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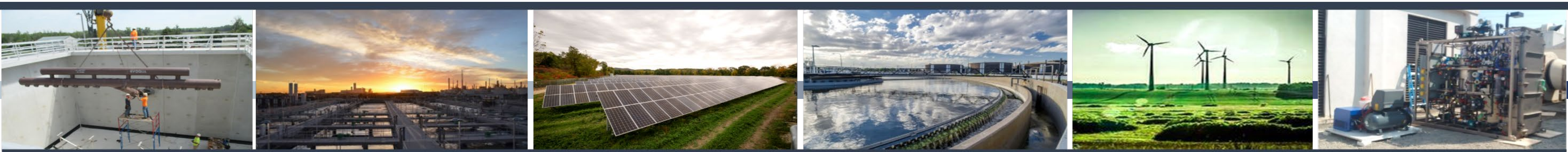
We will begin our presentation in a few minutes...



Leadership and Excellence in Environmental Engineering and Science

Stanley Consultants

Large-Scale PFAS Remediation

Lessons from an Aircraft Facility

June 10, 2026

Program Background

Program Objectives:

- Original: Prepare and publish an Engineering Evaluation / Cost Analysis (EE/CA) report for public comment and an Action Memorandum
- Conduct Non-Time Critical Removal Action Studies
- Site conditions required pivot of program to an assessment and not provide an EE/CA

Timeline & Team:

- 5-year program (October 2022 - September 2027)
- Project Lead: Stanley Consultants
- Primary Systems Designer/Implementer: AECOM
- Client: Aircraft Facility
- Various Subcontractors: labs, drillers, industrial waste management, etc.

Program Management Framework

Scoping Sessions

- First session held late 2023 to understand project and deliverables
- Second session held March 2026 after original deliverables no longer applicable

Workplan(s) and Quality Assurance (UFP-QAPP/WP)

- Critical document for basis, used for additional site investigation
- Workplan Amendments developed for each pilot study

Project Management Plan

- Addresses technical and management controls

Community Relations Plan (CRP)

- Established information repository
- Defined public involvement framework

Accident Prevention Plan (APP)

US Army Corps of Engineers®

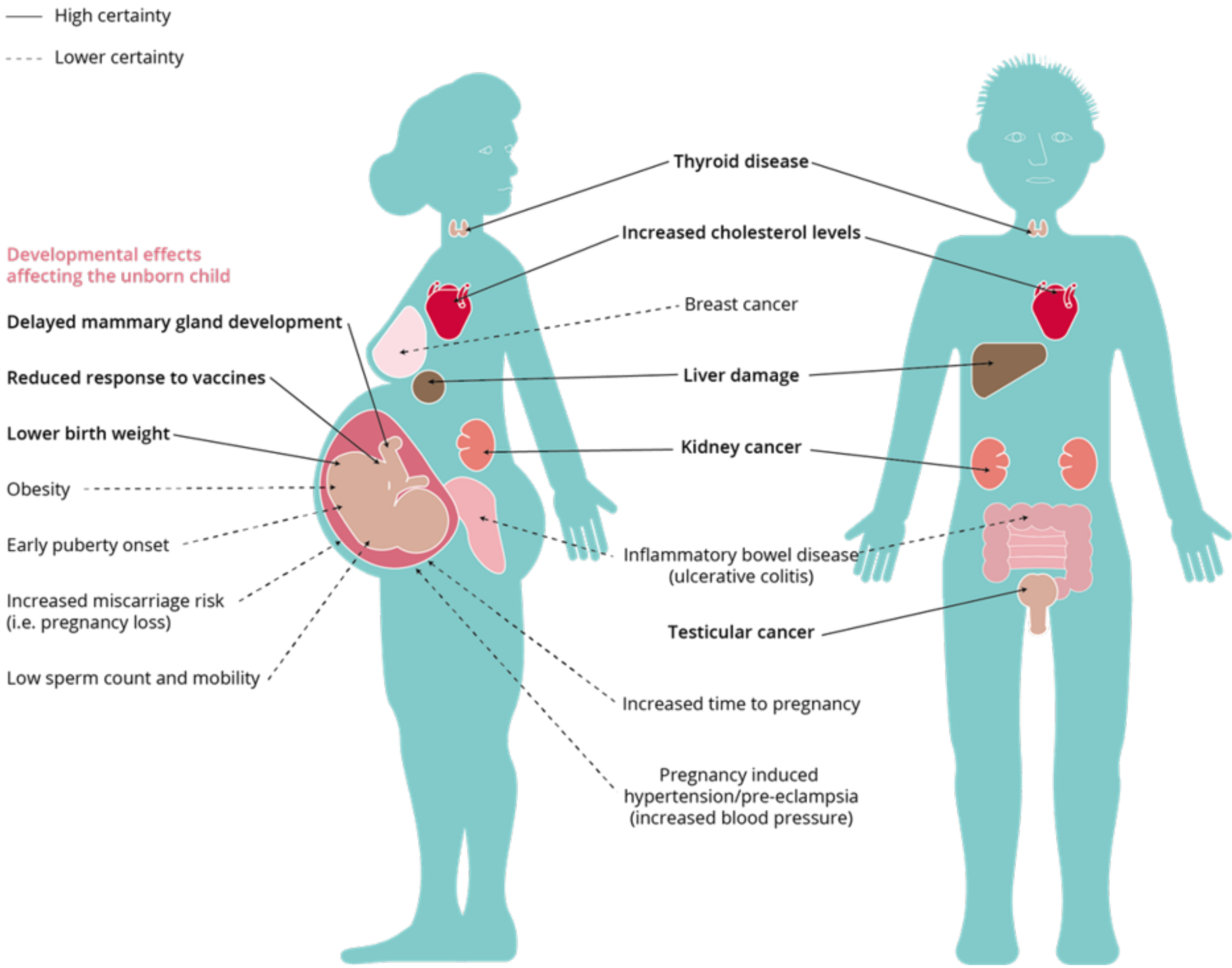
- Required by Army Corps of Engineers' Safety and Health Requirements Manual for certain types of contract work including:
    - Construction contract work
    - Service, supply and R&D
    - Hazardous, toxic, and radioactive waste site investigation, design or remediation activities
- **APP prohibits:**
    - Clothing that is new, water resistant, waterproof, stain-treated, contains Gore-Tex or has been washed with fabric softener
    - Personal products such as moisturizers, cosmetics and unapproved sunscreens
- **Site Safety Precautions:**
    - PFAS-free clothing, sunscreen and bug spray
    - Powder-free nitrile gloves
    - Food and beverage containers kept away from sample locations

https://www.publications.usace.army.mil/USACE-Publications/Engineer-Standards-Graphics/

PFAS-Specific Safety Considerations

Common adverse health concerns:

- Cancer
- High cholesterol
- Immune effects
- Reproductive and developmental effects



Sources: US National Toxicology Program, (2016); C8 Health Project Reports, (2012); WHO IARC, (2017); Barry et al., (2013); Fenton et al., (2009); and White et al., (2011).

