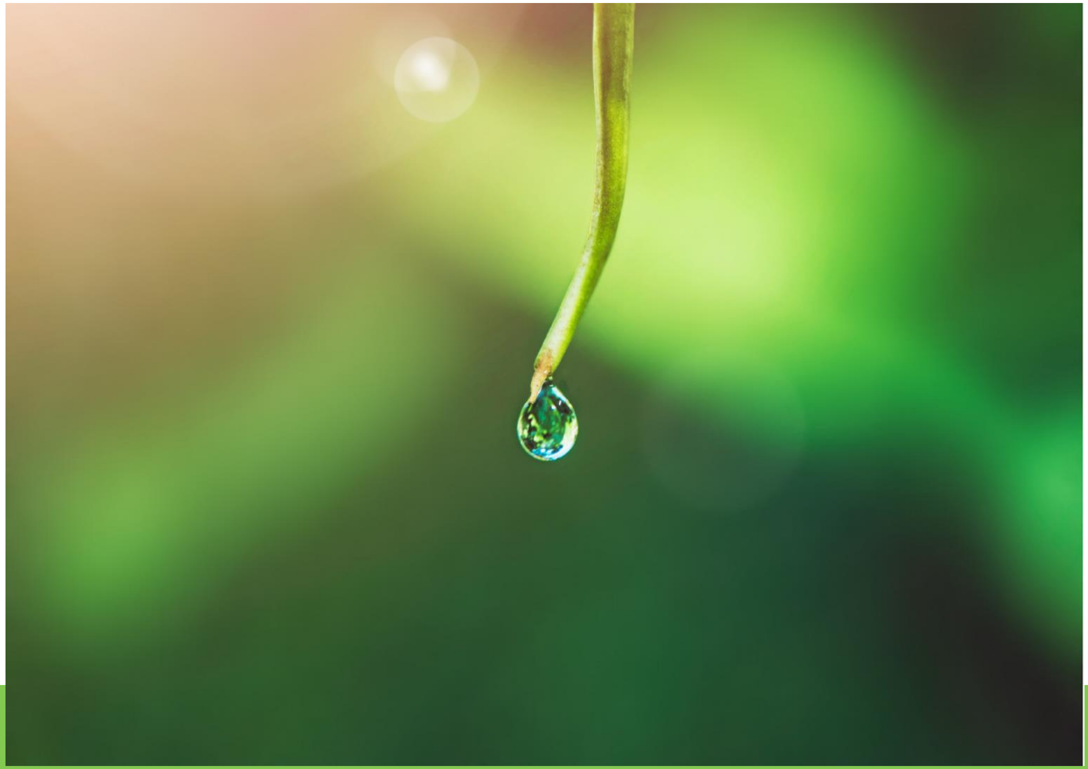
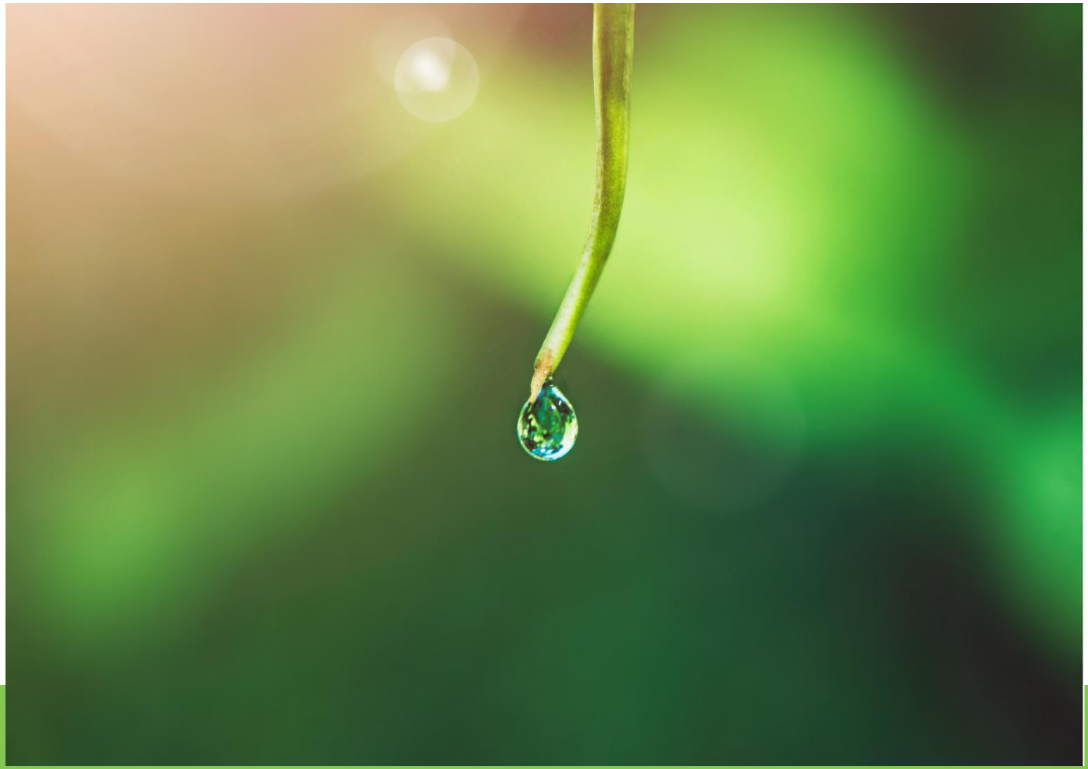


Sustainable IX Resin and Destructive Technologies Overview for Complete PFAS Treatment

ect2
Montrose Environmental Group

ESAA EnviroTech 2022



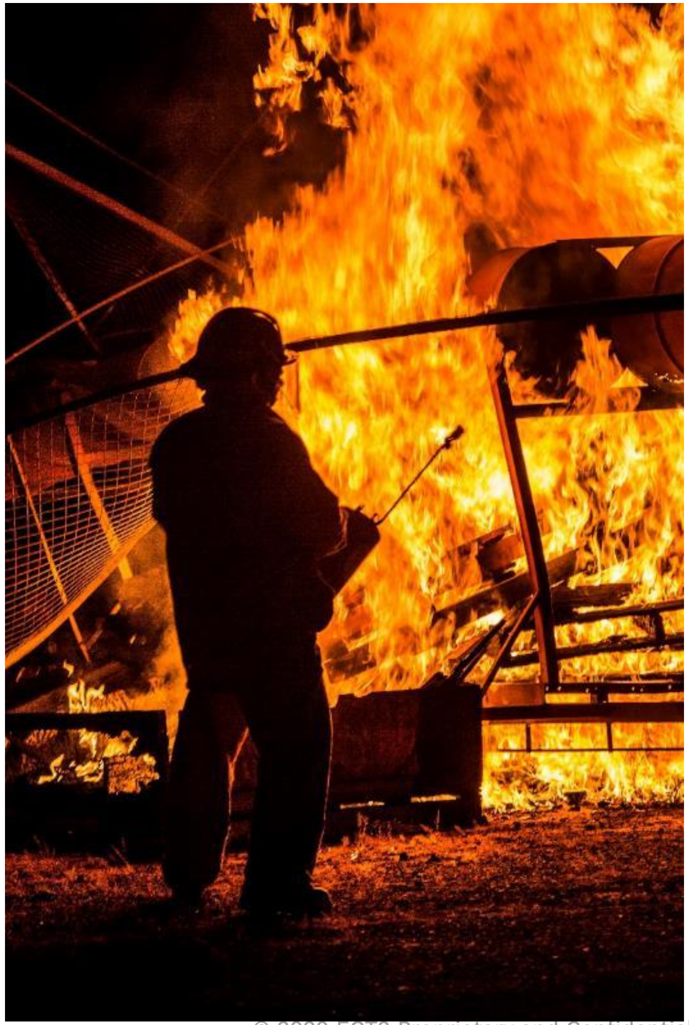
Waste Minimization and Destruction

ECT2
Montrose Environmental Group

ESAA EnviroTech 2022

Why is Destruction of PFAS Important?

