Nanofiltration Followed By Electrical Discharge Plasma for Destruction of PFAS and Co-Contaminants in Groundwater: A Treatment Train Approach

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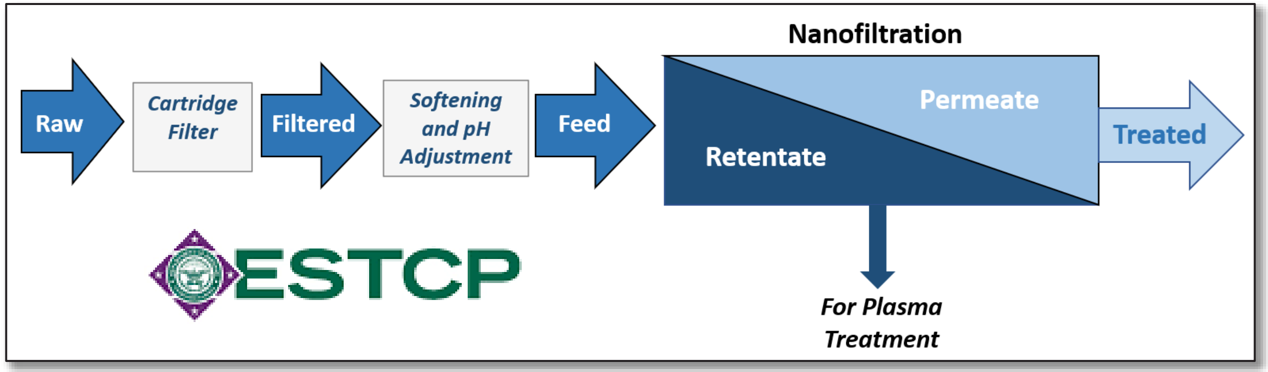
2023 International Symposium on Bioremediation and Sustainable Environmental Technologies



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CDM Smith

Technical Objectives

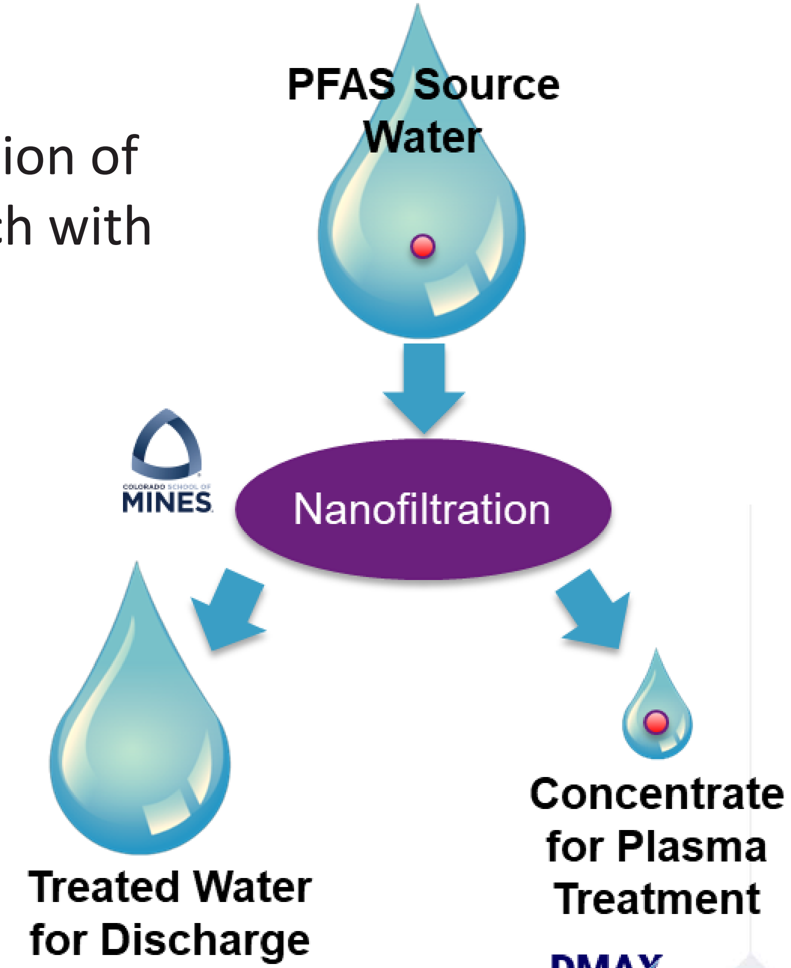
What's Needed?

- Since PFAS plumes are generally dilute (often a few ppb), remediation of PFAS-impacted water best lends itself to a treatment train approach with integrated ***PFAS concentration and destructive steps***

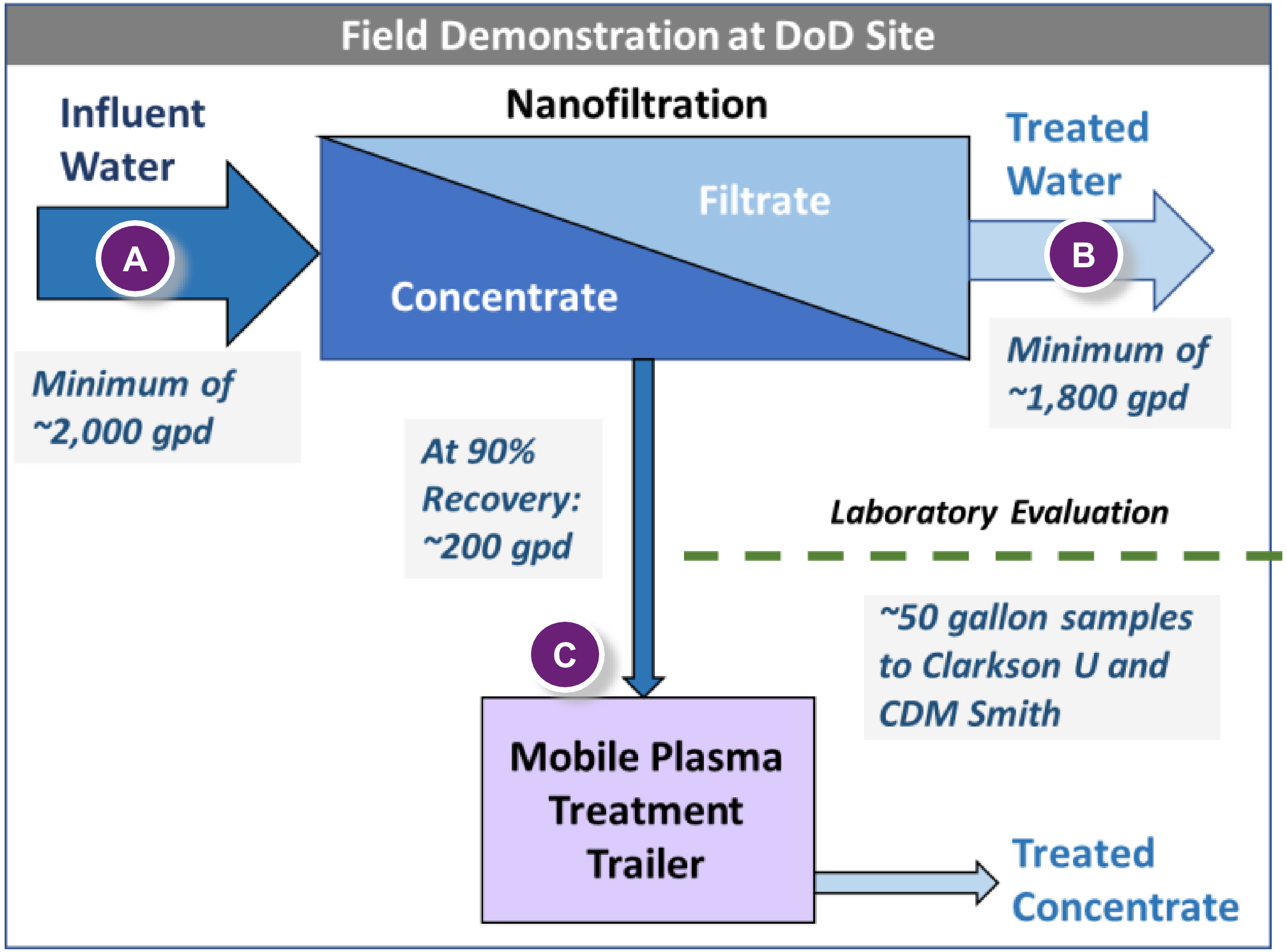
Our Objective

- Demonstrate and validate a field-scale integrated treatment approach:

