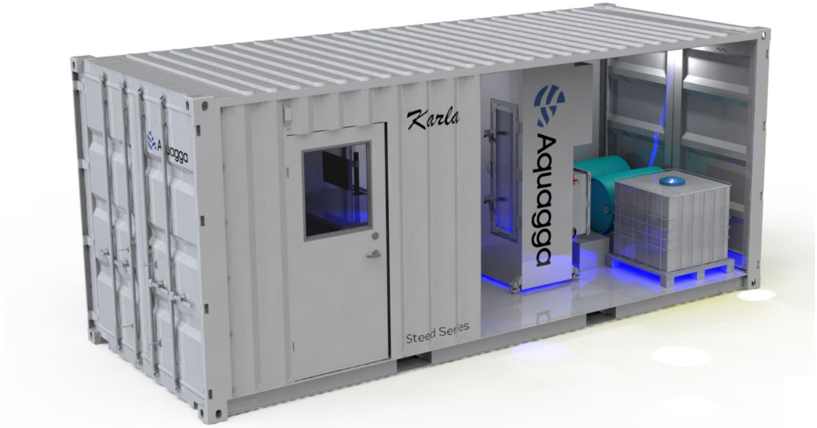
- Sub-critical water oxidation process at high pH
- Nucleophilic substitution of carboxylate with OH-, leading to decarboxylation and defluorination
- Have demonstrated <u>complete mineralization, including short chains</u>
- Simpler than supercritical water oxidation; operated at lower temperature and pressure
- Can be chemical intensive

Colorado School of Mines and Aquagga collaboration to bring the technology to market

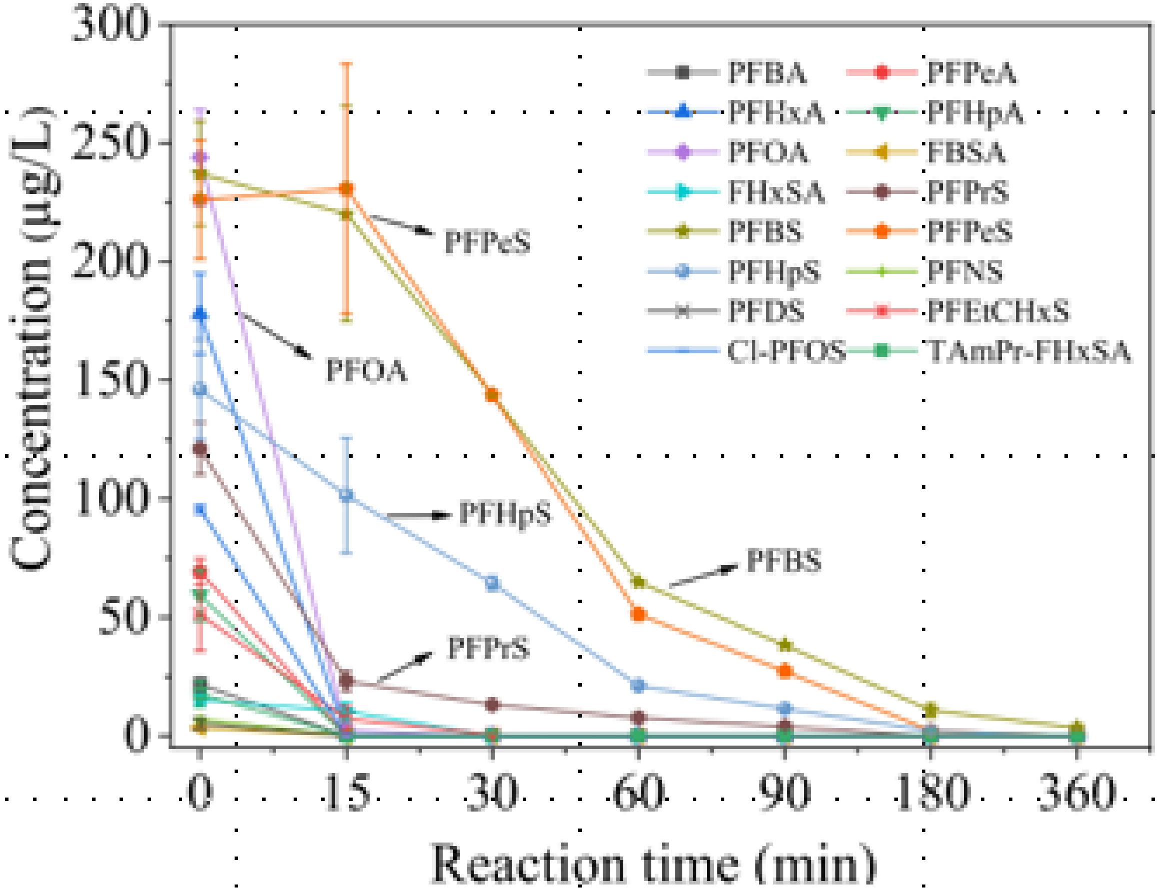
- Currently have a system that can treat 1 gpm, working on a 10 gpm system



