Evaluating PFAS Removal and Destruction Technologies for Landfill Leachate - NERPCA

Christian Kassar & Will Walkup - Black & Veatch

October 23, 2025

Agenda

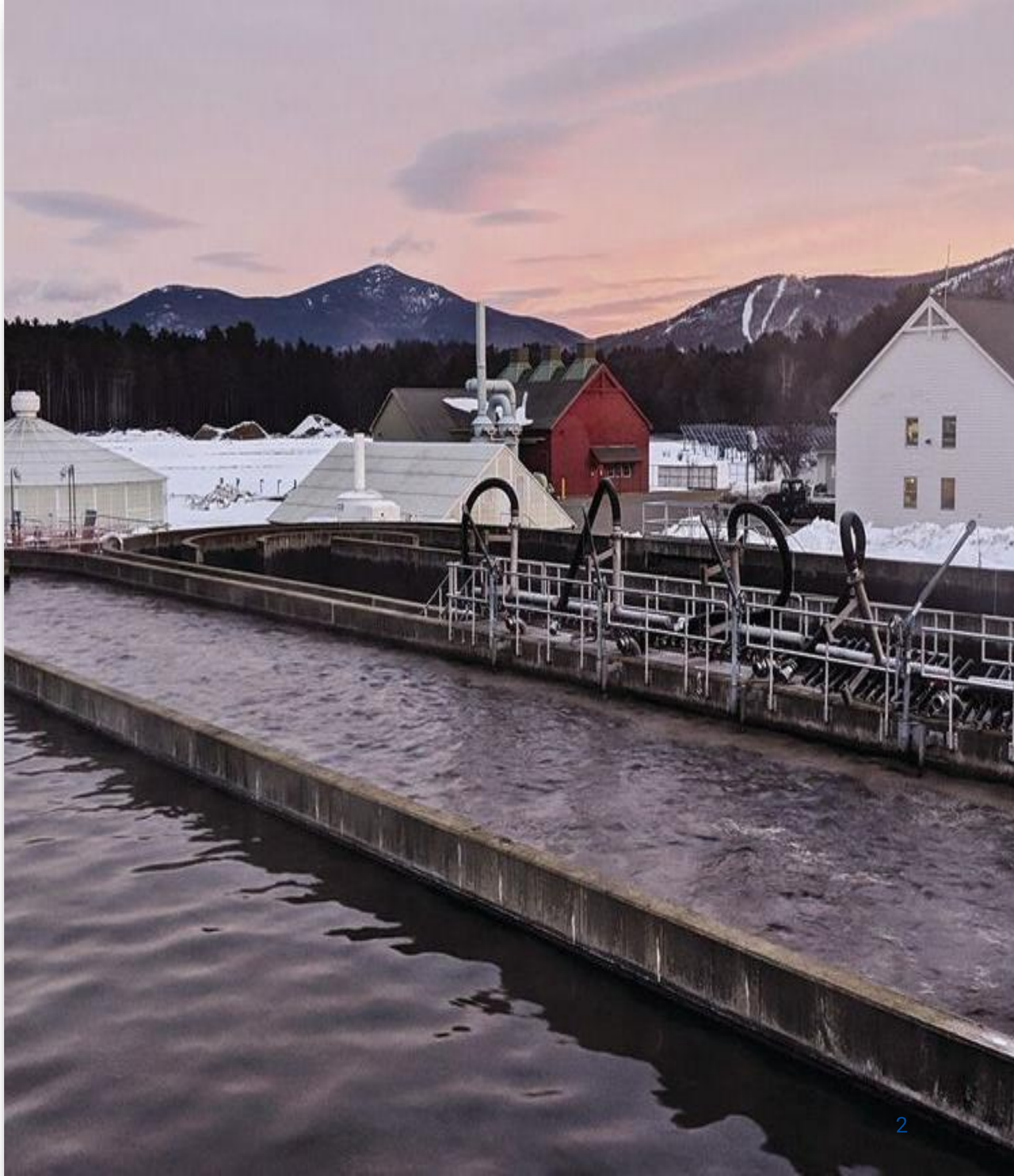
01 Project Overview

02 Leachate Characterization

03 PFAS Treatment Goals

04 Emerging Treatment Technologies

05 Conclusions



Project Overview

Project Overview

Task 2 – Preparation of Sampling Plan →

Task 3 – Leachate Sampling →

Task 4 – Data Analysis and Characterization →

Task 5 – Review PFAS Treatment Alternatives →

Task 6 – Pilot Testing →

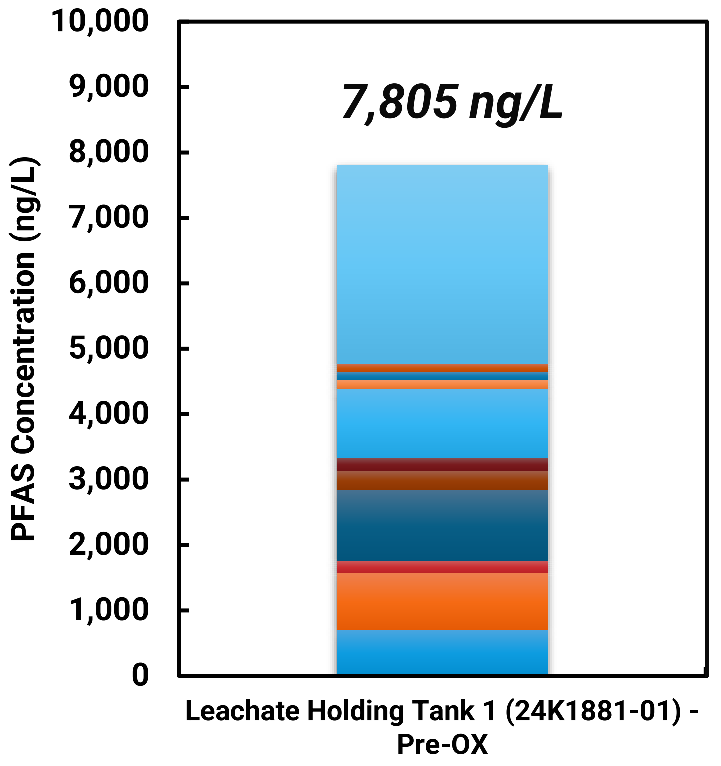
Task 7 – Siting Evaluation →

Task 8 – Conceptual Design Report/Presentation

WWTF Influent PFAS Load

Typical PFAS (US Landfills)
Low: 500-1,000 ppt, Avg.: 9,400-12,000
High: 93,100-120,000 ppt (or ng/L)

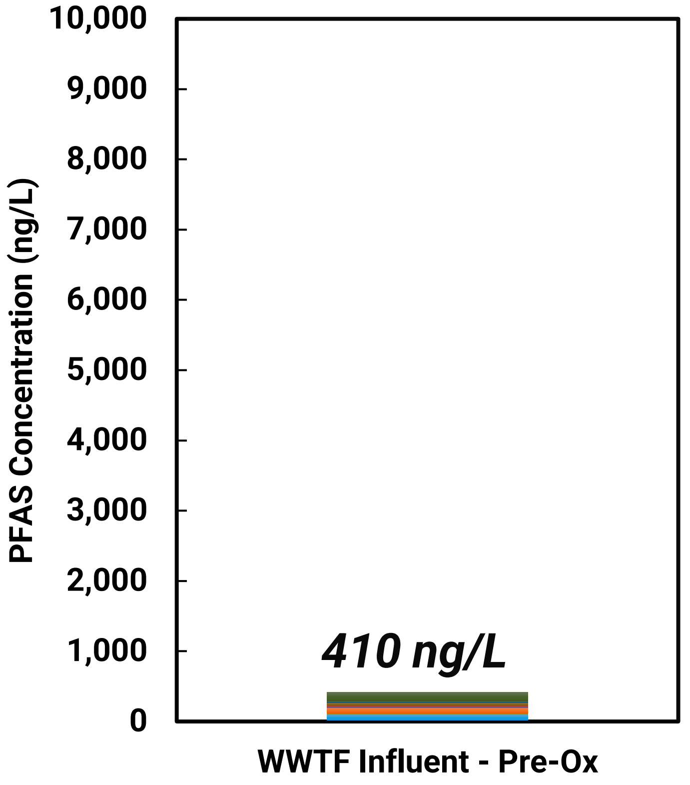
Landfill Leachate



60,000 GPD (0.06 MGD)

Impact on WWTF ~200 ng/L

WWTF Inluent



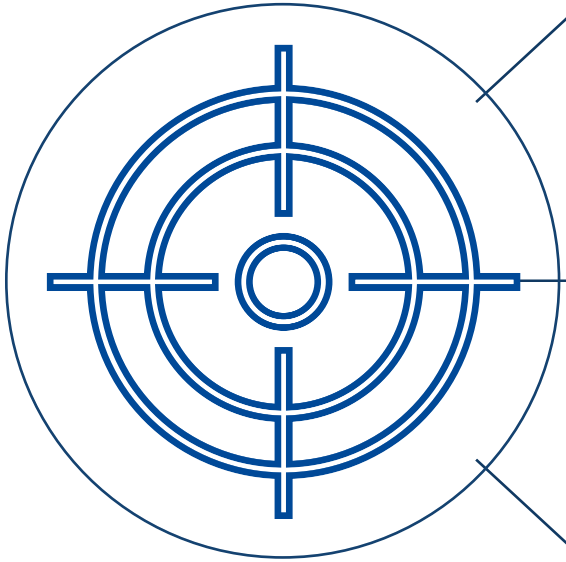
2.8 MGD

Dilute PFAS Concentrations

Targeting landfill leachate for treatment offers a practical opportunity to substantially reduce PFAS loading into the WWTF

