Innovative Approaches for PFAS Destruction

2024 Spring Conference
SW Louisiana Chapter
Air & Waste Management Association

March 7, 2024

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Chief Commercial Officer

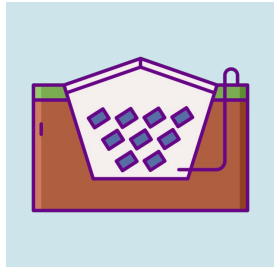
Revive environmental

Revive Environmental: Snapshot

- Water Technology company created in December 2022
- Structure: Founded by Battelle and Viking Global Investors
- Technology: Global Patents on PFAS Annihilator® and GAC Renew™
- Headquarters: Columbus, OH / CEO: David Trueba
- https://revive-environmental.com/

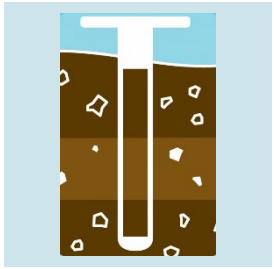
Target Markets and Applications

AFFF



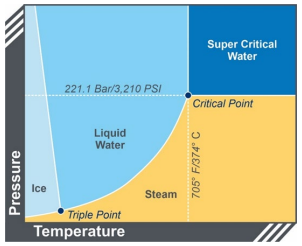
Landfill Leachate

Industrial Water

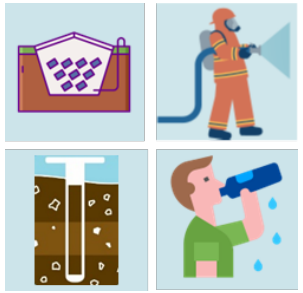


Groundwater Remediation

Learning Objectives



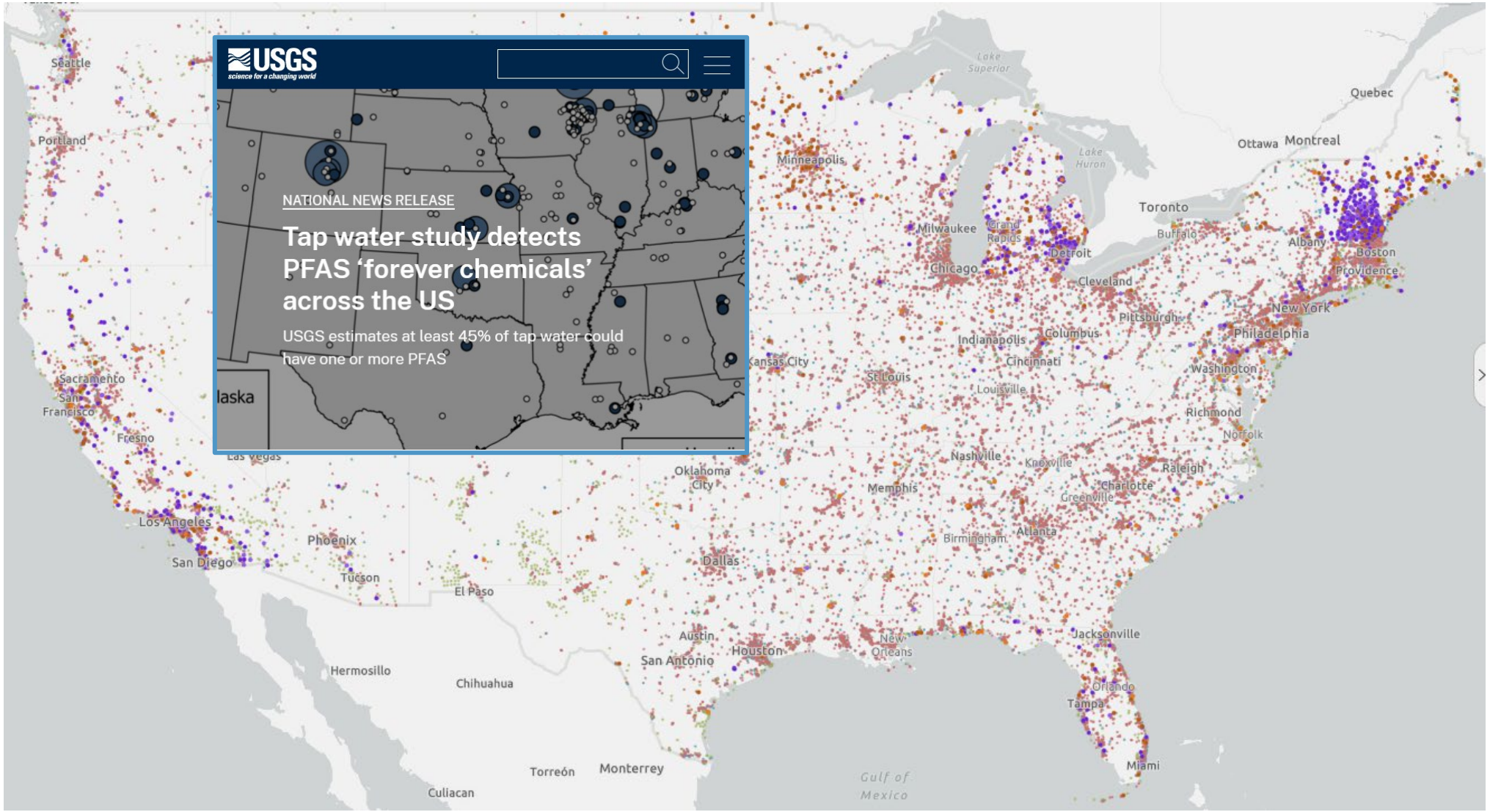
Review capabilities and commercial readiness of SCWO



Review application scenarios

Lessons learned in the deployment, commissioning, and ongoing operation and optimization of a SCWO unit

Not just ‘forever’ but ‘everywhere’ chemicals



Source: Presumptive Contamination Sites from [PFAS Sites and Community Resources map]

Proposed MCLs could require 99.9999% removal

Compound	Proposed MCLG	Proposed MCL (enforceable levels)
PFOA	Zero	4.0 parts per trillion (also expressed as ng/L)
PFOS	Zero	4.0 ppt
PFNA	1.0 (unitless) Hazard Index	1.0 (unitless) Hazard Index
PFHxS		
PFBS		
HFPO-DA (commonly referred to as GenX Chemicals)		

Source: EPA, Proposed PFAS National Primary Drinking Water Regulation
https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

Using PFOA as example…

If source contains 3,000 ppb
(or 3,000,000 ppt)

Achieving discharge of 4 ppt
(or 0.004 ppb)