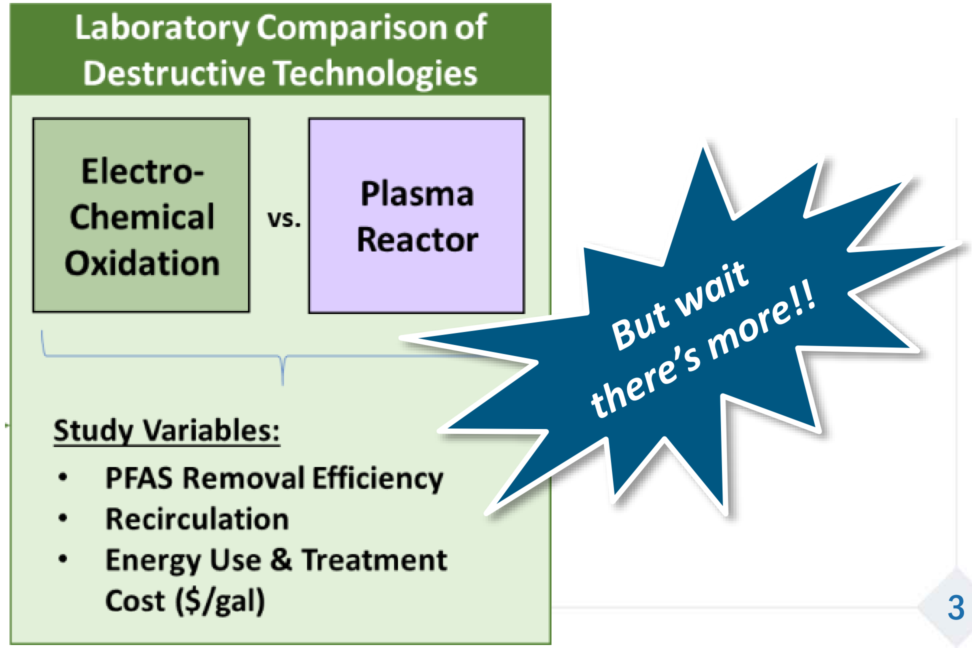
1. ***Nanofiltration*** to concentrate PFAS and co-contaminants
2. ***Electrical Discharge Plasma*** to treat concentrate
3. "Apple to Apples" Bench-scale comparison of ***Electrochemical Oxidation and Plasma***



Technical Objectives



- **A** Nanofiltration can process a ***minimum*** of 2,000 gpd of influent water (Feed)
- **B** ~1,800 gpd will be a treated effluent stream (Filtrate, ~90% of Feed)
- **C** ~200 gpd will be treated by plasma (Concentrate, ~10% of Feed)



Today's Presentation…

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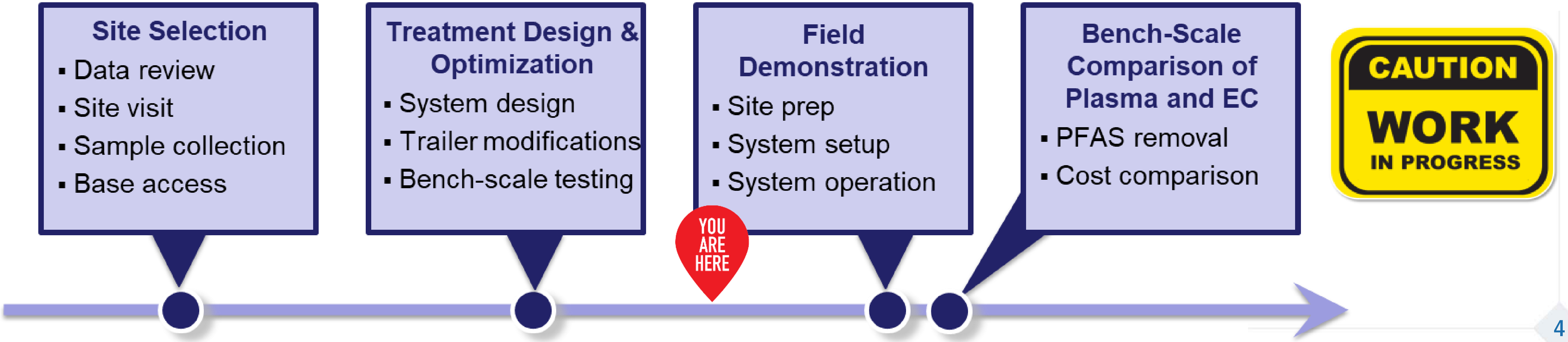
1. Overview: Nanofiltration and Enhanced Contact Plasma technologies
2. Source water characterization
3. Treatability testing results
4. Next steps



Coupling Concentration & Destruction

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Concentration	*Destruction*

Concentration

- Activated carbon
- Ion exchange resins
- Novel polymer adsorbents
- Silica coatings
- Zeolites
- Foam Fractionation
- Colloidal Gas Aphrons
- Nanofiltration
- Ultrafiltration
- Reverse Osmosis

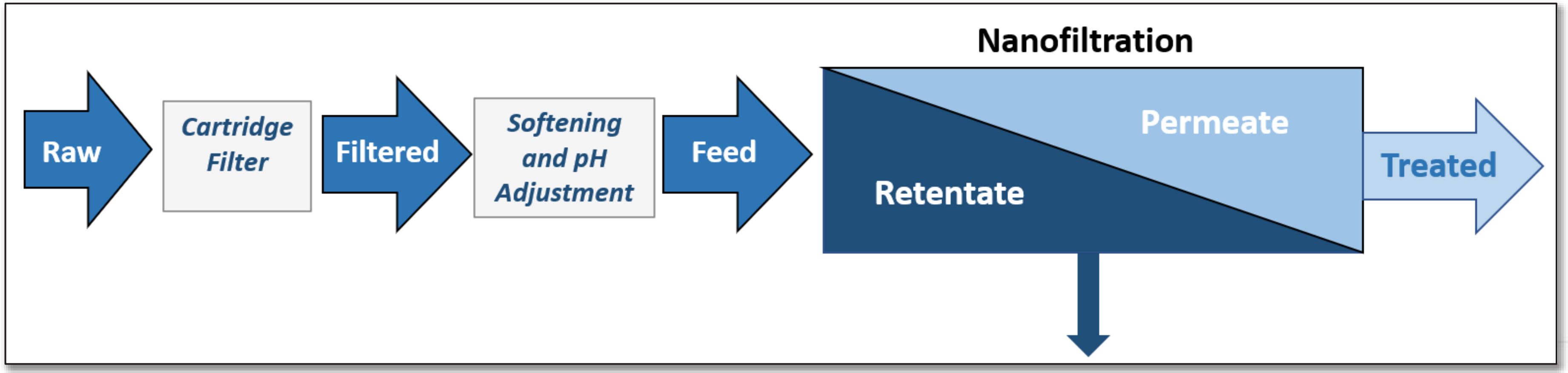
Destruction

- Electrochemical Oxidation
- Enhanced Contact Plasma
- Hydrothermal Alkaline Treatment
- Photochemical Oxidation
- Supercritical Water Oxidation
- Sonolysis
- Thermal Oxidation

KEY POINT: There are numerous opportunities to combine concentration and destructive technologies for the treatment of PFAS-impacted waters

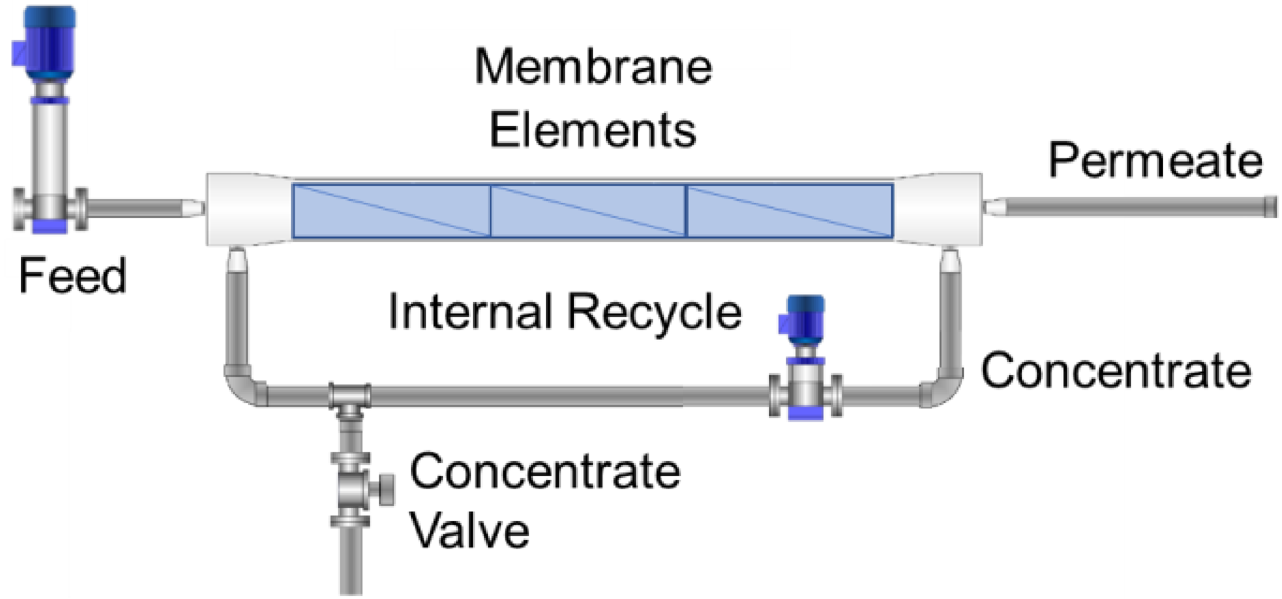
Nanofiltration: *The Basics*

- High-pressure separation process where solutes are retained by membranes and concentrated into a smaller volume of water (***retentate or concentrate***)
- Majority of feed water exits system as treated ***permeate (or filtrate)***
- ***% Recovery:*** proportion of feed water recovered as permeate
- ***% Rejection:*** proportion of solute (PFAS) retained by the membranes