- Persistence in the environment
- Possible human health effects
- Waste ownership and liability
- Moratorium on incineration
- Corporate sustainability goals
- Cost



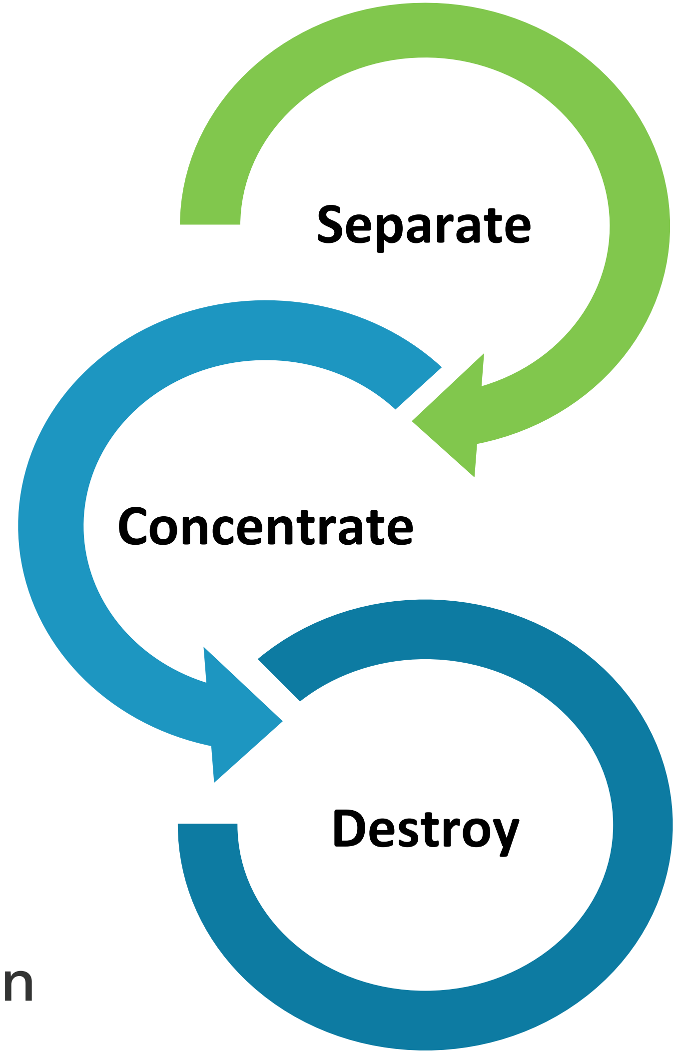
The Pathway to Complete PFAS Treatment

- **Separate** PFAS from liquid medium
  - Reduce liquid volume to be treated
- **Concentrate** PFAS via:
  - Membrane treatment
  - Foam fractionation
  - Regenerable Ion Exchange (IX) Resin

⇩

Million-to-One Concentration Factor

- **Destroy** PFAS to achieve complete mineralization
  - Multiple technologies showing promise



Environmental Scenarios Time

Scenario 1:

Add 2 liters of water to an Olympic-sized swimming pool

What do you end up with?

About 2,000,000 liters of water

Environmental Scenarios Time

Scenario 2: Oops……

Add 2 liters of **PFAS** to an Olympic-sized swimming pool

What do you end up with?

A problem ……….. about 2,000,000 liters of PFAS liquids

A hazardous substance?

A hazardous waste?

Environmental Scenarios Time

Scenario 3: Put the PFAS Genie back in the bottle

Treat the 2,000,000 liters in the pool with Regenerable IX media process

What do you end up with?

2 liters of highly-concentrated PFAS waste

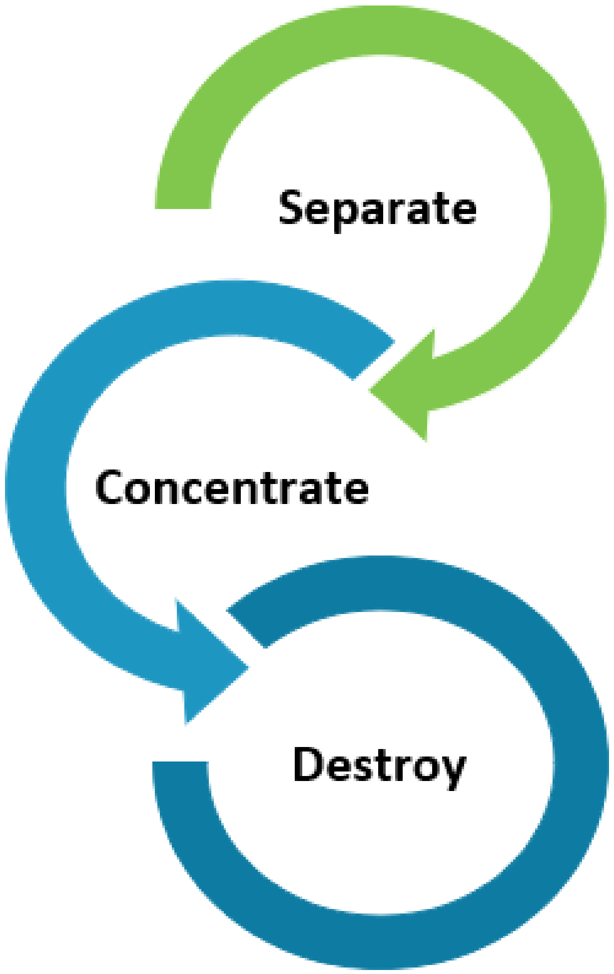
Deploy destruction technology on the waste

What do you end up with?

The Holy Grail – elemental carbon and fluorine

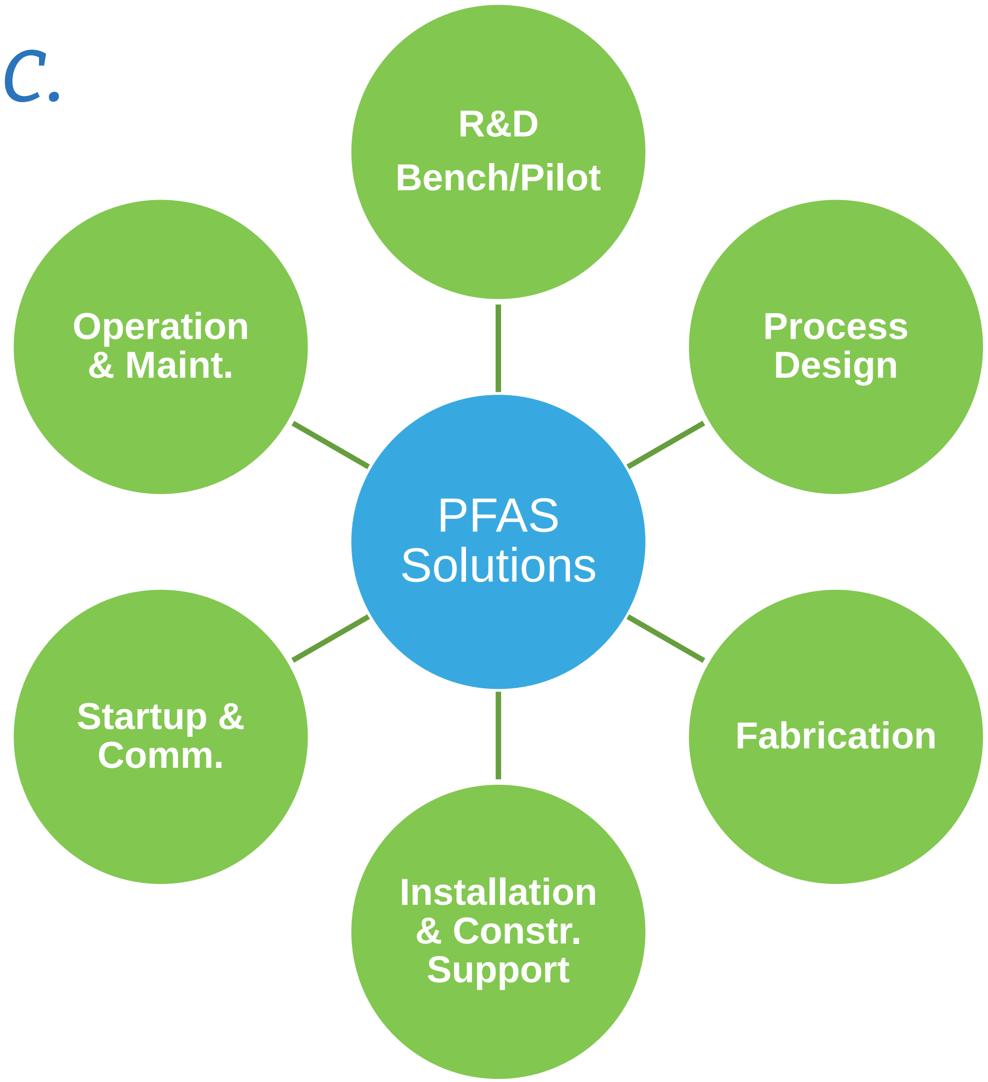
Agenda

- Who is ECT2?
- Separation and Concentration via Regenerable IX
- Destruction Technologies Overview
- ECT2 Data from Pilot Studies
  - Non-thermal Plasma
  - Electrochemical Oxidation
  - Hydrothermal Alkaline Treatment
  - Supercritical Water Oxidation
- Other promising destruction technologies
- Q&A