Requires 99.9999% removal
(4/3,000,000 = 0.0001%)

Overview of Disposal/Treatment of PFAS Waste Streams

Existing Methods of PFAS Disposal

Landfill Disposal

- Non-destructive
- AFFF mixed with stabilizer
- Immobilized and encapsulated
- Not all landfills take PFAS
- Readily available, low cost

Deep Well Injection

- Non-destructive
- Injected into tectonically stable strata
- Not available in all states

Incineration

- Destruction
- Products of Incomplete Combustion (PICs) still being studied
- State Moratoriums

On-Site Storage

- On-Site Storage
- Evaluating alternative disposal options
- Exposure and Spill Risk

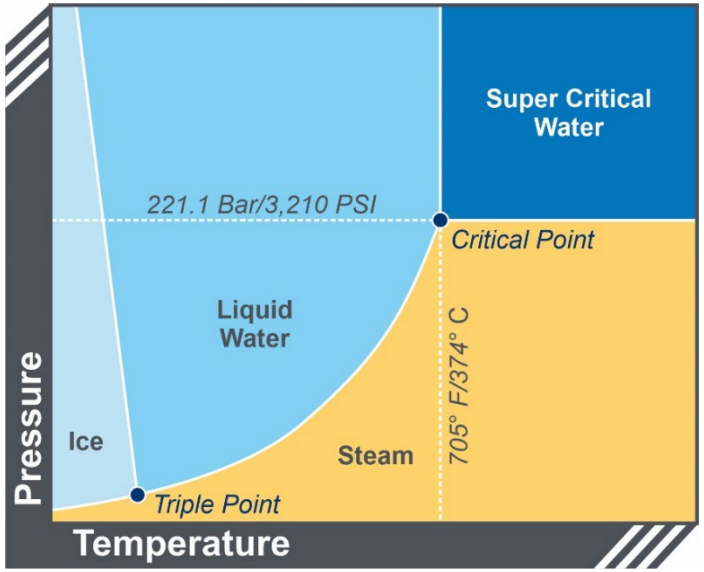
Innovative Technologies – Destruction

	SCWO (Supercritical Water Oxidation)	HALT (Hydrothermal Alkaline Treatment)	ECO (Electrochemical Oxidation)	Plasma
Readiness	• Commercial, Permitted • > 20 years Operational Success	• Pilot + Designing scaled-up system for testing	• Pilot	• Design + Initial field pilot
Strengths	• Most comprehensive depth and breadth of PFAS destruction • Can handle wide variety of contaminated aqueous matrices • Short residence time	• Very effective on long chain PFAS • Lower corrosion vs SCWO given lower temperatures • Short residence time	• Mobile unit • Effective on PFOA and PFOS • Multiple Providers	• Highly mobile, low-cost unit • Low energy consumption for PFAS destruction • Can handle PFAS-containing air streams
Consider-ations	• Susceptible to salt plugging • Susceptible to corrosion given high temperatures • Readiness being established for solid matrices	• Susceptible to salt plugging • May require long residence time to address short-chain PFAS	• Difficulty handling foam fractionated / concentrated waste streams • Effectiveness on short chain PFAS not yet proven • Long residence time	• Limited breadth and depth of PFAS destruction • Impacted by water quality • Long residence time • Potential for air emissions

Sources: TME: The Military Engineer, Society of American Military Engineers (July • August • Vol 115 • No 46), https://online.fliphtml5.com/fedq/opti/#p=55; Revive internal analysis

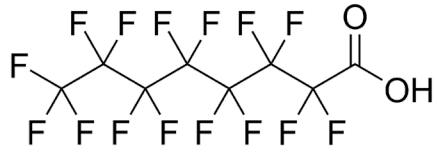
What is Supercritical Water Oxidation?

- Supercritical water exhibits unique properties
  - Gas and liquid phases become indistinguishable
  - Density is about 10% of water above the supercritical point
  - Water no longer behaves as a polar solvent
  - Oxygen is fully soluble

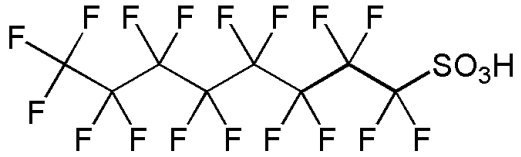


- High temperature in an oxidizing environment overcomes activation energy to break C-F bond