Environmental Compliance Framework

- **Engineering Evaluation / Cost Analysis (EE/CA)**
  - Required per CERCLA and NCP
  - Analysis of removal options for a Superfund hazardous waste site
  - Conducted prior to NTCRA
- **National Pollutant Discharge Elimination System (NPDES)**
  - The Office of Water is working to develop water quality criteria for PFAS in NPDES Permits
  - Method 1633 has been validated (officially adopted by EPA Dec. 2024 – mid-project)
  - EPA has published state guidance for reducing PFAS pollution

National Primary Drinking Water Regulations

Compound	Final MCLG	Final MCL (enforceable levels)[1]
PFOA	Zero	4.0 parts per trillion (ppt) (also expressed as ng/L)
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) Hazard Index	1 (unitless) Hazard Index

Regulations on these may be rescinded by government entities.

MCL Status	States
Proposed MCL only	CT, IL
MCLs less stringent than rule	ME, MA, MI, NH, NJ, NY, PA, RI, VT, WI

Aqueous Film Forming Foam (AFFF)

- AFFF is a known source of PFAS in fire fighting chemicals
- Banned from hangar fire suppression systems in most U.S. facilities in 2020
- 28 states have taken steps to regulate usage, discharge or disposal requirements

Field Sampling

General

Collecting samples the right way

Follow SOPs

Follow written steps

Use PFAS-Free materials

Use clean, non-reactive tools

Groundwater & Surface Water

Field-filtered & unfiltered PFAS

Pre-Design Investigation Sampling Goals

- Collect surface water data to evaluate design criteria for pilot treatment systems
- Collect groundwater and surface water data to evaluate surface water-groundwater interaction in the project area
- Complete a treatability study that will inform design of surface water treatment systems
- Collect groundwater and soil data that would be used for design of a groudwater treatment pilot study

Pre-Design Investigation Sampling Locations

- Sampling locations were selected to evaluate sources of PFAS that may be contributing to surface water impacts
  - Wells used for groundwater sampling were at locations in which the interaction between groundwater and surface water could be evaluated
- Data sources used to determine sampling locations:
  - Historical site data
  - Observations made during initial site visit
  - Review of surface water and stormwater maps

Pre-Design Investigation Design Rationale

Factors used to evaluate potential sampling location:

- Stormwater flow path is from a PFAS source area
- Data is needed for treatment system design
- The location is:
    - Within a groundwater plume for PFAS (or potential to be)
    - A stormwater outfall
    - Downgradient of the tributary
    - Easily accessible for sampling
    - Adjacent to an existing monitoring location
    - Within or near a legacy contaminant plume
- Each location met multiple factors, and each design factor was represented by 4+ sampling locations

Pre-Design Investigation Sampling Program - Frequency

- **Surface Water and Sediment Sampling**
  - Samples collected over a multi-year period at varying surface water flow conditions
- **Groundwater Well Sampling**
  - Groundwater samples were collected quarterly over a multi-year period

Pre-Design Investigation Sampling Program - Parameters

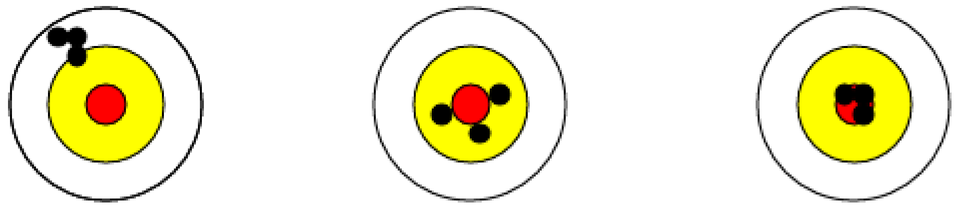
- PFAS
- VOCs
- Metals
- Water Quality Parameters
  - Parameters sampled in included cations, anions, and additional water quality parameters

Pre-Design Investigation – Quality Control

Multiple types of QC samples collected to confirm sample results met precision and accuracy criteria

- Field Blanks
- Equipment Blanks
- Trip Blanks
- Matrix Spike and Matrix Spike Duplicate

Figure 2.1 Precision and Accuracy



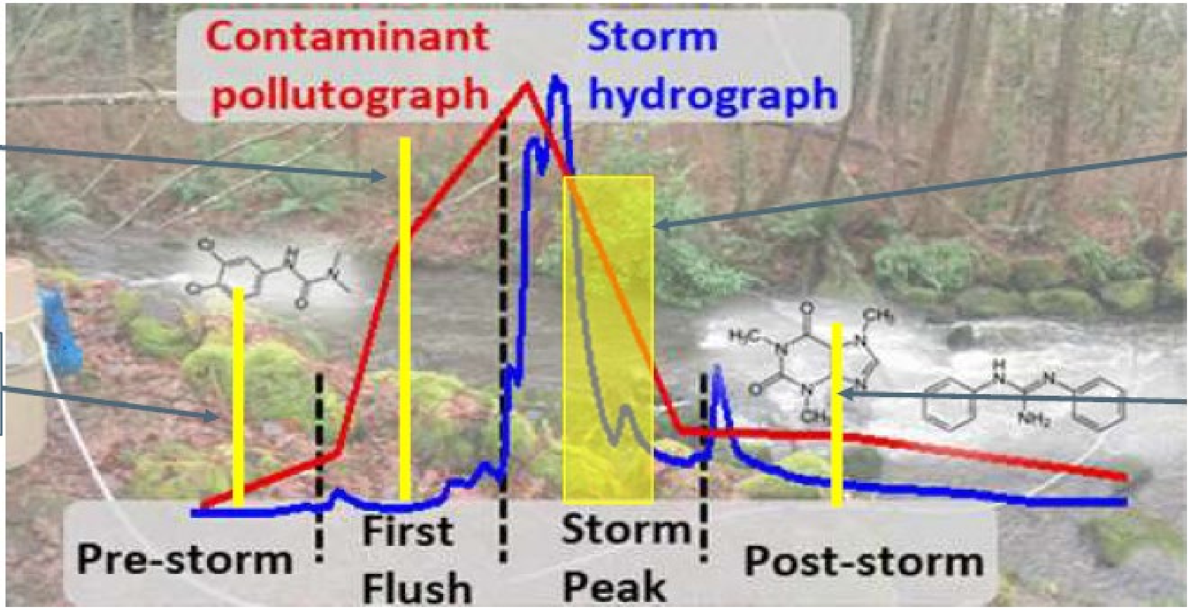
Environmental Health and Engineering, Inc, 2001