ECT2: *Emerging Compounds Treatment Technologies, Inc.*

- ECT2 is a solutions provider of cutting-edge technology solutions to remove emerging and difficult to treat contaminants, PFAS and 1,4-dioxane, from:
    - Investigation-Derived Waste
    - Groundwater
    - Surface Water
    - Construction Dewatering Liquids
    - Soil Washing Effluent
    - Drinking Water
    - Waste Water
    - Foam Spills
    - Landfill Leachate



State of Technology Development (ITRC)

Field-Implemented Treatment Technologies:

- **Ion Exchange Resin – Single-Use and Regenerable**
- **Granular Activated Carbon**
- Reverse Osmosis

Limited Application or Developing Technologies:

- In-situ Remediation with Colloidal Carbon
- Precipitation
- Nanofiltration
- Destruction

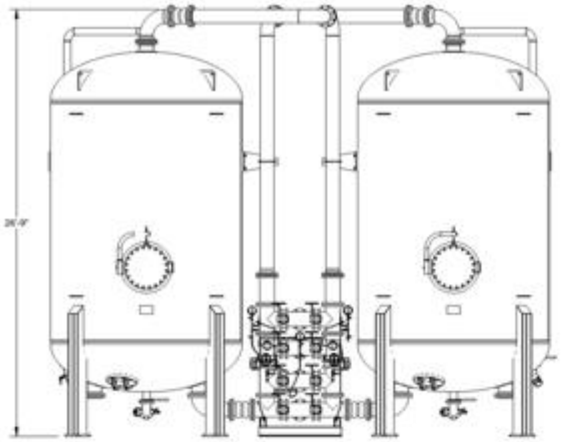
GAC vs. Ion Exchange for PFAS Treatment

	Granular Activated Carbon	Single Use Ion Exchange	Regenerable Ion Exchange
Treatment Mechanism	Adsorption	Adsorption and ion exchange	Adsorption and ion exchange
State of Development	Field-Implemented	Field-Implemented	Field-Implemented
Effectiveness	**Lower for short-chain PFAS**	**High**	**High**
Empty Bed Contact Time (EBCT)	**~ 10 min**	**2 - 3 min**	**2 - 3 min**
System Footprint	Large	Small	Medium
Typical Pretreatment	Sand or Cartridge Filters	Sand or Cartridge Filters with GAC	Sand or Cartridge Filters with GAC
Spent Media	Incinerated or Landfilled	Incinerated or Landfill	Regenerated
Waste Quantities Generated	**Very Large**	**Low**	**Negligible**

GAC vs. Ion Exchange
Comparative Footprint and Waste Profiles

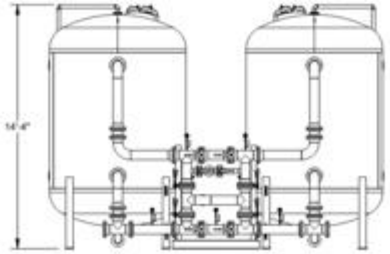
GAC

27 ft.



Regen. IX

14 ft.



Plant Layout (200 GPM)

GAC

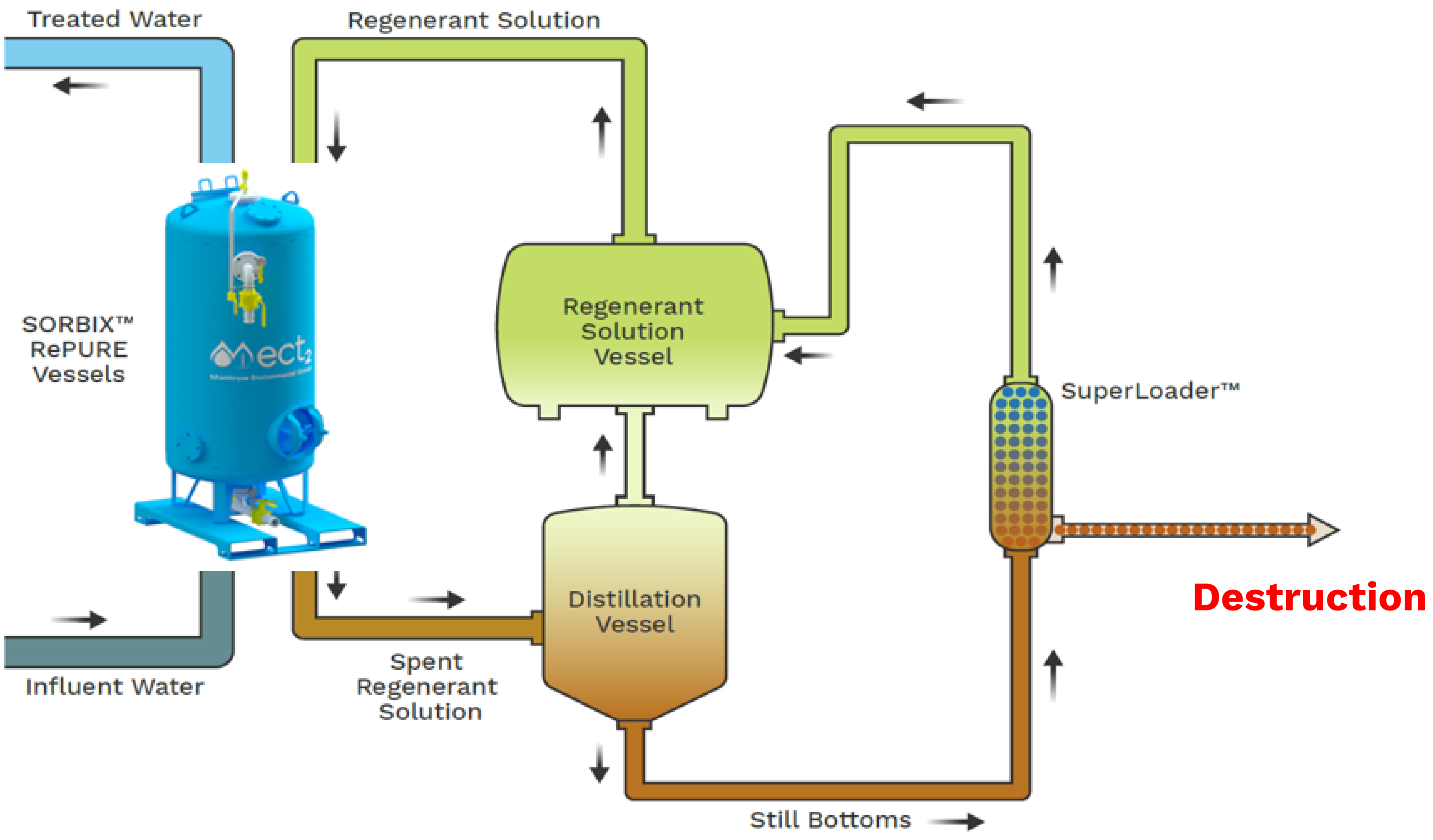
Source:	Surface water
Flow rate:	190 gpm
PFAS Influent:	6.6 µg/l
Waste Generated:	**914 tons**
Treatment Criteria:	0.07 µg/l