PFOA

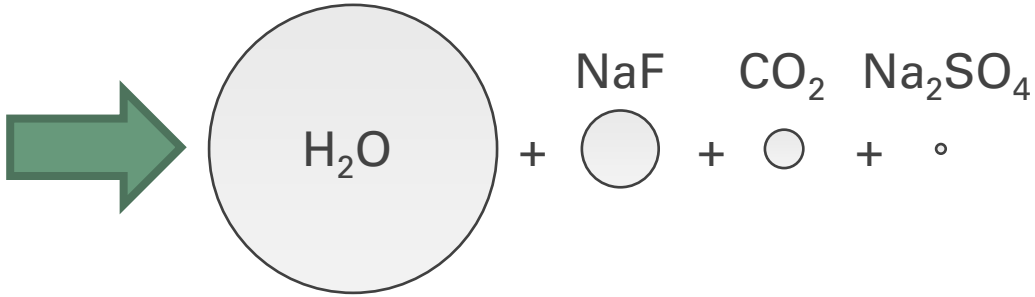


PFOS

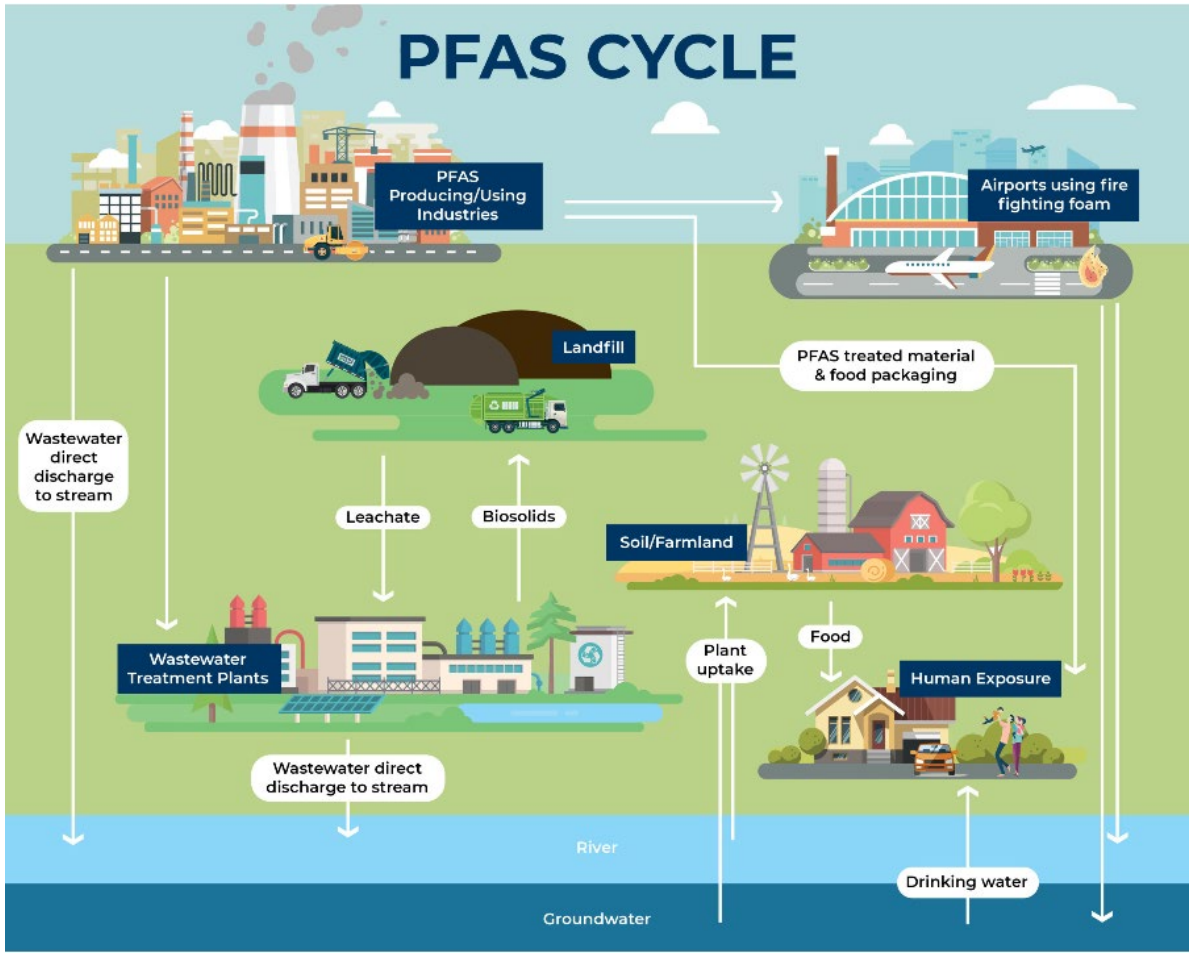


+ H_2O_2 (oxygen source)

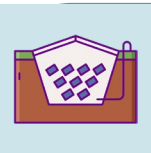
+ NaOH (Neutralization)



Challenges will differ by application/source

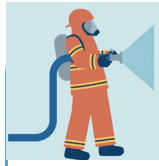


Source: Walnut Valley Water District, https://walnutvalleywater.gov/your-water/your-drinking-water/water-quality/



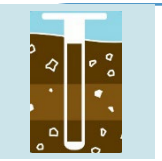
Landfill Leachate

- High Volume
- Recurring - Continuous
- High amount of co-contaminants



AFFF

- Lower Volume
- Very High PFAS (ppm)
- Concentrate vs Rinsewater



Soil / Ground Water Remediation

- High Volume
- Lower PFAS Concentrations
- In-Situ vs Ex-Situ

Industrial Wastewater

- Very High Volume
- Recurring - Continuous
- Low PFAS Conc
- PFAS concentration required

Current Commercial Application of SCWO

Landfill Leachate

Landfill Leachate

Foam Fractionation

PFAS Concentrate

Industrial Wastewater

Industrial PFAS

GAC

GAC Renew™

Foam Fractionation

AFFF

AFFF Stockpile

Changeout AFFF

Branch Network

PFAS in Groundwater

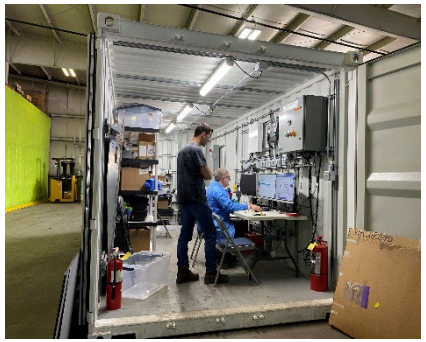
PFAS Concentrate

Foam Fractionation

Contaminated GW

Technologies Deployable by Revive

Commercial Operations



1st PFAS Destruction Technology to Commercialize in N America (March 2023)

- Treated over 55,000,000 gallons combined of landfill leachate, AFFF, industrial wastewater, and groundwater in 2023
- All discharge compliant with local and state regulations and validated by 3rd party analytical data prior to discharge

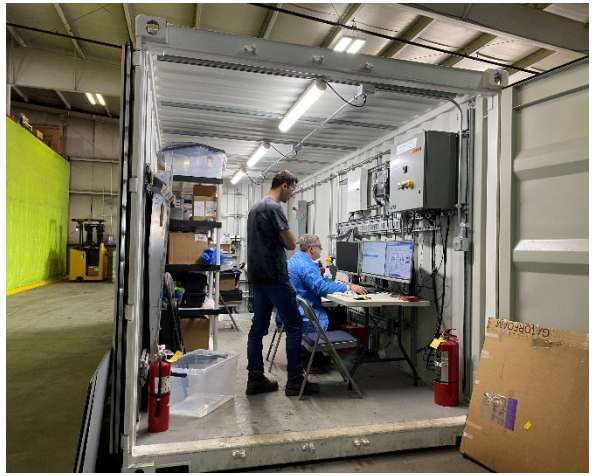
Establishing Central Facilities close to Customer Needs

- For Customers with one-time waste streams (e.g., AFFF) or low volume recurring waste streams (e.g., likely aggregate from multiple landfills)
- Work transparently with local and state regulatory partners to explain the technology, demonstrate destruction, and establish permits and monitoring

Deploying Mobile Units to Customers that require Onsite operations

- DOD field studies where comparing head-to-head vs other technologies
- Customers with sensitivity over transport offsite / out-of-state