Leachate Characterization and Treatment Goals

PFAS Treatment Goals



3 Highest Total PFAS Removal Possible

- Manage Short-chain Levels with more intense operational modifications
- Consider more stringent technology operation

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2 Balanced Total PFAS Removal

- Reasonable Operational Optimization (e.g., surfactant addition)
- Balance between removal and operational intensity

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1 Targeted PFAS Removal

- Long-chain PFAS removal
- Lowest CAPEX/OPEX

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Treatment Goals

Acronym	Target Conc. (ng/L; ppt)
PFHxS	9
PFOA	45
PFNA	ND
PFOS	15
PFDA	ND
8:2 FTS	132

Long Chain PFAS Removal	>95% (ND)
Total Removal	>80%

Leachate Water Quality

Parameter	Acronym	Unit	Influent
Iron	Fe	µg/L	7600
Alkalinity	Alk	mg/L	5550
Chemical Oxygen Demand	COD	mg/L	5220
Ammonia	NH3	mg-N/L	1420
Total Kjeldahl Nitrogen	TKN	mg/L	1550
Nitrate	NO_3^-	mg-N/L	Non-Detect
Sulfate	SO_4^{2-}	mg/L	8.1
Total Organic Carbon	TOC	mg/L	1340
Total Dissolved Solids	TDS	mg/L	13100
Total Suspended Solids	TSS	mg/L	80
Chloride	Cl^-	mg/L	6750
Volatiles	Total	µg/L	5.51
Benzene		µg/L	5.51
Toluene		µg/L	Non-Detect
Semivolatiles - BNA	Total	µg/L	384
Phenol		µg/L	384
Total Hardness		mg/L	558
Surfactants	MBAS	mg/L	1.01

WQ Takeaways

- High Organics
- High Solids
- High Metals
- High Alkalinity/Hardness

DW Best Available Technologies (BATs) - PFAS

Reverse Osmosis / Nanofiltration

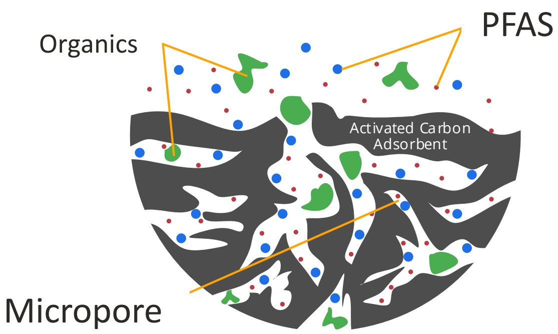
Removes a Wide Range of Contaminants + PFAS

Requires Substantial Pre-treatment

PFAS-Rich Brine Requiring Disposal

High Capital/O&M and Footprint

Granular Activated Carbon



Removes Organics Including PFAS

Extreme Changeout Frequency is Expected

High TOC and Metals Can Lead to Premature Breakthrough

Ion Exchange

Highly PFAS Selective

High Degree of Competing Anions (chlorides, sulfates, nitrates)

Changeout Likely Triggered by Rapid Fouling

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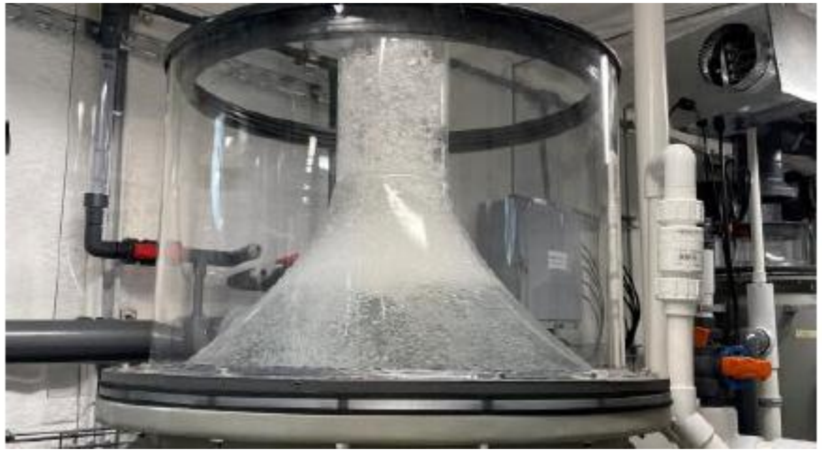
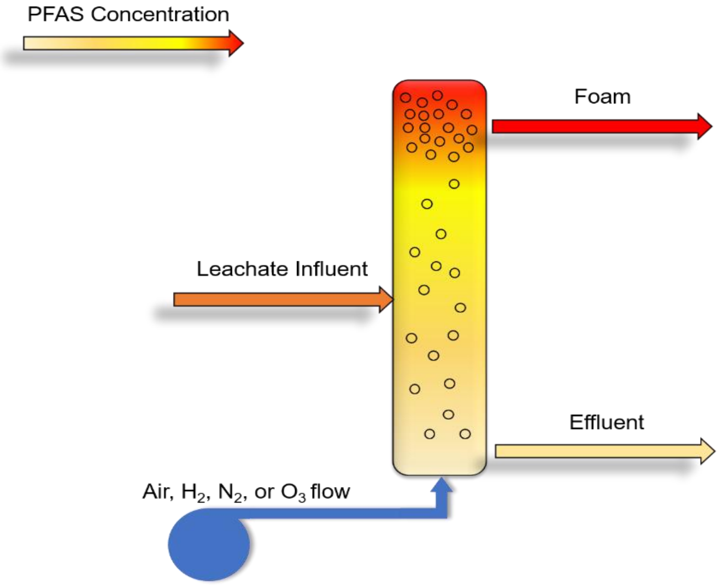
What technologies are we left with?

Foam Fractionation

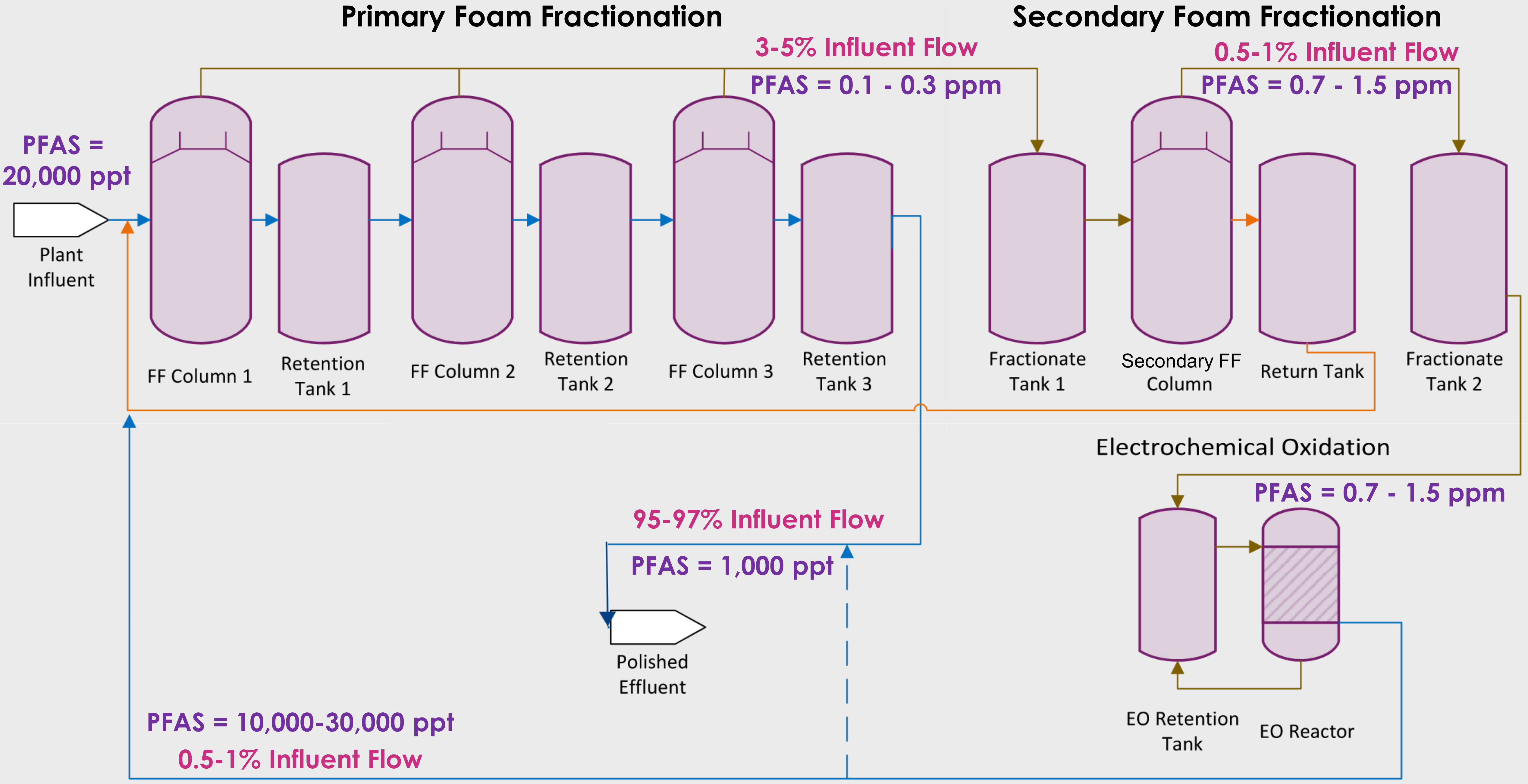


A Separation Technology that Completely Leverages Leachate WQ

- Selective for surface-active substances (e.g., PFAS, metallic ions, proteins)
- Reject stream up to 1,000X less than feed – by volume
- Additional surfactants (soap) may be added to enhance foaming



