PFAS
An Overview

Jim Cummings

Technology Assessment Branch/USEPA

Taiwan Technical Exchange

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PFAS Attributes

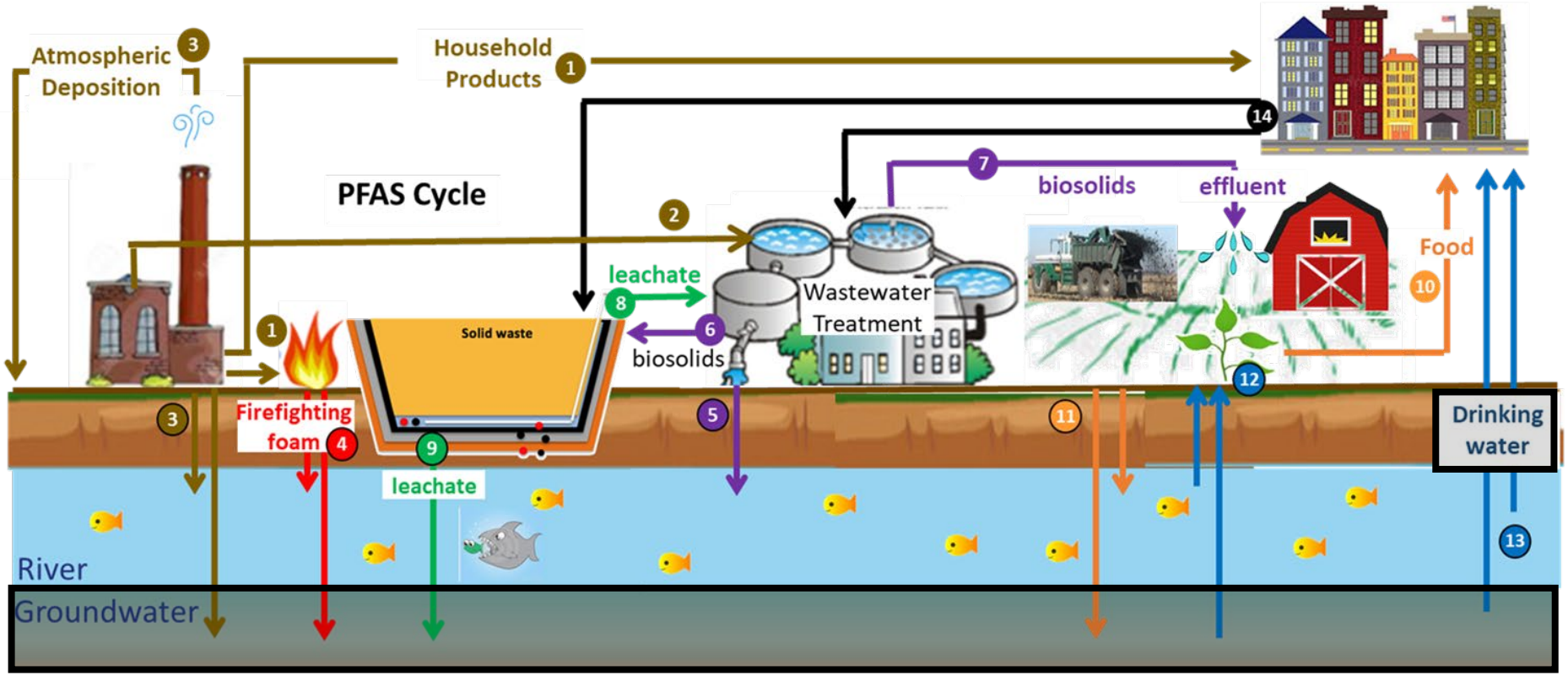
- MANY Compounds – 1000, 5000, 9000…the number keeps growing
  - Initial focus was on PFOA and PFOS

- MANY Industrial/Consumer Product Applications
  - AFFF –Aqueous Film Fire Fighting Foam used for actual aircraft fires and training
  - Teflon coating for cookware
  - Waterproof coating for clothing
  - Fume suppression for metal processing

- HIGH LEVEL OF VISIBILITY/CONCERN IN THE U.S.

- Increasingly stringent regulatory numbers – single digit ppt or lower
  - 90+% removal may not be ‘good’ enough

1. Industry produces firefighting foams (and other products) containing PFAS
2. Industry wastewater to wastewater treatment plant (WWTP)
3. Industry wastewater discharged to atmosphere and receiving waters
4. Firefighting foams release and transport to surface and groundwater
5. WWTP discharges to stream
6. WWTP biosolids to landfill
7. WWTP biosolids land applied at farms
8. Landfill leachate to WWTP
9. Landfill leachate to groundwater
10. Farm produce to communities
11. Farm recharges or infiltrates water/groundwater
12. Surface and groundwater plant uptake and irrigation at farms
13. Surface and groundwater use for drinking water
14. Community waste to landfill and WWTP



Courtesy of Jennifer Guelfo, Texas Tech University

PFAS Attributes (cont.)

- MANY Different physical and chemical properties
  - Anionic/Cationic/Zwitterionic
  - C-F bonds are the strongest in nature
  - Complicates treatment efforts/May require ‘treatment train’

- Some Traditional treatment technologies may not be effective enough, e.g.,:

  - In Situ Chemical Oxidation (ISCO) better for PFOA than PFOS
    - Some Concern re production of dead-end, possibly toxic daughter products

Traditional Technologies for PFAS

Incineration

- Current thinking is that 1000-1100 F may be needed to break the C-F bond
- Concern/uncertainty regarding creation of Products of Incomplete Destruction (PIDs)
  - Potential downstream recombination to form parent PFAS compounds
- **Analytical Methods/Standards** lacking for some PFAS compounds of possible interest
- NOTE – Australian PFAS project at Cement Kiln

Granular Activated Carbon/Ion Exchange(Ix) Resins

- Well-established technology in water supply industry
- May require pre-filter step for waste streams like landfill leachate
- Some differences in performance between C8 and C4 compounds
- Alternative sorbents under development w/ goal of better performance/lower cost