Know your site requirements



- Power
- Water
- Shelter
- Footprint

Footprint: 40’ x 40’ for 2 CONEX boxes + equipment

Annihilator Operational Requirements

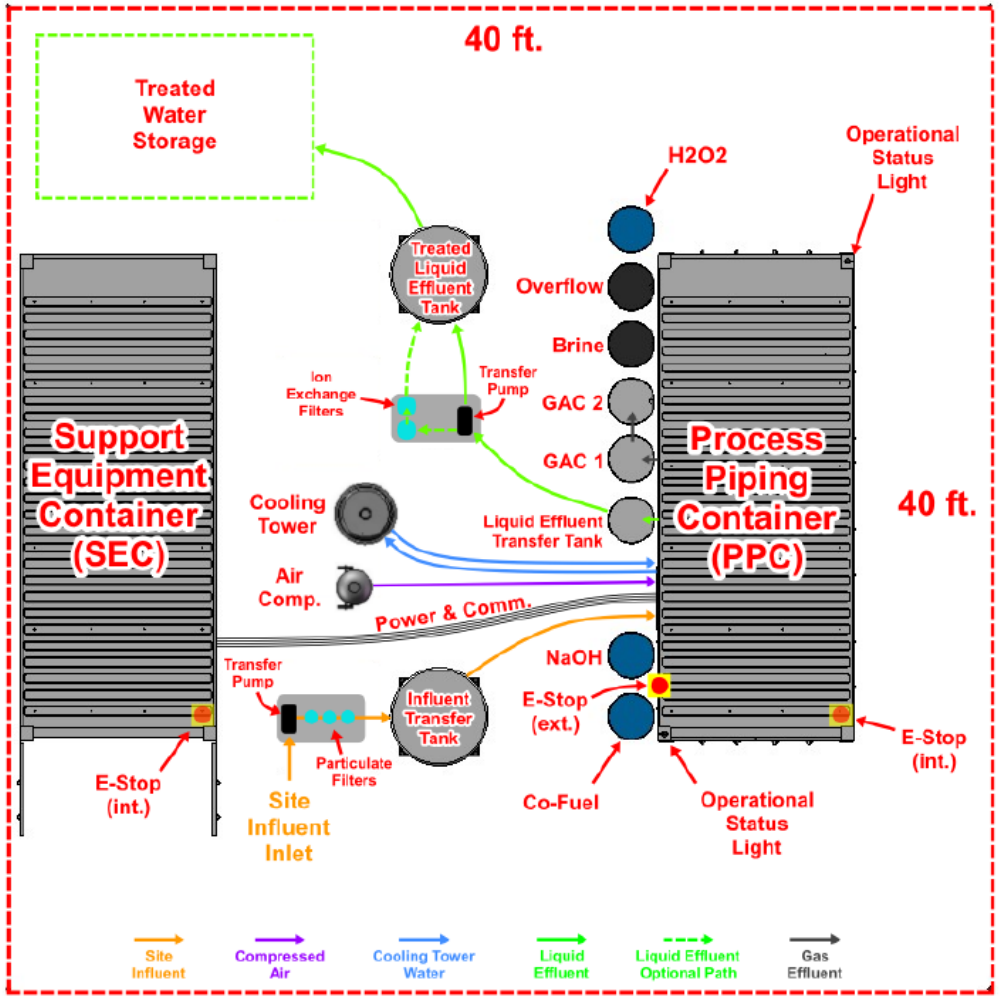


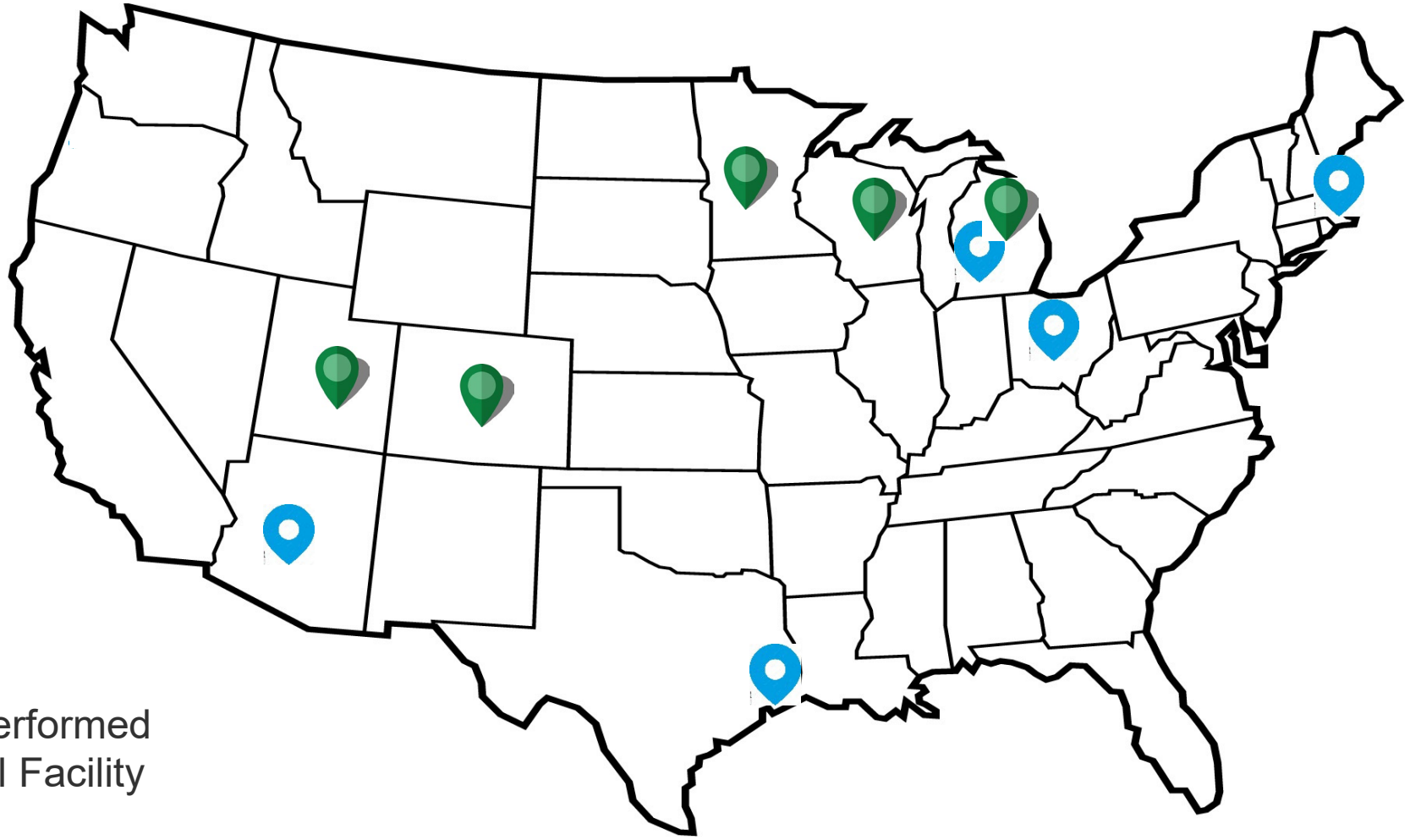
Figure 3. Typical M2 System Operational Configuration