Closed-Circuit Desalination (CCD)

- Newer membrane systems such as closed-circuit desalination (CCD) can achieve >20x concentration of PFAS-impacted waters



Semi-Batch Treatment Process

- During filtration, concentrate recirculated internally, concentrate valve closed
- Once a recovery (proportion of feed water recovered as permeate) setpoint is reached, concentrate valve opens
- With concentrate valve open, plug-flow flush displaces concentrate in system
- Concentrate valve closes, new cycle starts

Enhanced Contact Plasma: *The Basics*

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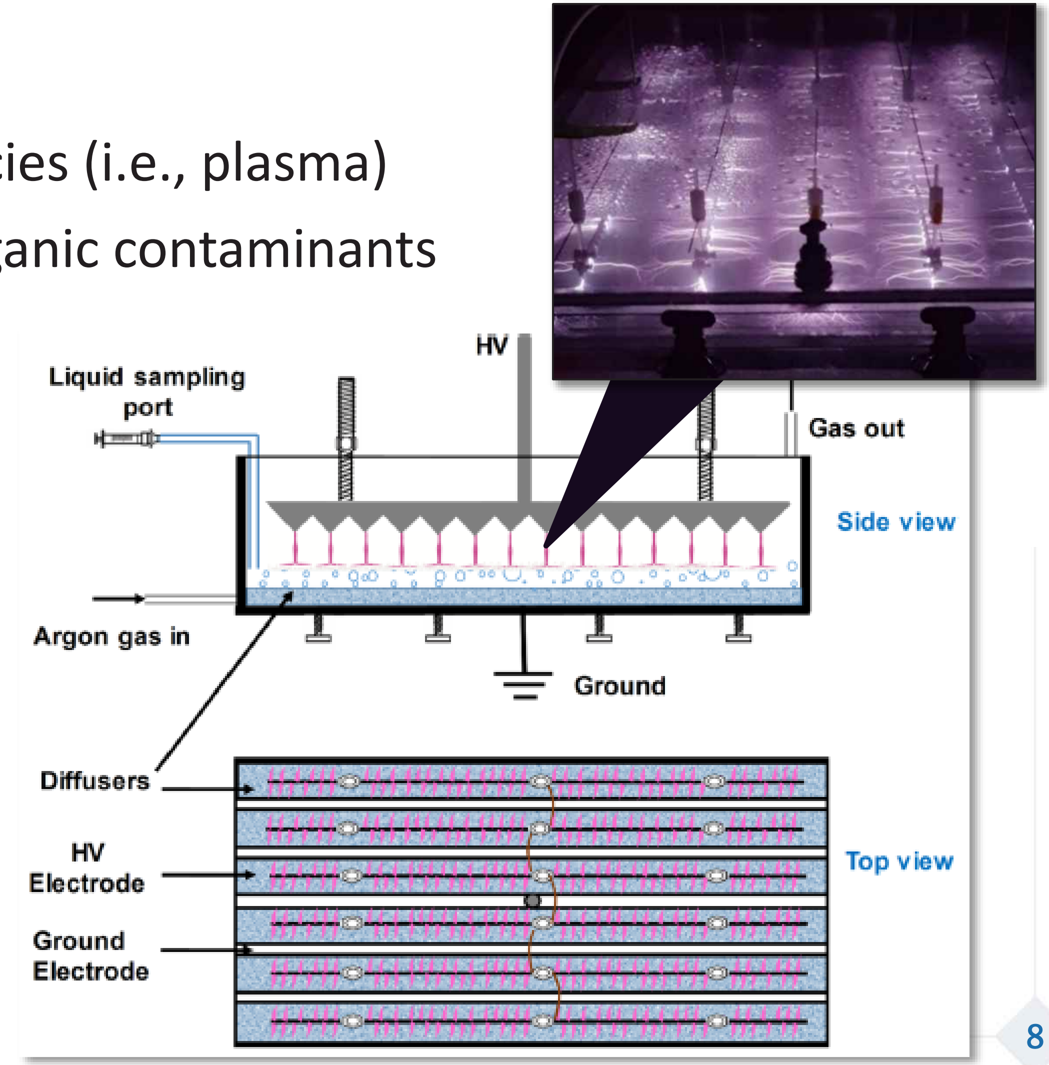
1 **Plasma-based water treatment** uses electricity to:

- convert water into a mixture of highly reactive species (i.e., plasma)
- rapidly and non-selectively degrade recalcitrant organic contaminants

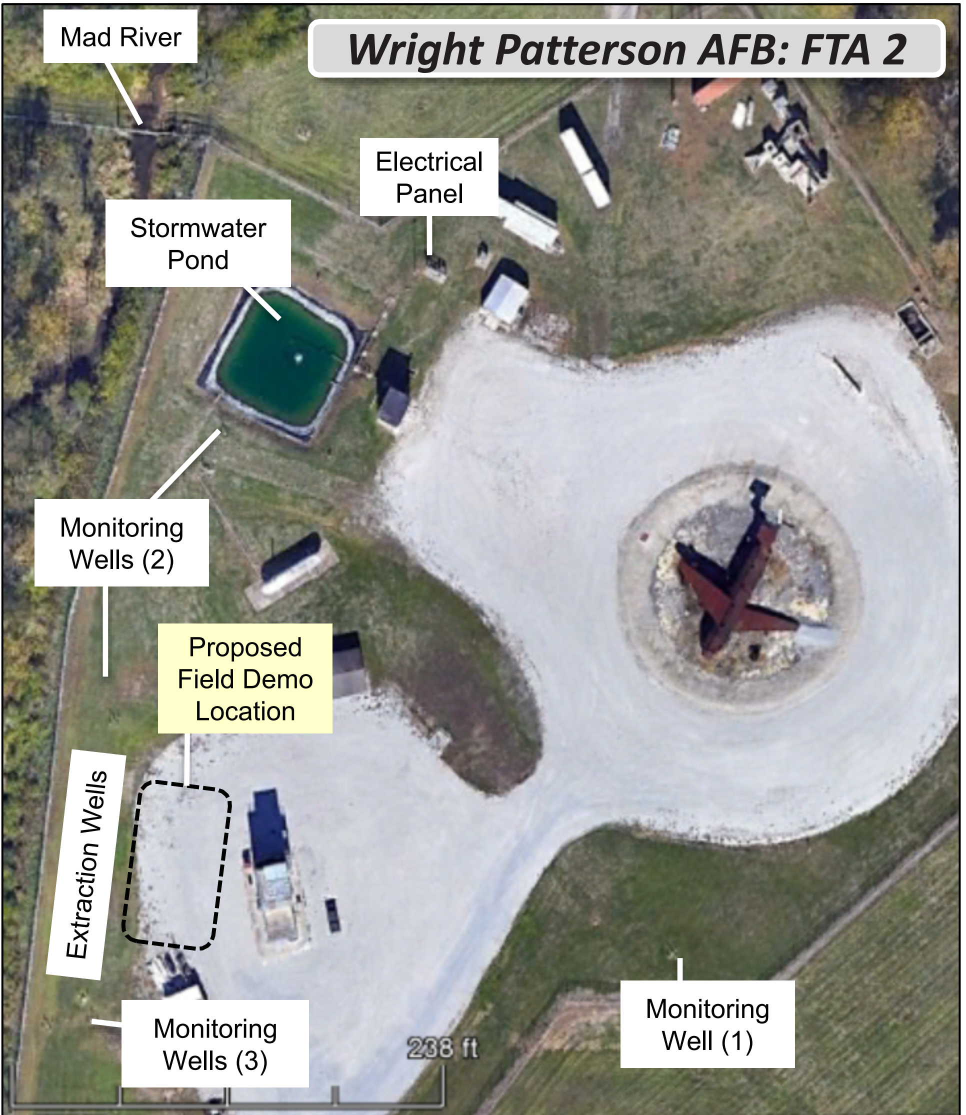
2 **Plasma Formation:** High voltage is applied between suspended electrodes (above the water surface) and submerged grounded electrodes