Soil Washing

- Plant/project in Australia

- DOD SERDP-ESTCP project in Alaska

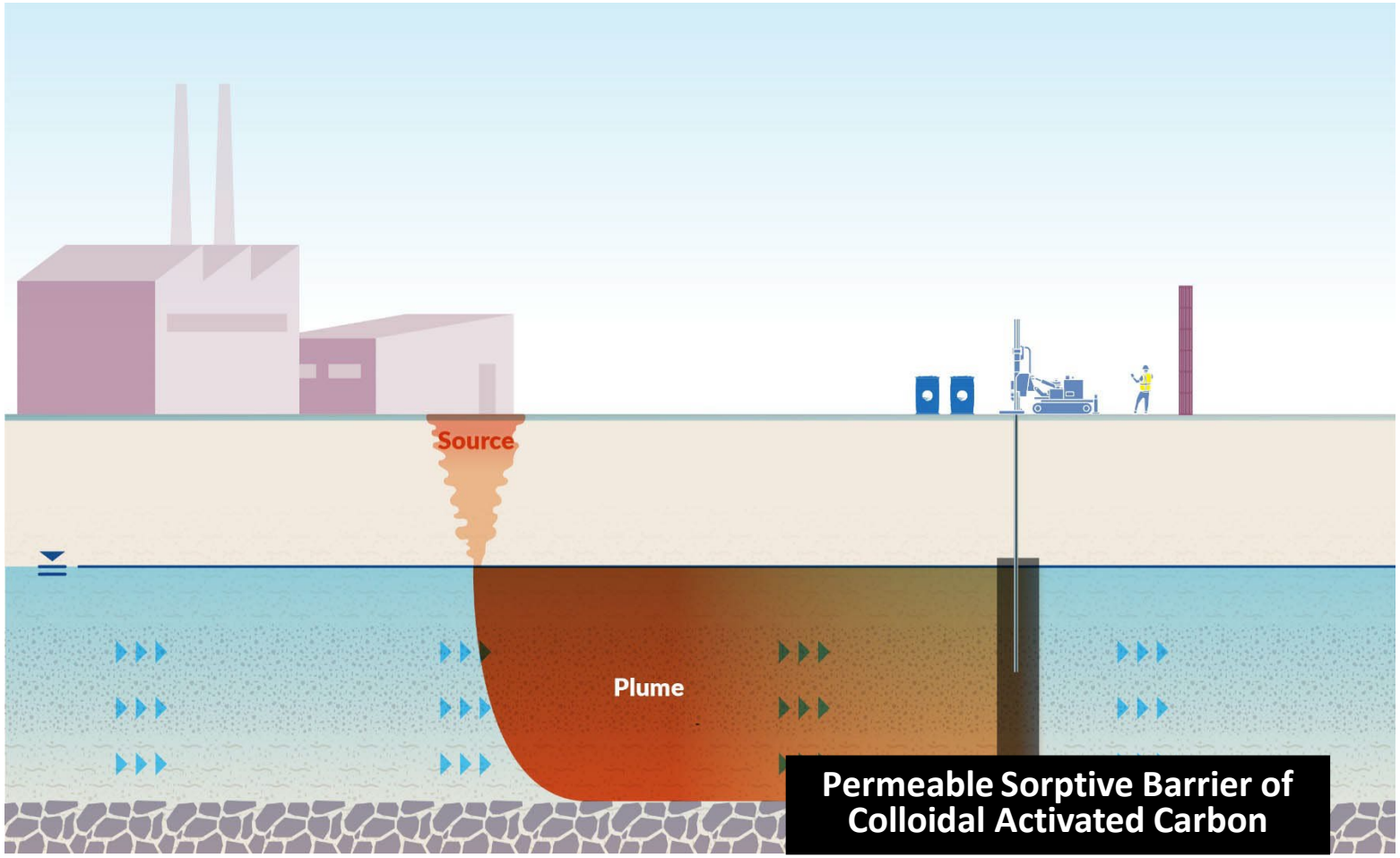
Innovative Technologies for PFAS

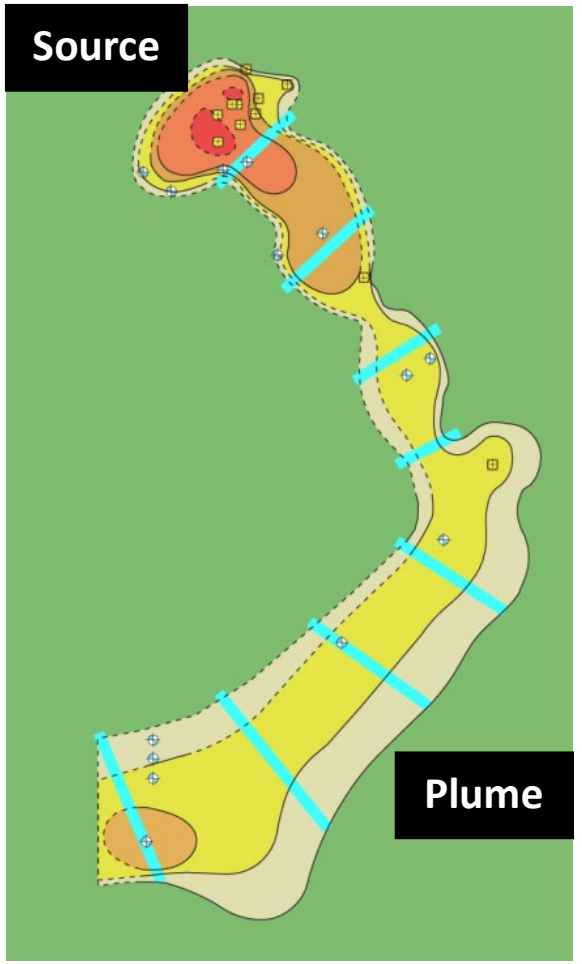
PlumeStop – 1-2 Micron-size Regenesis Colloidal Injected Activated Carbon

- ‘Traps’ (but does not ‘Treat’) PFAS
- Barrier(s) installed in the subsurface
  - Eliminates energy requirements associated with pump and treat
- Mass Flux tools used to map intervals of high mass transport
- Dozens of deployments worldwide