Treatability Study

- Bench scale treatability study was completed to evaluate optimal pre-treatment strategies to remove PFAS from surface water for an upcoming pilot study
- Study included pretreatment and PFAS adsorption evaluation
  - Pretreatment is required due to contaminants in the source water (primarily iron, manganese, TSS, and TOC) that may cause fouling which would impact removal efficiency of PFAS
  - PFAS adsorption evaluation including testing available sorbents to determine which was most effective for PFAS
- Findings from study was used to inform pilot system design

Stormwater Sampling

- Stormwater sampling completed to evaluate impacts of rain events
- 4 samples collected during rain events



"First Flush" grab sample shortly after rain begins

Baseline sample taken before rain event

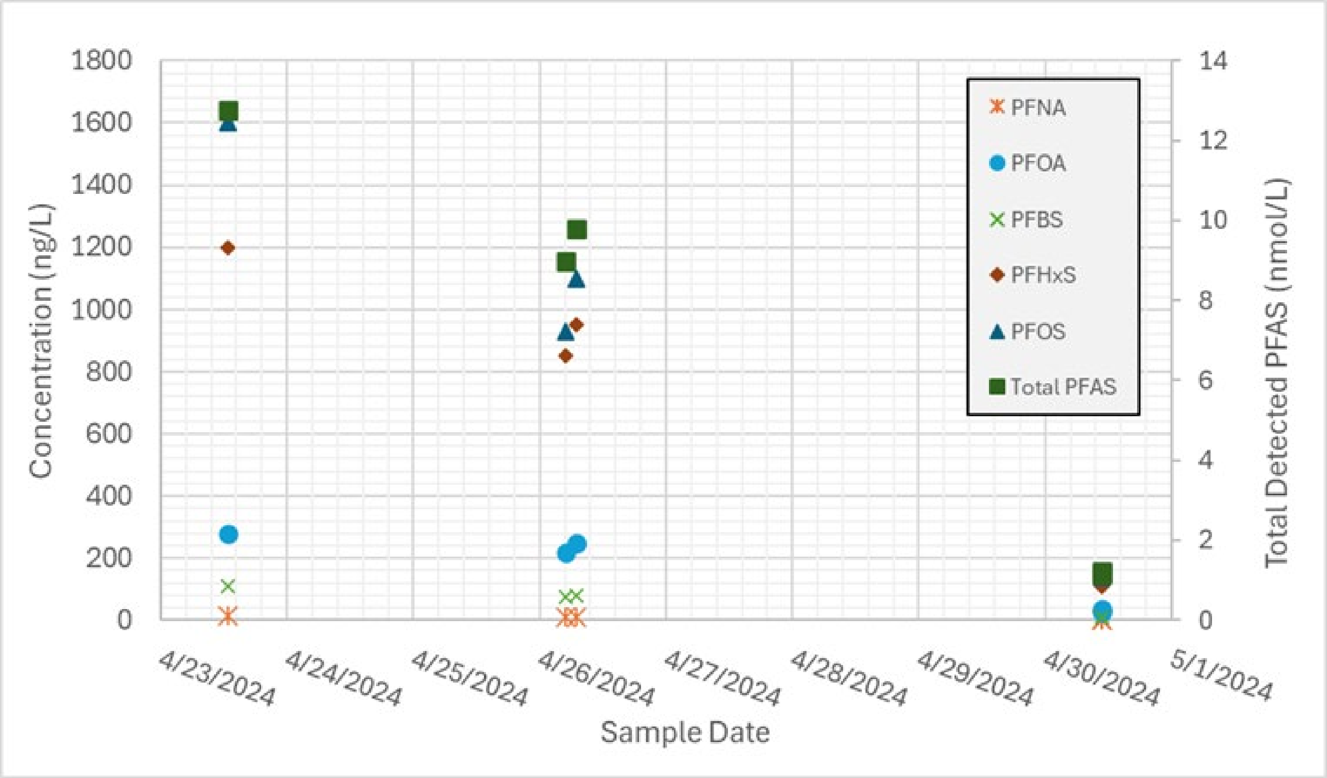
Composite sample capturing 2 hours of rain flow

Post-rain grab sample

Peter et al. 2020 https://doi.org/10.1021/acs.est.0c00872

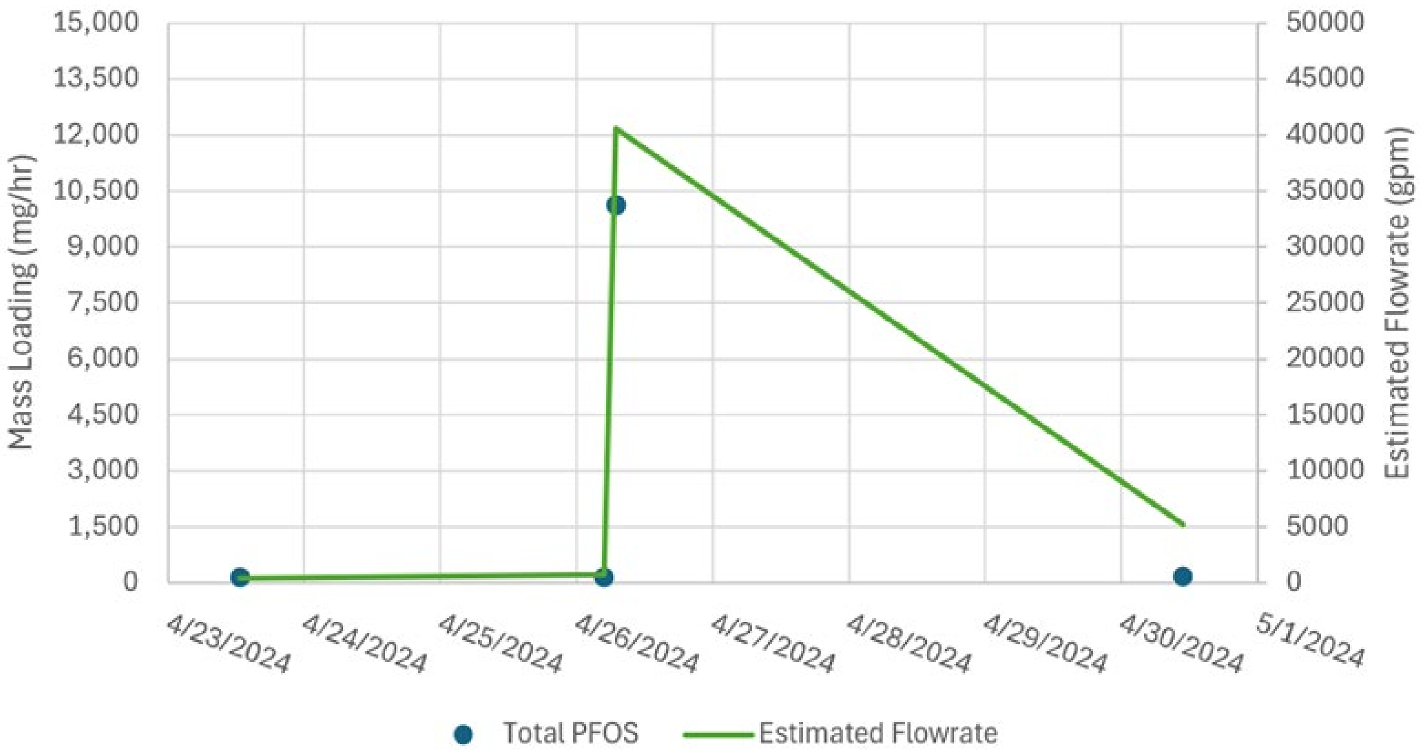
Stormwater Sampling Findings

- PFAS concentration was highest in the pre-event rain sample
- Concentrations in the storm event sample was lower than the pre-event grab but was higher than the sample collected after rain event