- 40 ft x 40 ft x 12 ft
- Electrical – 480V, 3-phase, 100 A Service
- On-Site Water – 30 gph, >40 psi
- Operational Temp > 35 deg F
- Will require air and liquid discharge permit.
- Pad: Concrete or rock
- Winterization ready

2024 PFAS Annihilator® Deployments

Regional Facility Deployments

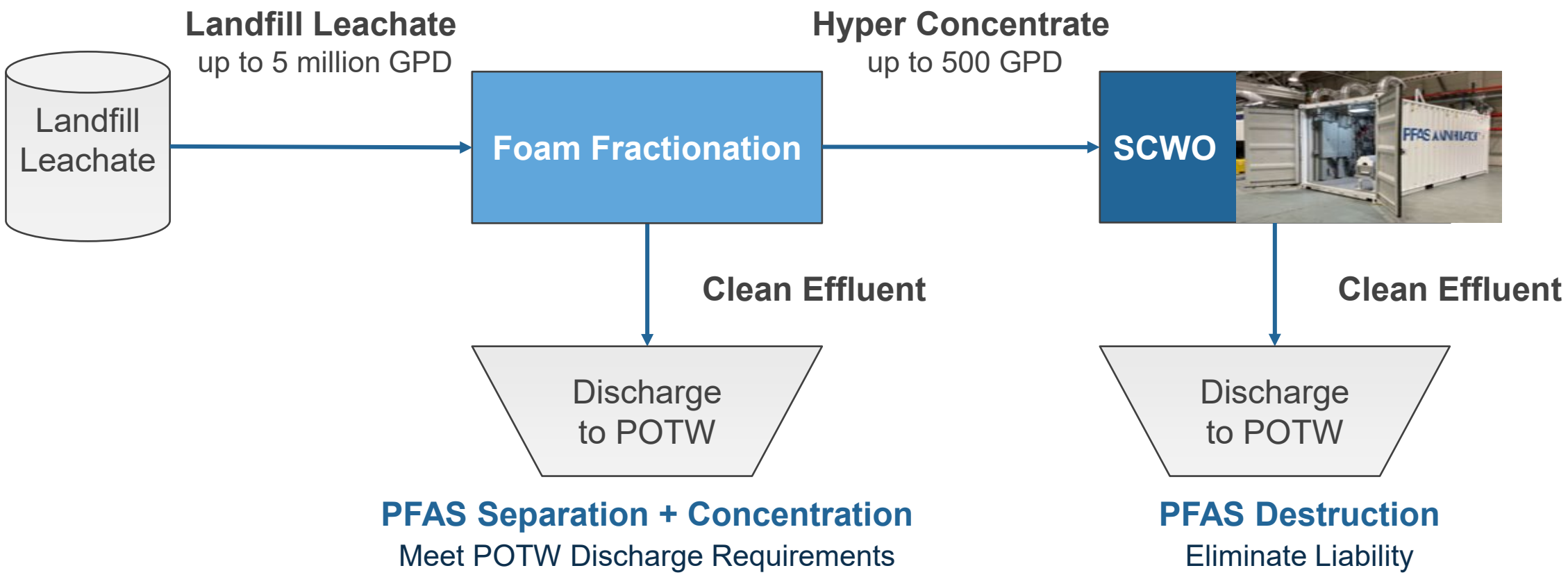
Customer Deployments (may ship to Regional facility)



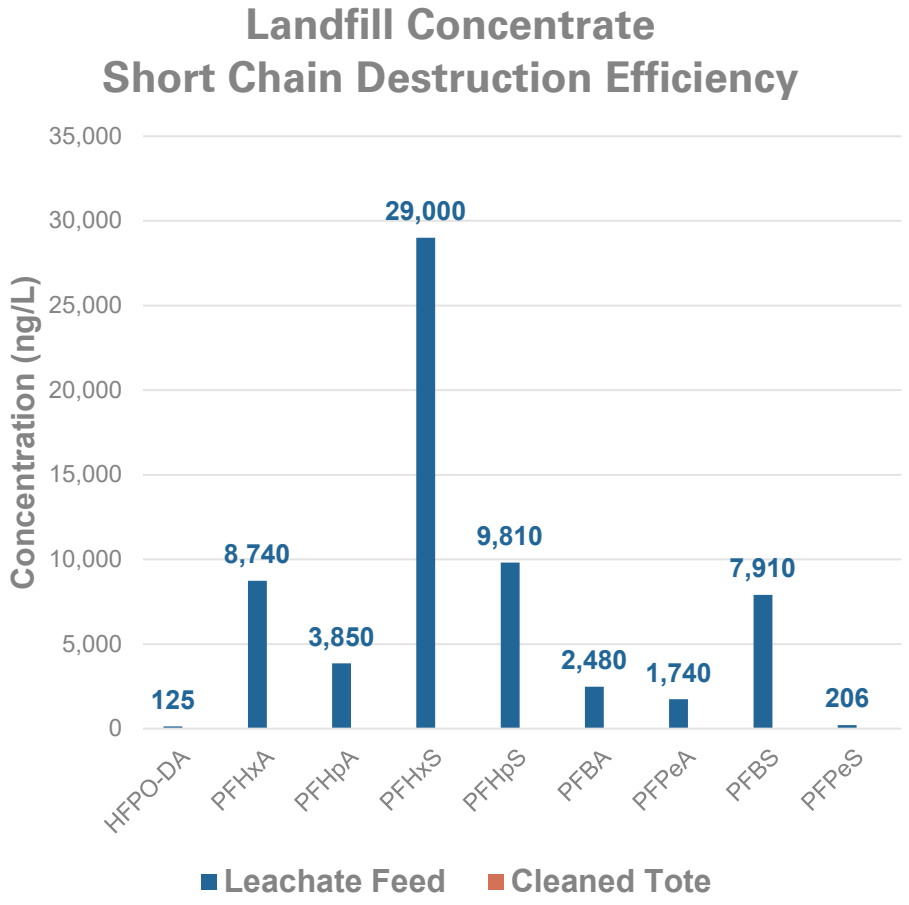
Does not include Treatability Assessments which can be performed in Ohio or at another Regional Facility