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

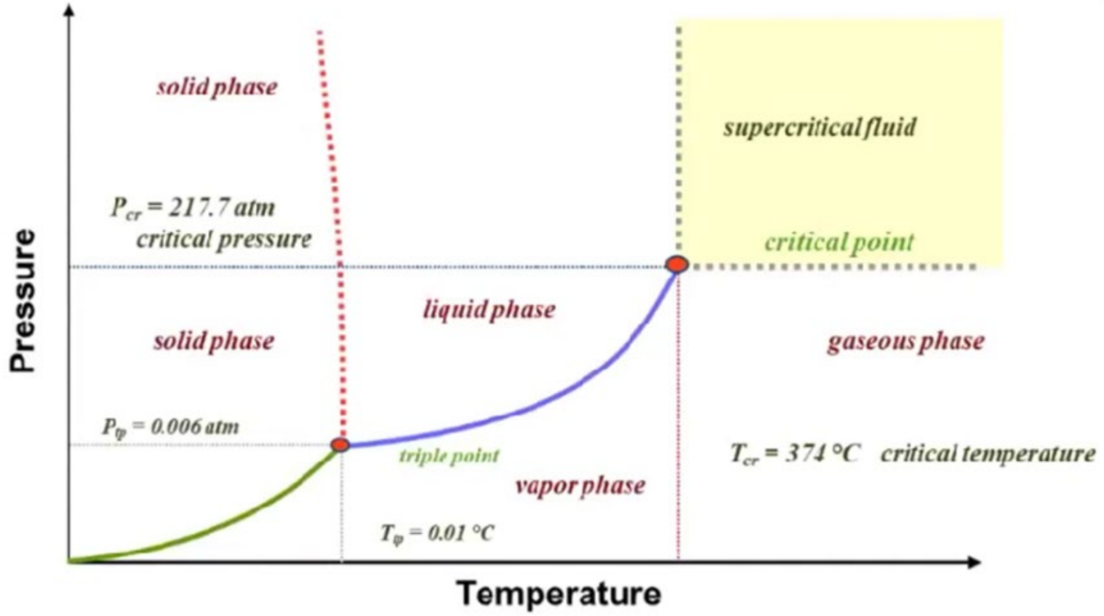


HALT Applied to AFFF – Disappearance of all Short Compounds



Supercritical Water Oxidation (SCWO)

- Bond cleavage, followed by oxidative radical attack and hydrolysis
- In-solution treatment
- Can also treat solids, i.e. spent GAC or resin
- Ionic salts fall out of solution – design of heating element is very important; NASA has a patent on a hydrothermal flame that is helpful in managing the salting out effect of SCWO
- 374 Water, Battelle Annihilator, Aquarden
- Special requirements:
  - Fuel source needed
  - High temperatures require careful consideration of heat exchange and material selection



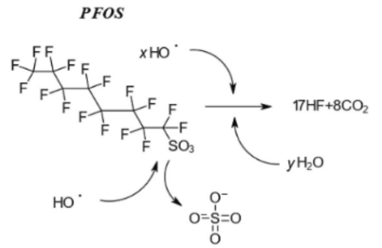
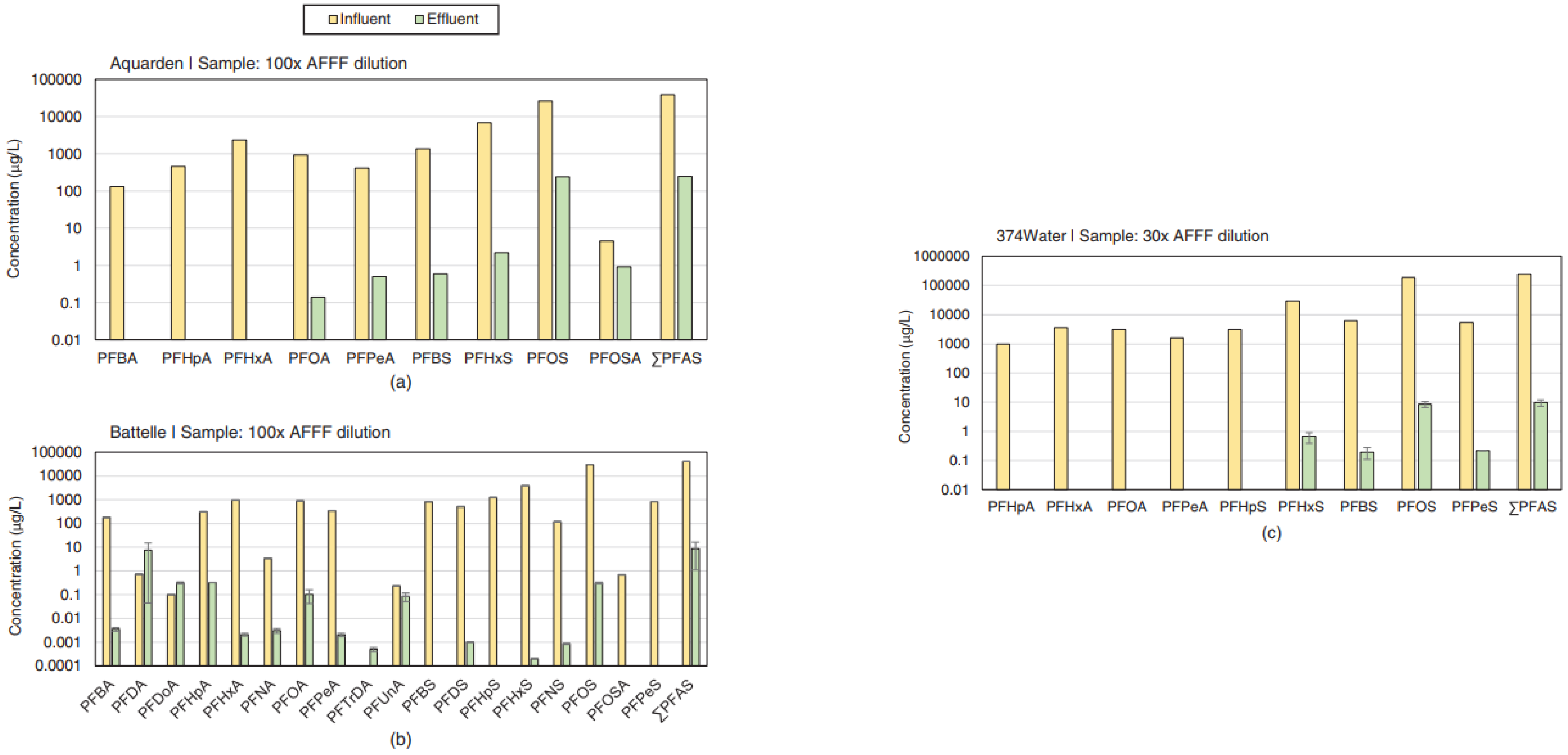


Fig. 6. Hypothesized SCWO reaction mechanism for PFOS destruction, showing initial C–S bond cleavage step followed by oxidative radical attack and hydrolysis steps forming final products of HF and CO_2.