Stormwater Sampling Findings

- Increased mass loading rate due to higher flow rate in this sample
- Flow rate did not return to baseline conditions four days after storm sampling
- System design needs to account for changing conditions during storm events



Project Screening Levels

Two sets of screening levels:

- PFAS Parameters
  - Screening levels have changed during the PDI
  - Screening levels for project are based on regulatory guidelines
- Non-PFAS Parameters
  - Water parameters compared to National Primary Drinking Water or National Secondary Drinking Water standards
  - Screening levels used since effluent from treatment systems would have to meet these criteria
  - Sediment samples compared to EPA's Regional Screening Levels (RSLs) for residential soil

Site Assessment Screening Levels for PFAS

- PFAS screening levels for site assessments were provided by regulatory agency
- Screening levels are typically based on EPA Regional Screening Levels (RSLs) with the following exceptions:
  - When the RSL was below the MDL of approved EPA methods (EPA 1633)
  - When the RSL was below proposed MCLs

Site Assessment Screening Levels for PFAS

PFAS Parameter	Abbreviation	Water Screening Level (ng/L)	Sediment Screening Level (ng/kg)
Hexafluoropropylene oxide dimer acid	HFPO-DA (Gen-X)	1.5	23,000
Perfluorobutanoic acid	PFBA	1,800	7,800,000
Perfluorobutane sulfonic acid	PFBS	600	1,900,000
Perfluorohexanoic acid	PFHxA	990	3,200,000
Perfluorohexanesulfonic acid	PFHxS	10	130,000
Perfluorononanoic acid	PFNA	5.9	19,000
Perfluorooctanoic acid	PFOA	4.0	70
Perfluorooctane sulfonic acid	PFOS	4.0	630
Bis(trifluoromethylsulfonyl)amine	TFSI	590	2,300,000
Perfluoropropanoic acid	PFPrA	980	3,900,000
Perfluorodecanoic acid	PFDA	0.52	60

PDI Results – PFAS Parameters

PFAS Parameter	Surface Water Approximate Concentration Range (ng/L)	Groundwater Approximate Concentration Range (ng/L)	Sediment Approximate Concentration Range (ng/kg)
HFPO-DA	Not Detected	Not Detected	Not Detected
PFBA	0.1 - 1,000	0.01 - 100,000	10 – 10,000
PFBS	0.01 - 1,000	1.0 - 10,000	10 – 1,000
PFHxA	1.0 - 10,000	0.01 - 100,000	10 – 10,000
PFHxS	0.01 - 10,000	0.10 - 100,000	10 – 10,000
PFNA	0.01 - 100	0.10 - 1,000	10 - 100
PFOA	1.0 - 1,000	0.01 - 100,000	10 – 1,000
PFOS	10 – 100,000	1.0 - 1,000,000	10 – 1,000,000
PFDA	0.01 - 10	0.10 - 1.0	10 – 1,000

Simulated Data

PDI Results – Summary

- 8 of 9 PFAS parameters included in the site assessment screening levels were detected in at least one sample
- Maximum concentrations were typically higher in groundwater samples than in surface water samples
- Surface water treatment and source reduction will be important pathways to reduce PFAS concentrations

Pre-Design Investigation Conclusions

- Comprehensive site characterization is crucial aspect of site remediation
- Depending on the site and contaminants of concern, site characterization can be an iterative process to refine areas of concern
- Data collected from the PDI were used to inform design basis for multiple different pilot studies to test various technologies for PFAS removal
- Using site characterization data during the design process reduces uncertainty and refines system design

PFAS Technologies and Innovations

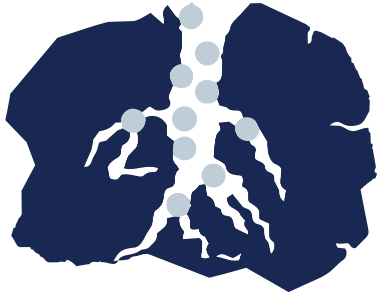
Numerous Materials/Technologies Available for PFAS Treatment

Advantages / Disadvantages / Limitations

Selection Process – Bench-Scale Testing

Pilot Testing Plans

Available PFAS Technologies and Innovations

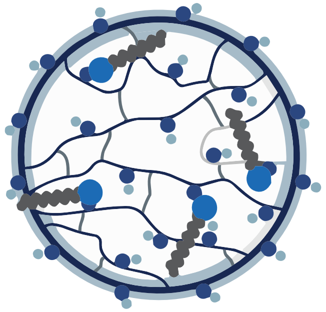


Carbon Based Adsorption

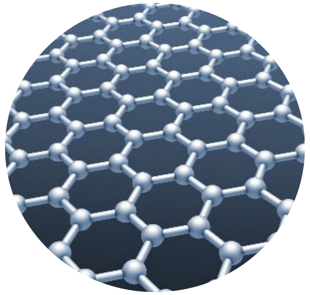
Granular Activated Carbon (GAC)

Powdered Activated Carbon (PAC)
Colloidal Activated Carbon (CAC)
(PAC) & (CAC) Finer Particle Sizes

Engineered Sorbents



Ion Exchange (IX)



Novel Sorbents

PFAS Adsorption Technologies

Granular Activated Carbon (GAC)

