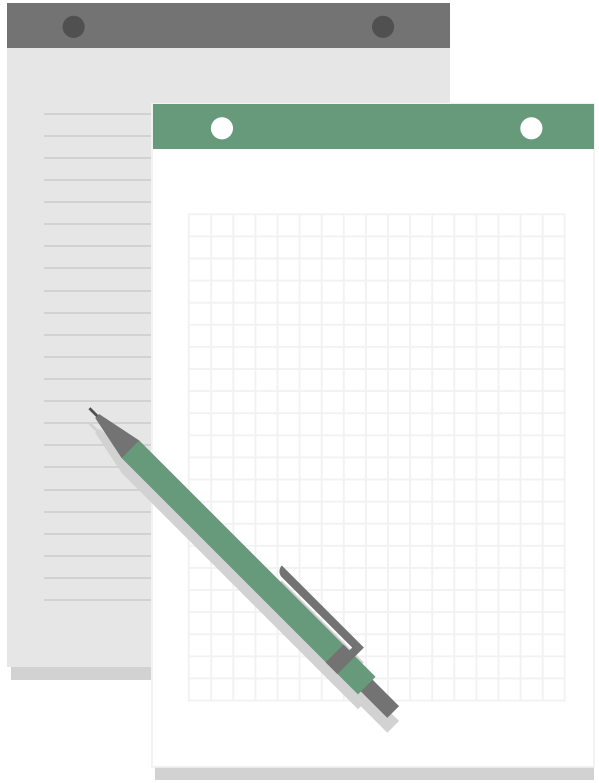
PFAS Treatment: The PFAS Annihilator

2024 Environmental Regulatory Conference
Eric Drugotch
September 10, 2024

Revive environmental

Today's Agenda

- Overview of Revive
- PFAS and why we're here
- Supercritical Water Oxidation
- PFAS Annihilator Program
- Data Review
- NH State Take Back Program
- Questions