From Pinkard 2021

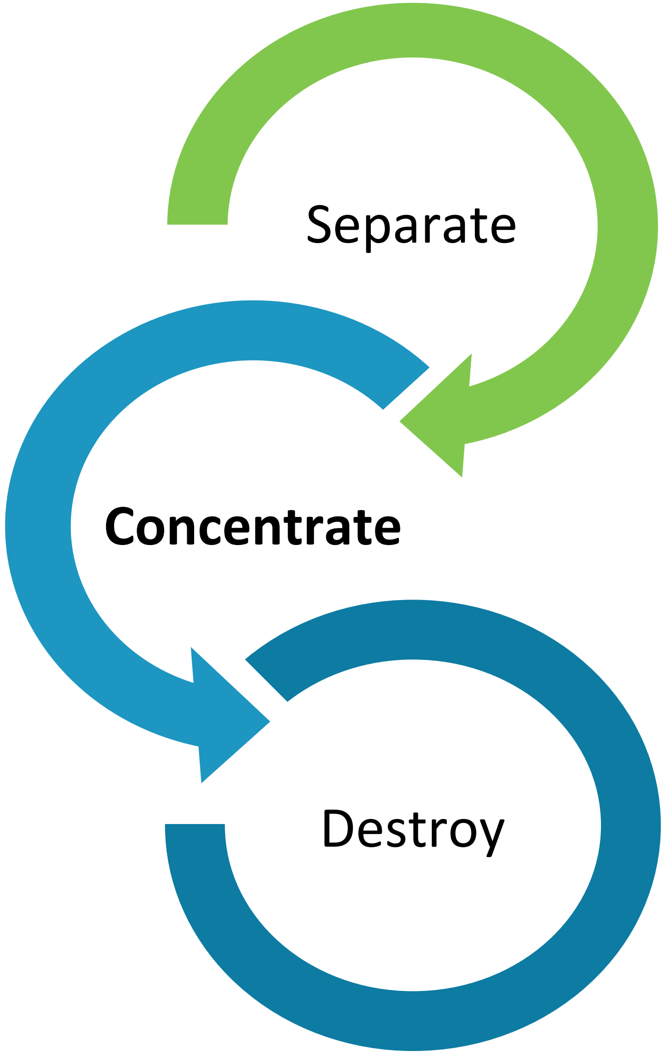
AFFF Treatment with Three Different SCWO Systems



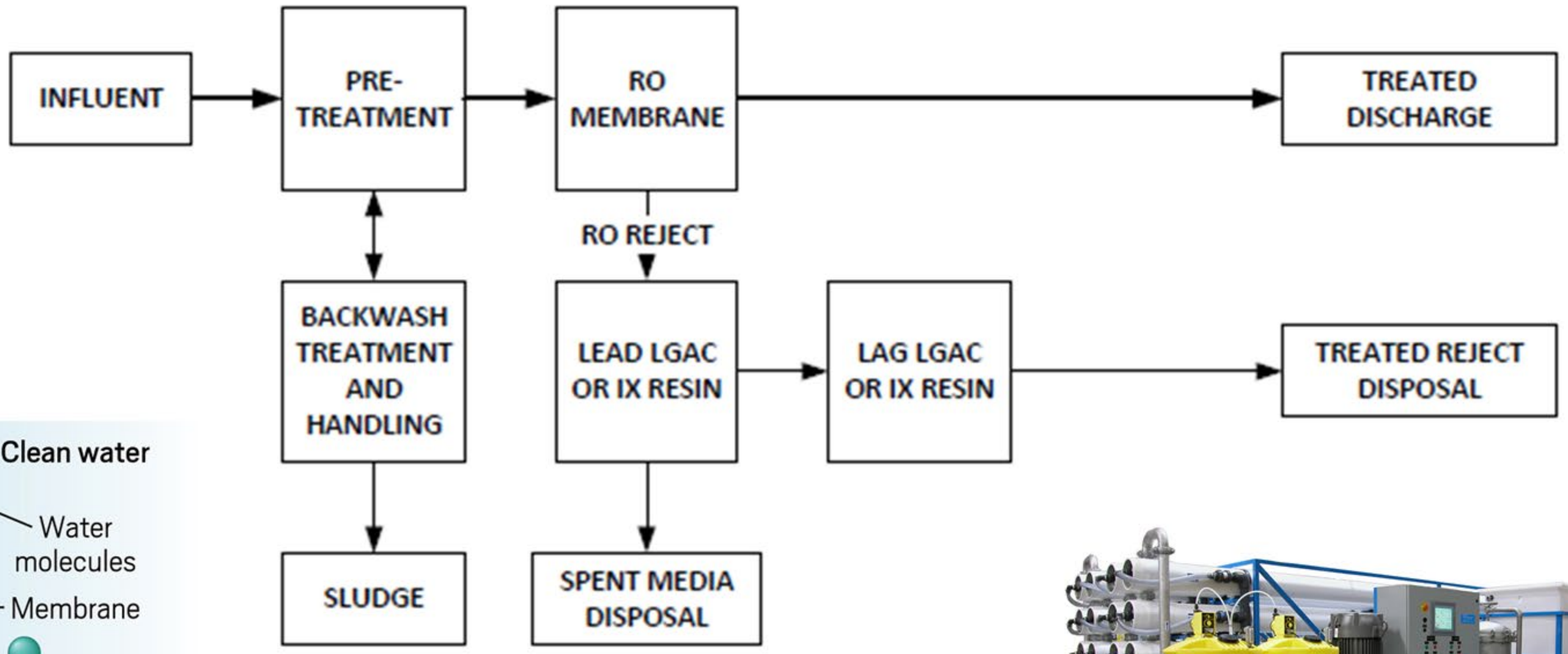
What's the Key to Making them Practical?