Commonly used for flow-through adsorption technology

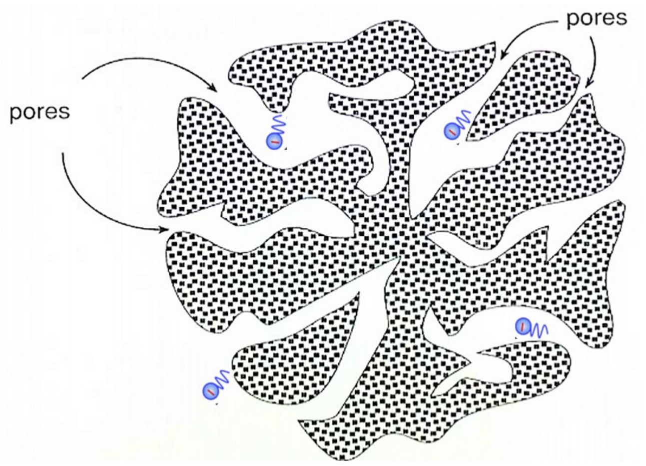
Advantages

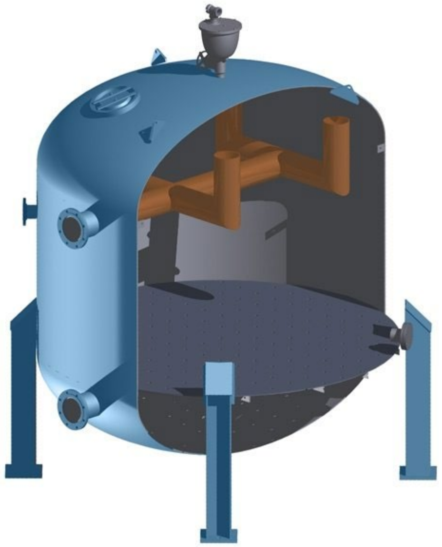
- Adsorbs PFAS Compounds
- Works Well for Long Chain PFAS Compounds (PFOA and PFOS)
- Taste and Odor Compound Removal (ex: geosmin) and TOC Reduction (DBPs)

Disadvantages

- Does NOT Work as Well for Short Chain Compounds
- Design for **10-30 Min Empty Bed Contact Time (EBCT)**

Bench Tested – Not Selected for Pilot Testing





PFAS Adsorption Technologies

Powdered and Colloidal Activated Carbon (PAC) & (**CAC)** - Finer Particle Sizes

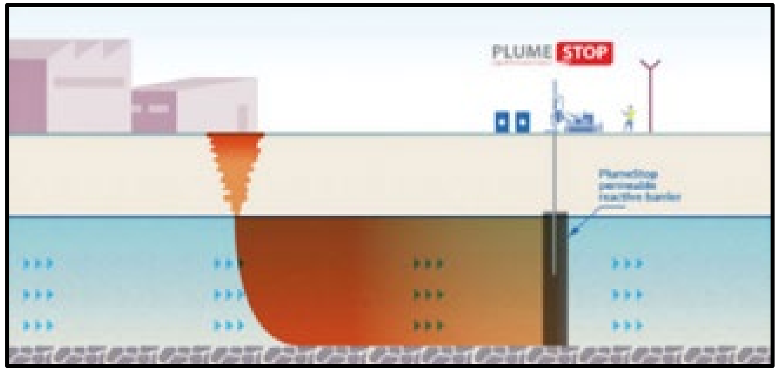
- Precludes Flow Through Applications
- Significantly Higher Surface Area
- Increased Number of Adsorption Sites Available
- Enhanced Opportunity for Improved Kinetics

Activated Carbon	Nominal Diameter Ratio	Surface Area/Mass (m^2/g)	Surface Area Ratio
GAC	3,000	0.0083	1
PAC	100	0.218	12,000
CAC	1	24	8,000,000

- **PAC** Used in Some Surface (Drinking) Water Treatment Applications
    - Particle Size Amenable to Removal Through Coagulation / Flocculation / Filtration
- **CAC** Used in In-Situ (Groundwater Remediation) Applications
    - Particle Size Amenable to Transport Into Aquifer Matrix
    - Recently Being Used in Ex-Situ (Pump and Treat) Application – Must Be Filtered Out of Bulk Water

PFAS Adsorption Technologies

Colloidal Activated Carbon (CAC)

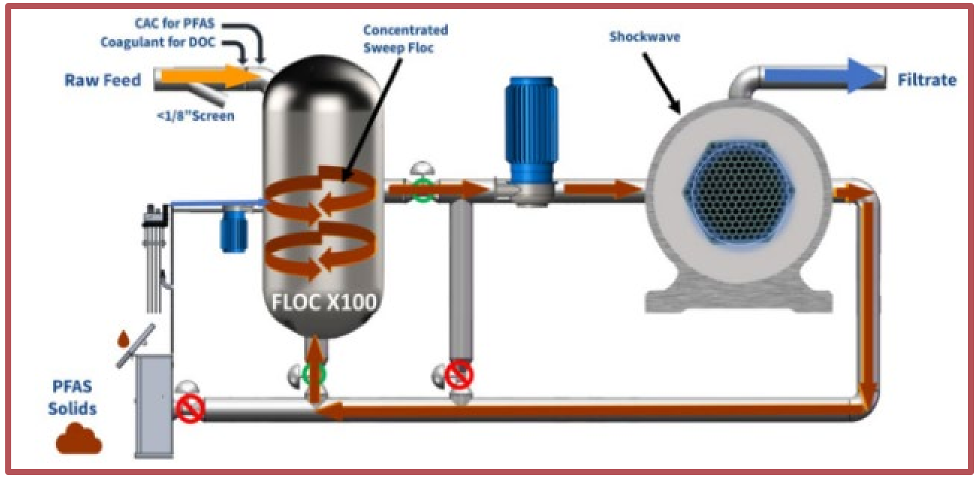


In-Situ Application (Groundwater Remediation)

- CAC Solution Injected Into Groundwater in Network of Wells
- CAC Disbursed in Groundwater and Retained by Aquifer Matrix
- Adsorbs PFAS Molecules, Demobilized and Biodegrade Over Time
- This Approach Was Proposed For Pilot Testing
- Pilot Not Pursued Due to CSM Data Gaps and Uncertainties

Ex-Situ Application (Pump and Treat Remediation)

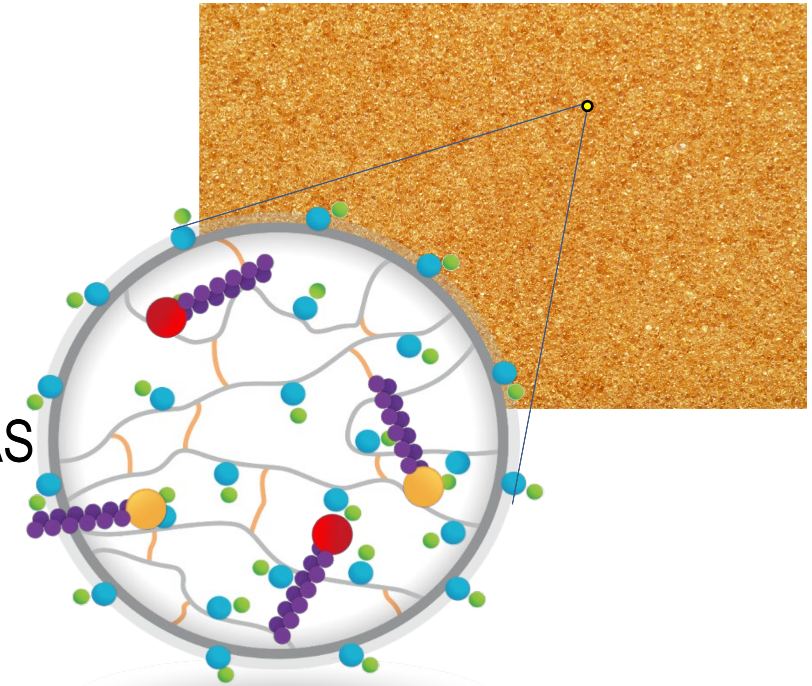
- CAC Added to High Energy Reactor (CSTR)
- Must Remove PFAS-adsorbed-CAC from Bulk Water
- Pursuing Continuous UltraFiltration (Cuf®) Pilot Study