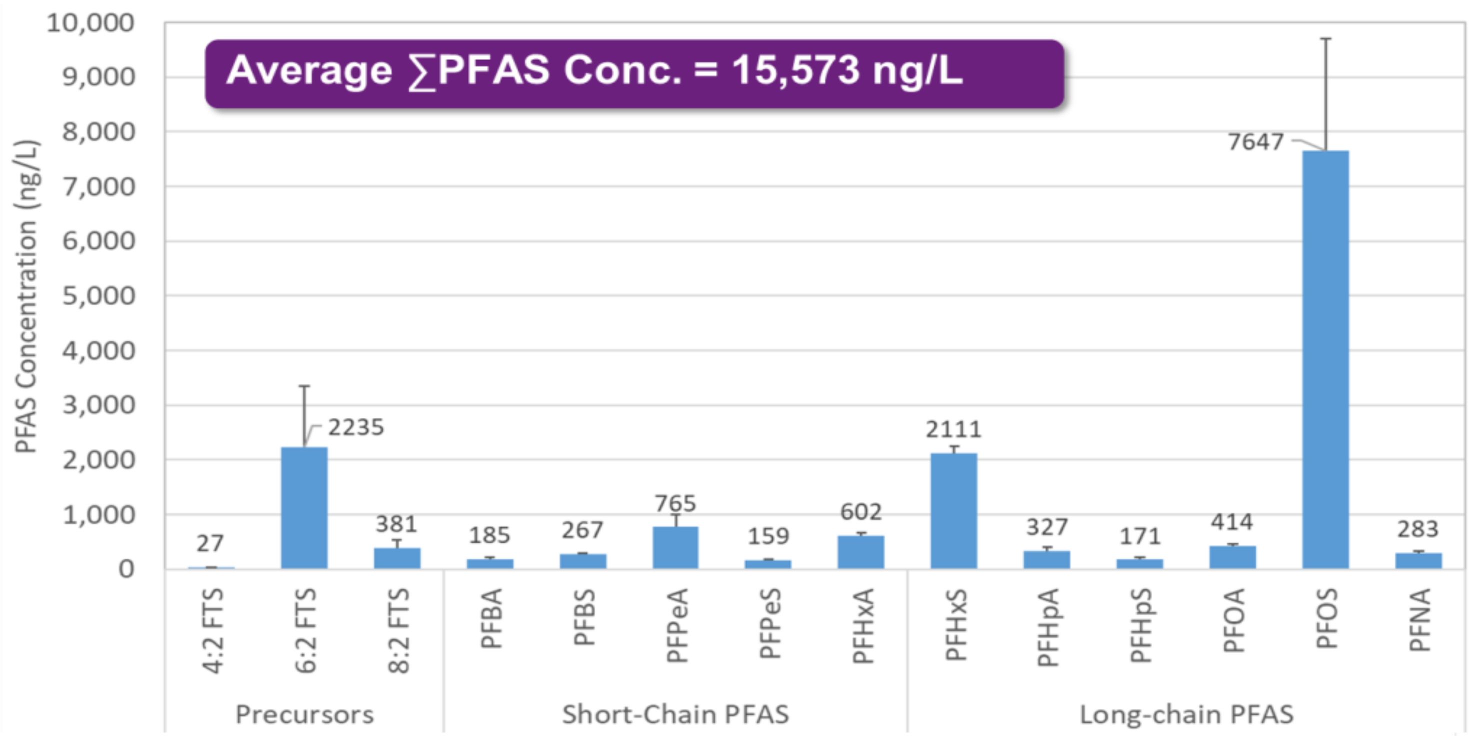
3 **Plasma Reactor Components**

- High voltage electrodes for generation of plasma
- Stainless steel strips as grounded electrodes
- Gas diffusers for bubble formation to drive PFAS to liquid surface



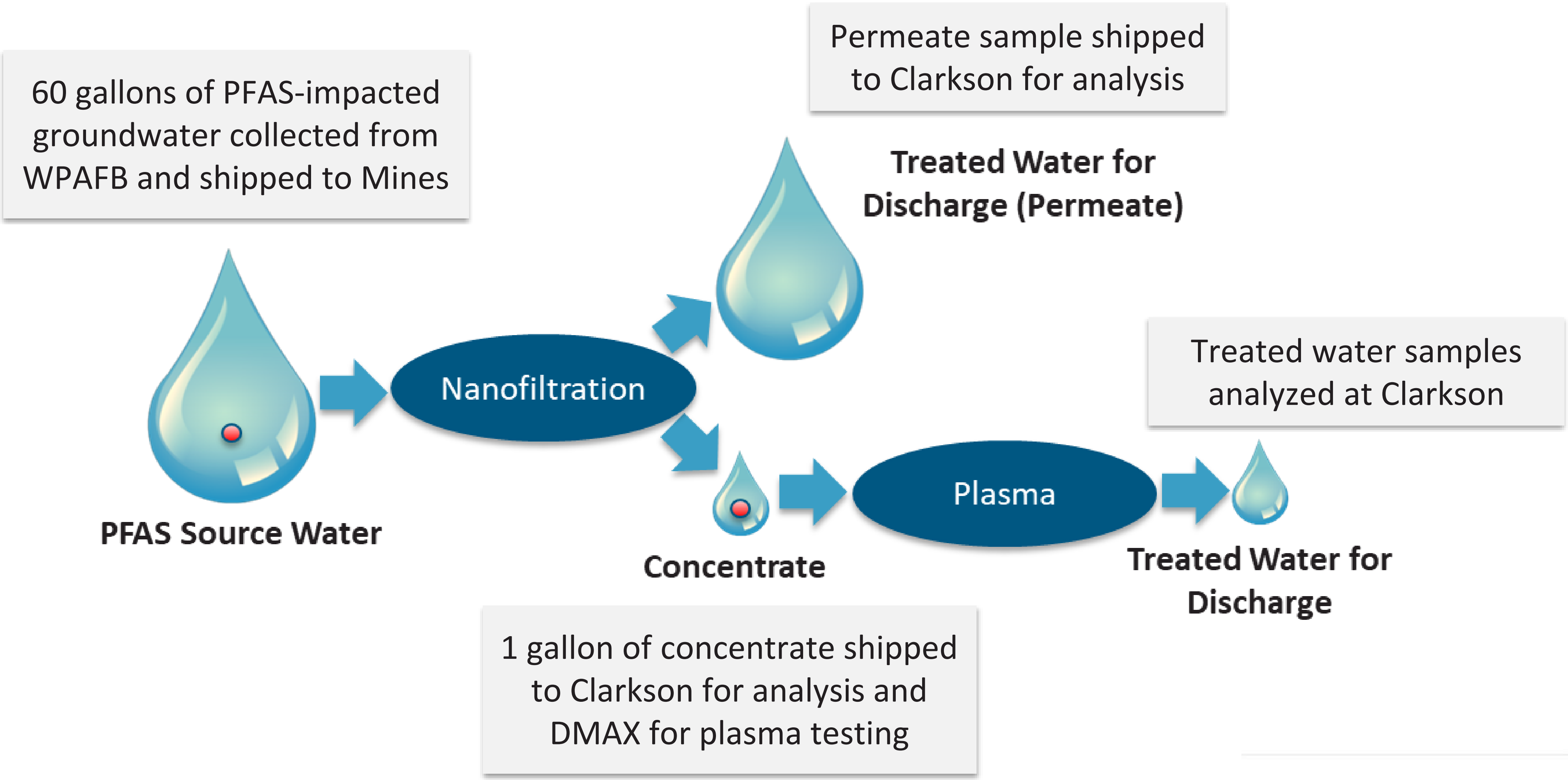
Source Water Characterization





- Samples collected from several extraction wells
- Most abundant PFAS: PFOS, 6:2 FTS, and PFHxS
- Elevated alkalinity, calcium, and iron

Bench-scale Treatability Testing



Nanofiltration:
Membrane Concentration Tests

Raw Water Tote → Pre-Filtration → Hardness Removal (Cation Exchange) → Closed Circuit Desalination → 10% Concentrate 1-gallon shipped to DMAX Plasma

Closed Circuit Desalination ↓ 90% Recovery Permeate

Membrane System/Experiment Specifications:

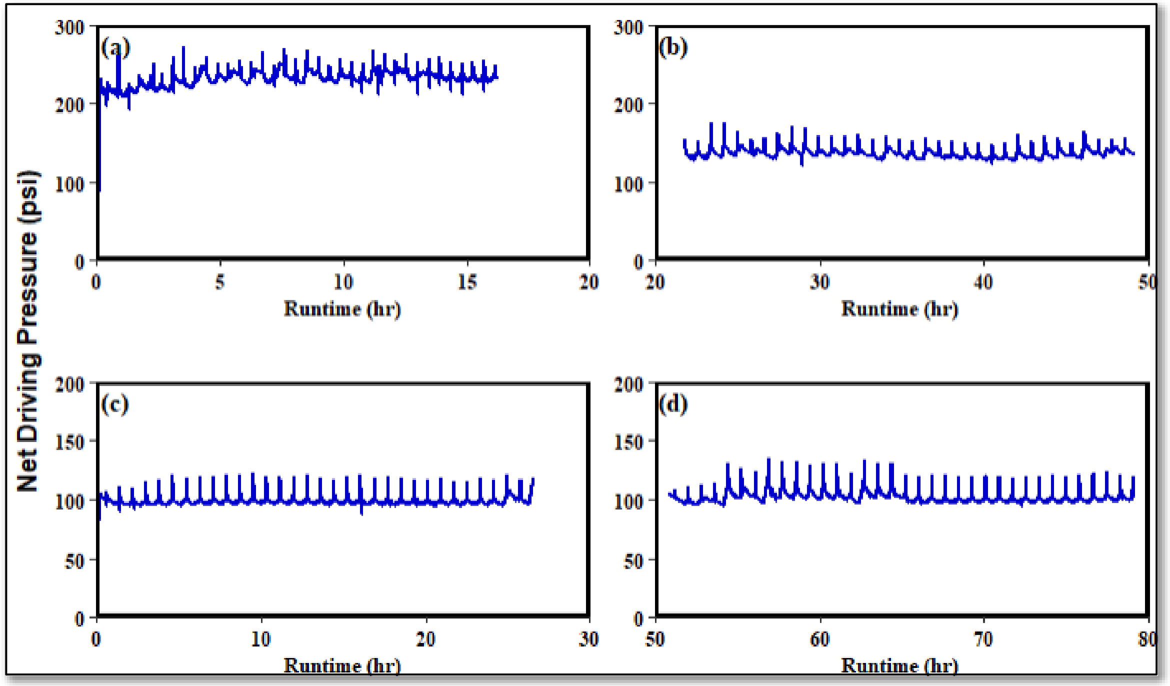
- Tested two membranes: NF-90 (tight NF) and CR-100
- System uses 0.14 m^2 of flat-sheet membrane in two cells
- Each sequence produced ~3.6 L of permeate, ~0.4 L of concentrate
- SCADA logs flow rate, pressure, conductivity, temperature
- Performed approximately 30 sequences up to 90% recovery
- Collected permeate and concentrate samples