Pilot Process Flow Schematic



Foam Fractionation

Leachate Influent

Compound	Concentration (ng L^{-1})
PFOA	9,800
PFOS	300
PFNA	250
PFHxS	650
PFBS	13,000

Primary Foamate

Compound	Concentration factor
PFOA	18x
PFOS	17x
PFNA	18x
PFHxS	17x
PFBS	2x

Secondary Foamate

Compound	Concentration factor
PFOA	143x
PFOS	93x
PFNA	108x
PFHxS	129x
PFBS	2x

Disposal or Destruction

PFAS Concentration

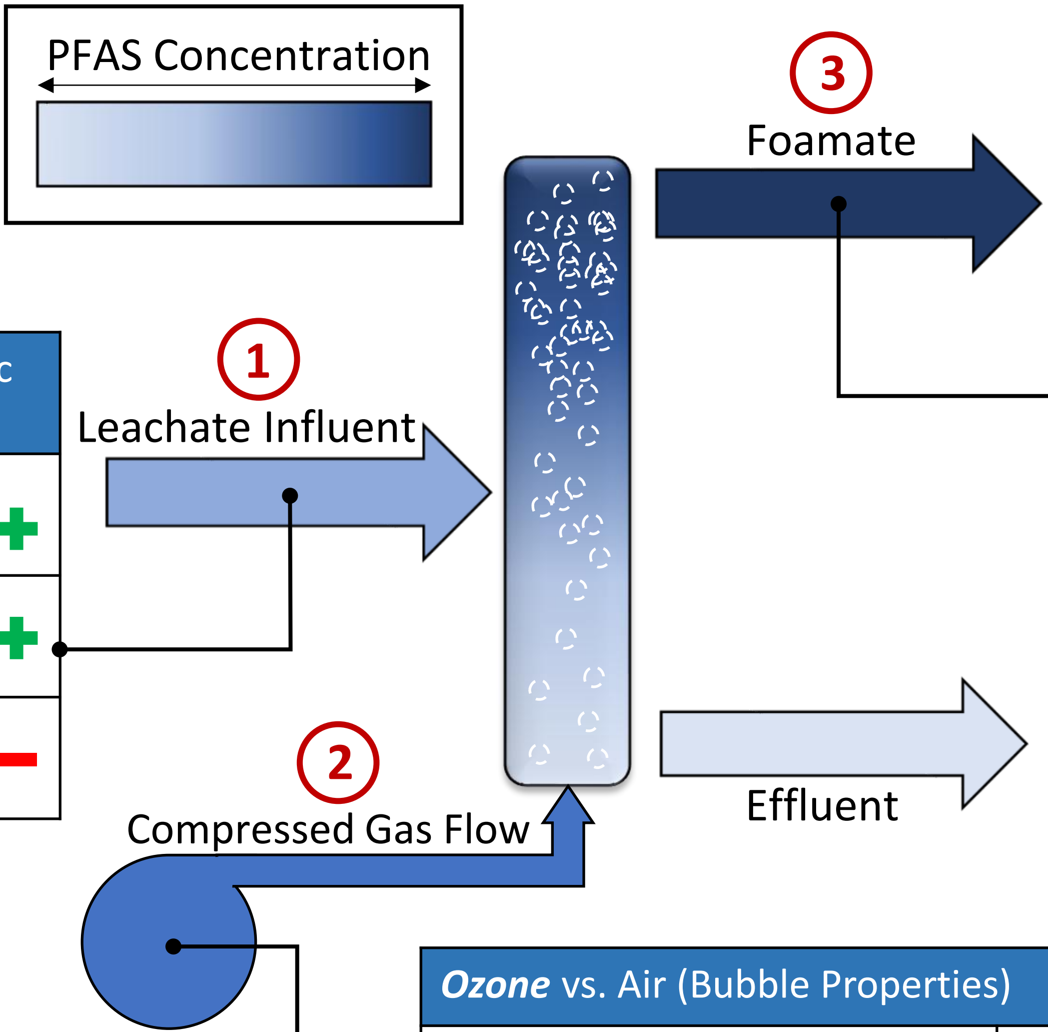
Effluent

Compound	Concentration (ng L^{-1})
PFOA	ND
PFOS	ND
PFNA	ND
PFHxS	ND
PFBS	12,000

Remove PFAS + reduce the volume

Polishing

FF Summary

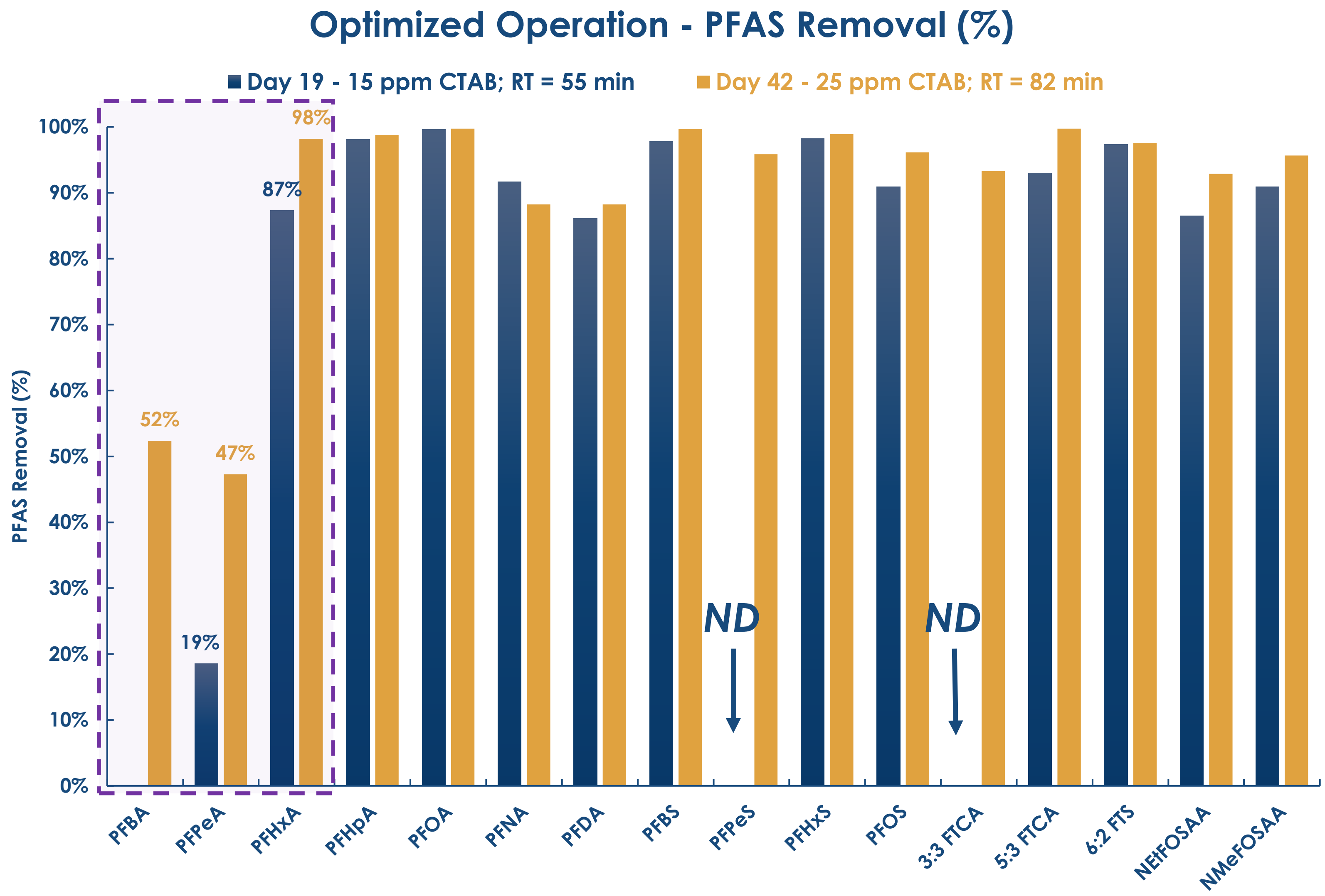


Addition vs. Absence of Cationic Surfactant (Co-Foaming Agent)	
Increased Foam Stability and Density	+
Bound to Anionic PFAS at Bubble Surface	+
Impact on Downstream Wastewater Treatability	−