PFAS in Groundwater: Management Options

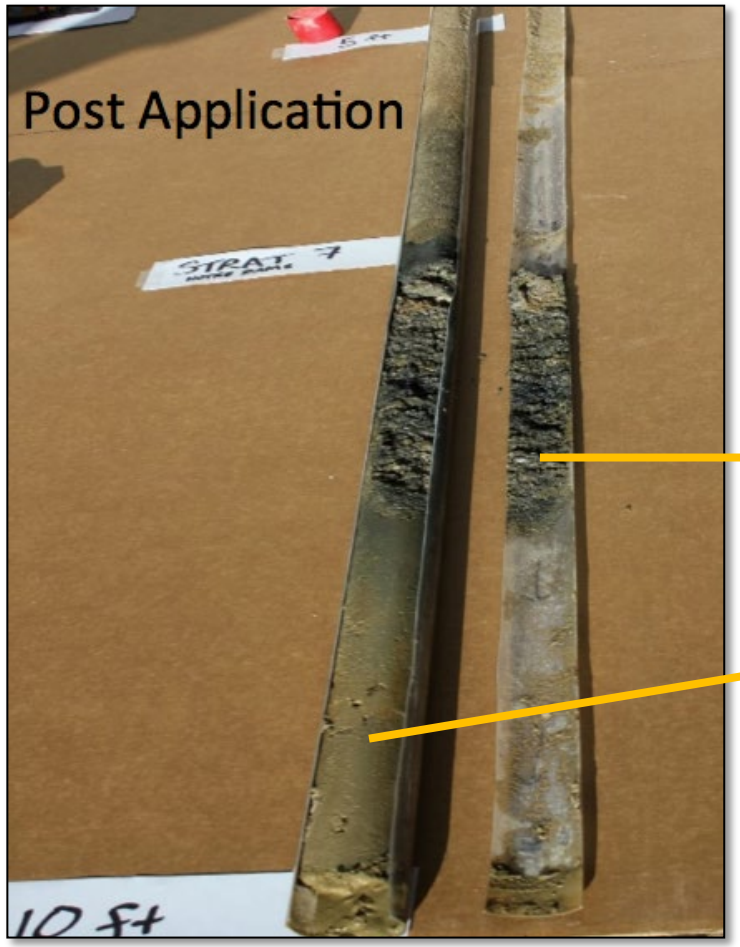
Passive Management With PlumeStop

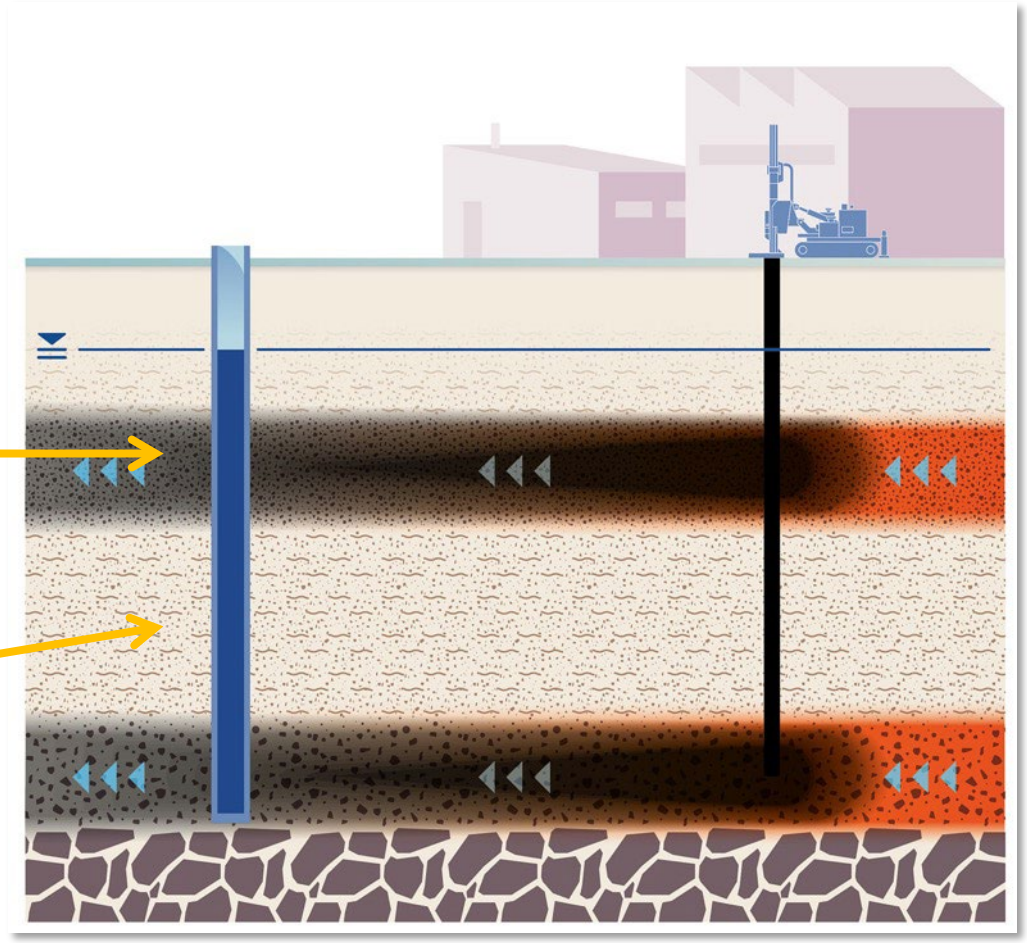




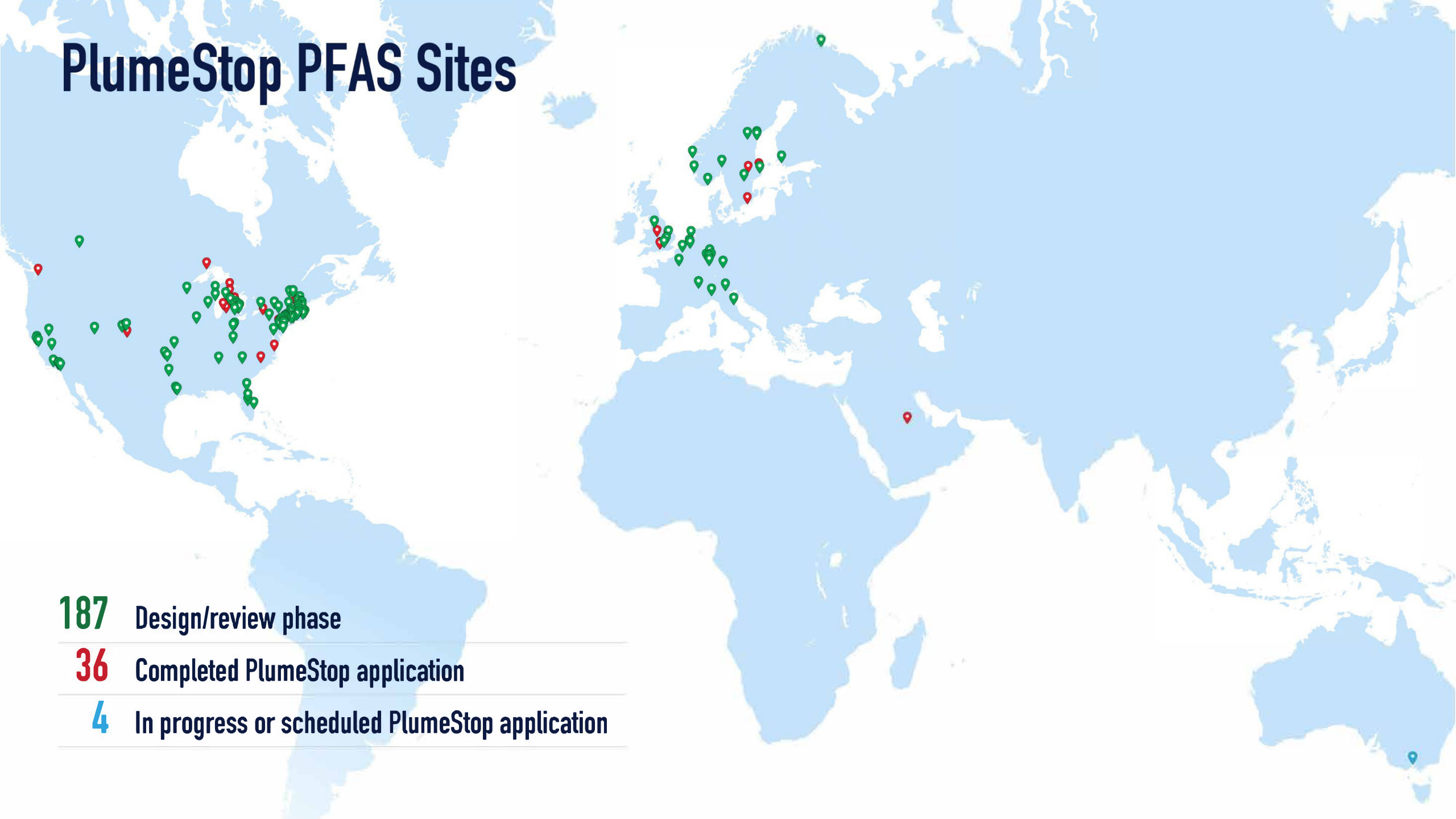
REGENESIS®

Treatment of Flux Zones





PlumeStop PFAS Sites



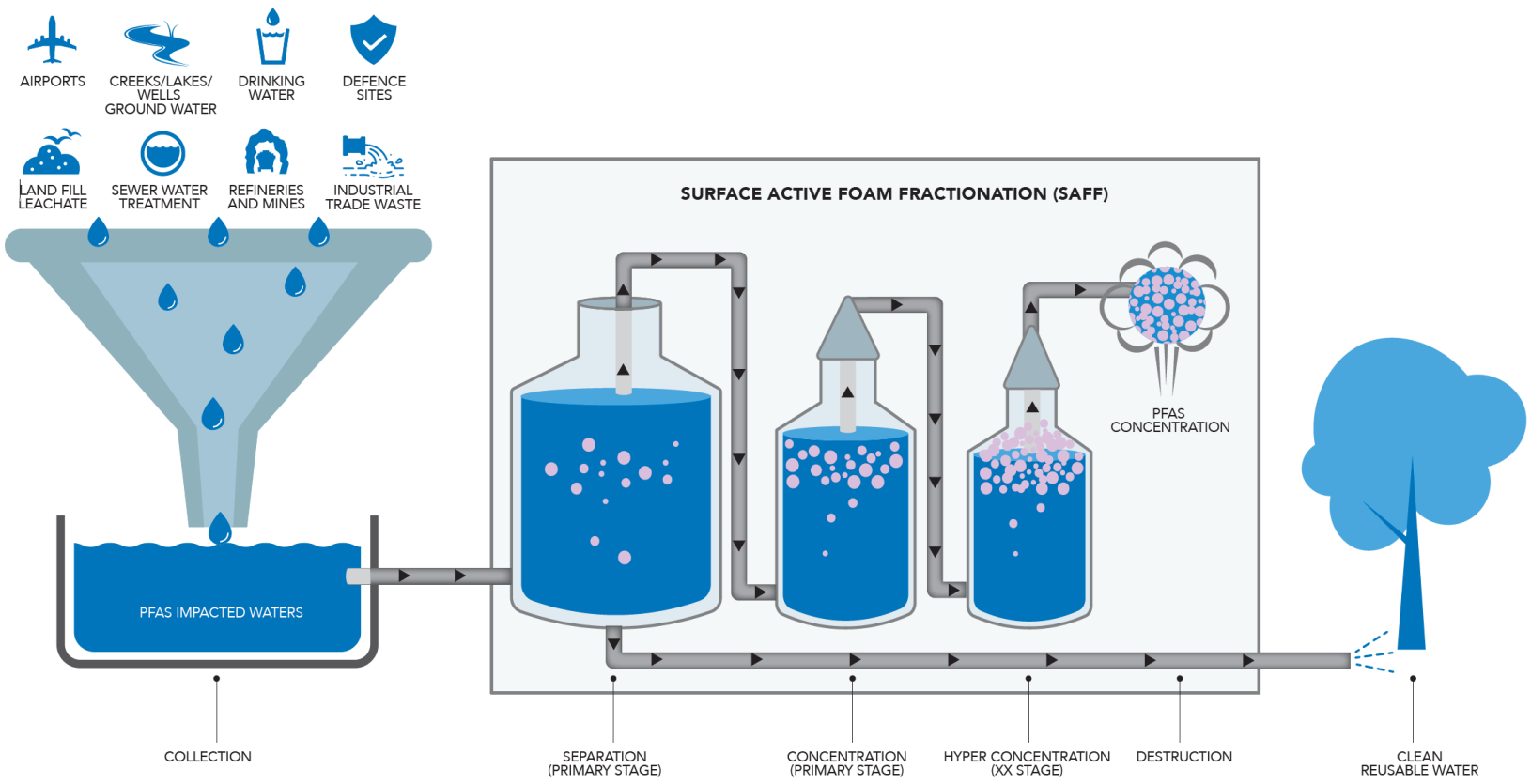
187	Design/review phase
36	Completed PlumeStop application
4	In progress or scheduled PlumeStop application