Regenerable IX

Source:	Groundwater
Flow rate:	180 gpm
PFAS Influent:	23 µg/l
Waste Generated:	**7 tons**
Treatment Criteria:	0.07 µg/l

Yes – these are the same scale

SORBIX RePURE^{TM} Regeneration Technology



13x
More effective treatment with PURE

>99%
Less waste generation with RePURE

67%
reduction in treatment system size

50%
reduction in lifecycle costs

Case Study : Former Pease AFB Groundwater Treatment for PFAS

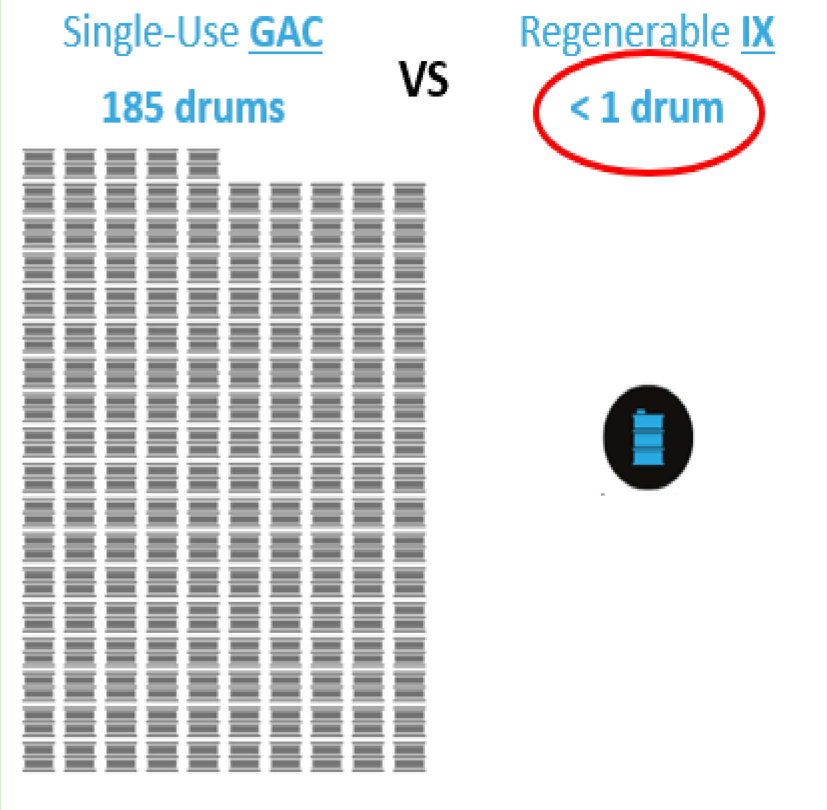
Portsmouth, NH

PFAS Source:	Former Fire Training Area
PFAS Concentration:	50 – 100 ug/L
Project Approach:	Mitigate impact to off-site drinking water (120 - 200 gpm design flow)
Treatment:	SORBIX RePure regenerable IX resin; On-site regeneration
Effluent Concentration:	ND since startup
Groundwater Treated:	50 million gallons since 2018
Waste Generated	None taken off-site; **50 gallons to date**

Full-Scale Regenerable IX System at Pease AFB

200 GPM Regeneration Facility

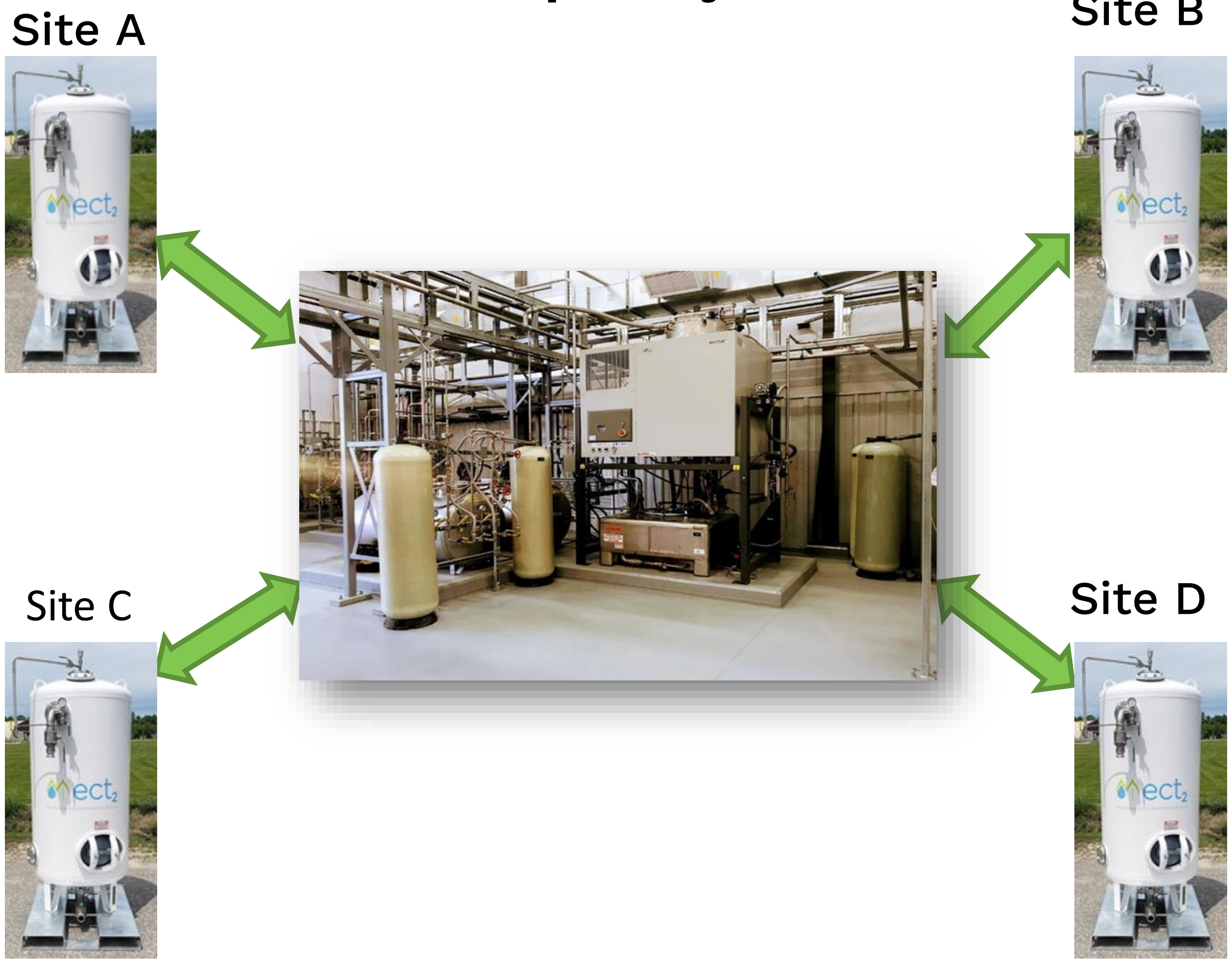
One Year of Waste



SORBIX RePURE Regenerable IX Treatment

Permanent System

Hub & Spoke 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 paired with AOP
- Zero-valent iron
- Alkali metal reduction

Goal: Complete mineralization

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

Select Destruction Technology Comparison

	Plasma (non-thermal)	Electrochemical Oxidation (EO)	Hydrothermal Alkaline (HALT)	Supercritical Water Oxidation (SCWO)
Simplicity of Implementation	Moderate	Moderate/ High	Moderate	Moderate
Reaction kinetics (reported to date)	Hours	Hours	**Minutes**	**Minutes**
Mechanism	Red/Ox	Ox	Nucleophilic substitution	Ox
High brine performance	Fair –kinetically slower in high TDS	**Good**	**Good**	TDS >2% is problematic
Optimal pH	Not pH sensitive	Neutral to Basic	pH >14	Basic
Biggest advantage	**Somewhat simple**	**Somewhat simple**	**Fast, effective, commercially available**	**Fast, effective**
Biggest limitation	Surface reactions, TDS, speed	Speed, perchlorate formation potential	pH alteration, salt addition	System design, salting out, co-fuel needs
Mineralization Potential	Moderate/ Unknown	Moderate but slow	**High**	**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
- Developers:
  - DMAX/Clarkson University
  - OnVector
  - Inentec/MIT
  - Drexel, U. of Michigan