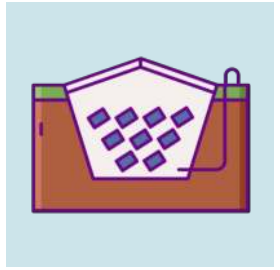


Revive Environmental: Snapshot

- 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/

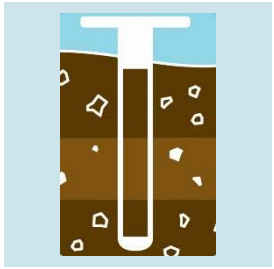
Target Markets and Applications

AFFF



Landfill Leachate

Industrial Water



Groundwater Remediation

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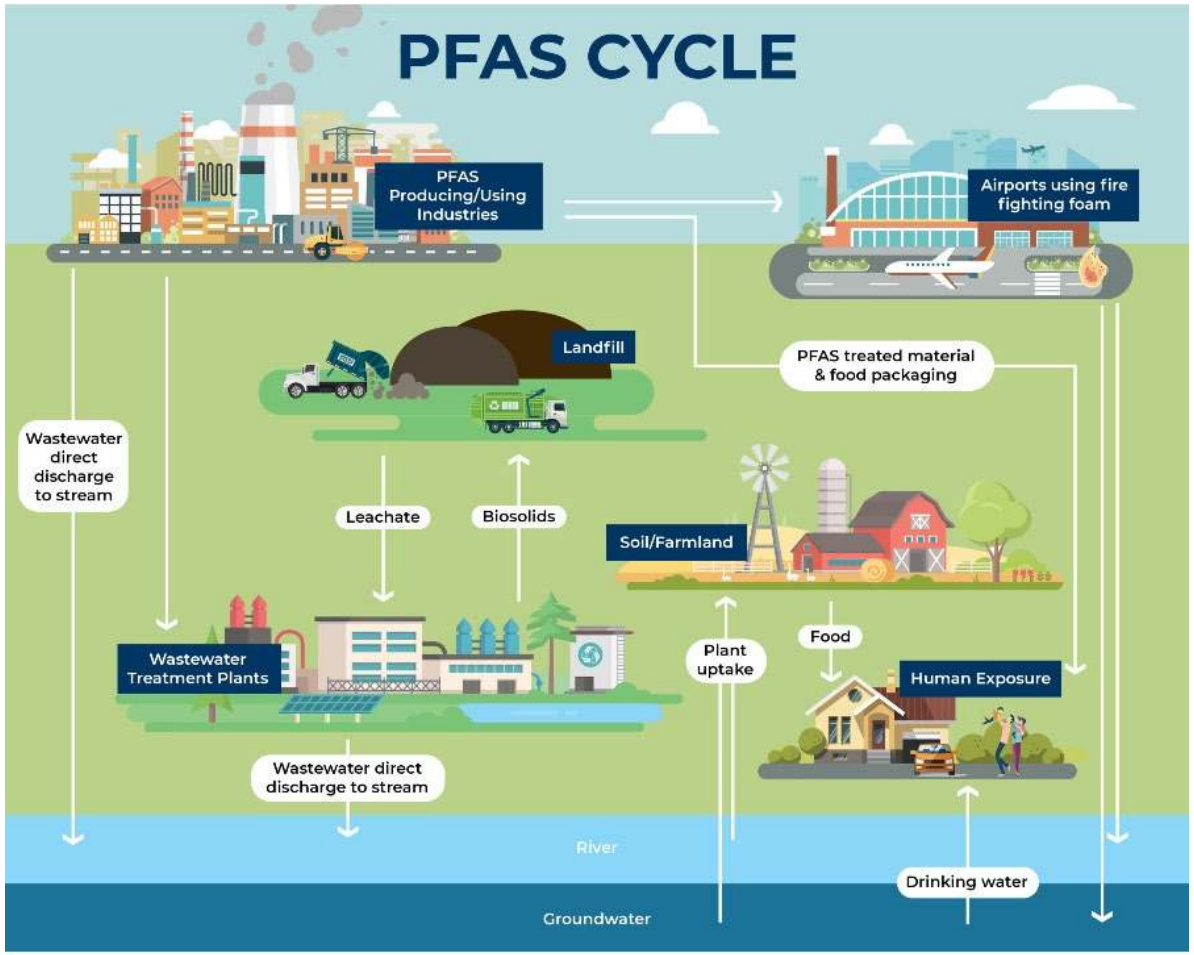
Challenges will Differ by Application/Source



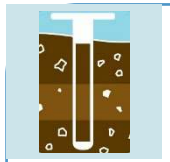
Source: Walnut Valley Water District, https://walnutvalleywater.gov/your-water/your-drinking-water/water-quality/

Drinking Water

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

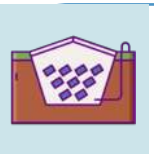
AFFF

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



Soil Remediation

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



Landfill Leachate

- Very High Volume
- Recurring - Continuous
- Low PFAS Concentration
- Removal via GAC, RO

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New EPA MCLs could require 99.9999% removal

Source: https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

Compound	Final Maximum Contaminant Level Goals	Final MCL (enforceable levels)
PFOA	Zero	4.0 ppt
PFOS	Zero	4.0 ppt
PFHxS	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
HFPO-DA (commonly known as GenX Chemicals)	10 ppt	10 ppt
Mixtures containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS	1 (unitless)	1 (unitless)
	Hazard Index	Hazard Index

- **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%)