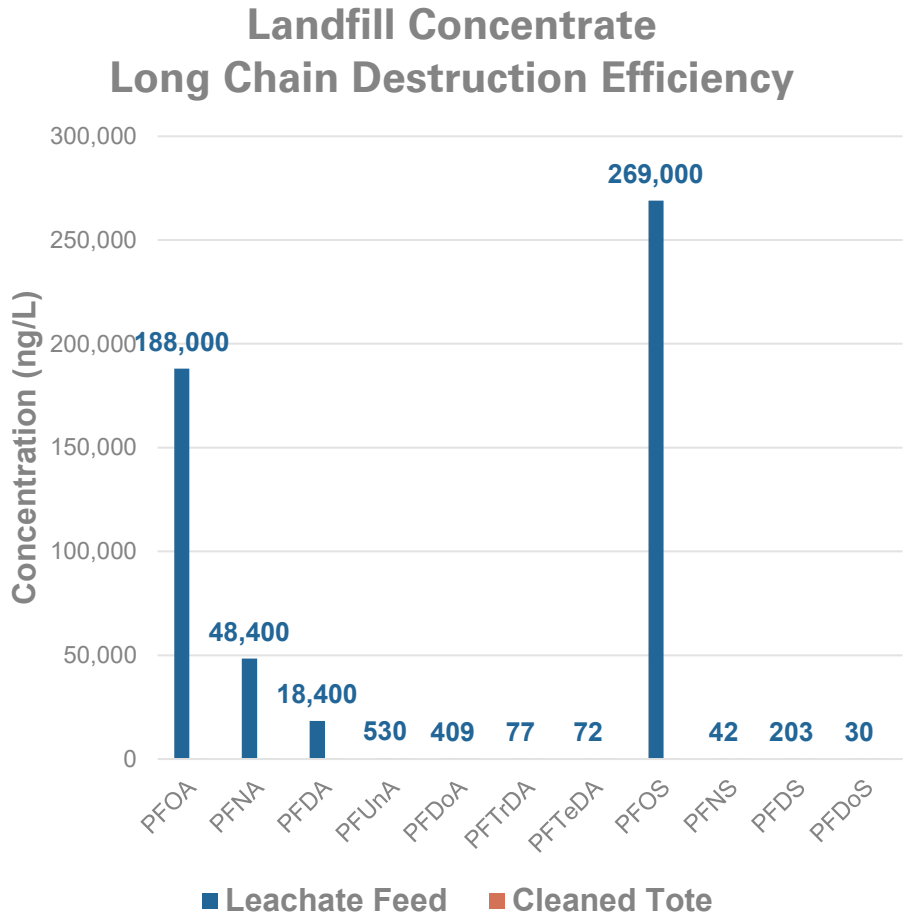
PFAS Destruction – Landfill Leachate

Process Flow: Landfill Leachate via FF then SCWO



Landfill Leachate: Short and Long Chain Destruction





Destruction Efficiency >99.99% when starting value above 2000 ng/L

PFAS Destruction – Aqueous Film-Forming Foam (AFFF)

Multiple Waste Streams - Different Challenges

Concentrate

- Very high concentration of PFAS
- Diversity in Carbon content of formulas
- Estimated 15M+ gallons across DOD, Airports, Civil (incl. O&G/AST)

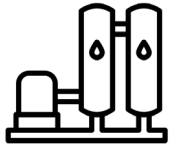
Rinsate

- High volume (typically 3x system capacity)
- Lower PFAS concentration
- Potential use of special rinse agents

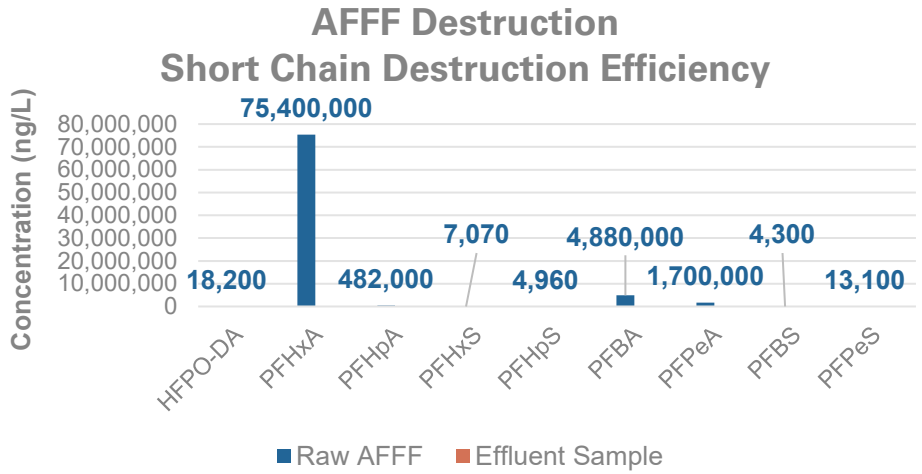
Firewater + Groundwater

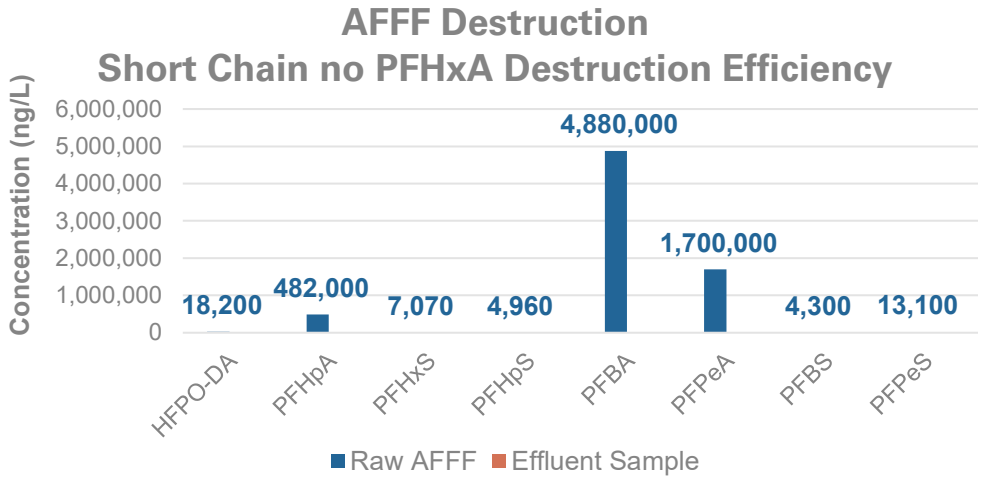
- Very high volume
- Lower PFAS concentration
- Co-contaminants incl other hydrocarbons