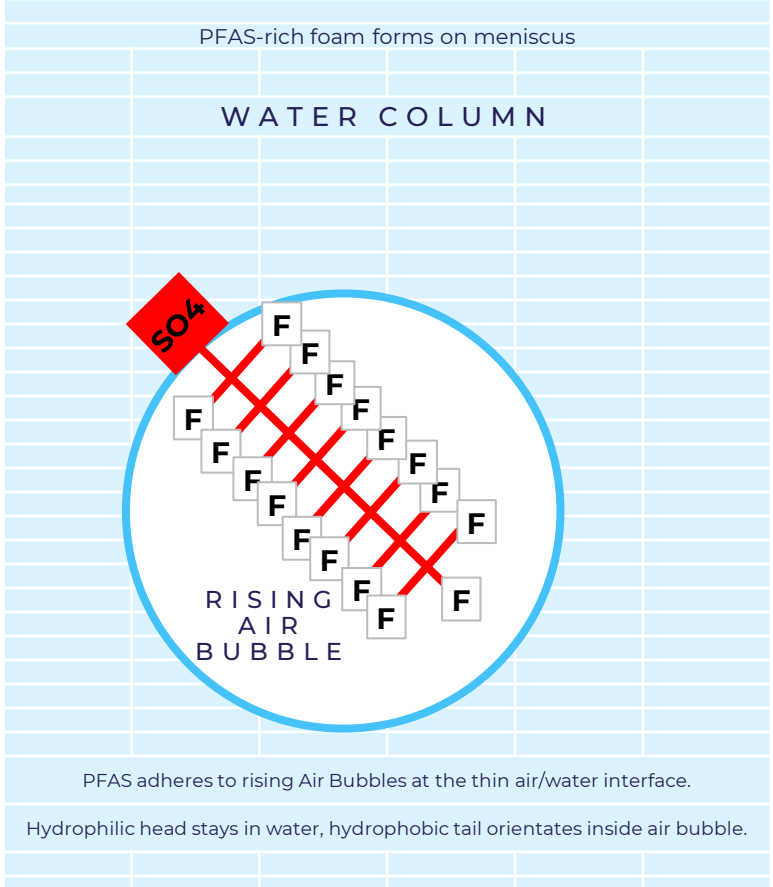
Foam Fractionation (FF)

- Bubbling mechanism transports PFAS to air/water interface
- Objective is to **CONCENTRATE** PFAS waste streams
  - Reports of up to 10e6 concentration for water
  - 700X concentration factor for landfill leachate
- Performance better for longer chain PFAS than shorter chain
  - Addition of surfactant may improve performance for shorter chain PFAS
- Follow-on Destruction technologies required for concentrate
  - SCWO, thermal and non-thermal plasma, etc.

Ex Situ Foam Fractionation

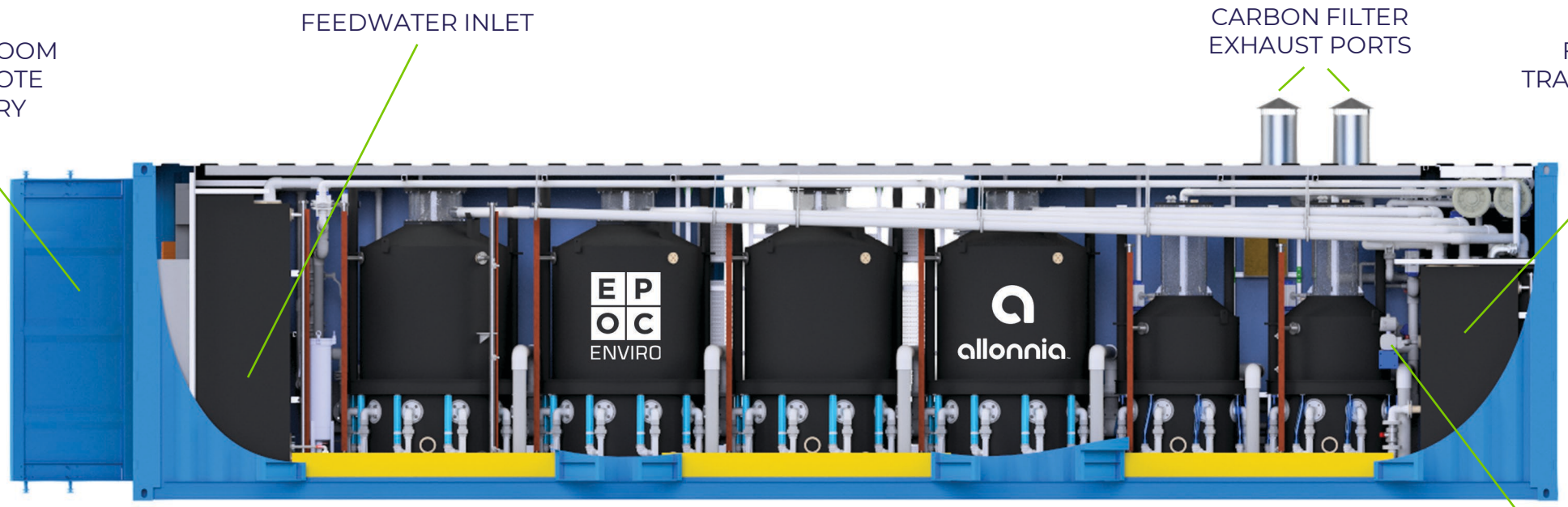
SAFF: The Basic Concept of Foam Fractionation





Slide provided courtesy of Allonnia, LLC

SAFF40® Container



Slide provided courtesy of Allonnia, LLC

First Full-Scale Landfill Leachate Application

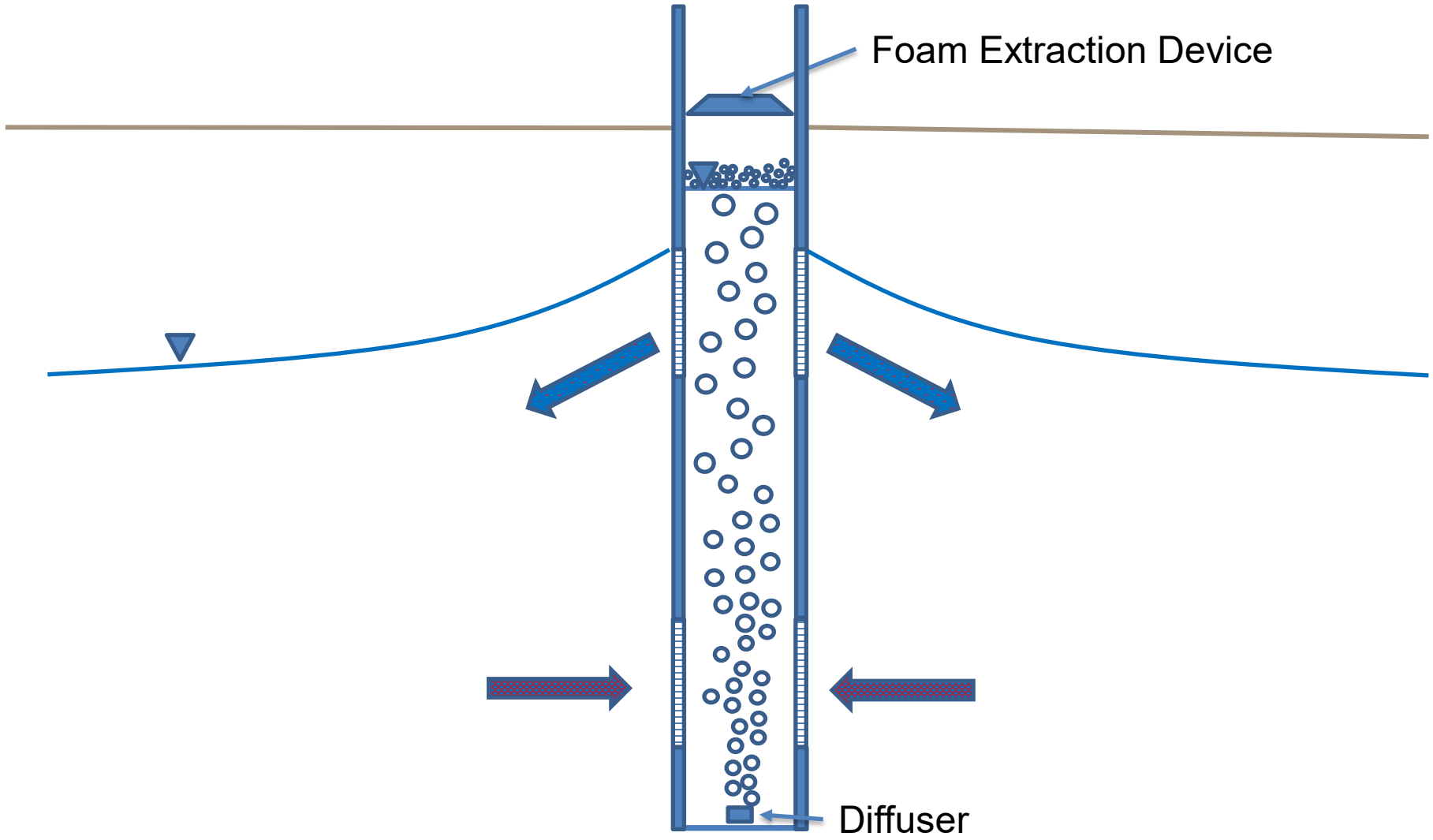
- January 2021 near Stockholm, Sweden by Envytech Solutions and EPOC Enviro (SAFF 40®)
- >26 MG (>100 ML) of water treated with zero contractual PFAS exceedances and **no issues with complex influent matrix**
- Concentration factor: **>30,000x**
- Length of operation: 18 months ongoing