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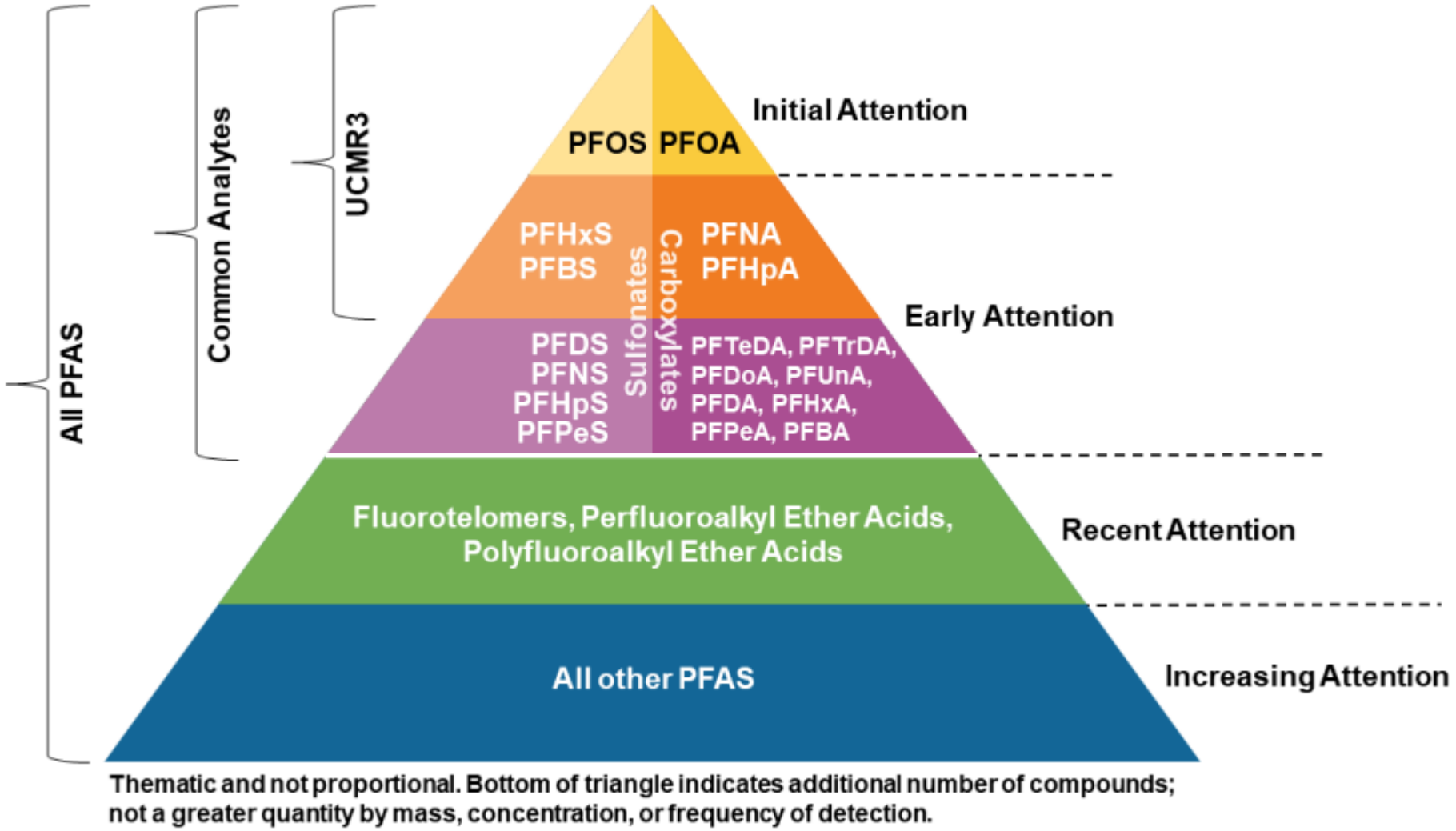
Spectrum of Concerning PFAS Contaminants



Source: J. Hale, Kleinfelder. Used with permission.