PFAS Adsorption Technologies

Ion Exchange (IX)

- IX Resins - Highly Porous Polymeric Material (Hydrocarbon-Based)
- Positively Charged Exchange Sites Adsorb Negatively Charged PFAS
- Removes Nearly 100% of the PFAS Until Resin is Exhausted (Full)
- Typically Design for **2-6 Min Empty Bed Contact Time (EBCT)**
- Competing Anions and Negatively Charged Particles



Simplified Resin Bead

Polystyrene Polymer Chain

Divinylbenzene crosslink

Fixed ion exchange group (i.e., Na^+)

Exchangeable counter ion (i.e., Cl^-)

ECT2 SORBIX Anion Exchange Resin (AER) – Selected for pilot testing

Requires pretreatment in many cases, TSS and TOC reduction

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PFAS Adsorption Technologies

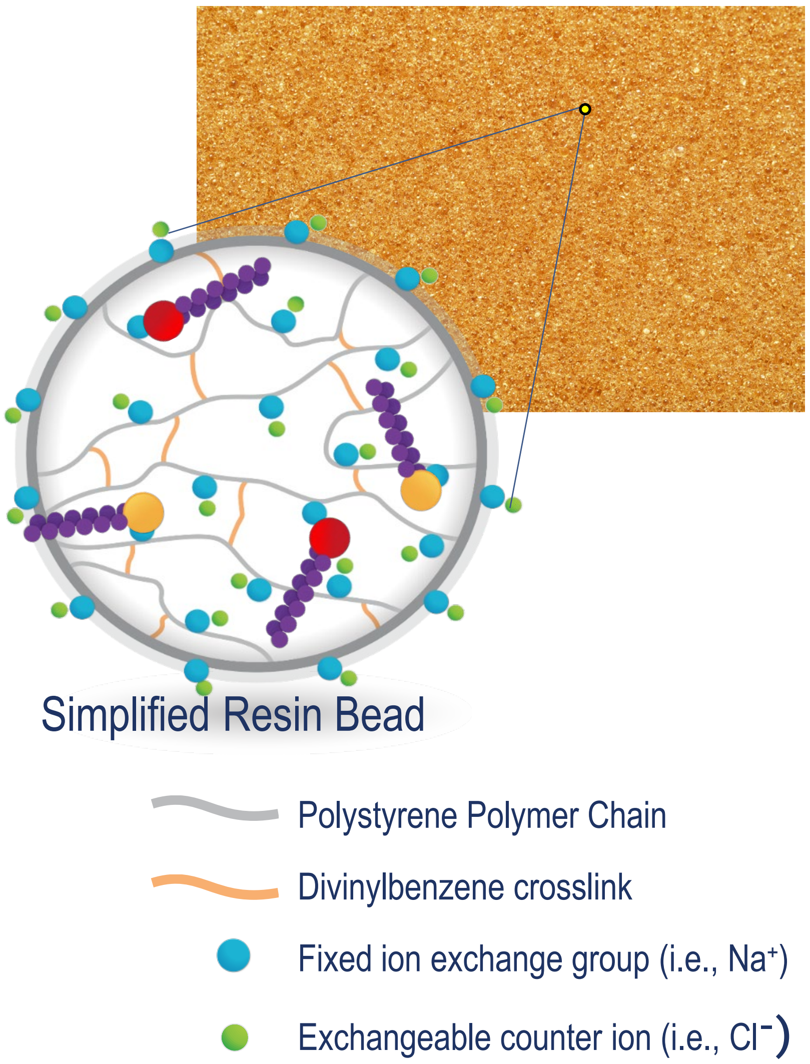
Ion Exchange (IX)

Advantages

- Effective on Broad Range of PFAS, Including Short Chains
- Significantly Smaller Footprint Than GAC
- Significantly Higher PFAS Removal Capacity Than GAC

Disadvantages

- Most Resins Used for PFAS Removal Can't be Regenerated
- Short Chain PFCA Removal Decreased by Elevated Chloride (PFBA, PFPeA, PFHxA)
- IX Adsorbs Other Anions, Shortening IX Resin Lifespan
- Generally Doesn't Remove Co-Contaminants – Pretreatment Needed



PFAS Adsorption Technologies

Novel Sorbents – Flow-Through Media Application (like IX and GAC) or non-packed bed (fluidized) applications

- Synthesized or Modified Materials **- Faster Adsorption Kinetics**, **Higher Degree of Selectivity/PFAS Affinity**
    - Metal-Organic Frameworks (MOFs)
    - Covalent Organic Frameworks (COFs)
    - Hydrogels and Fluorinated Variants
    - Cyclodextrin-Based Adsorbents – **Cyclopure Dexsorb+ (Bench Tested, Not Selected for Pilot Testing)**
    - Surface Modified Clays – **Fluoro-Sorb® 200 (Bench Tested, Selected for Pilot Testing)**

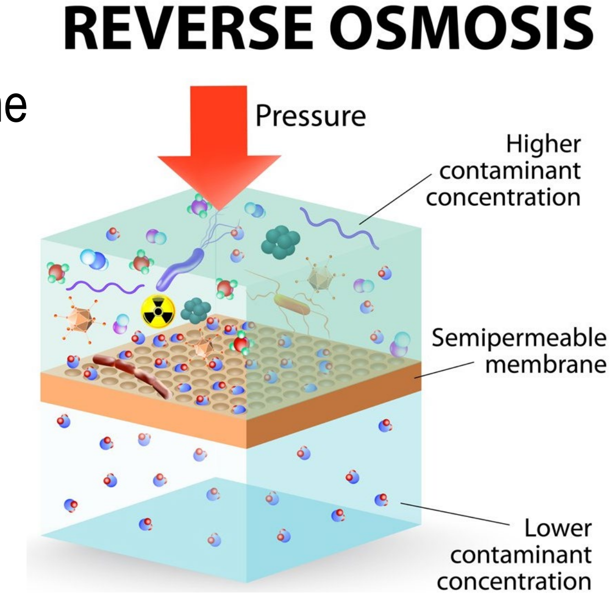
- Flow-Through Application– Like GAC/IX, Needs Influent Water With Low TSS/TOC, Often Requires Pretreatment **(Fluoro-Sorb 200 Used for Flow-Through Pilot Testing)**