1. **Queensland, Australia**
   Groundwater
2. **New South Wales, Australia**
   Landfill leachate
3. **Minnesota, USA**
   Surface water
3. **Michigan, USA**
   Landfill leachate/Industrial Wastewater
4. **Confidential Site, East Coast USA**
   Surface water
5. **Confidential Site, East Coast USA**
   Groundwater
6. **New England, USA X2**
   Landfill leachate
7. **Confidential Site, Spain**
   Foam deluge system
8. **Confidential Site, UK**
   Foam deluge system
9. **Helsingborg, Sweden**
   Landfill leachate.
10. **Brottby, Sweden**
    Landfill leachate
11. **Stockholm, Sweden**
    Landfill leachate

In-Situ Foam Fractionation

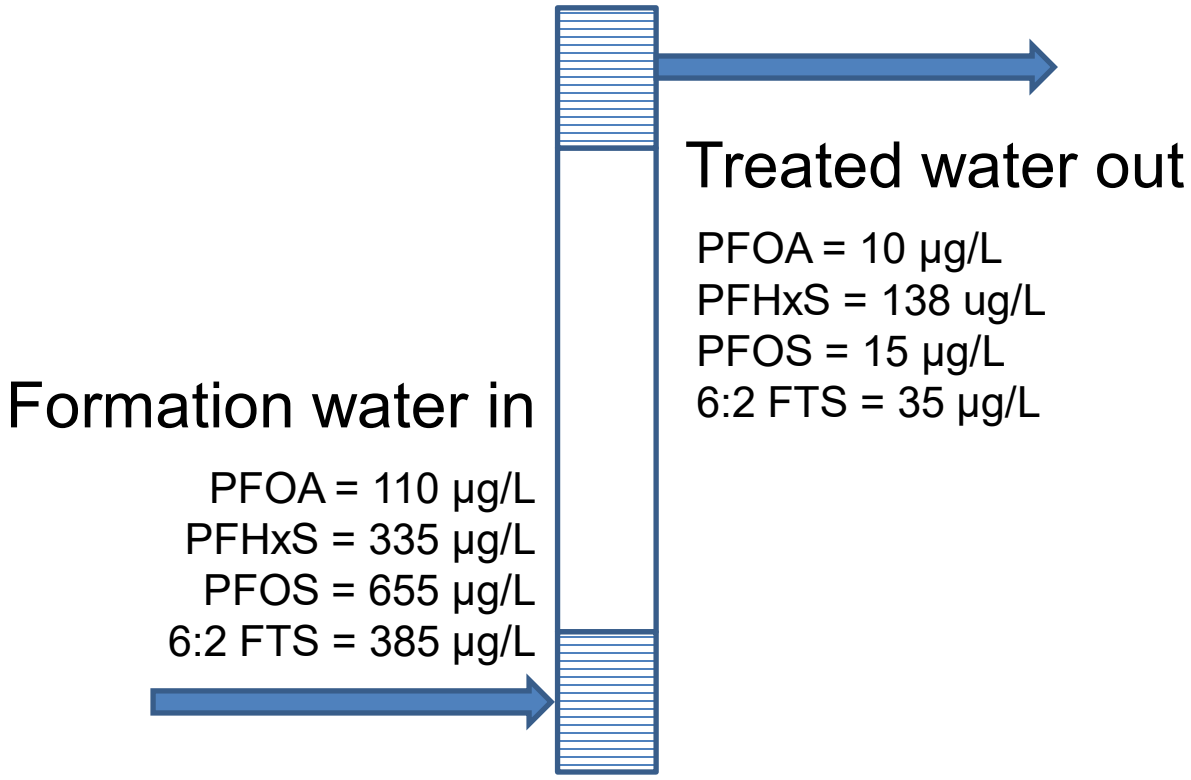
D-FAS Conceptual Approach

Geosyntec consultants



U.S. Patent 10,752,521

Concentration Reductions Through the Well



System Layout

Geosyntec consultants

Super Critical Water Oxidation (SCWO)

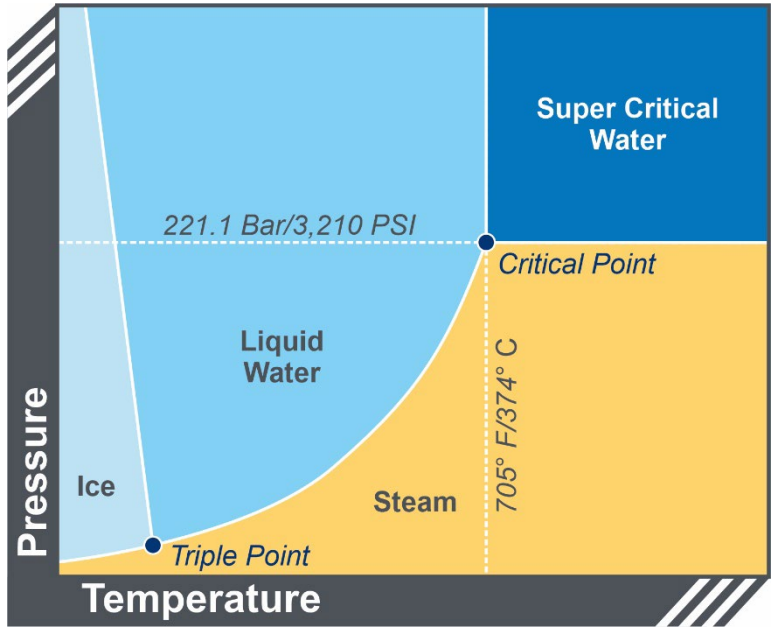
- Contaminants almost completely miscible in water at elevated temperature and pressure c. 374 C//210psi
- Developers working on metallurgy to address corrosion issues
- Vendors developing flow through configurations
  - Much more cost-effective than batch processing
- Numerous US and International firms developing/offering SCWO
- NOTE: Aquagga developing **sub-critical** variant – Hydrothermal Alkaline Treatment (HALT) process

SCWO (cont.)

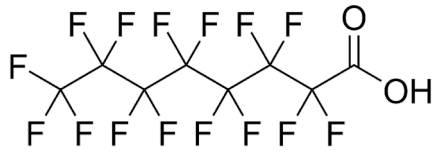
- Generally able to handle co-contaminants
- Able to process ‘pumpable slurries’ – NOT Soil

What is Supercritical Water Oxidation?

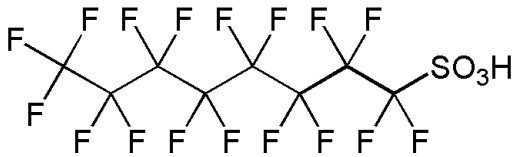
- Supercritical water exhibits unique properties
  - Gas and liquid phases become indistinguishable
  - Density is about 10% of water above the supercritical point
  - Water no longer behaves as a polar solvent
  - Oxygen is fully soluble
- High temperature in an oxidizing environment overcomes activation energy to break C-F bond



PFOA

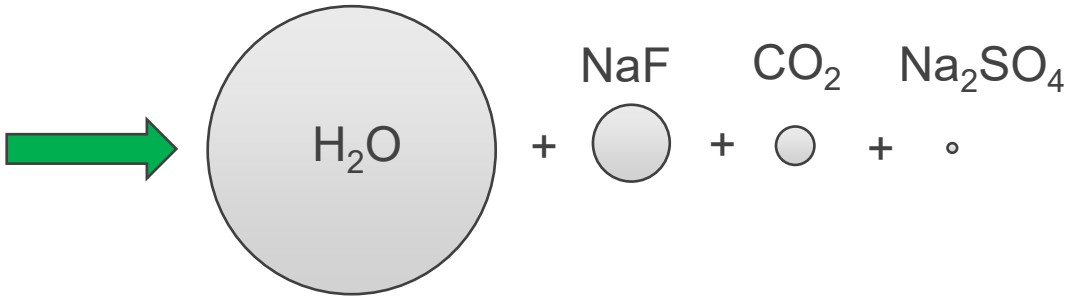


PFOS



+ H_2O_2 (oxygen source)