Bench-scale CCD system

Nanofiltration: *Operational Results*

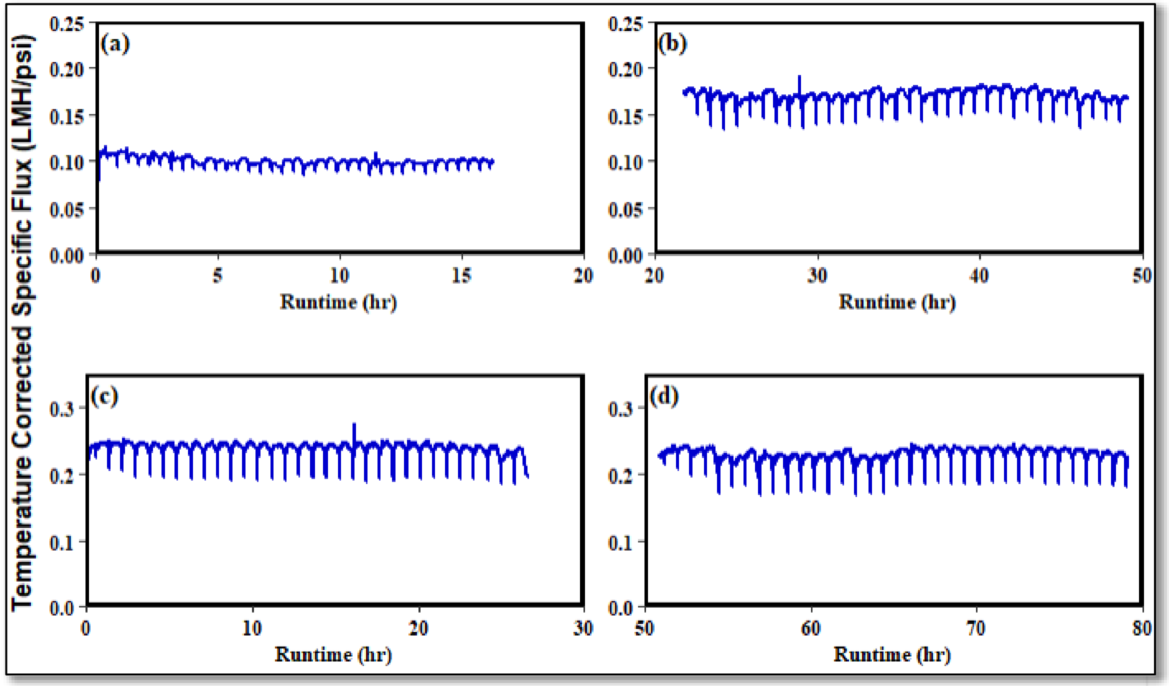
Net Driving Pressure

NF-90 (tight NF) | **CR-100**



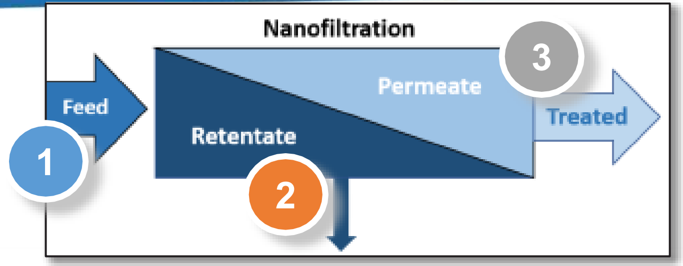
Temperature Corrected Specific Flux

NF-90 (tight NF) | **CR-100**

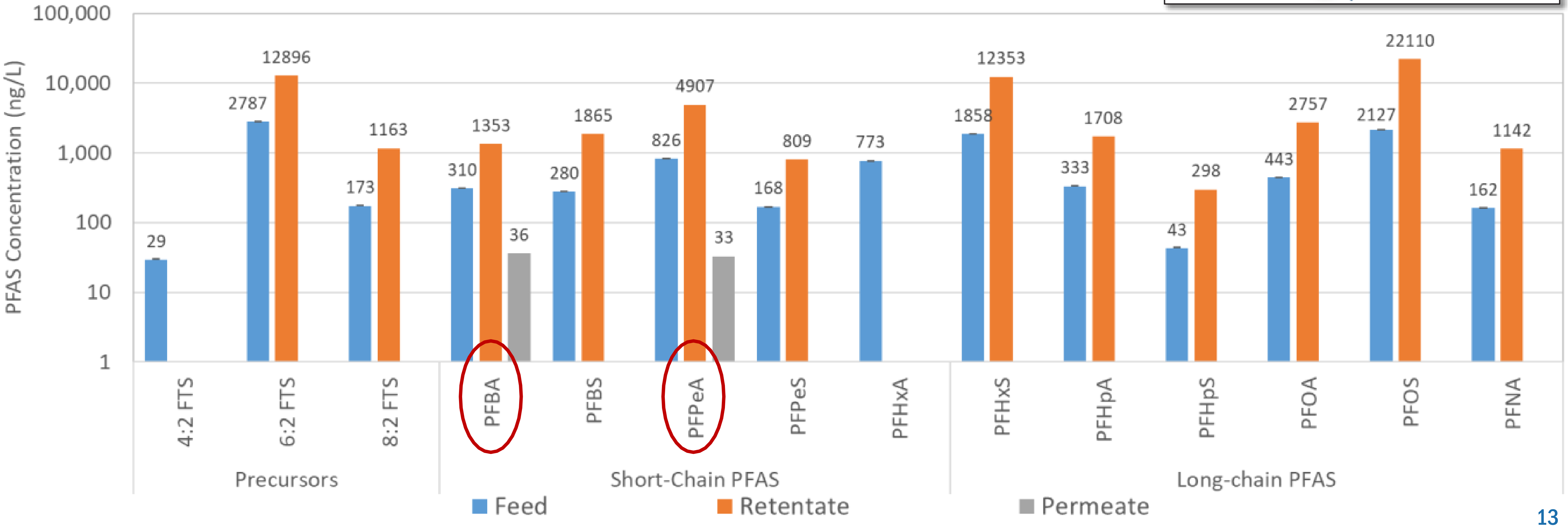


KEY POINT: No decrease in permeability was observed for both membranes indicating that CCD treatment of pretreated groundwater did not result in membrane fouling.