Refoaming vs. Multistage (Reactor Configuration)	
Increased PFAS Concentration Factor	+
Reduced Foamate Volume	+
Additional Effluent Polishing May be Required	−

Ozone vs. Air (Bubble Properties)	
Enhanced PFAS Targeting	+
Increased Enrichment Factor (Degree of Foaming)	+
Safety and Cost Considerations	−

Foam Fractionation - Further Optimization



15 ppm CTAB; RT = 55 min

Long Chain Removal	96.3%
Short Chain Removal	71.9%
Total Removal	**83.5%**

25 ppm CTAB; RT = 82 min

Long Chain Removal	99.8%
Short Chain Removal	87.4%
Total Removal	**92.7%**

Summary Table - 60,000 GPD Facility - Lvl 5 estimate

	FF-1	FF-2	FF-3	FF-4
Total Project Cost Estimate	$6.8M to $8.3M			
Annual O&M Cost Estimate	$70K to $125K			
20-Year Life Cycle Cost	$8.4M to $9.2M			
Footprint	2,000 - 3,200 ft^2			
Concentration Factor	500X-4,000X			

Destruction Technologies

Electrooxidation

- Oxidation Pathway

1) **Indirect oxidation** (via Radical Reaction with oxidative species created from influent)
2) **Direct oxidation** (via Direct Electron Transfer after adsorption onto the anode surface)

- Generates byproducts including CO_2, SO_4^{2-}, and F^-

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Lead Release

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High Changeout Frequency

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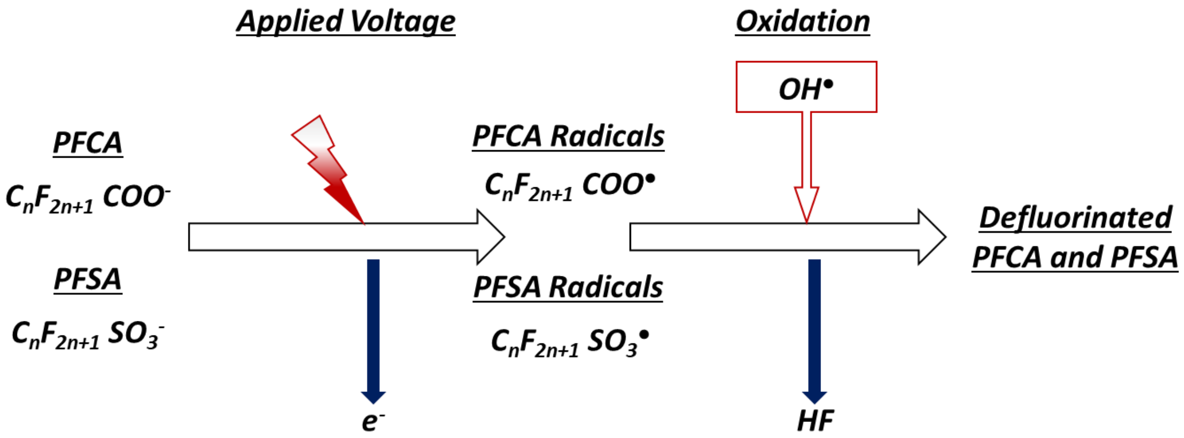
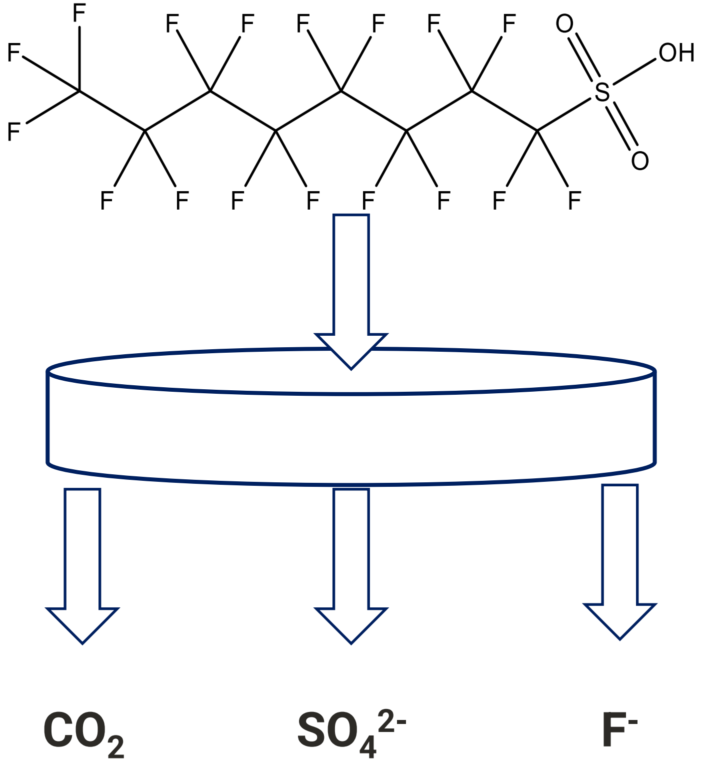
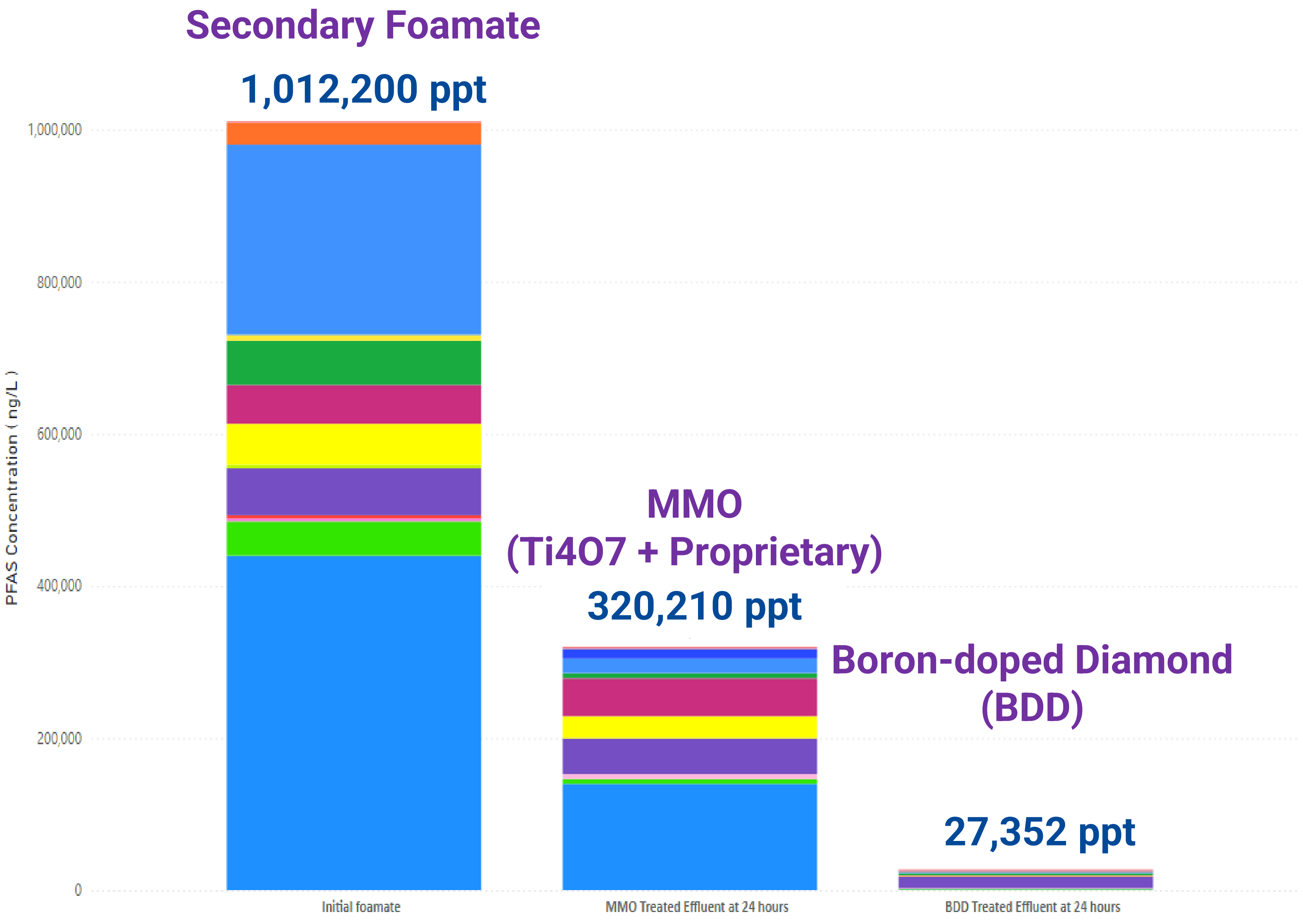
Long Service