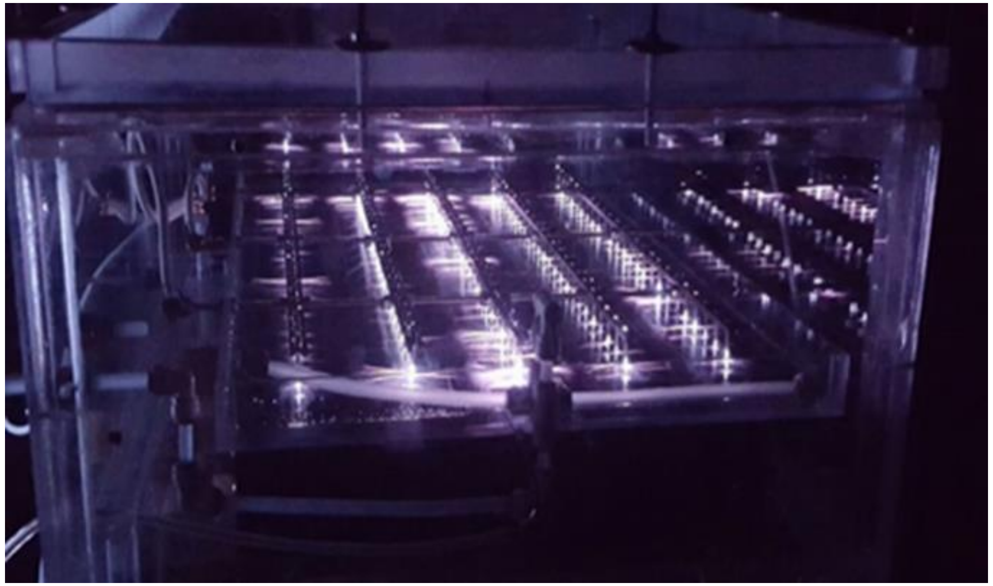


Photo credit: DMAX

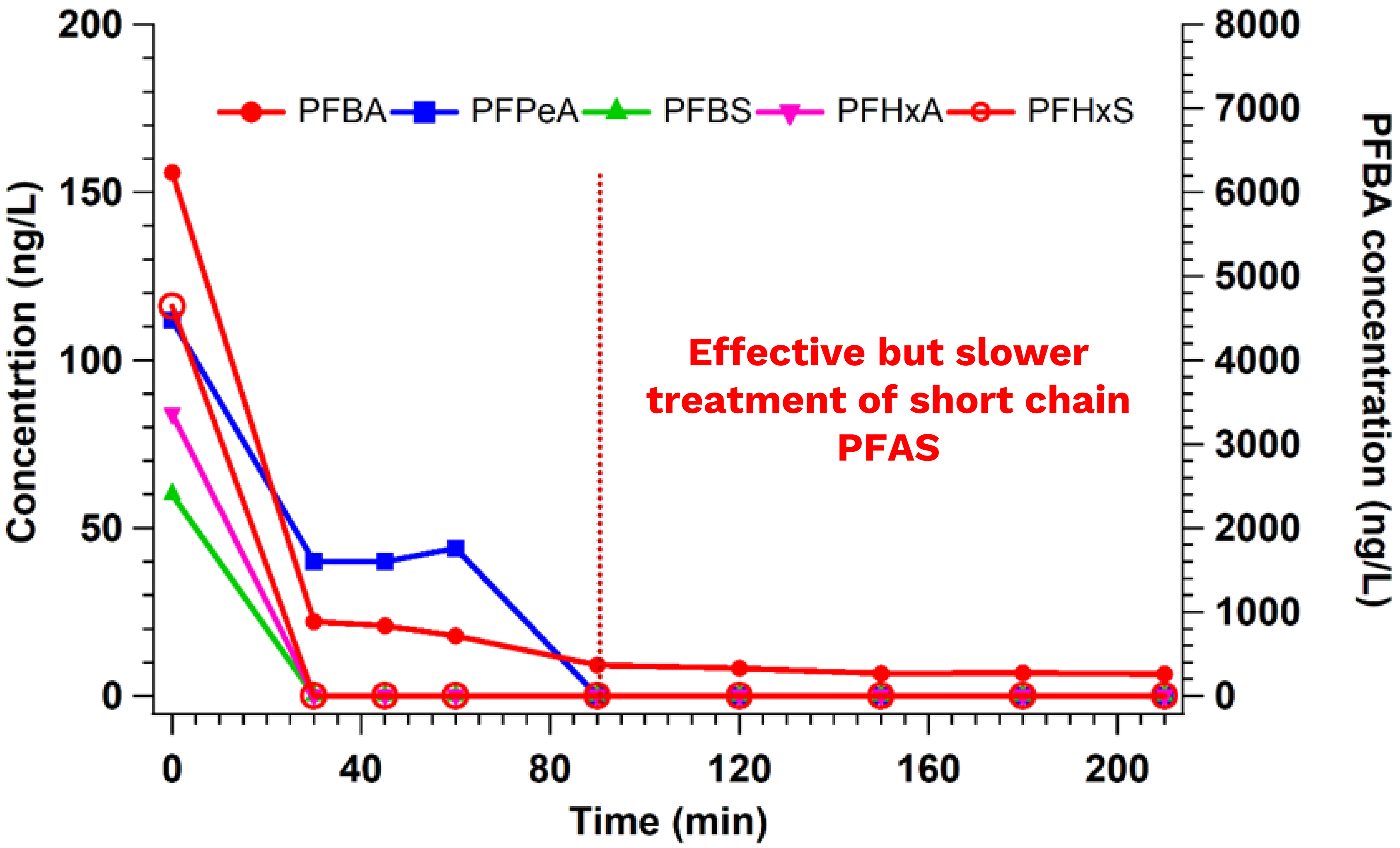


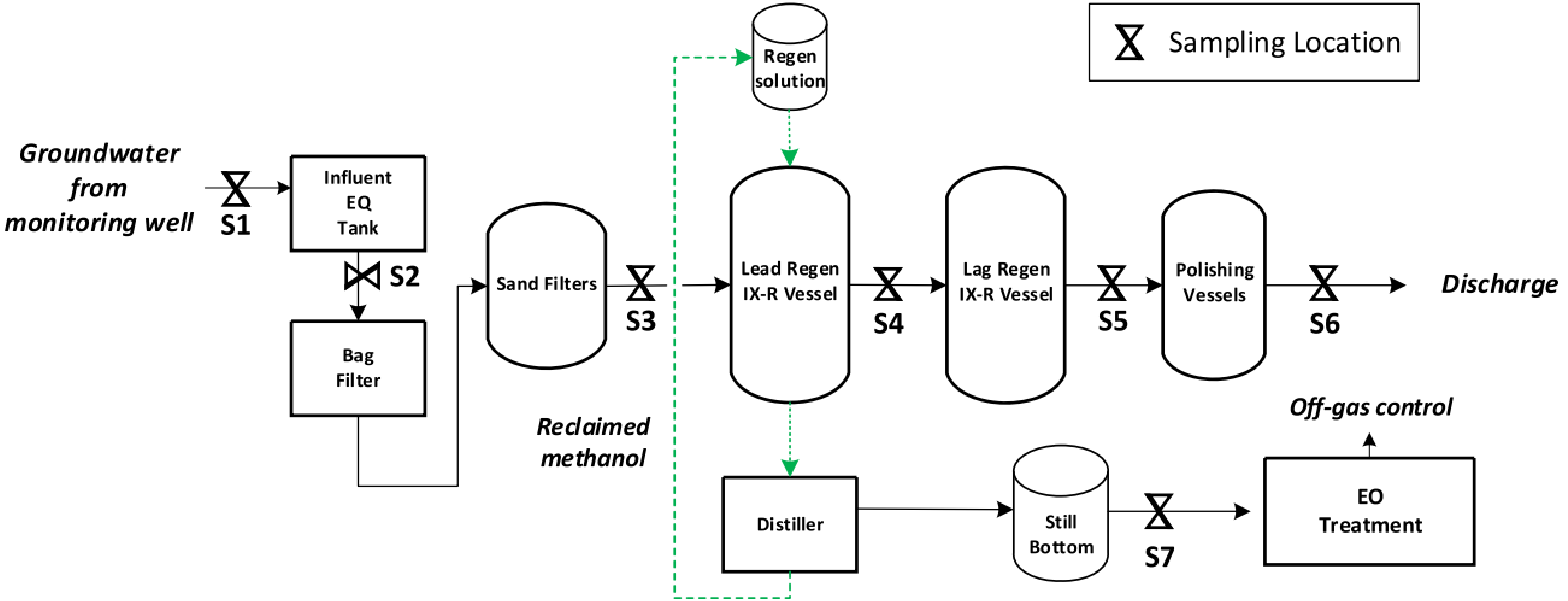
FIGURE 59 - PFAAS CONCENTRATIONS PROFILES IN THE PRESENCE OF CTAB; CTAB CONCENTRATION WAS INCREASE TO 0.2 MM AFTER EACH 30 MINUTES