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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

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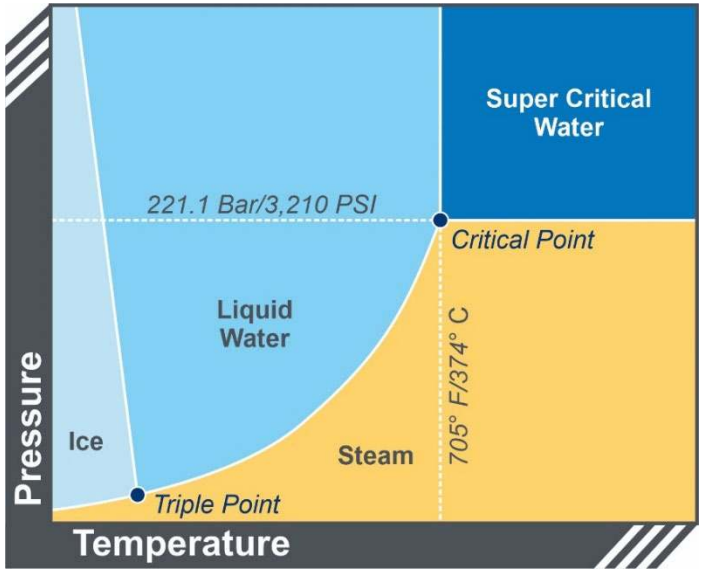
Technology Overview

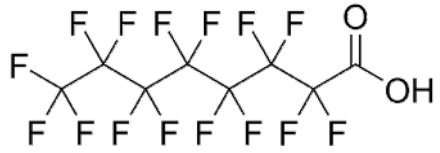
What is Supercritical Water Oxidation?

- 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

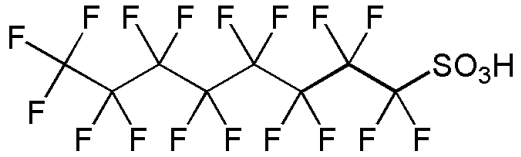


- High temperature in an oxidizing environment overcomes activation energy to break C-F bond

PFOA

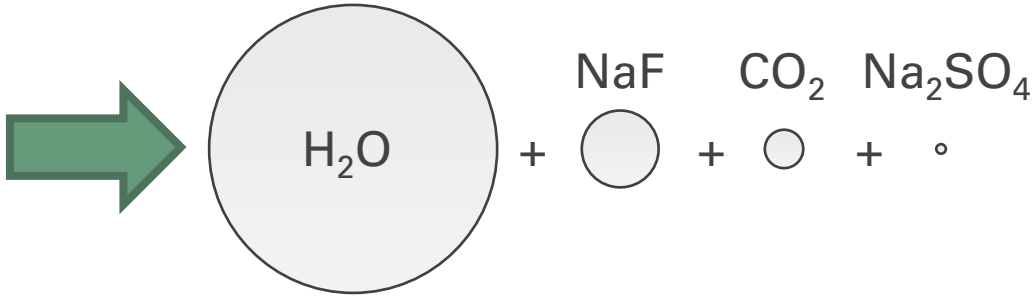


PFOS



+ H_2O_2 (oxygen source)

+ NaOH (Neutralization)



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PFAS Annihilator®: Tracking, treatment, annihilation

Chain of Custody
Batch receipt tied to analytical data and operating parameters

Influent, Effluent Testing
Regular sampling of all aqueous and vapor streams to ensure full destruction

PFAS destruction
Full combustion of all organic compounds incl. all PFAS analytes

No Harmful Byproducts
SCWO reaction results in clean water, nominal CO_2, and inert salts (e.g., NaF)

PFAS Annihilator® meets EPA Framework and is Ready to Scale

Technology
Ready w/ Capacity to Scale Now

Materials
Already processing AFFF, Leachate, Wastewater

Analytical
Verified by EPA 1633 + Peer Reviewed literature

Efficacy
Broad + Complete Mineralization;
no PICs, PIDs, or harmful byproducts

Community
No Environmental Justice concerns/impacts

Regulatory
Operating + permit-compliant in multiple states

PLUS...