Electrochemical Oxidation - Choice of Anode



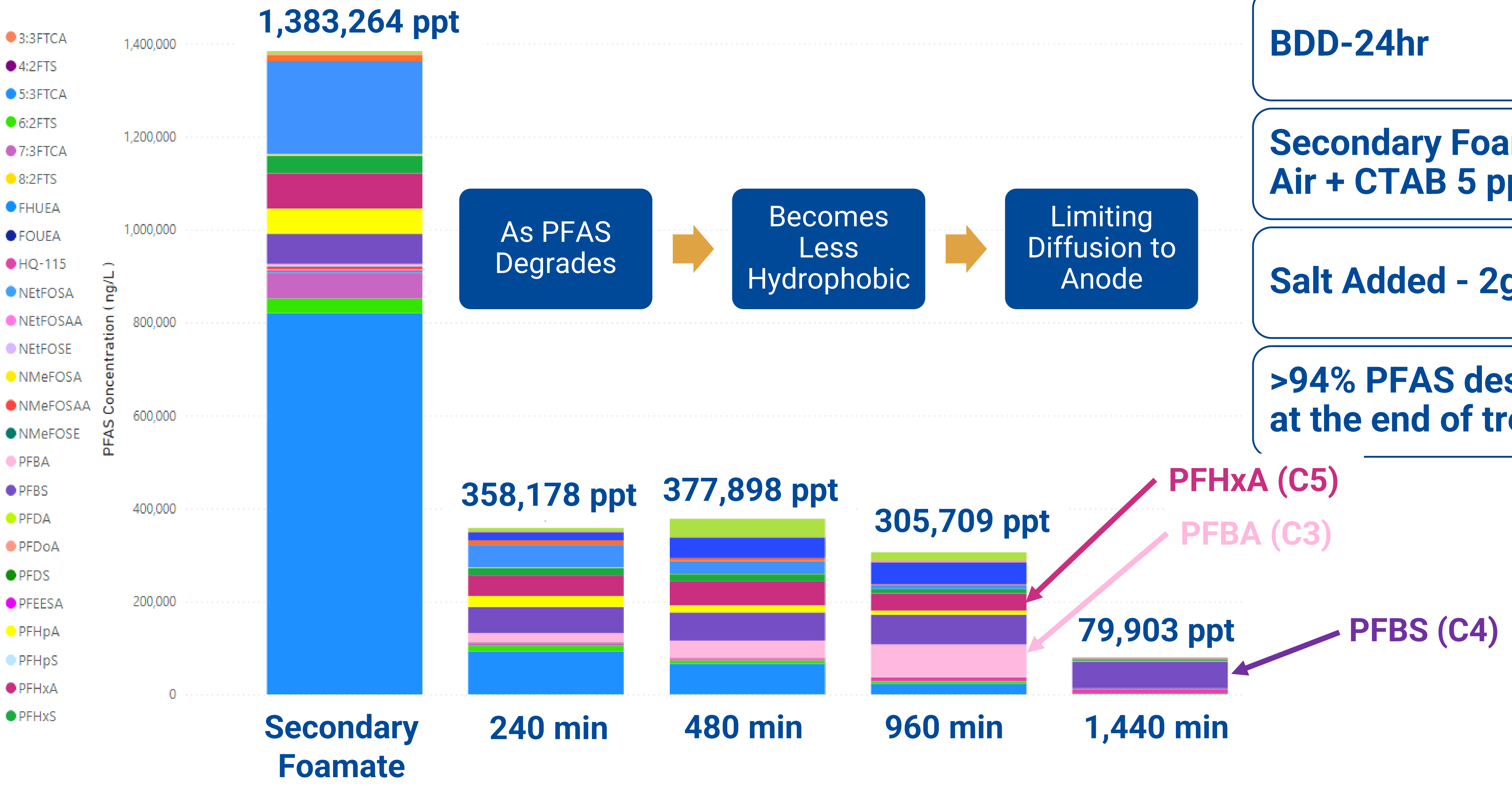
MMO and BDD Electrode

Secondary Foamate- Air+ CTAB 5 PPM

Salt Added - 2 g/L

97% Destruction for BBD and 69% destruction for MMO

Electrochemical Oxidation - BDD Kinetics



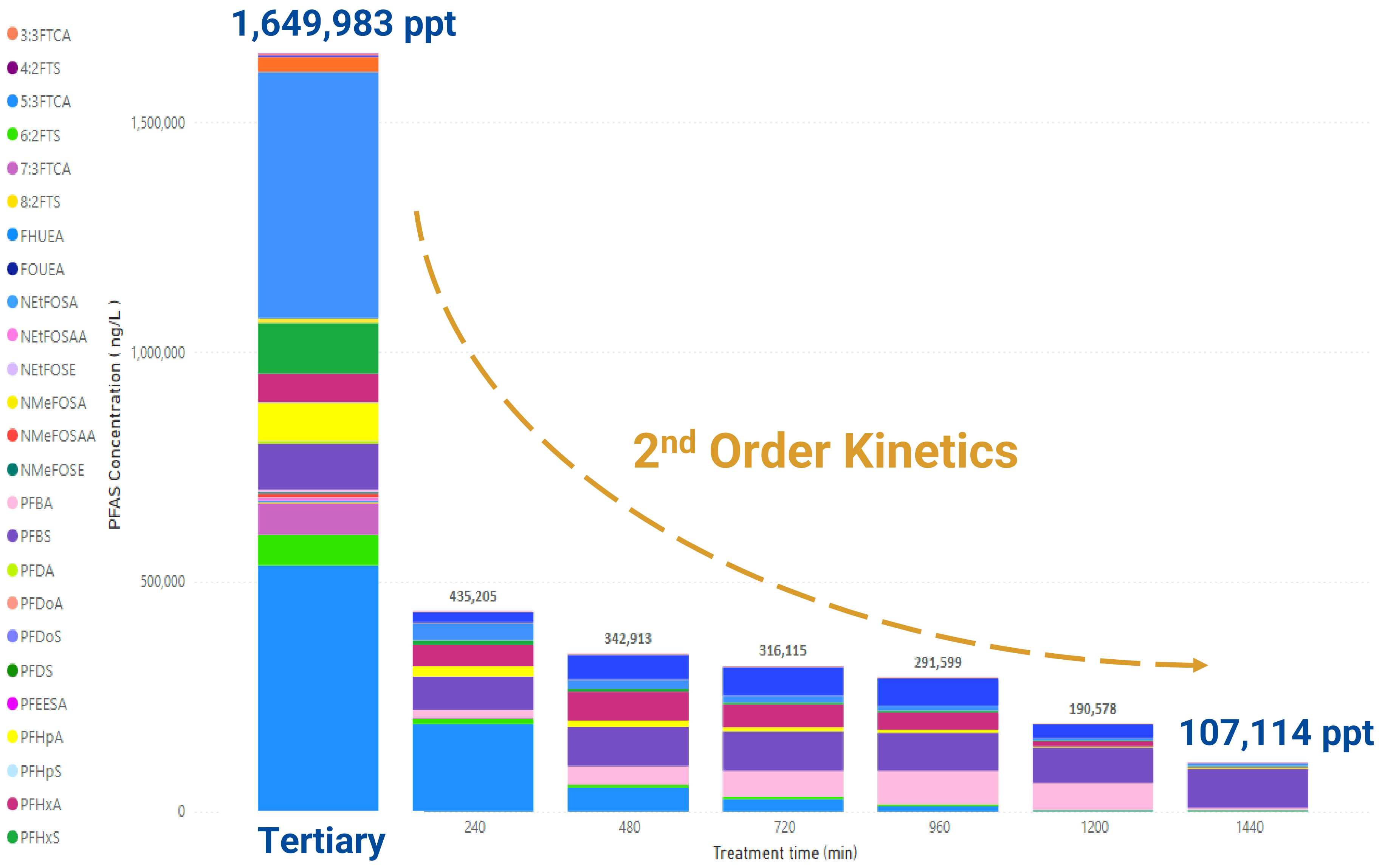
BDD-24hr

Secondary Foamate – Air + CTAB 5 ppm

Salt Added - 2g/L

>94% PFAS destruction at the end of treatment.