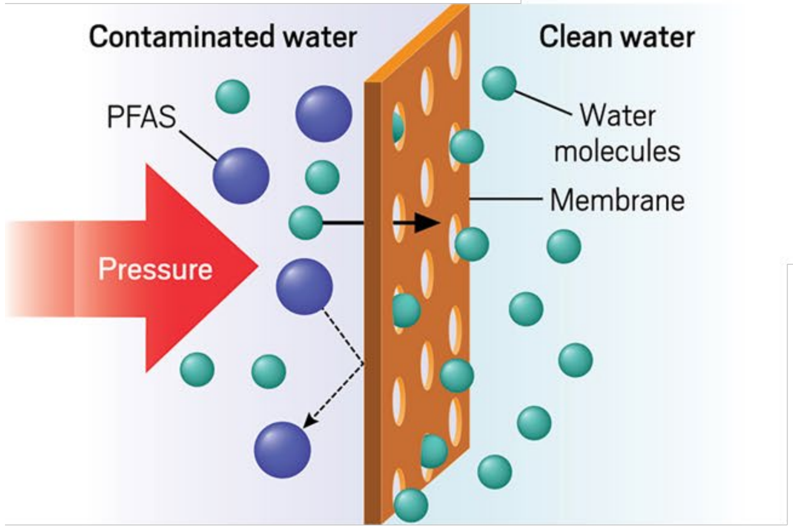
- Reduce liquid volume to be treated
- Increase concentration of PFAS
- PFAS concentration options:
  - Membrane treatment-
    - Still too much volume
  - Foam fractionation-
    - Effective on PFOS and PFOA
    - Partially effective on short chains
  - Regenerable Ion Exchange (IX) Resin