Batch-by-Batch Confirmation of Destruction

Certificate of Annihilation (verified analytical)

Ready to Scale + Units Available

2 Central Processing Facilities
Michigan + Ohio; expanding across US

7 Mobile Units Available
For deployment Onsite or at Revive facility

$ Cost Competitive
vs Incumbent/Legacy Technologies

Source: USEPA's Interim Guidance on Destroying and Disposing of Certain PFAS and PFAS-Containing Materials That Are Not Consumer Products (https://www.epa.gov/pfas/interim-guidance-destroying-and-disposing-certain-pfas-and-pfas-containing-materials-are-not)

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Deployment + Commercial Operations

Current Commercial Application of SCWO

Landfill Leachate

Landfill Leachate → Foam Fractionation → PFAS Concentrate

Industrial Wastewater

Industrial PFAS → GAC → GAC Renew™

Industrial PFAS → Foam Fractionation

AFFF

AFFF Stockpile → Changeout AFFF

Branch Network

PFAS Annihilator®

PFAS in Groundwater

Contaminated GW → Foam Fractionation → PFAS Concentrate

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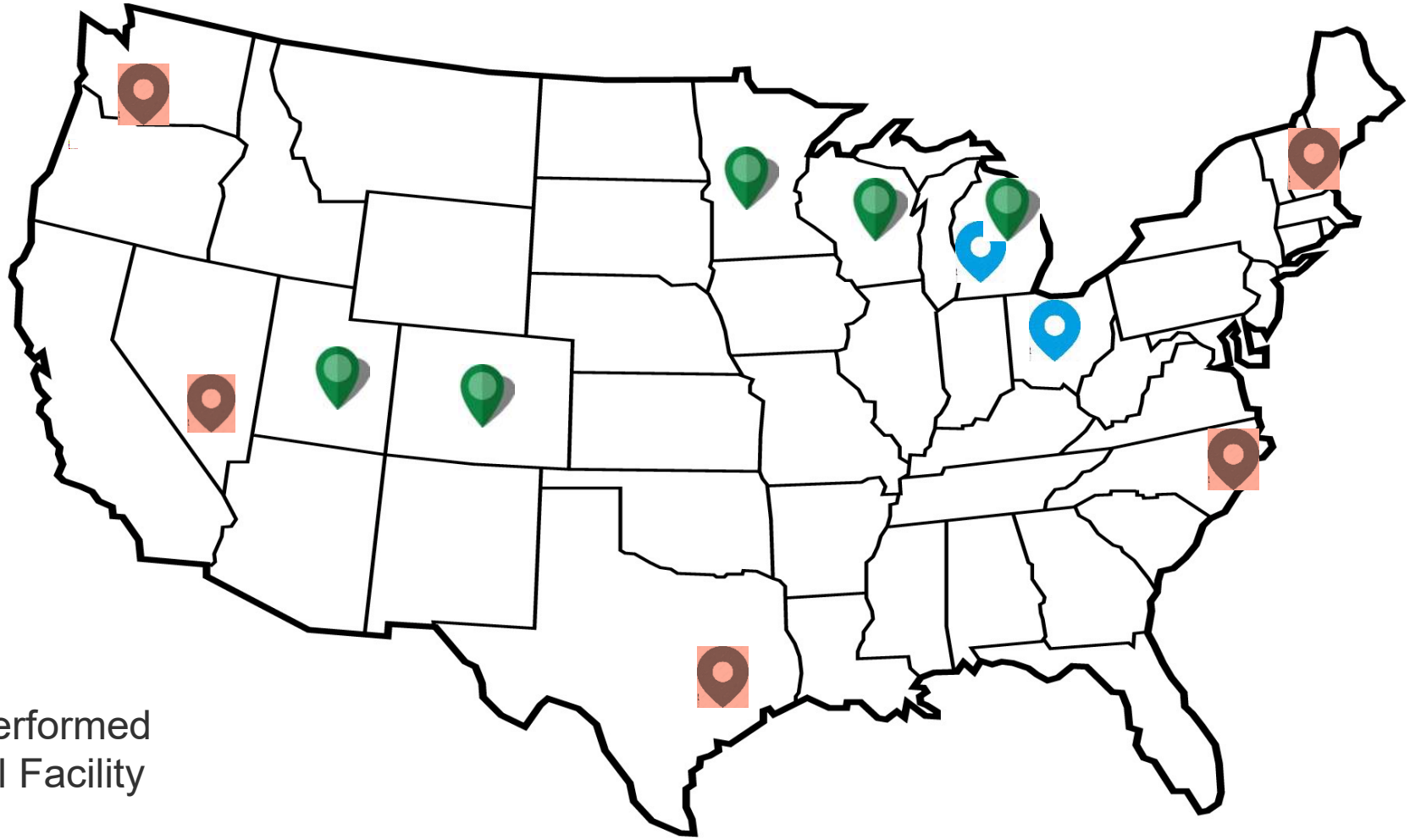
PFAS Annihilator® Deployments