Electrochemical Oxidation - With Tertiary Foam Frac



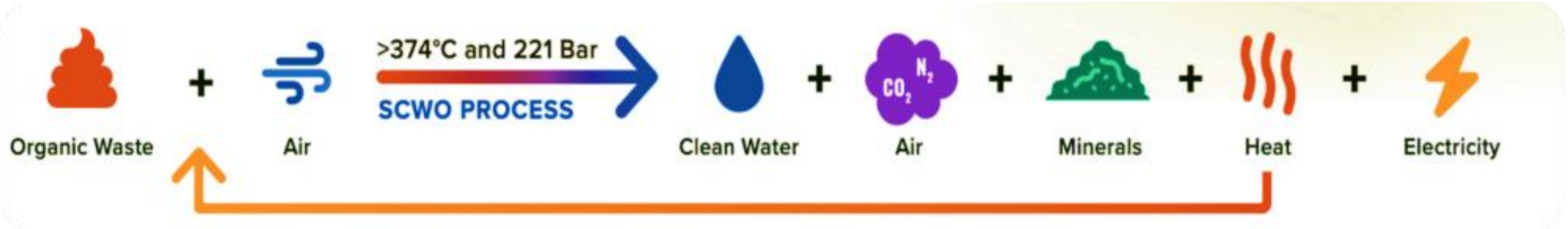
BDD-24hr

Tertiary Foamate – Air + CTAB 15 ppm

Salt Added - 2 g/L

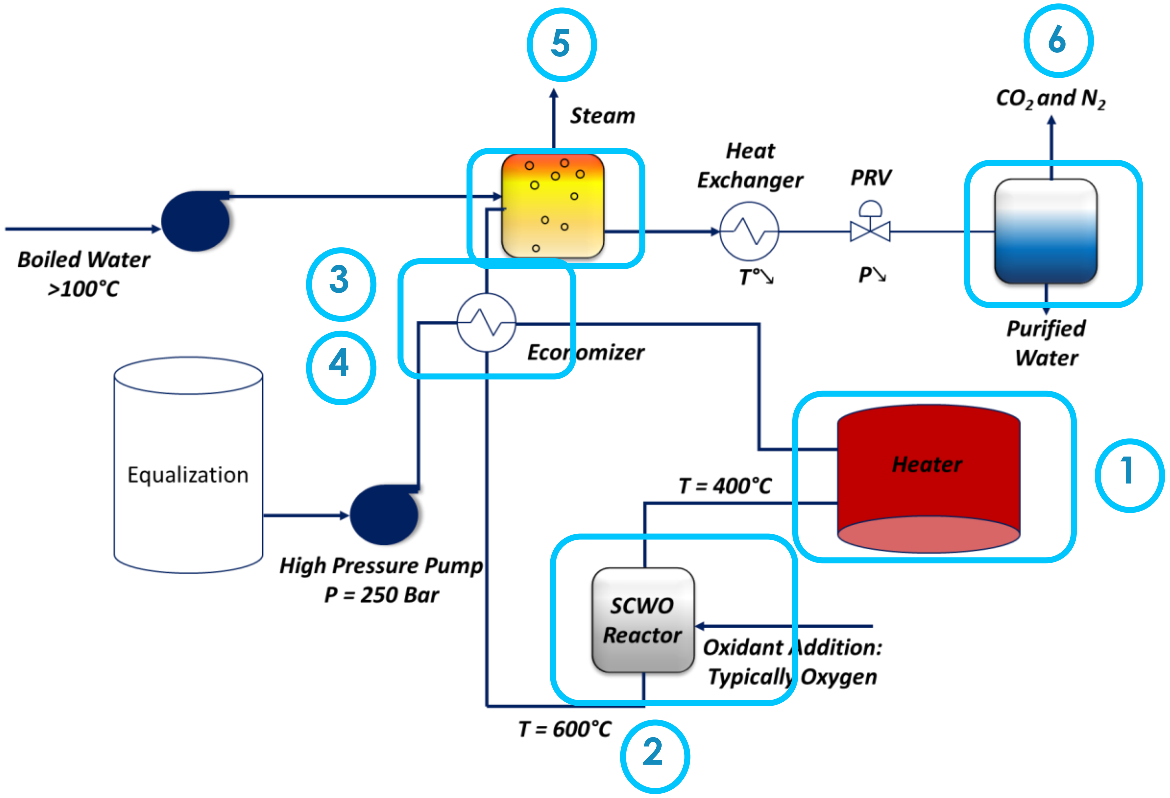
>90% PFAS destruction at the end of treatment.

Supercritical Water Oxidation (SCWO)



Non-selective Destruction

- **C-F bonds easily broken** – High temp Effective for oxidation with air only
- **Water as non-polar solvent** –becomes a dense single phase with properties like those of a gas and solvent properties like those of a non-polar solvent.
- **Oxygen is entirely soluble** in supercritical water, enabling the rapid oxidation of organics, including PFAS compounds



Supercritical Water Oxidation (SCWO) - Performance

PFAS	Influent1	SCWO-1	Influent2	SCWO-2
PFBA	**7,750**	**ND**	**5,100**	**ND**
PFPeA	**5,750**	**ND**	**3,600**	**ND**
PFHxA	**15,500**	**ND**	**12,000**	**ND**
PFHpA	**2,100**	**ND**	**1,600**	**ND**
PFOA	**11,000**	**ND**	**8,200**	**ND**
PFNA	**280**	**ND**	**190**	**ND**
PFDA	**385**	**ND**	**270**	**ND**
PFUnA	<50	ND	<50	ND
PFDoA	<50	ND	<50	ND
PFTrDA	<50	ND	<50	ND
PFTeDA	<50	ND	<50	ND
PFBS	**14,500**	**ND**	**11,000**	**ND**
PFPeS	**89**	**ND**	**<50**	**ND**
PFHxS	**665**	**ND**	**550**	**ND**
PFHpS	<50	ND	<50	ND
PFOS	**335**	**ND**	**940**	**ND**
PFNS	<50	ND	<50	ND
PFDS	<50	ND	<50	ND
PFDoS	<50	ND	<50	ND
HFPO-DA (GenX)	<200	ND	<200	ND

Both SCWO influents were reduced to **ND levels**

Short residence times ranged between 10-17 seconds (**bench-test**)

Short-chain compounds were completely mineralized with both technologies

If foamate were to be used, **higher residence times** required

IPA (4-6% to meet 160-200 g/L COD)

10-50 g/L Na2CO3 to help prevent HF formation

Hydrothermal Alkaline Treatment

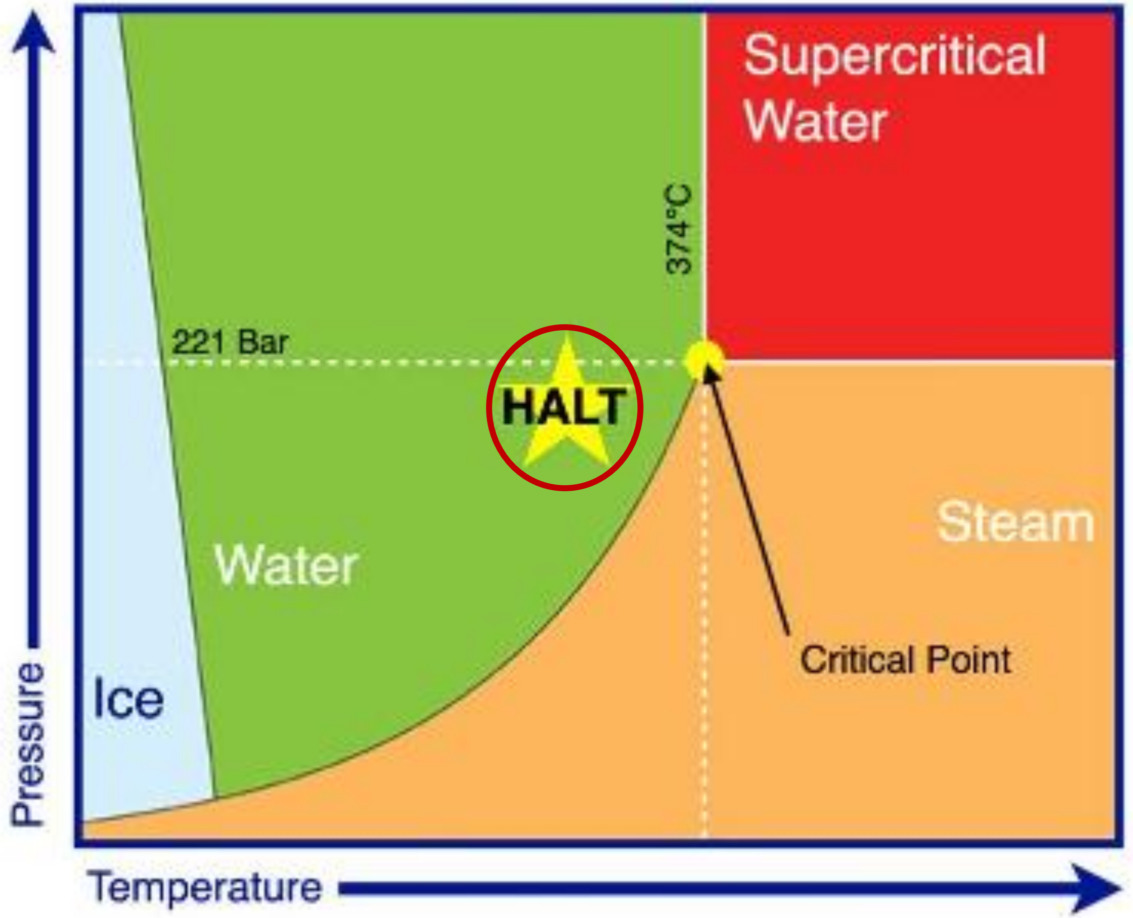
SCWO but at Lower Temps and Pressures

- Subcritical <374˚C
- Salts Remain Soluble
- NaOH Additive
- Slower Kinetics

Colt
1 gph
Available

Steed
5-10 gph
Deployed

Stampede
60 gph
Expected in Early 2027

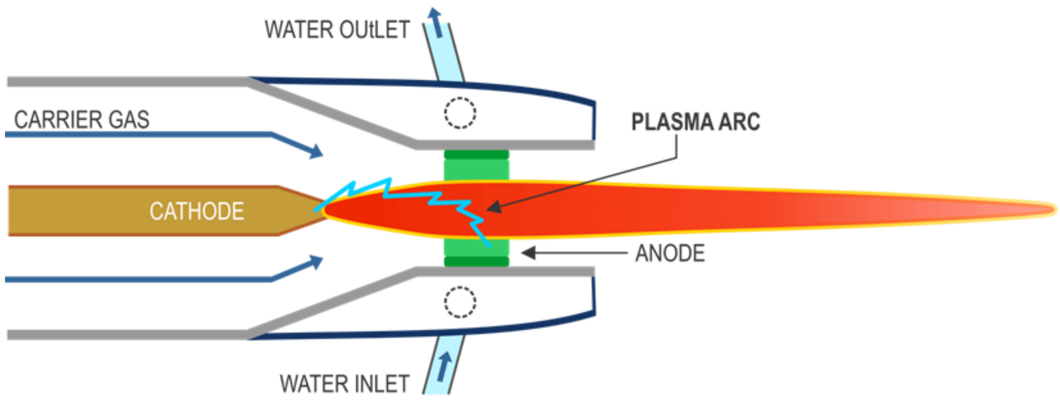


HALT operates at subcritical conditions, eliminating complexities associated with containing supercritical water