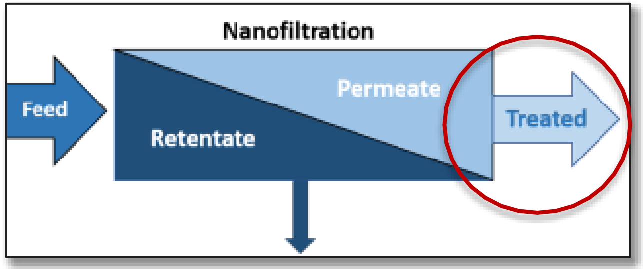
Nanofiltration: *Performance Results*



CR100 Membrane

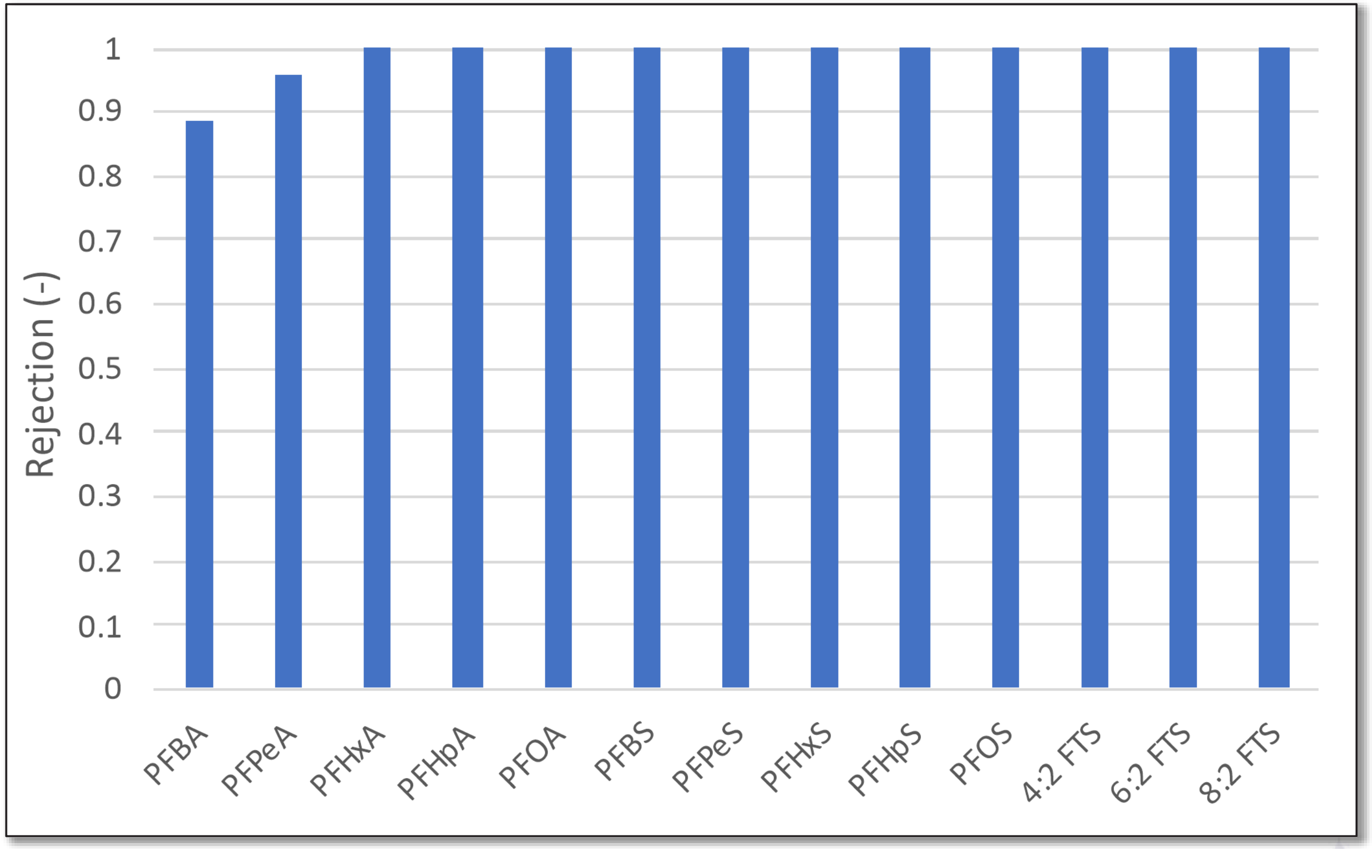


Nanofiltration: *Performance Results*

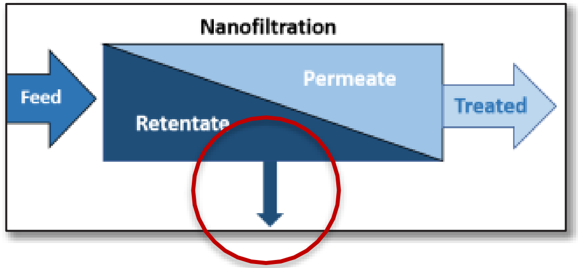


- Concentrations of most PFAS in the CR100 permeate were below respective detection limits (Rejection ≈ 1)
- Two exceptions: PFPeA and PFBA (Rejection = 0.96 and 0.88, respectively)
- Smaller solutes are harder to remove with membranes
- Bench-scale systems tend to underpredict rejection