Permitted Facilities

Customer Deployments
(may ship to Regional facility)

Future Facilities



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

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PFAS Destruction – Aqueous Film-Forming Foam (AFFF)

NH State Take Back Program Summary

Impact to New Hampshire

- Around 10,000 gallons of PFAS-laden aqueous fire-fighting foam (AFFF) removed from the state
  - 10 collection events state-wide
  - Dozens of fire departments participated
- Material to be destroyed in the PFAS Annihilator
- Reduced potential for PFAS discharge in communities around the state
- Eased liability burden for local fire departments

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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%

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PFAS Destruction – Landfill Leachate

Results: PFAS Destruction of F.F. Hyperconcentrate

Results

- Treated >1 million gallons of landfill leachate
- Treated leachated PFAS concentration was below discharge criteria
- Generated 14 gallons of hyperconcentrate
- Hyperconcentrate destroyed in Revive's PFAS Annihilator

PFAS compound[1,2]	Hyperconcentrate	Treated Effluent (Sample #1)[3]	Treated Effluent (Sample #2)[3]
PFOA	7,180,000	0.277	0.263
PFOS	3,380,000	0.232^	0.225
GenX[4]	ND	0.682	0.679
PFHxS	432,000	0.266	0.264
PFNA	234,000	0.228	0.227
PFBS	301	0.161	0.161
PFHpA	716,000	0.158	0.157
PFHpS	185,000	0.186	0.185
NEtFOSAA	114,000	0.521	0.518
5:3 FTCA	52,600	4.07	4.05
PFHxA	44,600	0.376	0.374
PFOSA	42,600	1.72	0.171
PFPeS	18,400	0.118	0.117
6:2FTS	8,780	5.72^	5.43^
PFPeA	1,500	0.514	0.511

1 All concentrations are reported in ng/L.
2 Only showing PFAS analytes detected in the hyperconcentrate.
3 All Treated Effluent results are detection limit (DL) and thus Non-Detect (ND), except for those marked with a ^ which are above the DL but below the Limit of Quantification (LOQ)
4 GenX = Hexafluoropropylene oxide-dimer acid (HFPO-DA). GenX was not detected in the hyperconcentrate but is shown here given inclusion in US EPA MCLs.