- Passive Application – In-Stream Gabion Baskets **(Fluoro-Sorb® 400 Used for In-Stream Pilot Testing)**

PFAS Separation (Concentration) Technologies

High Pressure Membranes – Reverse Osmosis, Nanofiltration

- Removes Up to 99.9% of All PFAS Compounds
- May Require Multiple Pass RO/NF System to Meet Treatment Goals
- Typ. 75-80% of RO Feedwater Passes Through Membrane As Produced Water (Filtrate)
- 20-25% Rejection Rate (Concentrate)
- Treatment of Concentrate Can Be Problematic / Costly
- High Energy and Overall Operational Costs



PFAS Separation (Concentration) Technologies

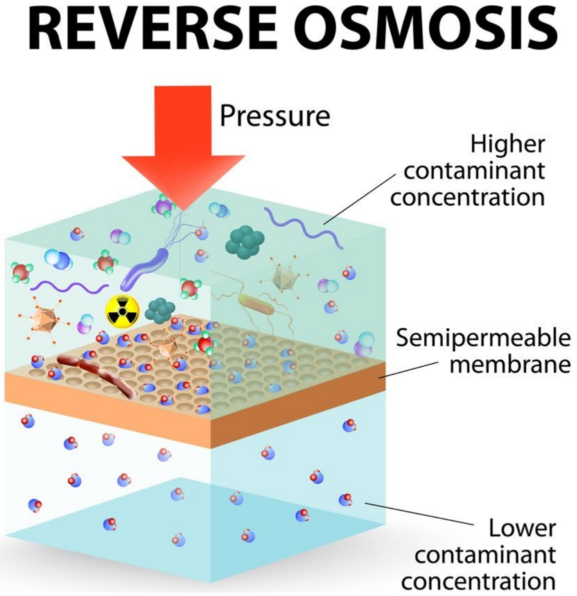
High Pressure Membranes – Reverse Osmosis, Nanofiltration

Advantages

- Effective on Broad Range of PFAS, Including Short Chains
- Not Adversely Impacted by Elevated Chloride Concentrations
- Effectively Removes a Variety of Co-Contaminants

Disadvantages

- Managing the Concentrated Reject Stream
- High Energy and O&M Costs
- Corrosion Control Required – Filtrate is Often Corrosive



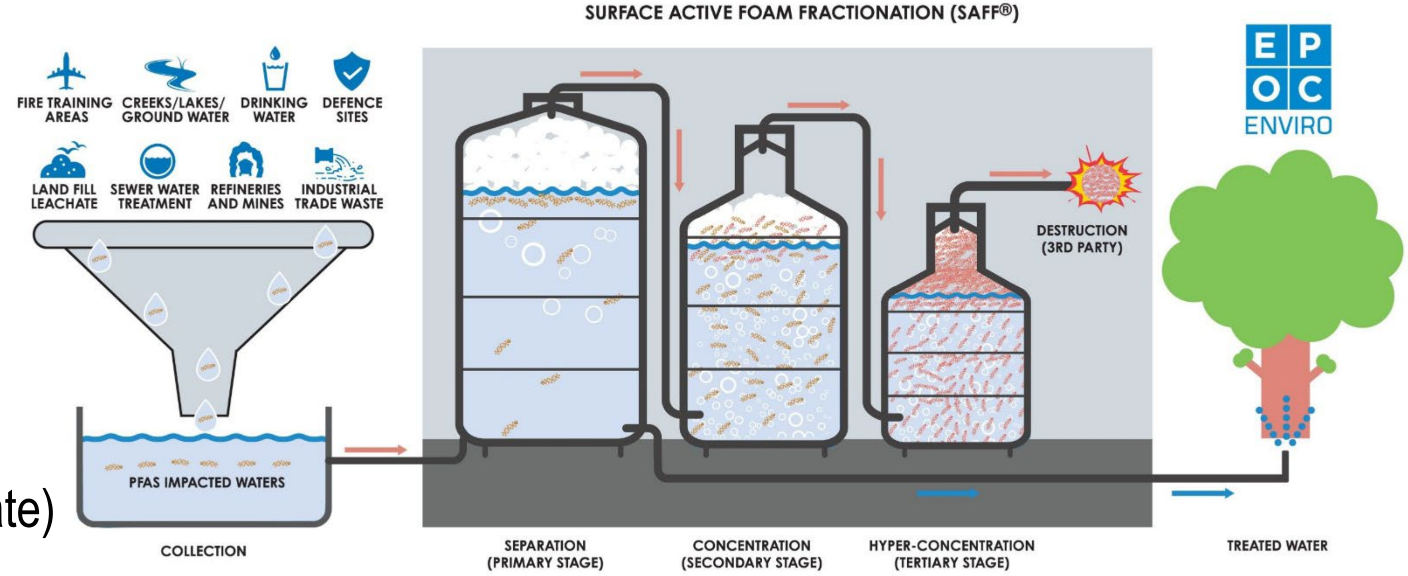
PFAS Separation Technologies

Foam Fractionation – Surface Active Foam Fractionation (SAFF)

- Removes up to 99.999% of all PFAS Compounds
- No Chemicals (Claim), Media/Resin, or Membranes
- Water flows down, air flows up; PFAS captured by air bubbles
- Must Manage Concentrate
- More Effective for Long Chain PFAS, polishing or longer detention times required for short chain PFAS

PFAS Separation Technologies

Foam Fractionation – Surface Active Foam Fractionation (SAFF)



Advantages

- Simple Process
- Low Energy Cost

Disadvantages

- Effectiveness with Short Chain PFAS
- Management of Concentrated PFAS (Foamate) Required

PFAS Destruction Technologies

Adsorption Media – Solid PFAS-Concentrated Waste

- Landfill (Not Destruction)
- Thermal Decomposition – Incineration, GAC Regeneration
- IX Resin Regeneration (Transfer PFAS from Solid to Liquid Matrix)

Aqueous Concentrated Wastes

- Electrochemical Oxidation
- Non-thermal Plasma
- Supercritical Water Oxidation
- Photocatalysis - PRD – Photoactivated Reductive Defluorination (Enspired Solutions) to be Pilot Tested
- High Alkalinity Thermal Treatment - HALT (Aquagga) to be Pilot Tested

PFAS Destruction Technologies

Photoactivated Reductive Defluorination (PRD) - PFASigator

- Chemical Reaction Breaks Fluorine-Carbon Bonds
- Liquid Catalyst Added - Cetyltrimethylammonium Bromide (CTAB)
- CTAB Forms Surfactant Micelle, Serves as Reactive Cage
- Proprietary Electron Donor Added – Joins Micelle Surface
- UV Light Breaks the Fluorine-Carbon Bonds