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 (on-site pilot project at Wright-Patterson Air Force Base)

Photo credit: AECOM

Electrochemical Oxidation (EO) Pilot



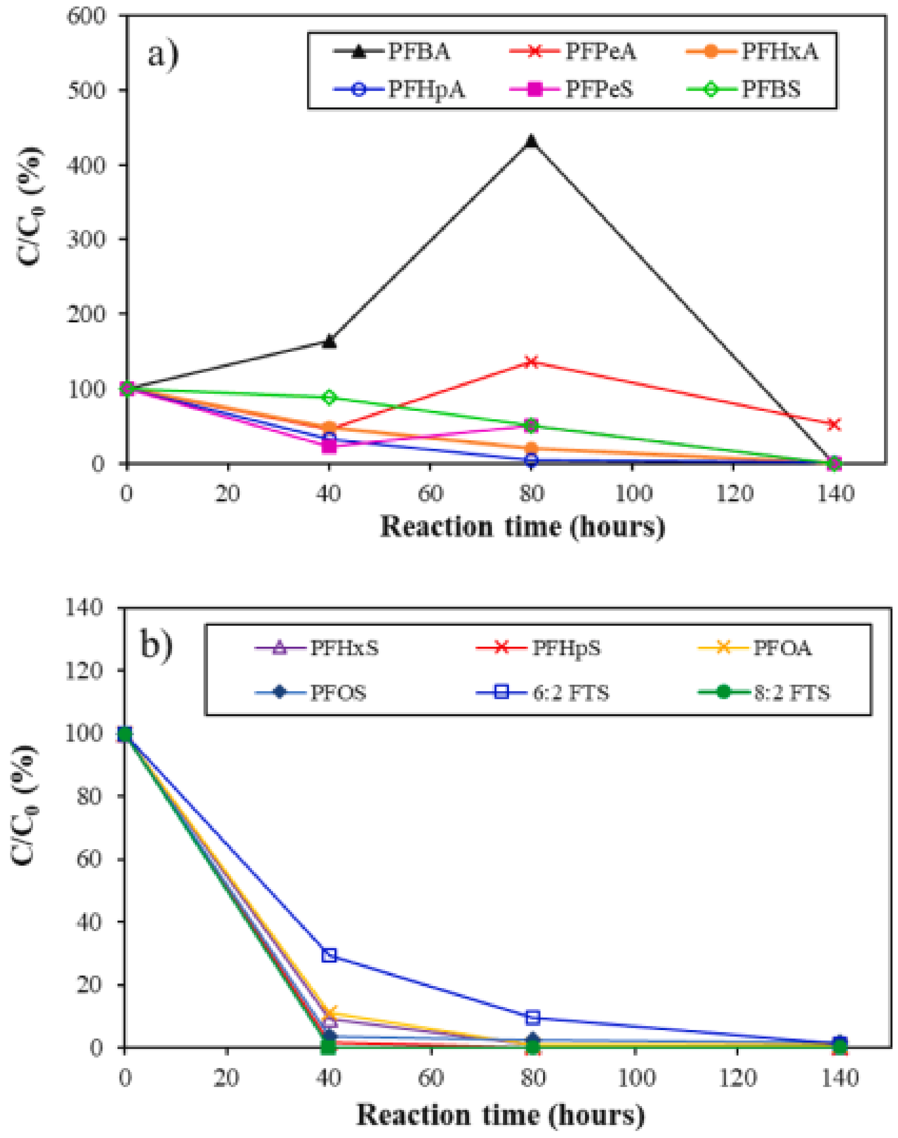


Fig. 6. Degradation profiles of (a) short-chain PFAAs and (b) long-chain PFAAs and precursors in SB1 treated using bench scale EO reactor at the University of Georgia.

Effective but slower treatment of short chain PFAS

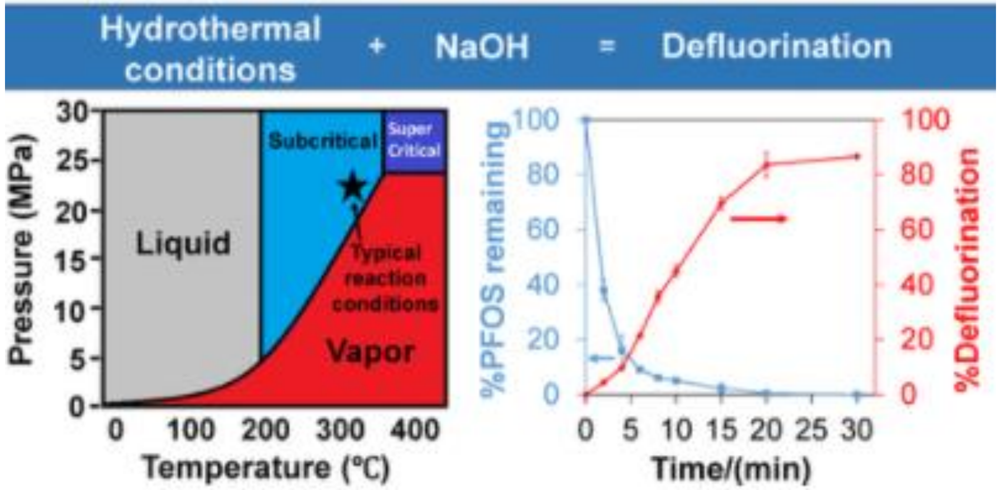
Faster treatment of long chain PFAS

From Liang et al., 2022

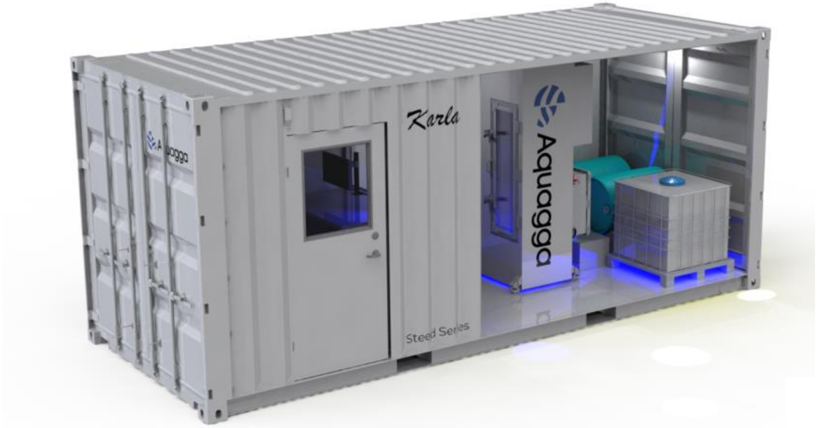
Hydrothermal Alkaline Treatment (HALT)