Complete PFAS Treatment



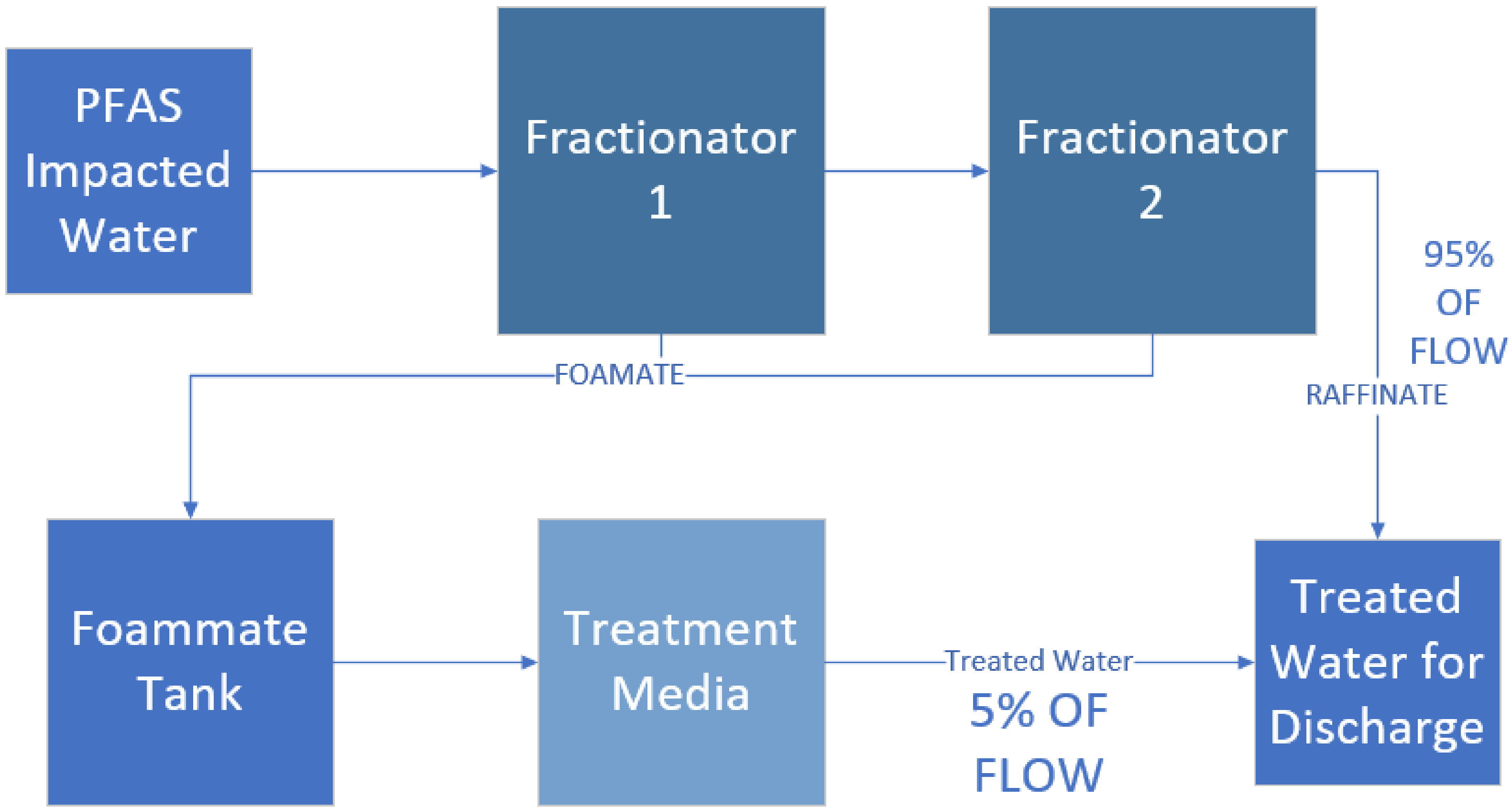
Reverse Osmosis





Foam Fractionation

Highly effective for upfront bulk PFAS removal

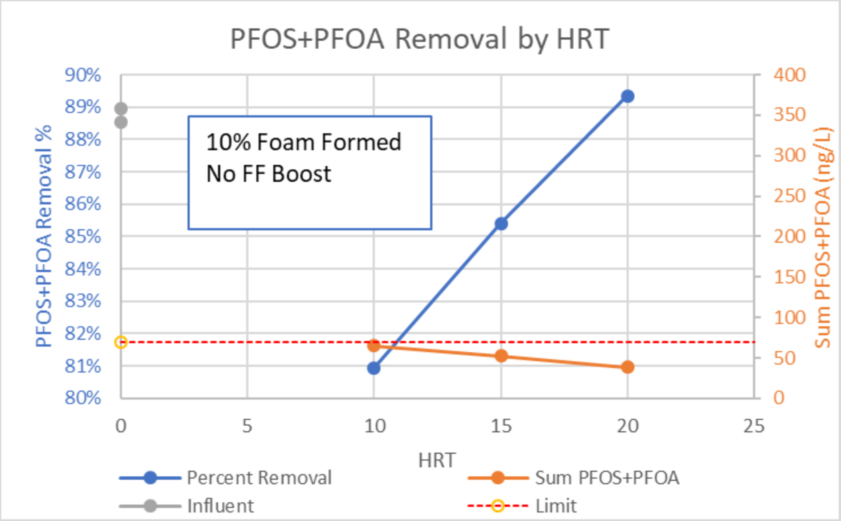


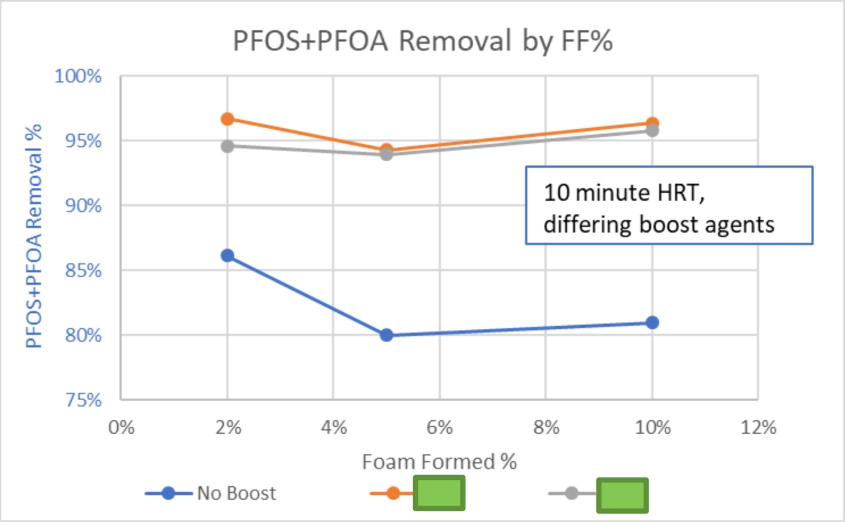
Foam Fractionation (FF) for PFAS
Concentration

- Agnostic to elevated levels of TDS, NOM, etc.
- Simple operation, few moving parts
- Nothing to clog or build DP
- Low energy, low pressure
- Low operating expense
- Can be a very effective pretreatment or treatment step for difficult-to-treat waters
- Challenge: often struggles with short – chain PFAS removal