CR100 Membrane

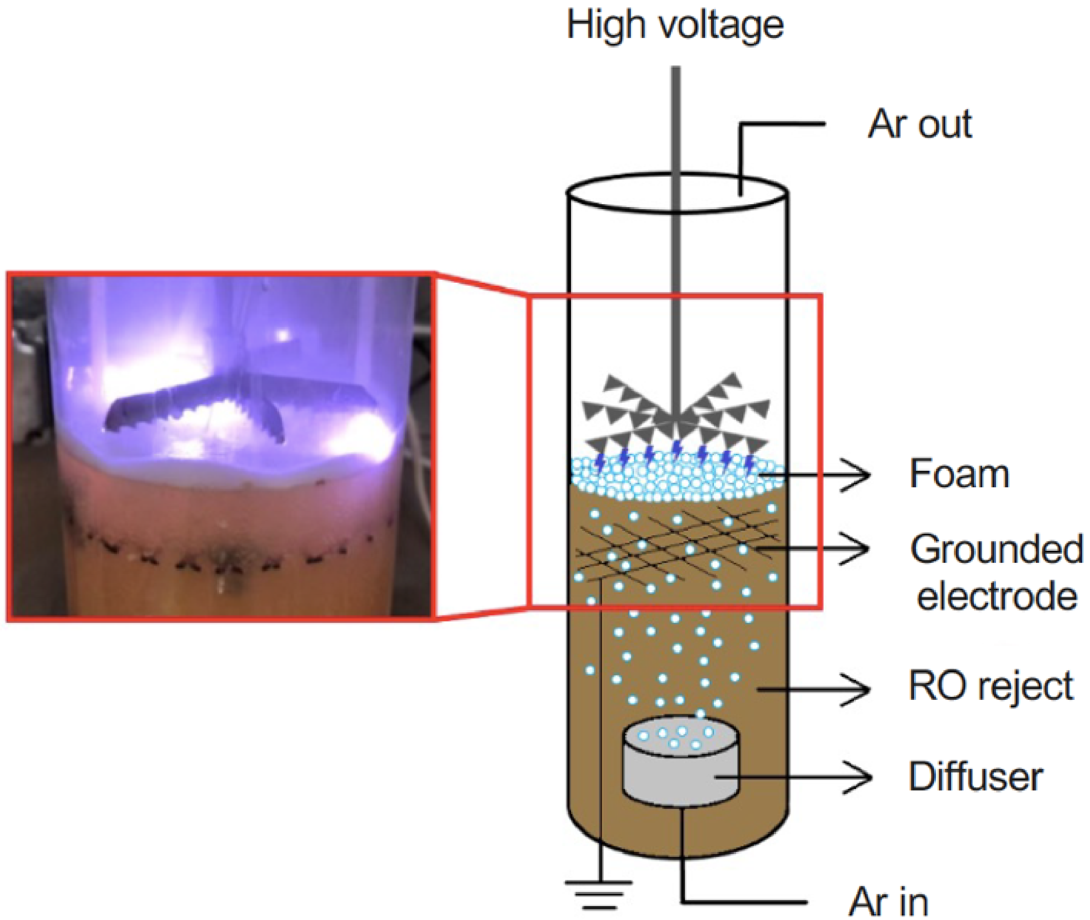


Enhanced Contact Plasma:
Retentate Treatment

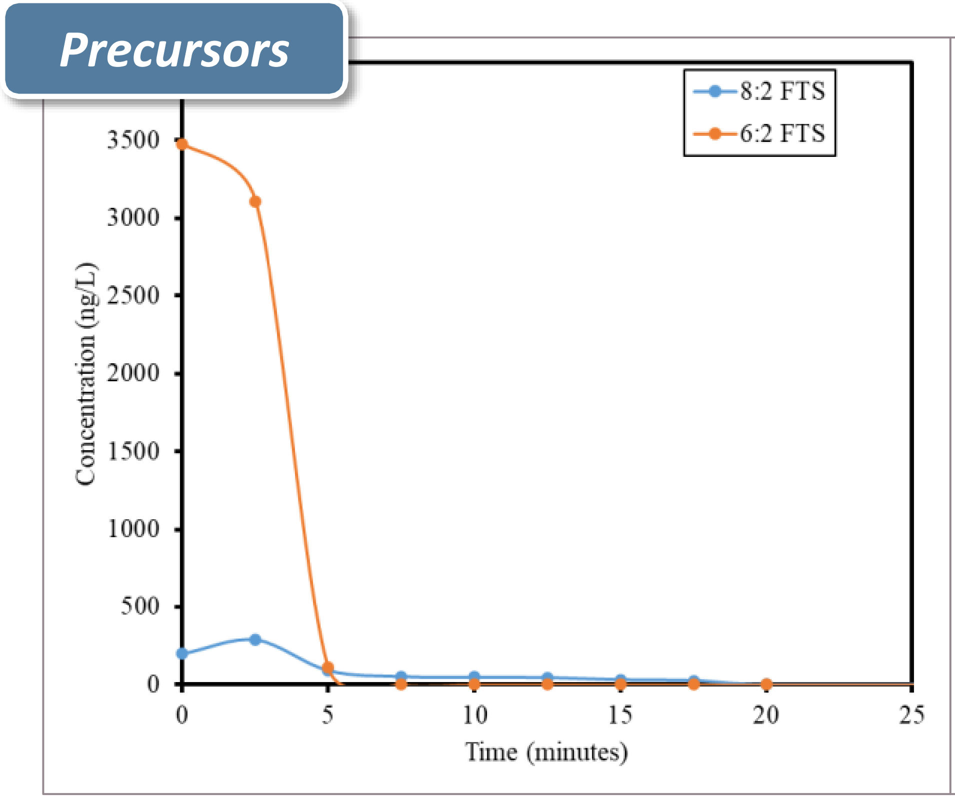


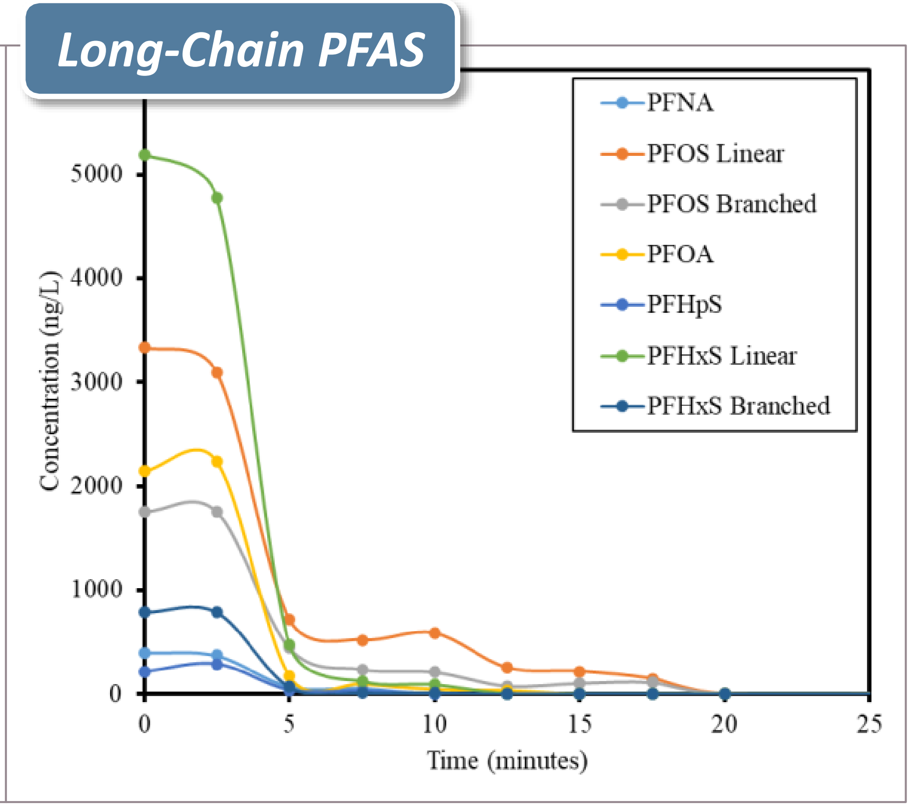
Batch bubble column reactor with liquid recirculation

- Treated liquid volume: 3.1 L
- Treatment time: 180 min
- Gas flowrate adjusted to maintain foam height
- Proprietary surfactant addition every 15 min
- Solution recirculated through heat exchanger at 10°C



Enhanced Contact Plasma: *Performance Results*

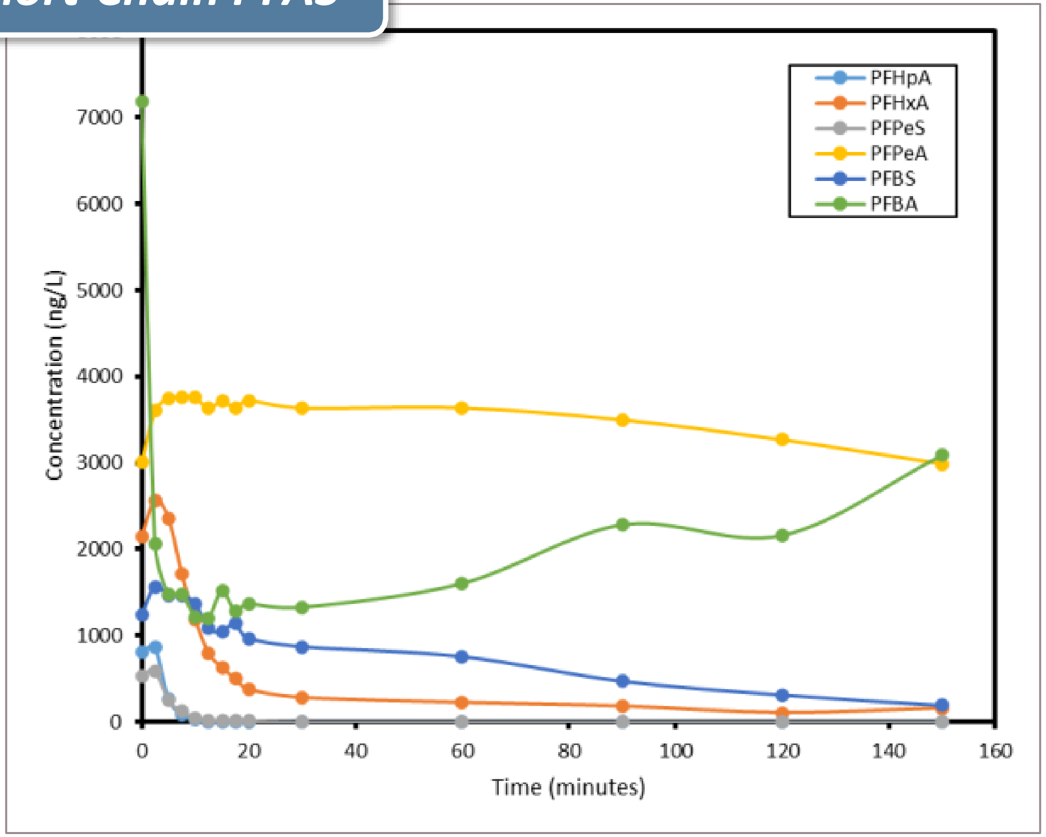




- Concentrations of all identified precursors and long-chain PFAS were below respective detection limits (2-7 ng/L) within 20 minutes; many within 5 minutes of treatment

Enhanced Contact Plasma: *Performance Results*

Short-Chain PFAS



- Short-chain PFAS removal varied from 57% to >99% within 150 minutes of treatment
- Sulfonates readily degrade over course of treatment while carboxylates exhibit greater treatment times
- Production of PFBA and slow decline of PFPeA can be attributed to the degradation of long-chain PFAS and unidentified precursors
- For the field demo, lower flowrates and/or multiple passes will be necessary to achieve short-chain PFAS removal

Key Points

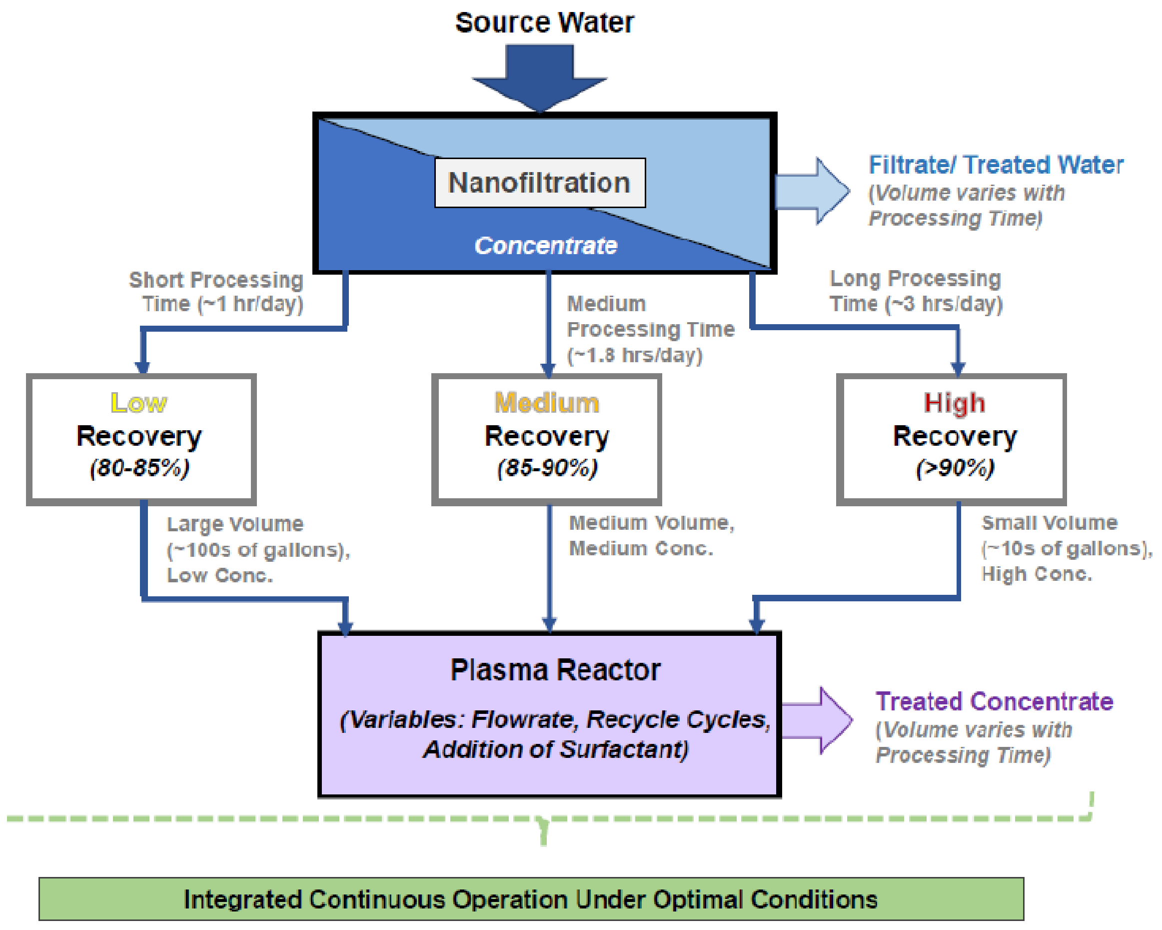
- Nanofiltration achieved up to 10x concentration of source water and 88->99% PFAS separation using closed circuit desalination
- Both membranes (NF90 and CR100) operated well with little to no reductions in permeability
- Plasma achieved complete removal of identified PFAS precursors and long-chain PFAS to below detection limits; longer treatment times required for short-chain PFAS