- 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

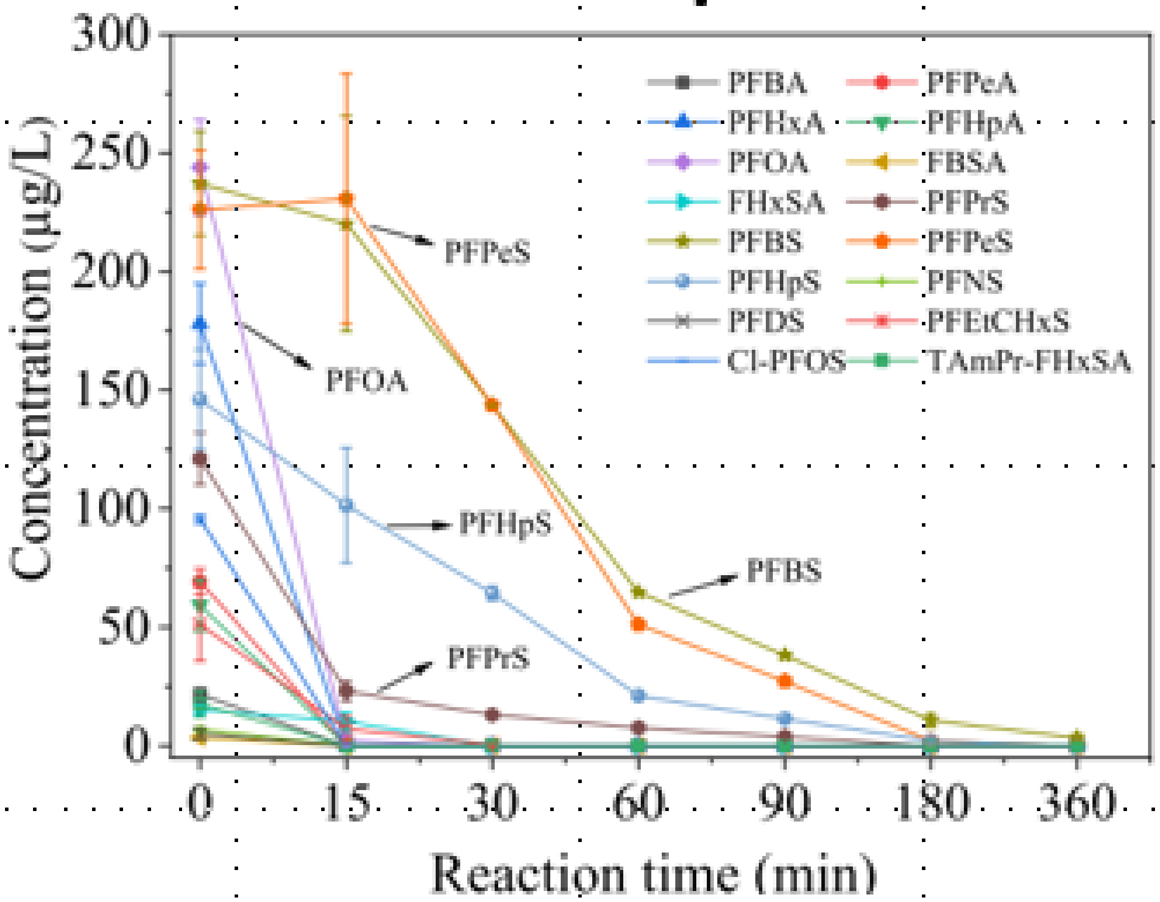
Developer: Colorado School of Mines and Aquagga



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



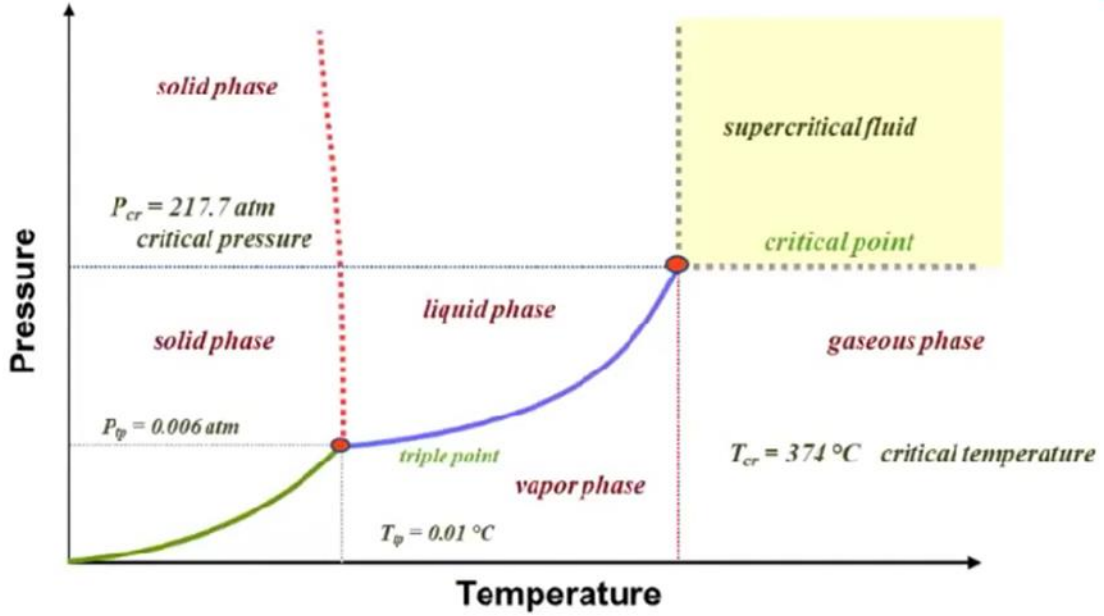
HALT Applied to AFFF – Disappearance of all Short Compounds



Effective and rapid treatment of short and long chain PFAS

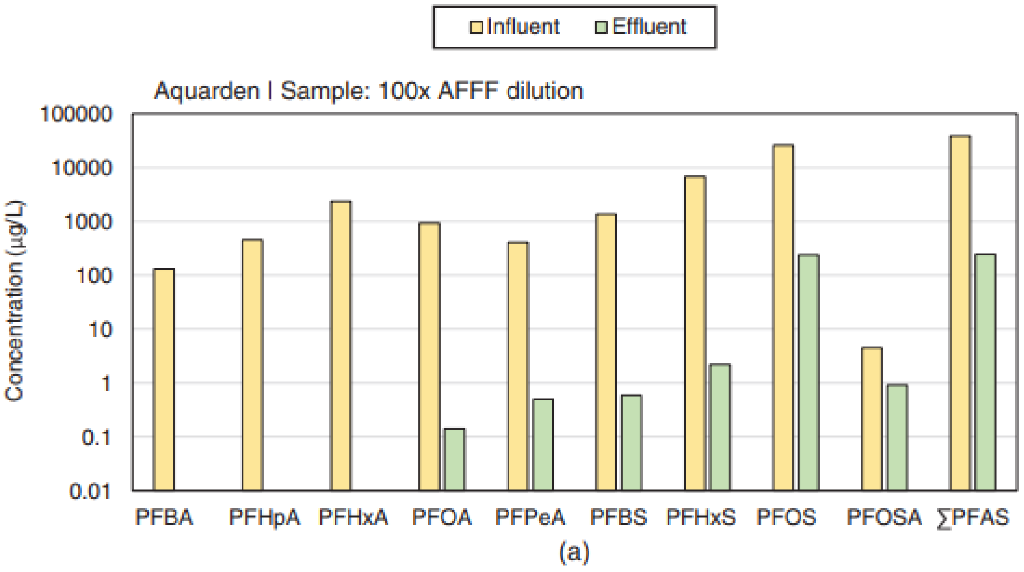
Supercritical Water Oxidation (SCWO)