ECT2 Full-Scale FF System
RAAF Base Tindal, AU

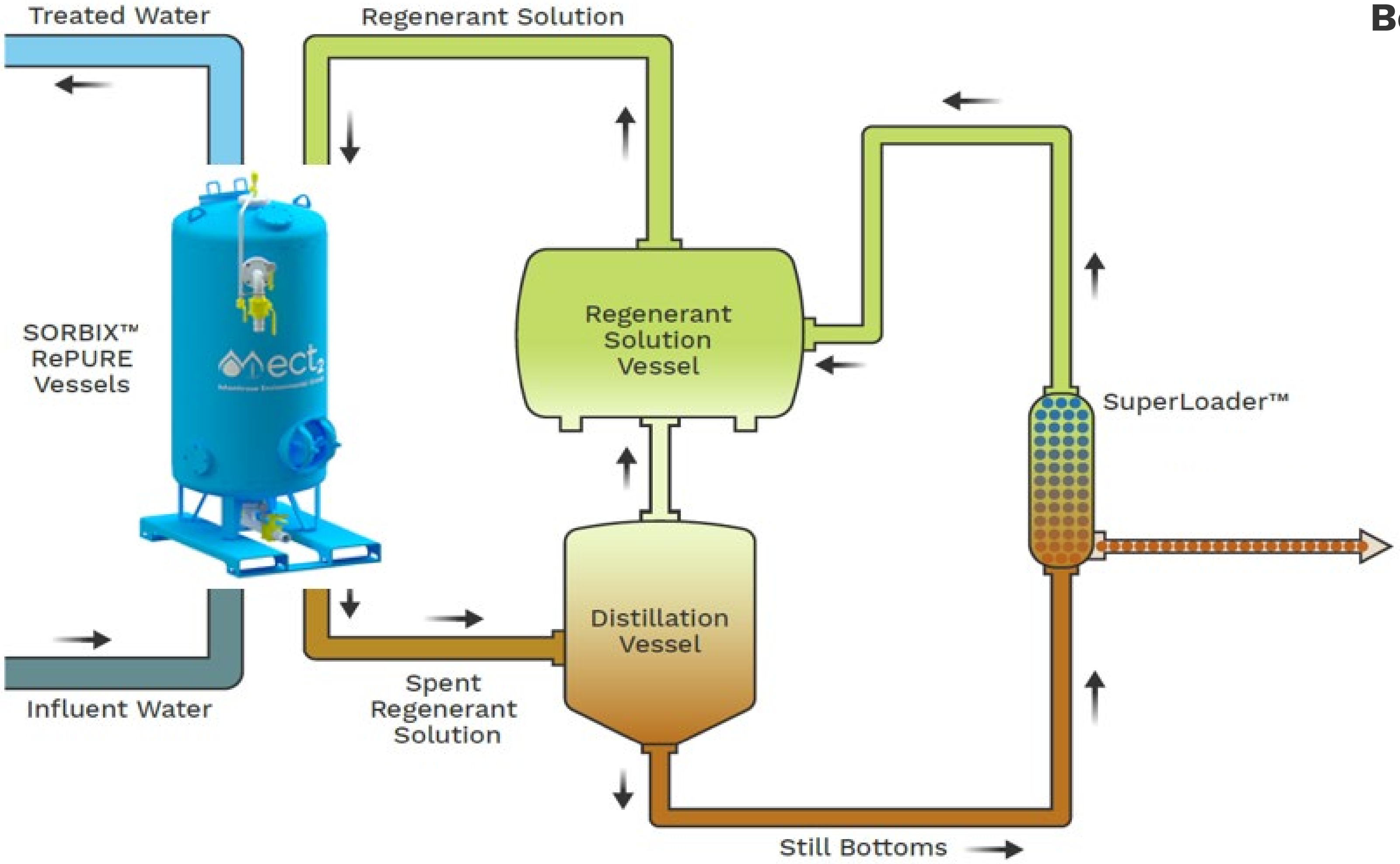
Benefits of Adding Foam Boosting Agents





Mobile FF System
Under Construction

SORBIX RePURE™ IX Resin Regeneration Technology



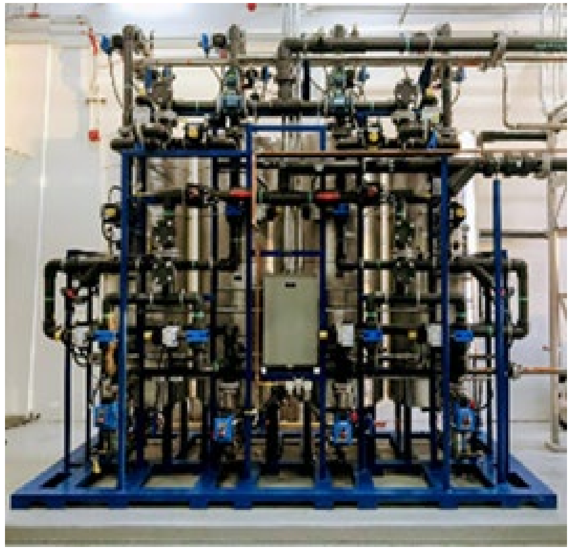
Benefits of the technology

- Patented waste reduction technology
- Ability to treat short-chain PFAS to non detect for complete PFAS removal
- Combines well with onsite PFAS destruction technologies