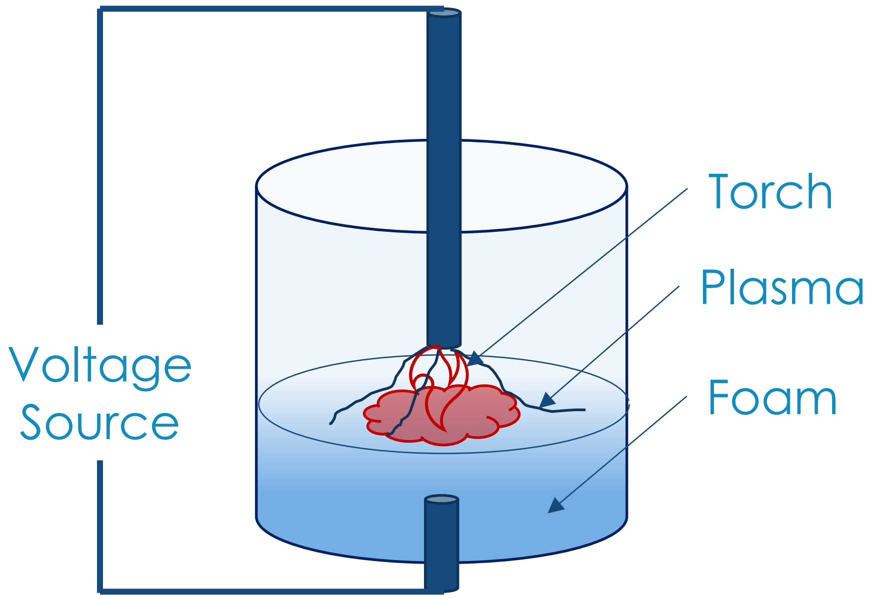
Plasma Treatment

Surface Degradation

- High Electrical Potential to form Plasma
- Utilizes Argon gas (**Traditional Plasma**) or Steam (**Thermal Plasma**)
- In addition to oxidation, involvement of reductive species (hot aqueous e^{-})
- Addition of heat/torch enhances kinetics (>3500˚F)



PLASMA TORCH SCHEMATIC



Destruction Technology Review

Technology	Life Cycle Cost	Footprint	Performance Expectation	Capacity	Tech Maturity	Operational Complexity
Electrooxidation (EO)	5	4	3	5	4	4
SCWO	1	2	5	2	4	2
HALT	2	3	4	3	3	3
Plasma	3	4	4	4	2	2
	EO	*EO/Plasma*	*SCWO*	*EO*	*EO/SCWO*	*EO*

Summary Table - 60,000 GPD Facility - Lvl 5 estimate

	EO-1	EO-2	SCWO-1	SCWO-2
20-Year Life Cycle Cost	$6.6M - $7.6M		$25M - $27.5M	
Footprint	1500 - 1850 ft^2		~10,000 ft^2	
Max Flow (gpd)	500 - 600 gpd		600 gpd	
Treatment Efficiency	Meeting Enforceable PFAS Targets Only		Non-Detect	

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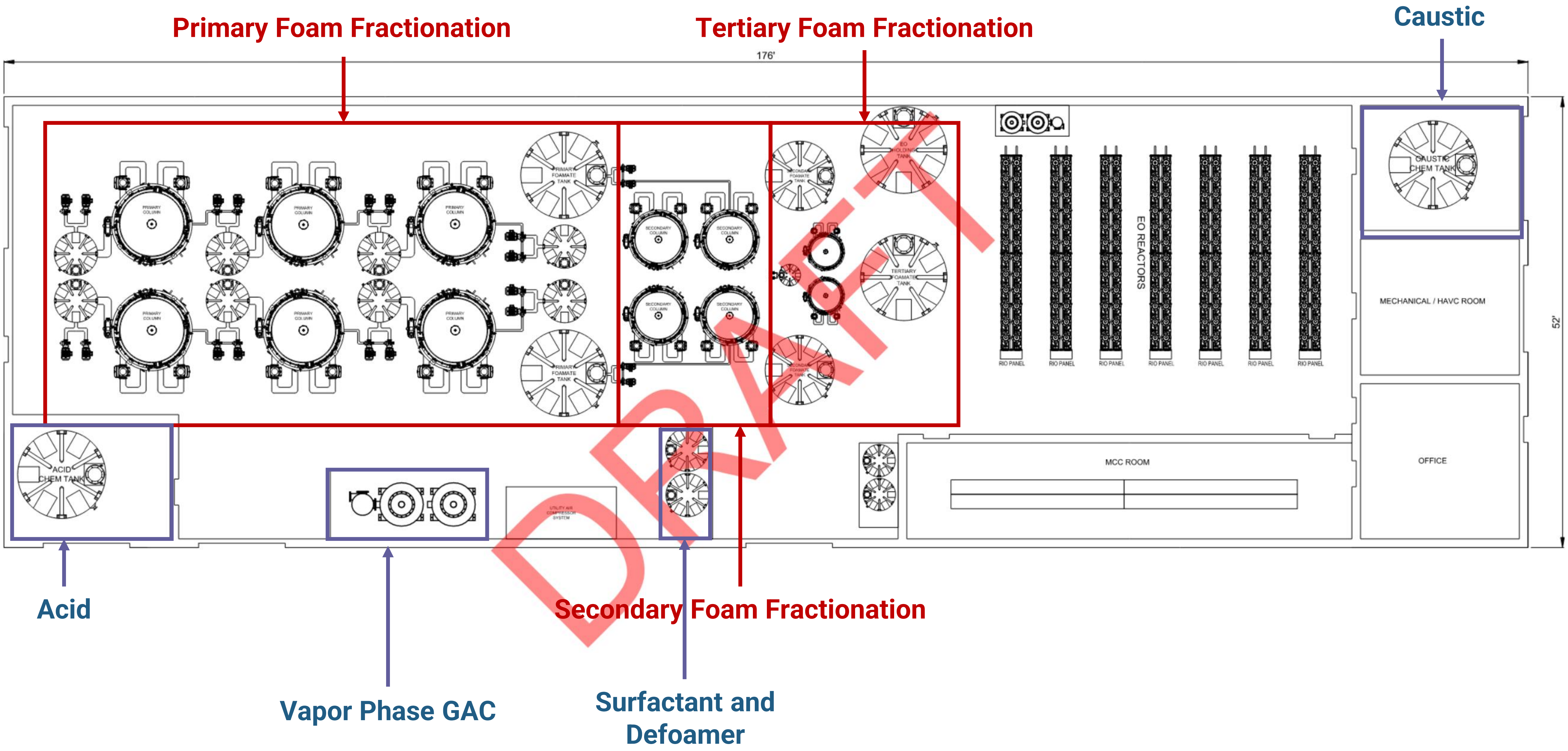
What to Expect at Full-scale?