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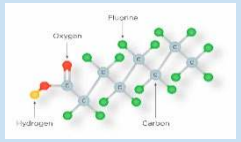
Summary



>99.99% Destruction

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

State Take Back Programs

- Safely disposing of 10,000 gallons of material from the state of New Hampshire

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 facilities
- Multiple influence waste streams
- Regional deployments across US

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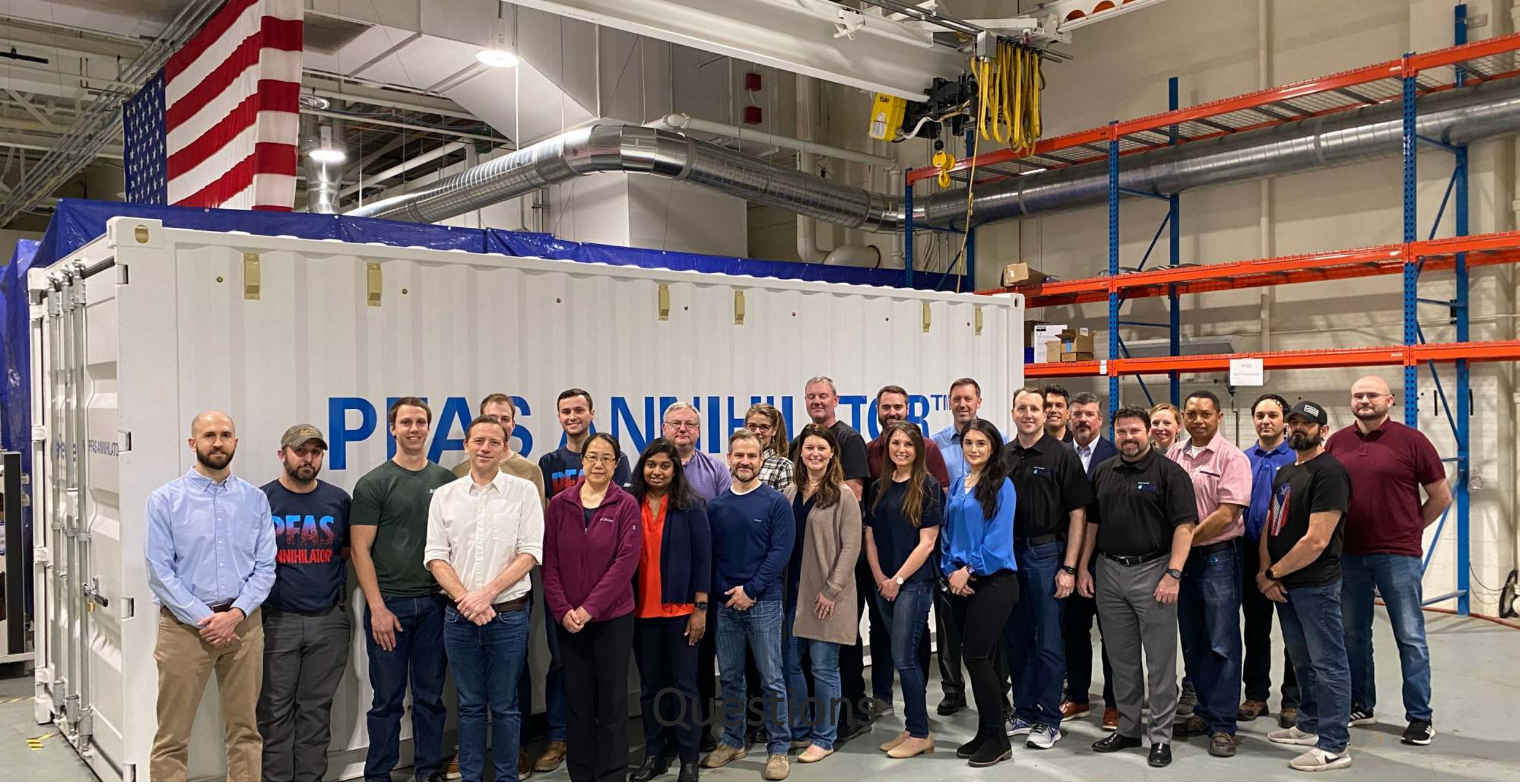

Thank You and Questions

RENEW. RESTORE.

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