Treatment Scenarios for AFFF Waste Streams

Scenario	PFAS Concentration	Pre-/Treatment	Transport	Destruction
 Concentrate	Very High	None		
 Rinsate	High	Separation + Concentration 		Discharge Clean Effluent to POTW
 Firewater/ Groundwater	Moderate to Dilute	• Foam Fractionation (FF) • Reverse Osmosis (RO) • Granular Activated Carbon (GAC) • Ion Exchange Resin (IX)		

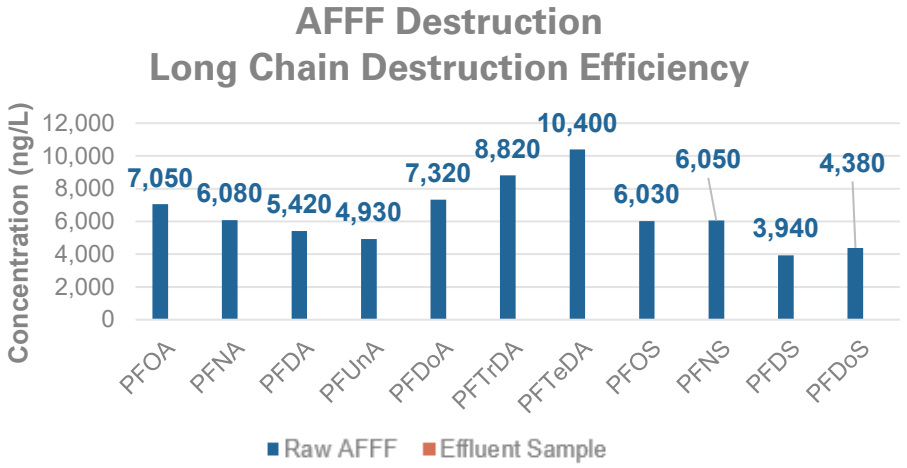
AFFF: Short and Long Chain Destruction





ANSULITE 6% AR-AFFF

Destruction Efficiency >99.99% when starting value above 1000 ng/L



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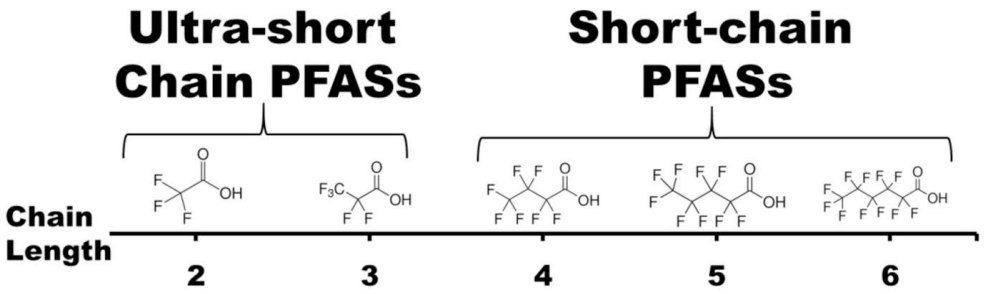


AFFF Concentrate: SCWO Destruction Results

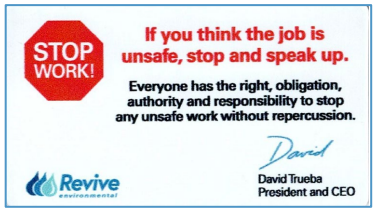
ANSULITE 6% AR-AFFF

			AFFF Production (ng/L)		
	Classification	More Information	Raw AFFF	Effluent Sample	% Destruction
PFBA	Carboxylic Acid	Short Chain	4,880,000	2.41	99.9990%
PFPeA	Carboxylic Acid	Short Chain	1,700,000	2.27	99.9973%
PFHxA	Carboxylic Acid	Short Chain	75,400,000	3.14	99.9999%
PFHpA	Carboxylic Acid	Short Chain	482,000	0.698	99.9971%
PFOA	Carboxylic Acid	Long Chain	7,050	1.17	99.6681%
PFNA	Carboxylic Acid	Long Chain	6,080	1.01	99.6678%
PFDA	Carboxylic Acid	Long Chain	5,420	0.899	99.6683%
PFUnA	Carboxylic Acid	Long Chain	4,930	0.819	99.6677%
PFDoA	Carboxylic Acid	Long Chain	7,320	1.21	99.6694%
PFBS	Sulfonic Acid	Short Chain	4,300	0.714	99.6679%
PFPeS	Sulfonic Acid	Short Chain	13,100	0.52	99.9206%
PFHxS	Sulfonic Acid	Short Chain	7,070	1.17	99.6690%
PFHpS	Sulfonic Acid	Short Chain	4,960	0.823	99.6681%
PFOS	Sulfonic Acid	Long Chain	6,030	1	99.6683%
PFNS	Sulfonic Acid	Long Chain	6,050	1	99.6694%
8:2FTS	Fluorotelomer	Fluorotelomer	22,300	3.69	99.6691%
PFDS	Sulfonic Acid	Long Chain	3,940	0.653	99.6685%
PFDoS	Sulfonic Acid	Long Chain	4,380	0.726	99.6685%
4:2FTS	Fluorotelomer	Fluorotelomer	1,680,000	5.32	99.9937%
6:2FTS	Fluorotelomer	Fluorotelomer	188,000,000	22.4	99.9998%
PFTrDA	Carboxylic Acid	Long Chain	8,820	1.46	99.6689%
PFTeDA	Carboxylic Acid	Long Chain	10,400	1.73	99.6673%
PFOSA	Carboxylic Acid	Fluorotelomer	4,570	0.758	99.6683%

ANSULITE 6% AR-AFFF

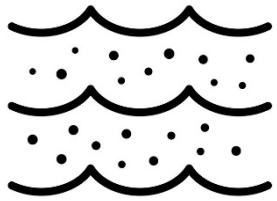
			AFFF Production (ng/L)		
	Classification	More Information	Raw AFFF	Effluent Sample	% Destruction
NMeFOSA	Carboxylic Acid	PFCA and PFSA precursor	4,840	0.802	99.6686%
NEtFOSA	Carboxylic Acid	PFCA and PFSA precursor	2,430	0.402	99.6691%
NMeFOSAA	Carboxylic Acid	PFCA and PFSA precursor	15,900	2.64	99.6679%
NEtFOSAA	Carboxylic Acid	PFCA and PFSA precursor	13,900	2.3	99.6691%
NMeFOSE	Carboxylic Acid	PFCA and PFSA precursor	40,100	6.65	99.6683%
NEtFOSE	Carboxylic Acid	PFCA and PFSA precursor	35,200	5.85	99.6676%
HFPO-DA	Carboxylic Acid	Gen X	18,200	3.02	99.6681%
Adona	Carboxylic Acid	3M	16,900	2.8	99.6686%
PFMPA	Carboxylic Acid	UNK	15,300	2.53	99.6693%
PFMBA	Carboxylic Acid	UNK	14,600	2.42	99.6685%
NFDHA	Carboxylic Acid		18,500	3.06	99.6692%
9Cl-PF3ONS	Sulfonic Acid		17,900	2.82	99.6849%
11Cl-PF3OUdS	Sulfonic Acid		26,900	4.4	99.6729%
PFEESA	Carboxylic Acid	UNK	5,150	0.855	99.6680%
3:3 FTCA	Fluorotelomer		40,600	6.73	99.6685%
5:3 FTCA	Fluorotelomer		919,000	18	99.9608%
7:3 FTCA	Fluorotelomer		127,000	21	99.6693%