Case Study : Former Pease AFB Groundwater Treatment for PFAS

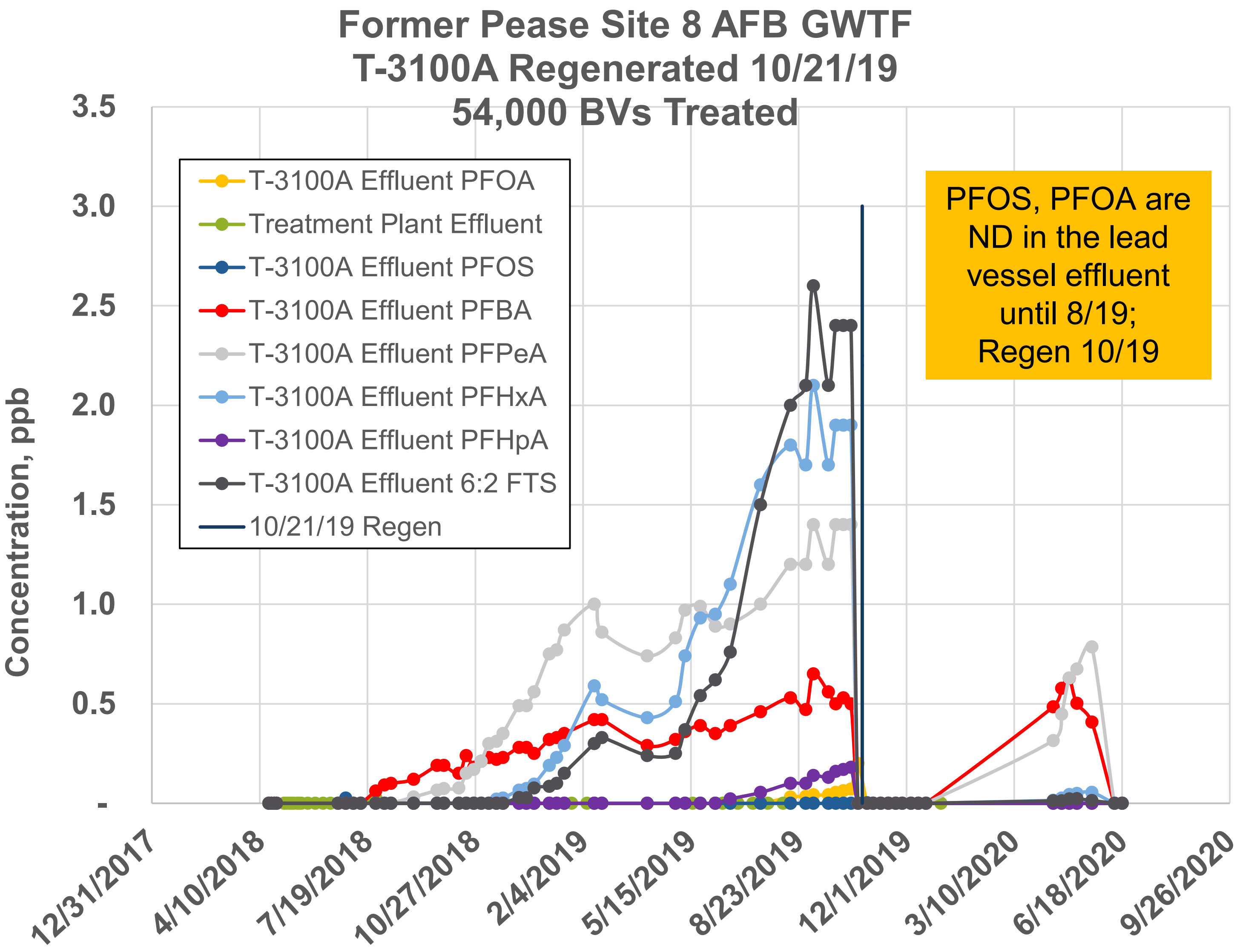
Portsmouth, NH

PFAS Source:	Former Fire Training Area
PFAS Concentration:	50 – 100 ug/L
Project Approach:	Mitigate impact to off-site drinking water; 120 gpm design flow
Treatment:	SORBIX RePure Regenerable IX Resin; IX Resin Regenerated On-Site
Effluent Concentration:	100% compliance
Groundwater Treated:	> 60 million gallons since 2018
PFAS Waste Generated	< 50 gallons; **None taken off-site**



Data

Regen Results



Long chain PFAS (PFOS, PFOA) have long breakthrough horizons

Short chain PFAS solutions:

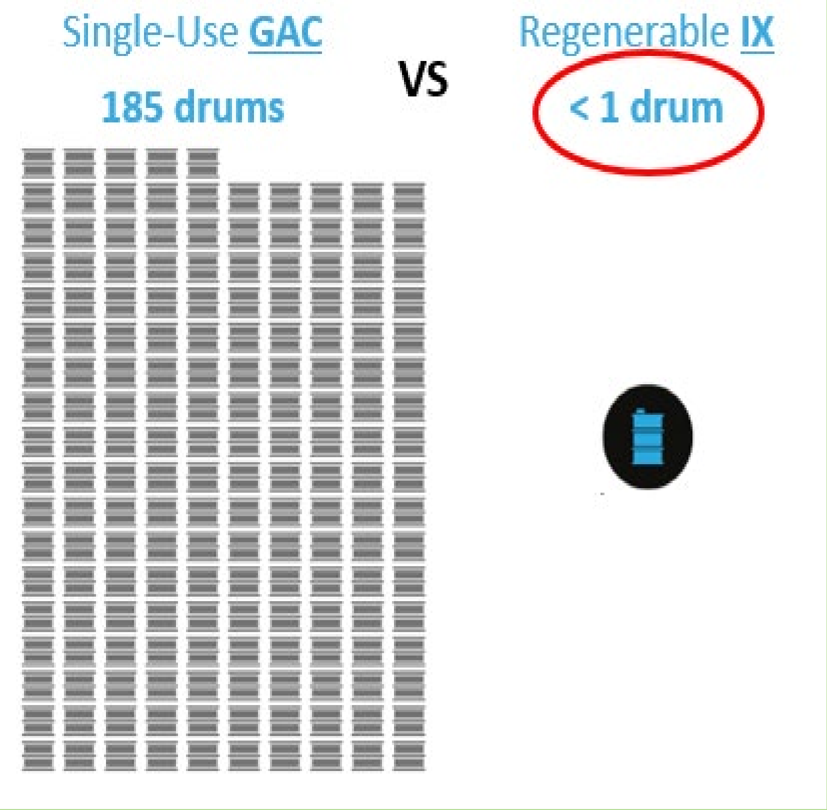
- Single use resin can be used to polish water for short chains

  OR

- Regenerable resin type and rate of regeneration can be tailored to achieve low level short chain PFAS discharge