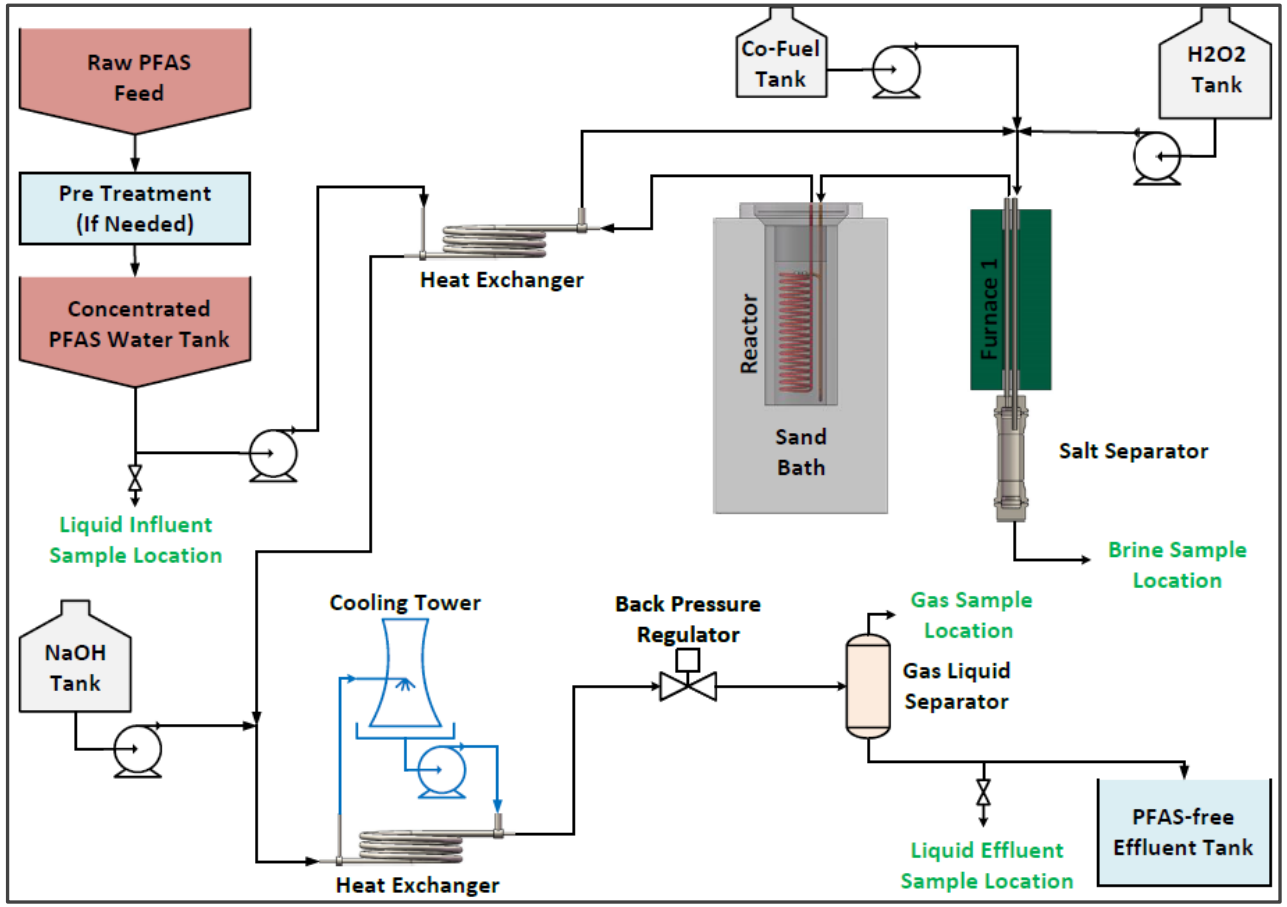
+ NaOH (Neutralization)



BATTELLE

PFAS Annihilator™ Process Flow

- Water is pretreated and concentrated (if necessary)
- The water is heated to supercritical temperature and pressure using one or more heat sources
- Feed is oxygenated with H_2O_2 or air
- A neutralizing agent (NaOH) is added to remove hydrofluoric acid in effluent
- The effluent is cooled
- Generated gas is separated from the liquid
- Effluent streams are further treated (if necessary) and discharged



BATTELLE

Bioremediation for PFAS?

- It was once thought that microbes could not degrade CVOCs
  - Enhanced Reductive Dechlorination (ERD) – i.e., Bio now a frequent component of remedial efforts
- Some now think/hope that the same thing will happen w/ PFAS
  - CAUTION: ‘Maybe’ – but C-F bonds are the strongest in nature
- Research underway:
  - Find naturally-occuring micro-organisms that can degrade PFAS
  - ‘Synthetic Biology’ to engineer microbes w/ requisite capability

‘Other’ Destruction Technologies

- **Sonication**
  - Bursting micro-bubbles generate intense heat at micro-scale
  - DOD project to deploy in a horizontal well
- **Non-Thermal Plasma**
  - Argon gas transports PAS to air/water interface
  - High energy destruction
  - Better performance on C8 than C4
- **Thermal Plasma**
  - VERY high temperature destruction following concentration step