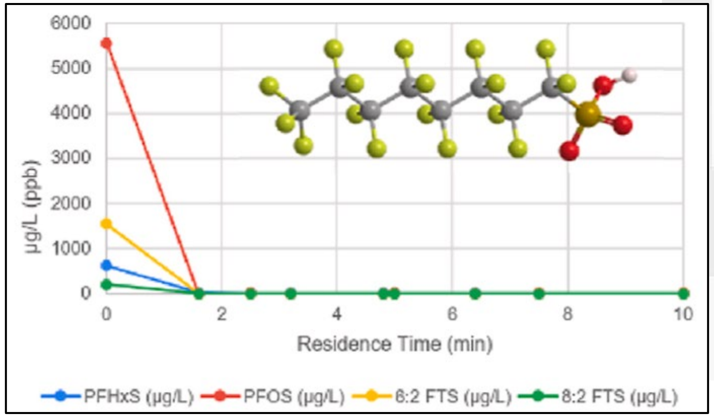
- Operates at Standard Temp./Pressure, Automated Batch Operation, pH from 3-12, Aerobic or Anaerobic, Claims 99%+ PFAS Destruction

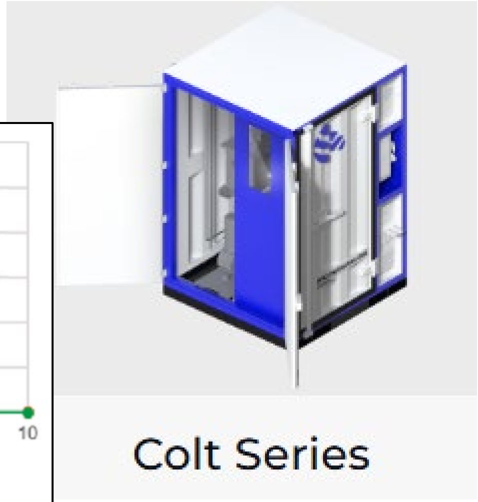
- Will be pilot tested on SAFF Foamate

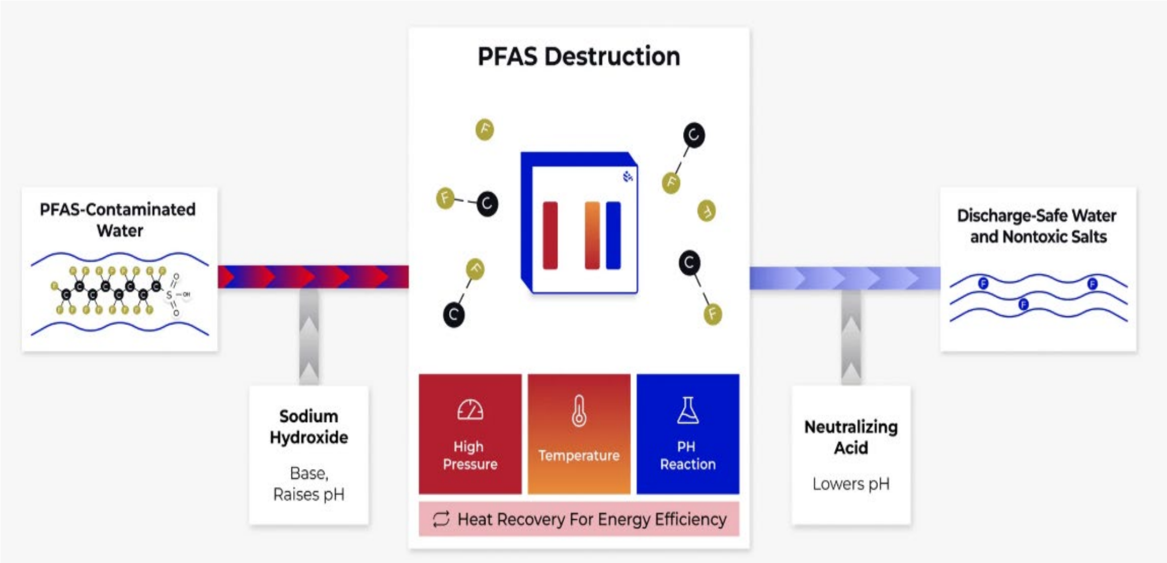
PFAS Destruction Technologies

High Alkalinity Thermal Treatment - HALT

- Destroys PFAS Using High Pressure, Temperature and pH
    - High Pressure - ~ 20 Megapascals (~2900 psi)
    - High Temperature - ~350 Degrees C (~660°F)
    - High pH - > 14 SU
- Cleaves Head Group First (e.g. sulfonate)
    - Successively Cleaves Fluorine-Carbon Bonds
- **Automated Continuous Flow Operation**
- Claims 99 to 99.99% PFAS Destruction
- Will be pilot tested on SAFF Foamate







Pilot Testing Program Design

Pilot Testing Program

- Gabion Basket Pilot Test Called Off Due to BASH Hazard
- Flow-Through Adsorption Media - 2 Varieties in Pressure Vessels – Facilities in Construction – Start-up Late July 2026
- Foam Fractionation - Allonia System to be Piloted Late Summer 2026
    - Two Foamate Destruction Technologies To Be Piloted:
    - PRD destruction technology
    - HALT destruction technology
- Pump-and-Treat CAC Adsorption – Purifics Continuous UltraFiltration (Cuf) – Start-up TBD

Translation to Full-Scale Design

- Design Parameters Derived From Pilot Data; Scaling Factors and Considerations; Risk Reduction

Key Takeaways

- Maintain close collaboration with the client and project team
- Key success factors: proactive communication, organizational agility, and the ability to adapt quickly
- Complete PDI prior to initiating pilot testing
- Design-build delivery enables greater flexibility
- Build contingency into work plans

Questions?

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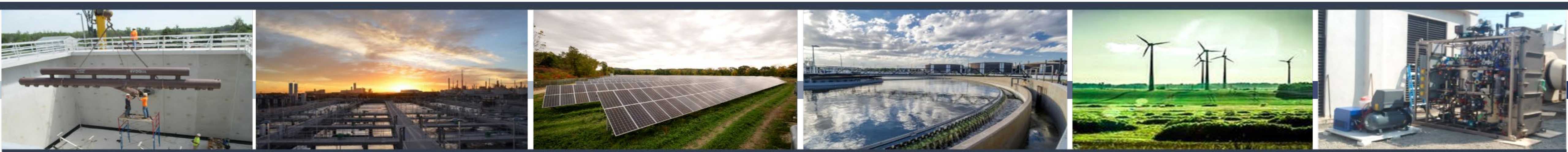
Would you like to watch this event again?
A recording of today's event will be available on our website in a few weeks.

Need a PDH Certificate?
Board Certified Individuals will be emailed a PDH Certificate for attending this event within the next week.

Questions?
Email Marisa Waterman at mwaterman@aaees.org with any questions you may have.



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