Full-Scale Regenerable IX System at Pease AFB

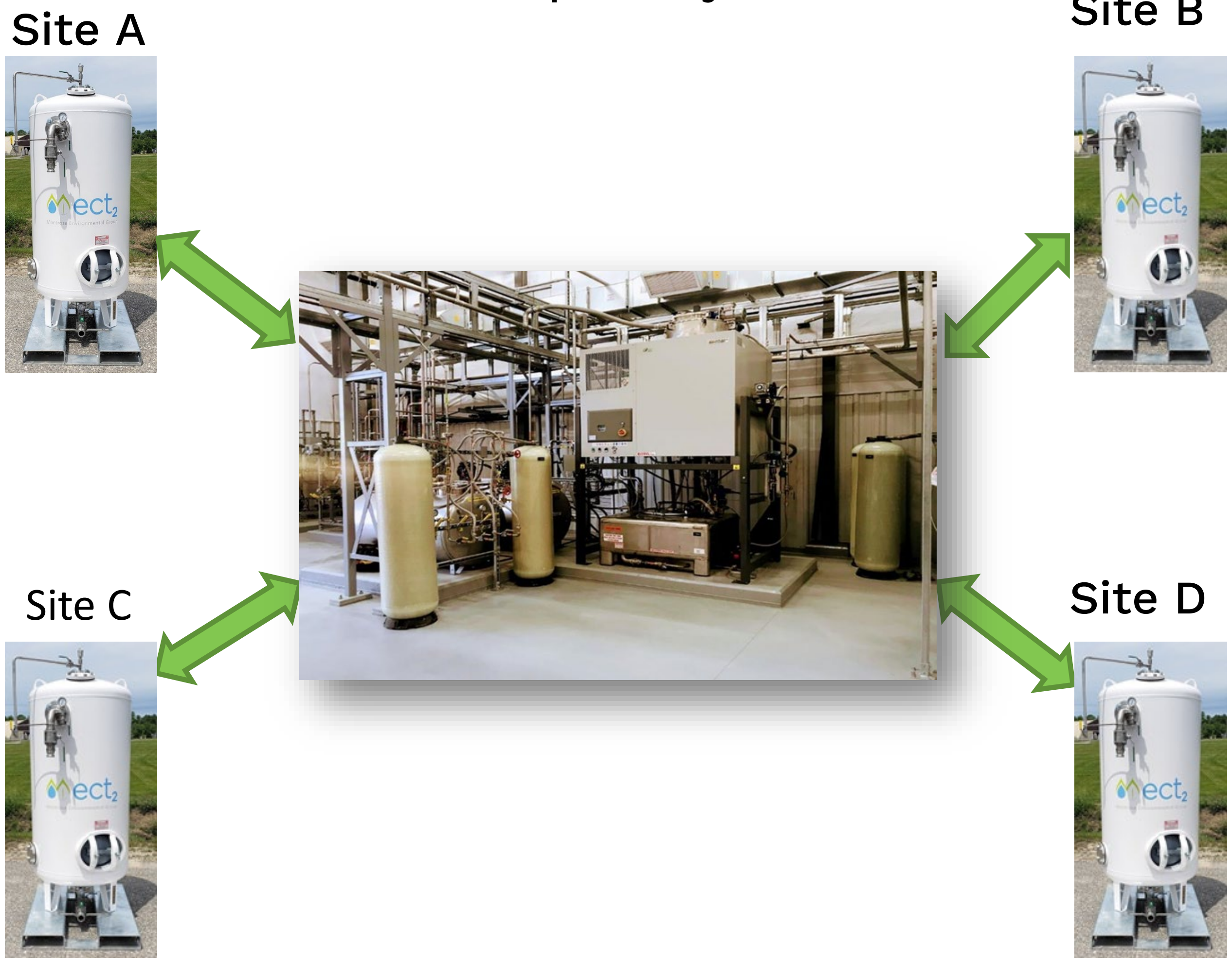
One Year of Waste



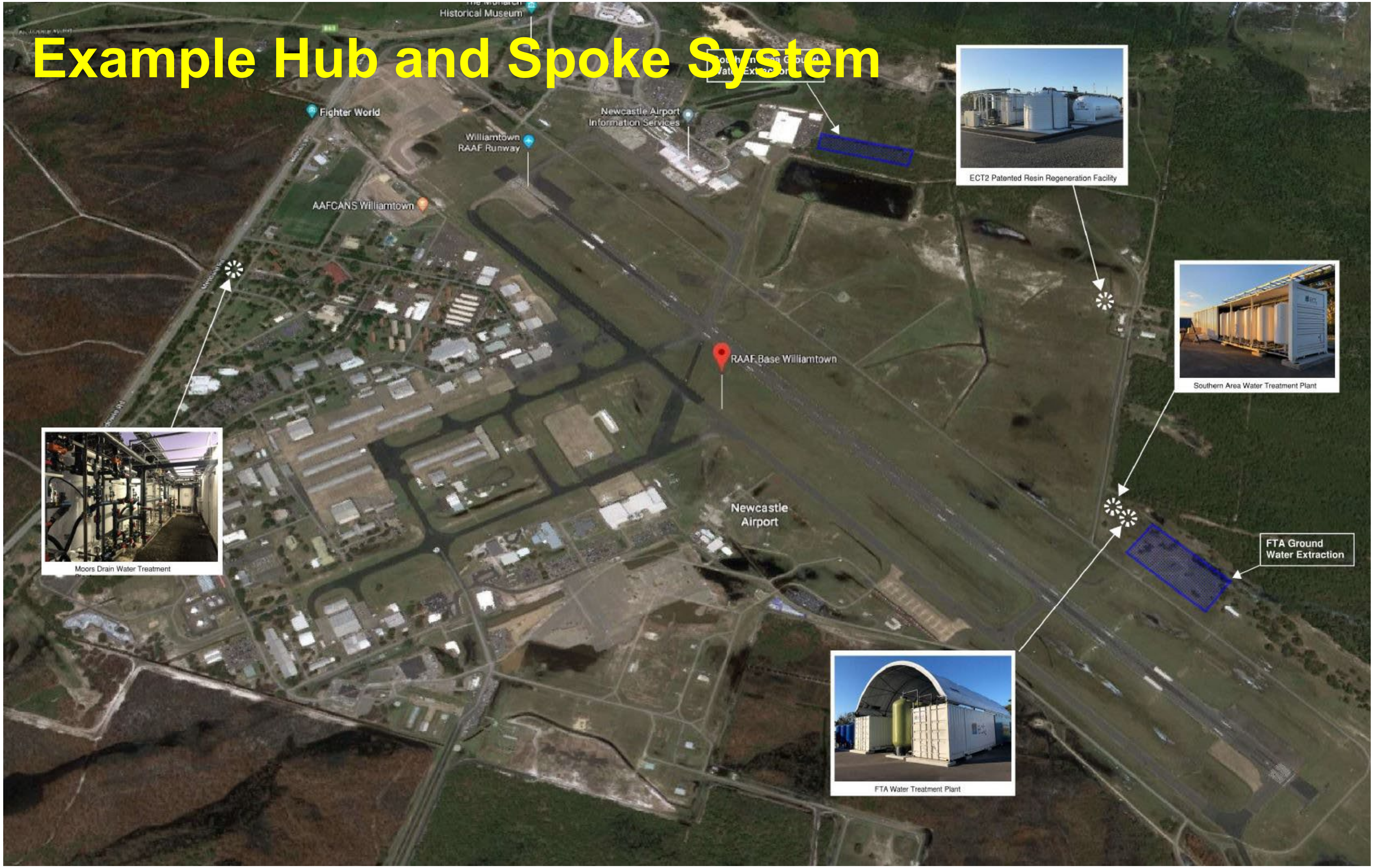
Central Regeneration Maximizes the Benefit

Permanent System

Hub & Spoke System



Example Hub and Spoke System



Bottom Line

- Incineration and landfilling are falling out of favor
- Onsite PFAS destruction is becoming proven technology
- Complete mineralization (onsite) is within reach
- Upstream PFAS concentration and volume reduction are key to making these technologies practical
- Foam fractionation, reverse osmosis and regenerable IX resin are examples of PFAS concentration options
- Hub & spoke systems optimize efficiency and maximize cost effectiveness

Questions?

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