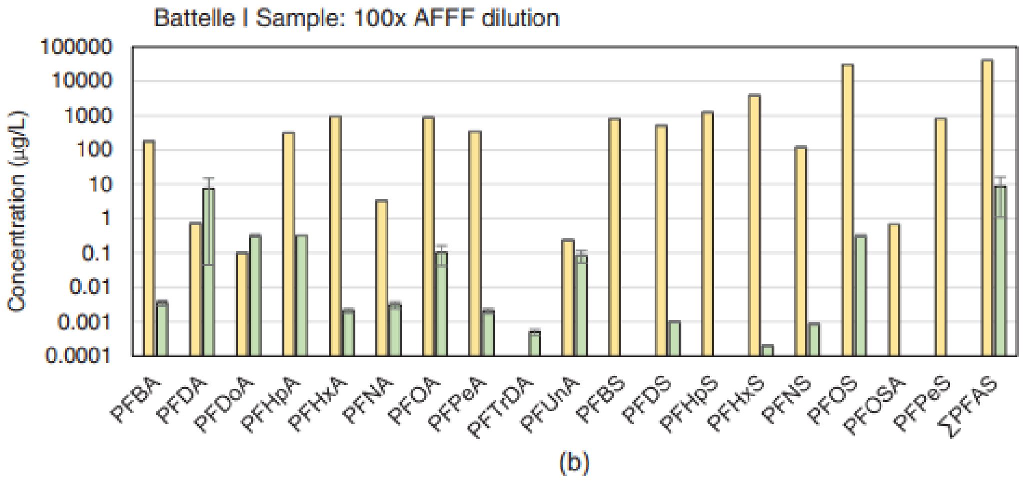
- Bond cleavage, followed by oxidative radical attack and hydrolysis
- **Can also treat solids, i.e. spent GAC or resin**
- Ionic salts fall out of solution – design of heating element is very important; NASA has a patent on a hydrothermal flame that is helpful in managing the salting out effect of SCWO

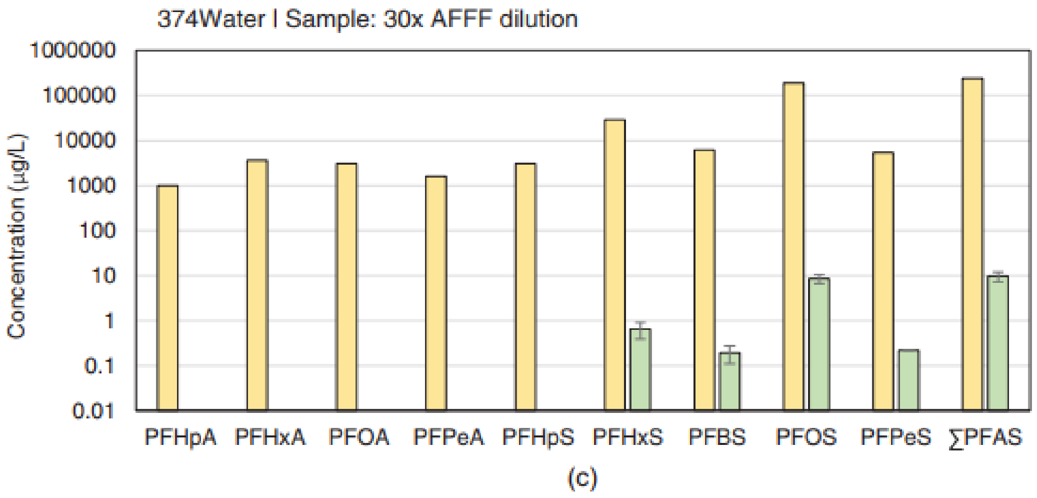


- Developers:
  - 374 Water, Battelle Annihilator, Aquarden

AFFF Treatment with Three Different SCWO Systems



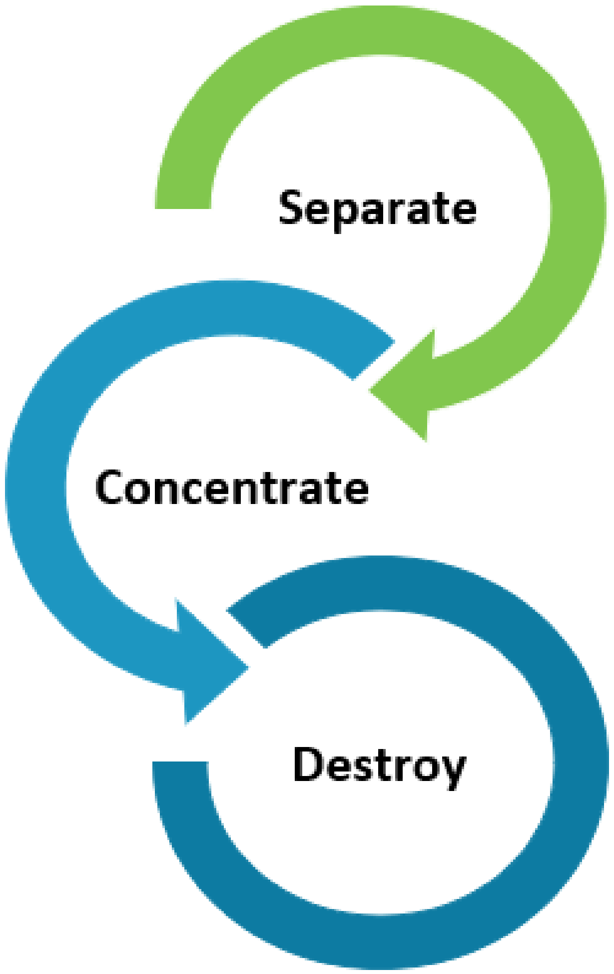


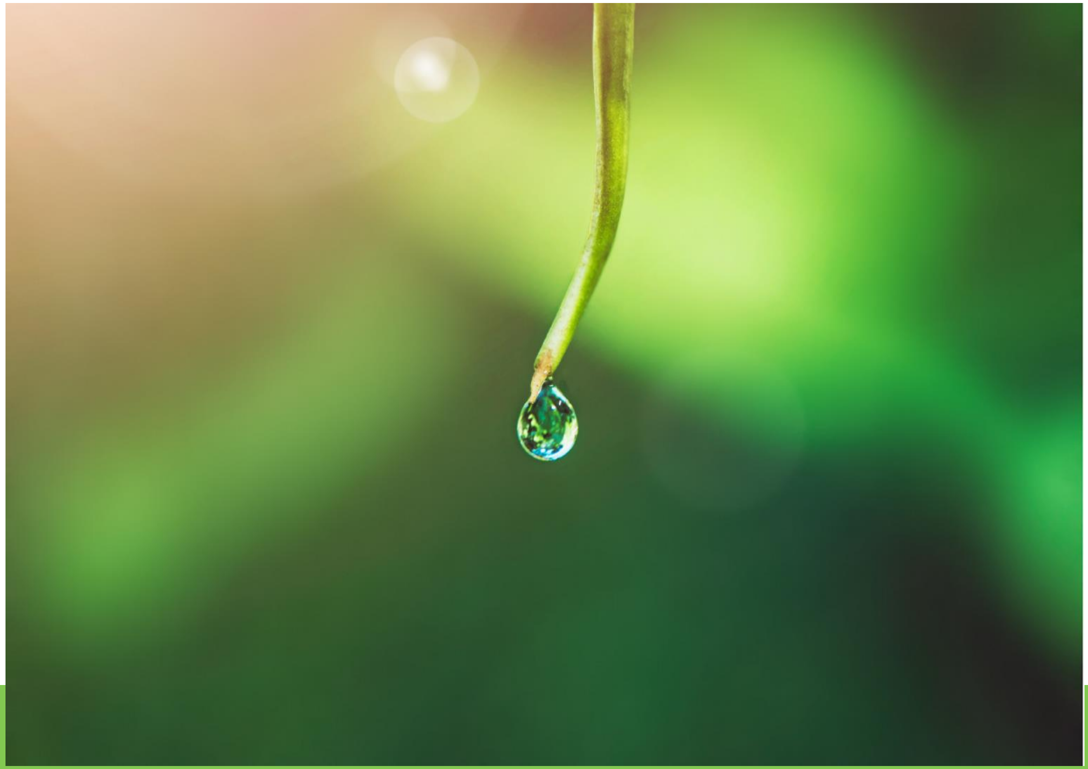


Effective and rapid treatment of short and long chain PFAS

Summary

- You can't destroy PFAS without concentrating it
- Regenerable IX is an affective means to concentrate at a million-to-one ratio
- Several destruction technologies are showing promise in the near-term
  - Non-thermal Plasma
  - Electrochemical Oxidation
  - Hydrothermal Alkaline Treatment
  - Supercritical Water Oxidation
- More are on the way – this is the new frontier
- Q&A





Sustainable IX Resin and Destructive Technologies Overview for Complete PFAS Treatment

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