Lessons Learned



Lead with Safety + Transparency

SCWO is established but new to our Customers and Regulatory Partners and to their sites

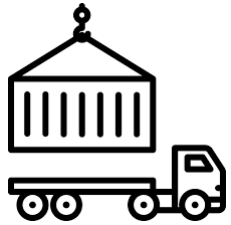


High Salts need to be Managed

Precipitation across heat exchangers on way to SCWO reactor can cause plugging if not addressed proactively

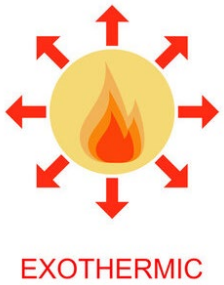
Every Influent is Different

Analysis critical to design optimal operational parameters and any needed pretreatment



Not all Challenges are Technology

Transport, weather, local vendors, site readiness, and other factors need to be addressed to deliver success



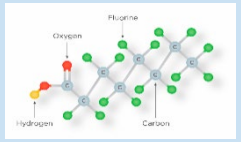
More PFAS/Organics the Better

AFFF and other concentrated organic streams provide best economics and generate heat that is recovered

People > Technology

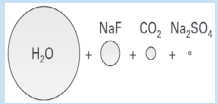
Revive model is to bring best talent to safely and effectively operate wherever we deploy

Summary



>99.99% Destruction

- Short- and Long-chain compounds
- Dilute or Concentrated streams



Minimal Waste

- PFAS is mineralized not moved
- By-products: Water, Inert salts, CO_2

Highly Efficient

- Short residence time (<30 seconds)
- Heat Exchangers for influent/effluent

Permit Ready

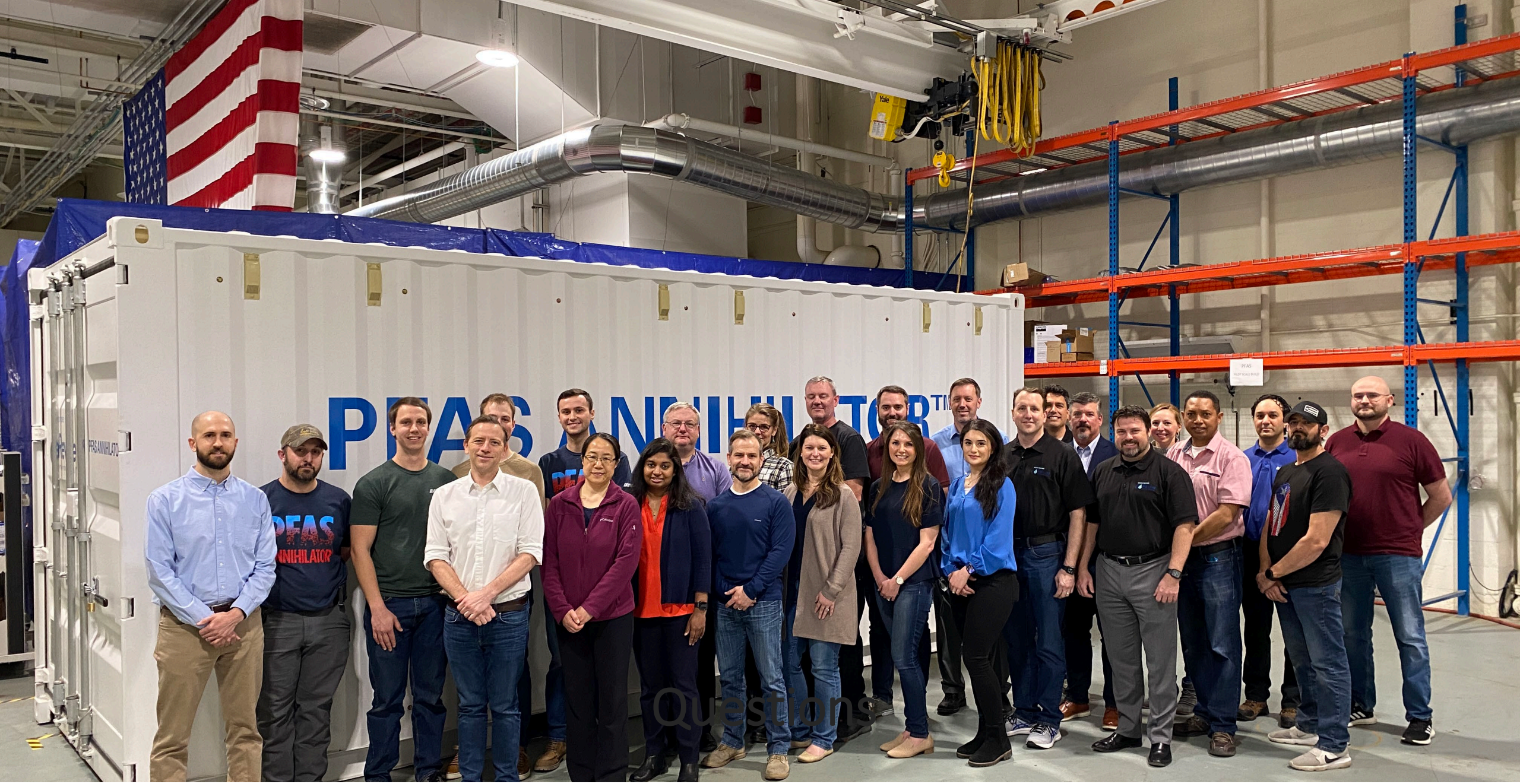
- Effluents below 12 ppt Michigan permit thresholds
- Process underway across other states

Complementary

- Works well with pre-concentration
- Not inhibited by organic co-contaminants

Commercial Ready

- Full-scale commercial operation at permitted facility
- Multiple influence waste streams
- Regional deployments across US



Thank You and Questions

RENEW. RESTORE.

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