Sonication

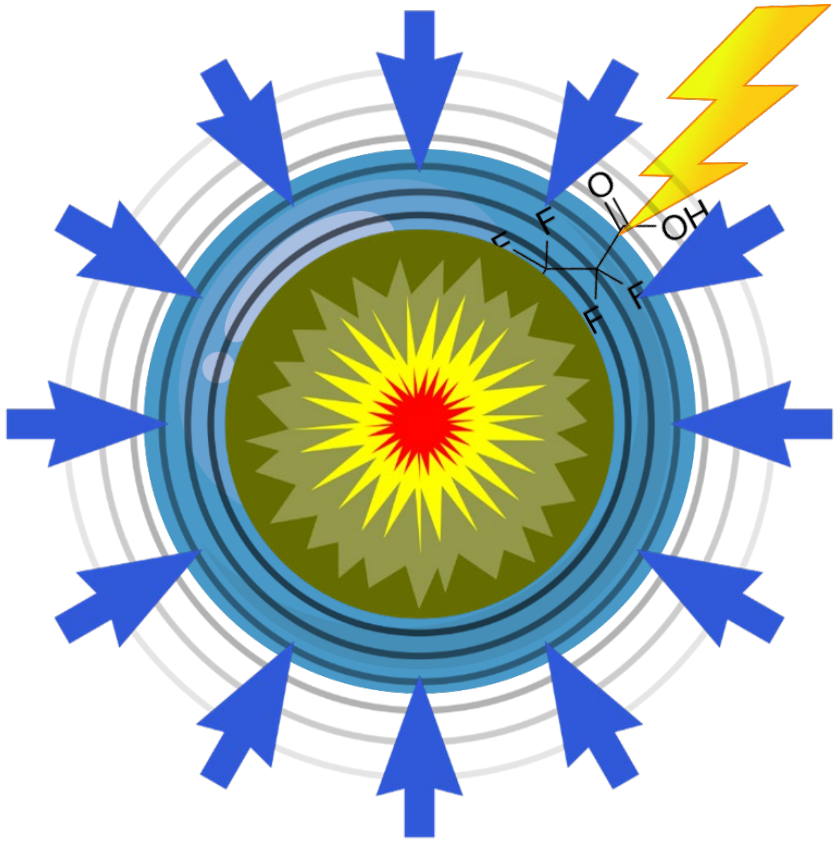
Sonolysis

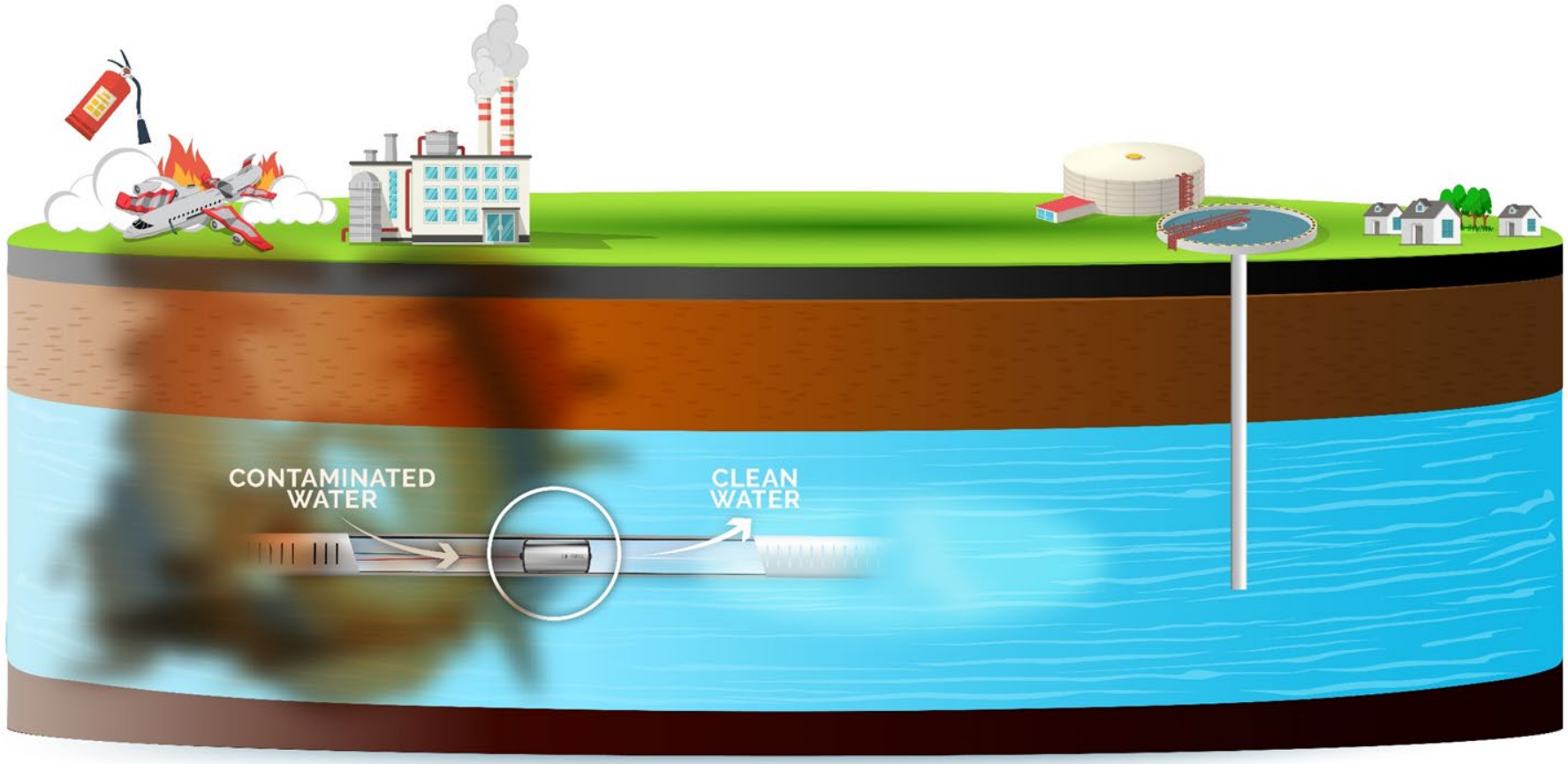
Sound waves >19 kHz create cavities in liquids

PFAS sorb to the cavity interface

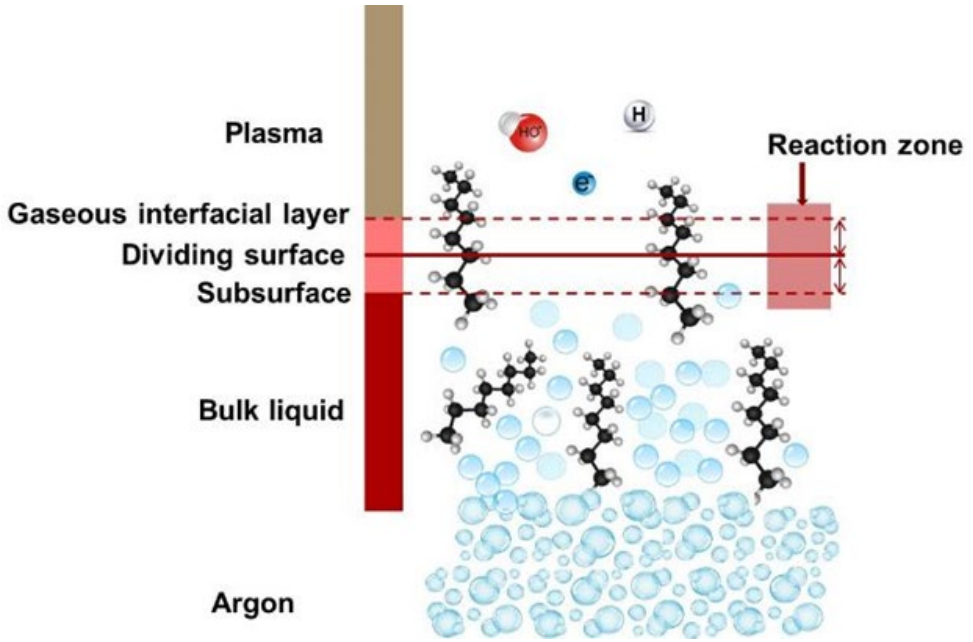
Cavities collapse at maximum radius creating extreme localized conditions

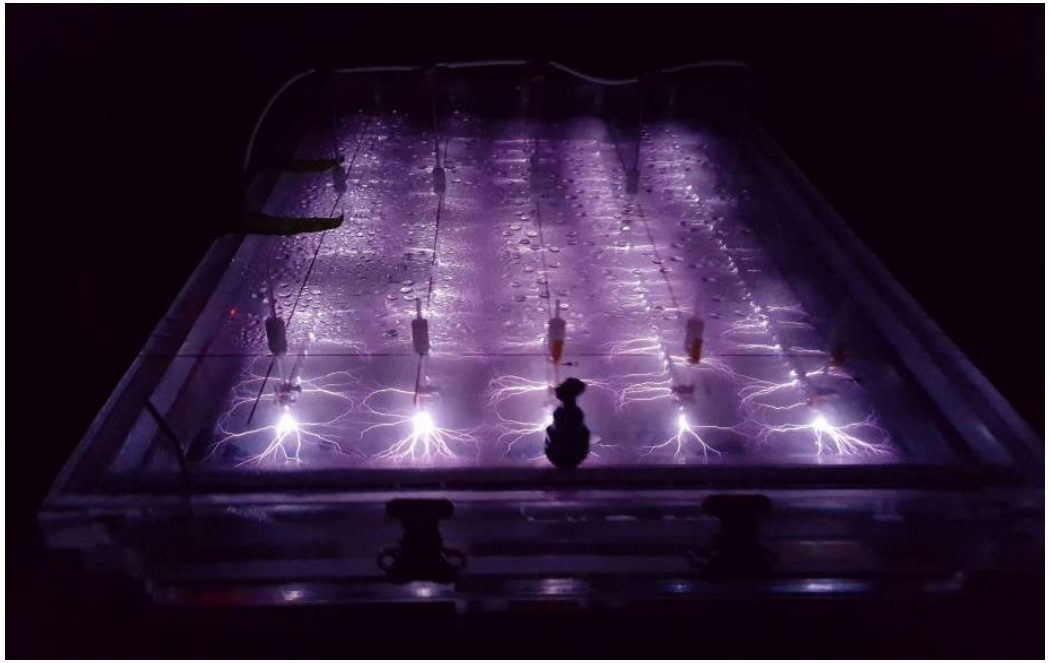
- High heat (**5000 °K)**
- High pressure (**1000 bar)**
- Cleaves bond between hydrophobic and hydrophilic portions of molecules