For the field demonstration…

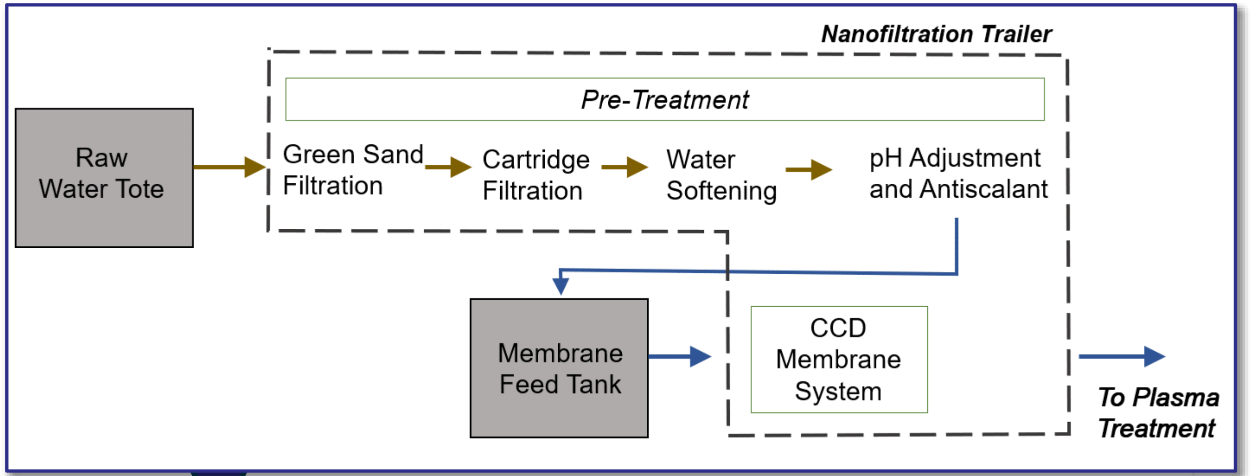
- Pretreatment required to manage water chemistry at the site
- Lower flowrates and/or multiple passes will be necessary to achieve short-chain PFAS removal

Next Steps: *Field Demonstration*

Experimental Plan



Trailer Modifications



Nanofiltration Trailer

Plasma Trailer

Acknowledgements

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Plasma Reactor Design & Operation

CDM Smith — Charles Schaefer
Electrochemical Oxidation Testing

QUESTIONS?

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Technical Resources

Nanofiltration

- Liu, C.J. et al. (2021). Rejection of Per- and Polyfluoroalkyl Substances (PFASs) in Aqueous Film Forming Foam by High-Pressure Membranes. Water Research, 188, 116546.

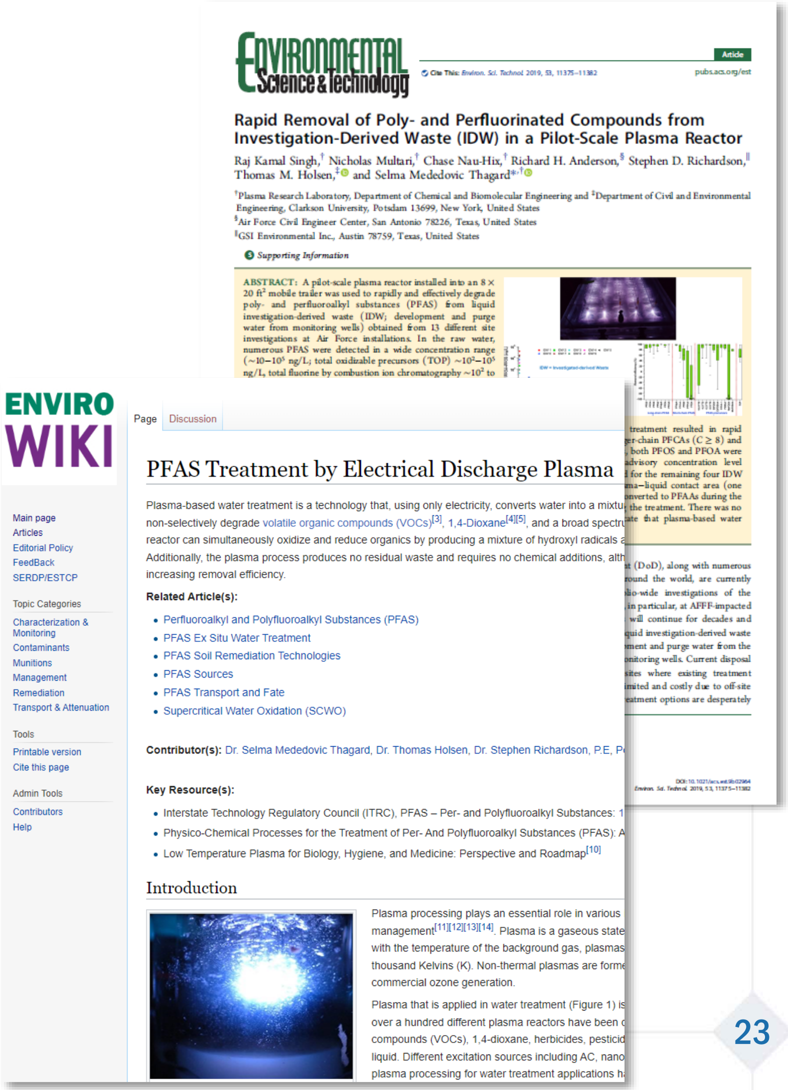
Enhanced Contact Plasma

- Nau-Hix, C. et al. (2021). Field Demonstration of a Pilot-Scale Plasma Reactor for the Rapid Removal of Poly- and Perfluoroalkyl Substances in Groundwater. Environmental Science & Technology: Water, 1(3), 680-687.

- Singh, R. K. et al. (2019). Rapid Removal of Poly- and Perfluorinated Compounds from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor. Environmental Science & Technology, 53(19), 11375–11382.

Electrochemical Oxidation

- Fang, Y. et al. (2022). Removal and destruction of perfluoroalkyl ether carboxylic acids (PFECAs) in an anion exchange resin and electrochemical oxidation treatment train. Water Research 230, 119522.



Next Steps:
Destructive Technology Comparison

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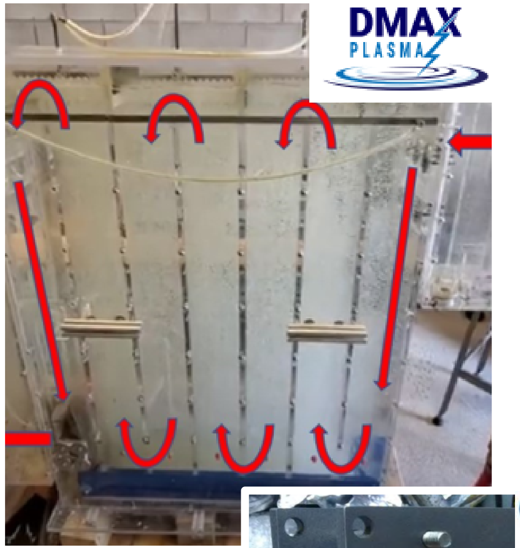
Objective

Direct comparison of two PFAS destructive technologies based on:

- PFAS removal efficiency
- Energy use & treatment cost ($/gal)

"Apples to Apples" Comparison

- Both technologies will use nanofiltration concentrate generated during the field demonstration.
- Technologies will be tested under similar controlled operating conditions.
- Key elements: i) assessing PFAS defluorination relative to the applied current density (mA/cm^2) and ii) verifying the longevity of the technologies.



Enhanced Contact Plasma:
Performance Results

- Concentrations of most PFAS in the CR100 permeate were below respective detection limits (Rejection = 1)
- Two exceptions: PFPeA and PFBA (Rejection = 0.96 and 0.88, respectively)

Pre-treatment:	**Post-treatment:**
ΣPFAS = 55.8 µg/L	ΣPFAS = 6.4 µg/L
TOPA = 24.2 µg/L	TOPA = 6.3 µg/L