CONTAMINATED
WATER
CLEAN
WATER

Non-Thermal Plasma





HOW IT WORKS

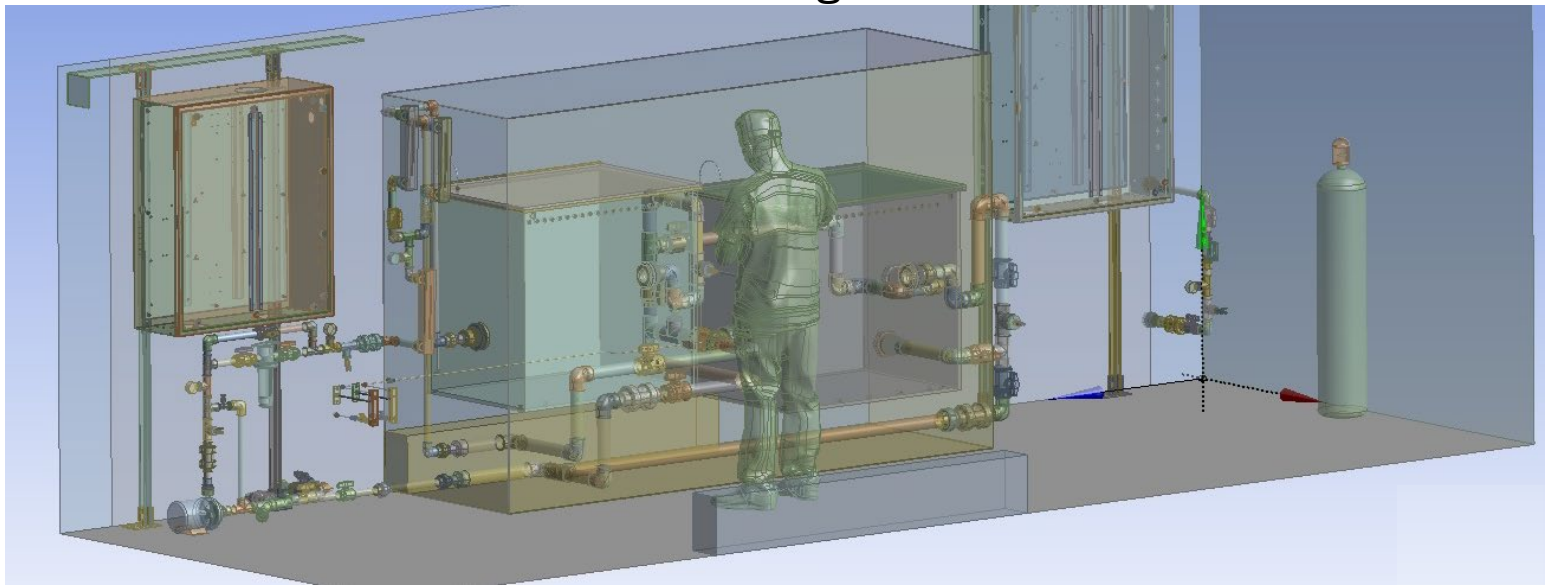
1. Gas diffusers pump gas bubbles from the bottom of the reactor
2. PFAS compounds adsorb to the bubbles and are transported to the liquid surface, creating a layer of PFAS concentrated water
3. High voltage electrodes discharge plasma to break C-F bonds to “Degrade and Destroy” PFAS

Thermal Plasma

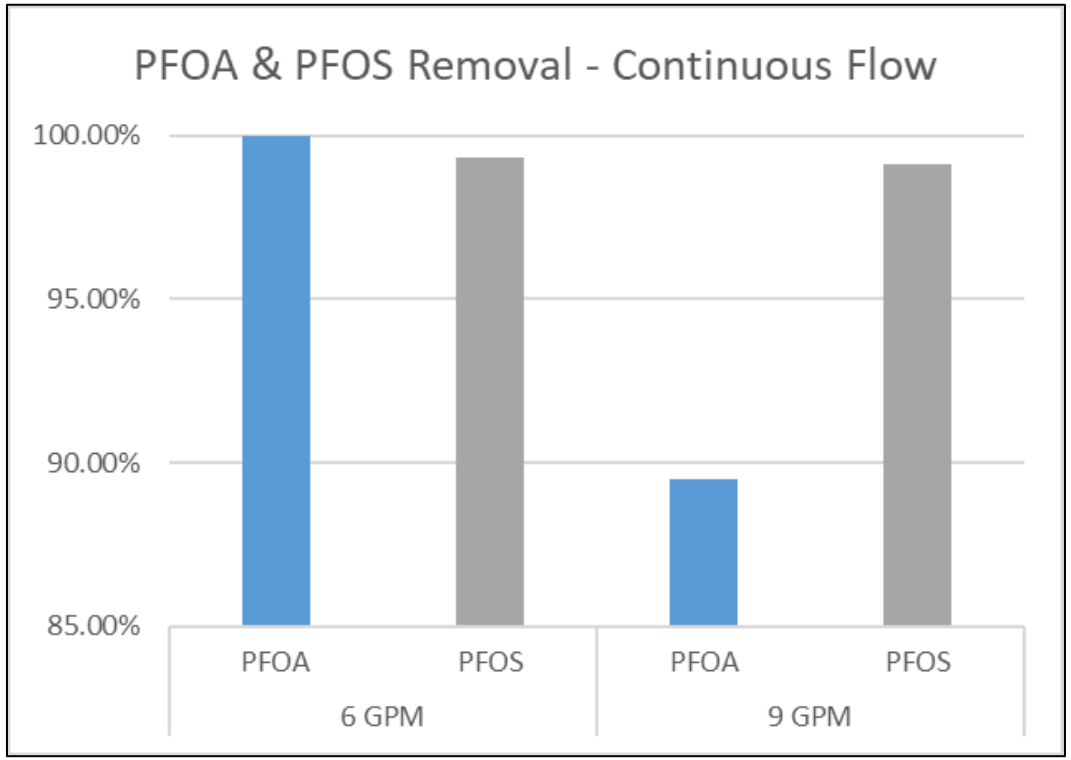
THE SOLUTION –
DMAX PLASMA ECo-PRe™

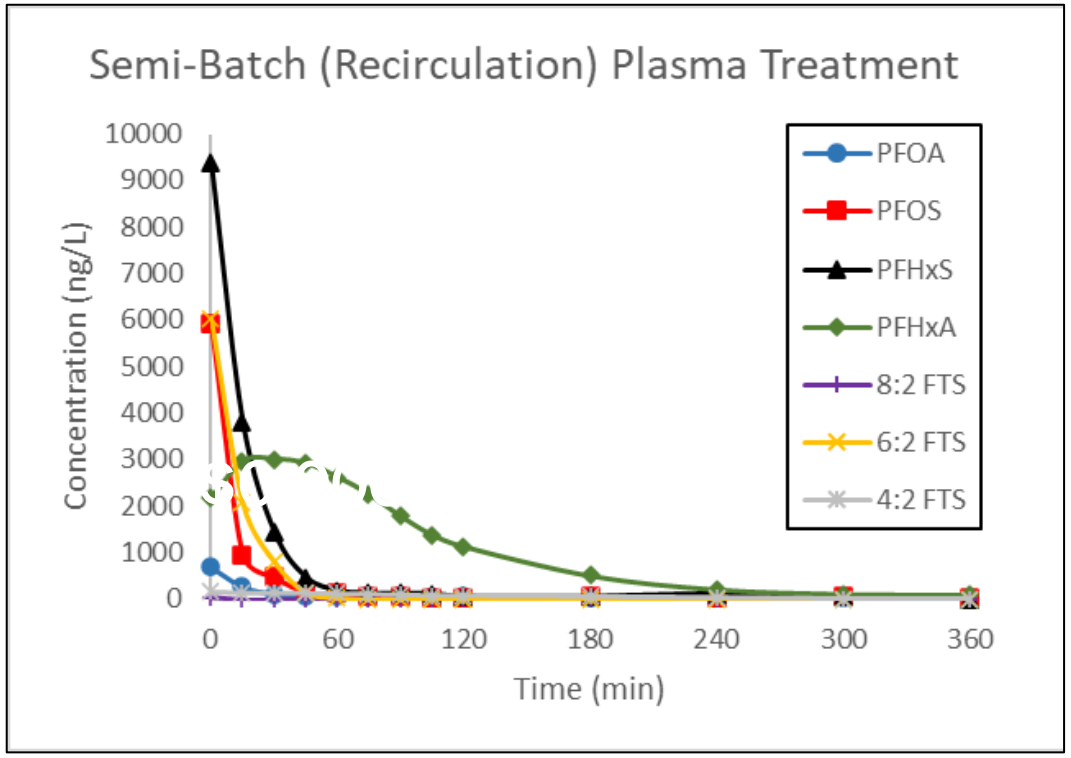
- ✓ Field proven PFAS "Degradation and Destruction" solution
- ✓ Cost Effective – Low Energy & Operating Expense
- ✓ High Scalable Throughput
- ✓ Treat Any PFAS mix, Anywhere (mobile available)
- ✓ No Hazardous By-Products
- ✓ Safe & Durable Operation

DMAX Plasma 4th generation mobile treatment trailer



FIELD PERFORMANCE: CONTINUOUS AND SEMI-BATCH





	6 Gallons Per Minute		9 Gallons Per Minute	
	PFOA	PFOS	PFOA	PFOS
Initial (ng/L)	499	6304	619	6127
Final (ng/L)	BDL	43	65	55

	PFOA	PFOS	PFHxS	PFHxA	8:2 FTS	6:2 FTS	4:2 FTS
Initial (ng/L)	689	5938	9396	2168	42	6034	158
Final (ng/L)	33	29	BDL	102	BDL	BDL	BDL

PFAS Resources

- **Serdp-estcp.org**
  - **Dozens of DOD PFAS related projects – Analytical methods, toxicology, remediation technologies**

- **Itrcweb.org**
  - **Interstate Regulatory and Technology Council PFAS documents**

Contact Information

Jim Cummings

cummings.james@epa.gov

202-566-0868

www.clu-in.org