Foam Fractionation Layout - 0.5 MGD



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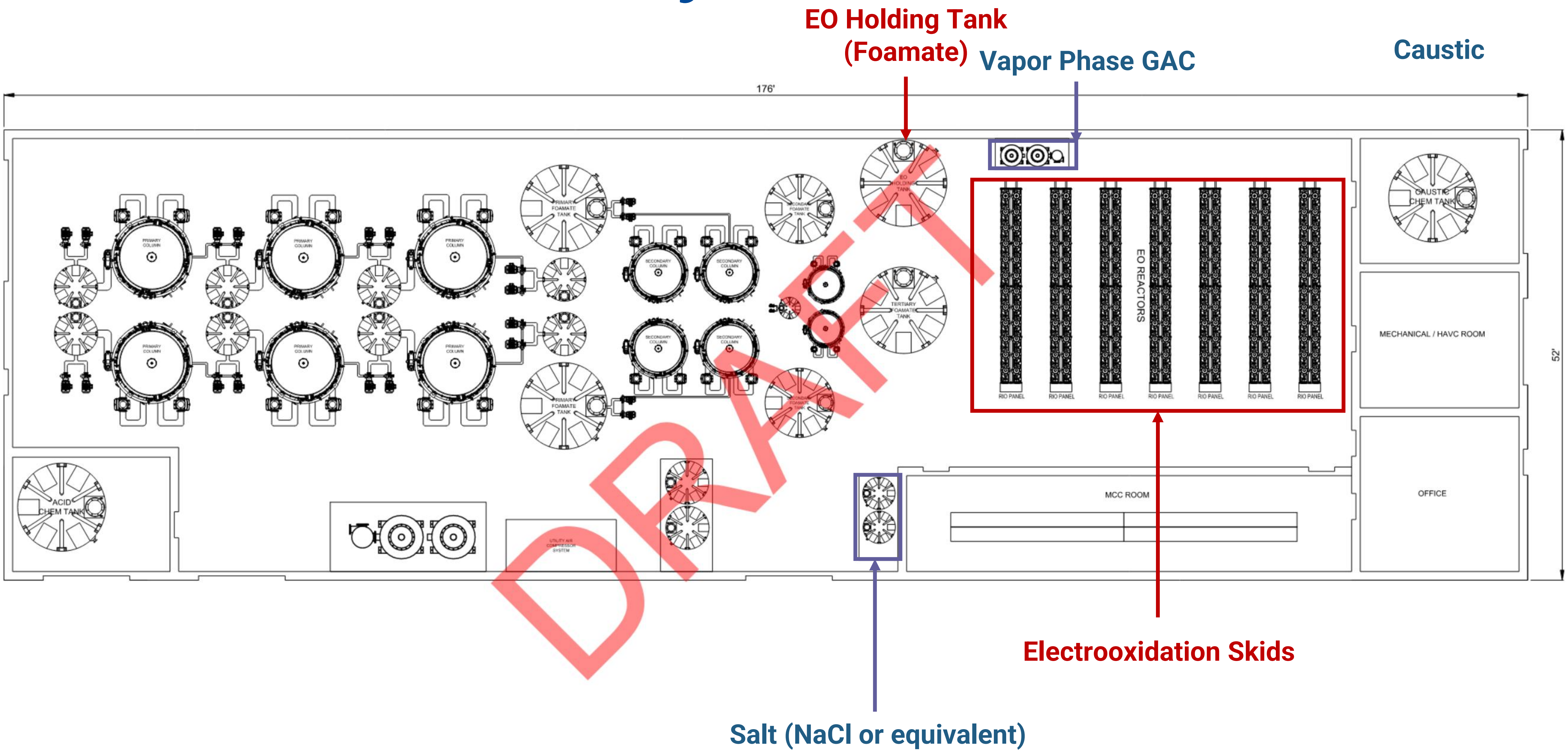

Conclusions

Landfill leachate is a **major source of PFAS** entering the WWTF; **pre-treating leachate** is an effective way to **reduce PFAS loadings**.

Drinking Water PFAS BATs require **robust pre-treatment** for successful implementation.

Foam Fractionation is highly **selective for long-chain PFAS** and **works well with strong matrices** (“dirty” streams).

Site-specific alternatives evaluation is recommended for **destruction technologies** (e.g., SCWO, EO) due to their **emerging nature**

Bench and pilot testing are strongly **recommended** to validate technology performance

If budget allows, **pilot multiple technologies** to inform **multi-vendor procurement** and **design decisions**.

Foam Fractionation “Concentrates PFAS”; SCWO “Destroys all Organics”; EO “Operator Friendly”

Discussion

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Thank You

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Review

PFAS in landfill leachate: Practical considerations for treatment and characterization

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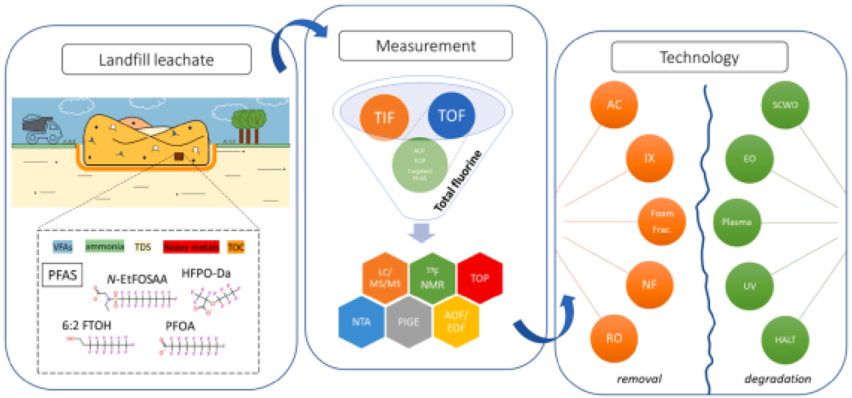
HIGHLIGHTS

- PFAS speciation in leachate is dominated by mobile short-chain PFAS.
- Analytical techniques should be combined for complete leachate characterization.
- Foam fractionation optimization is beneficial for downstream destruction.
- Emerging destruction technologies show promising results but need further research.
- Treatment trains should be adaptable to varying flow and leachate characteristics.

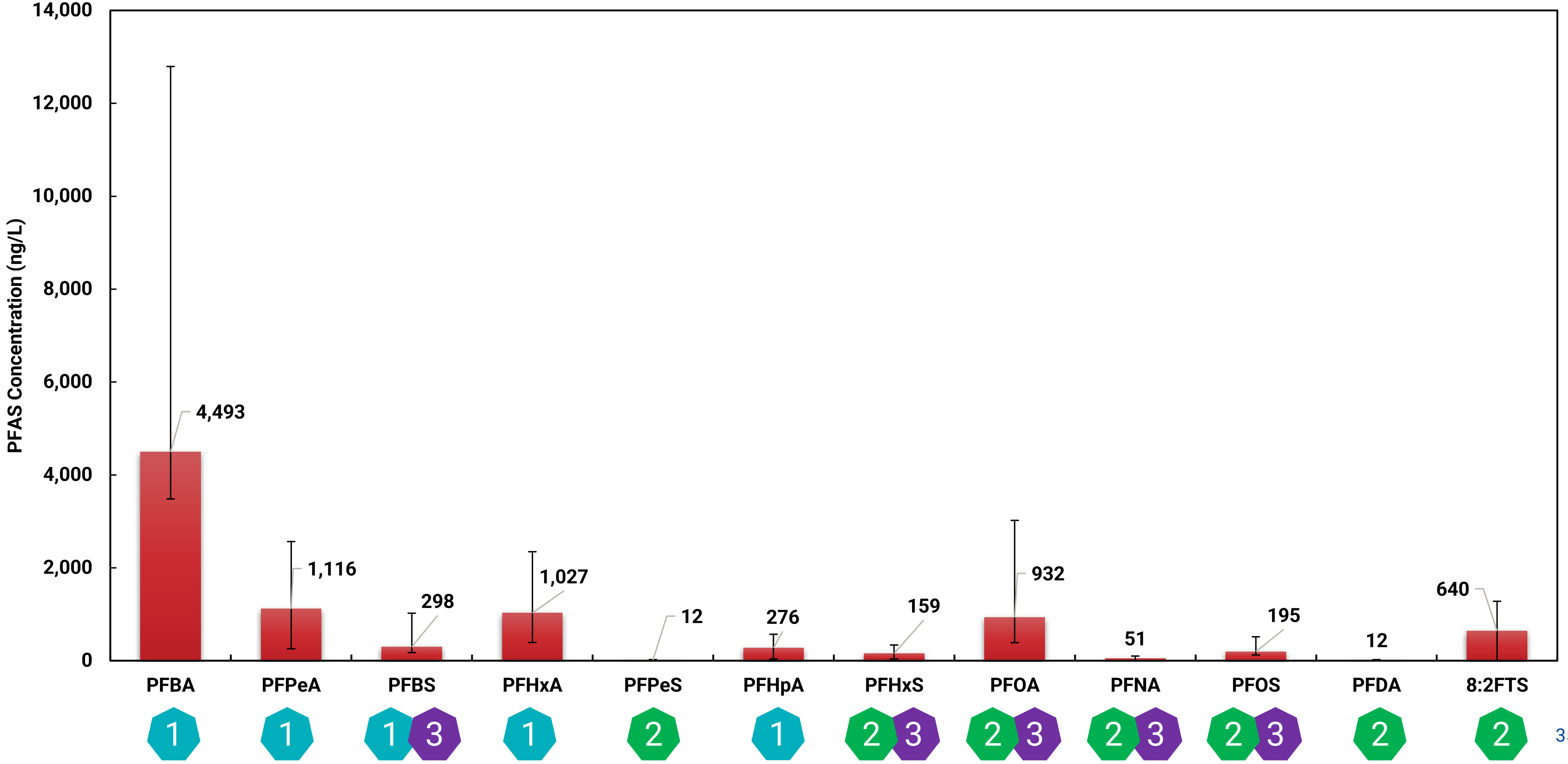
GRAPHICAL ABSTRACT



PFAS Characterization

- 1 **Short-chain PFAS:** typically, more abundant, harder to remove, but lower health concern (higher thresholds)
- 2 **Long-chain PFAS:** easier to remove, but typically stricter regulations (e.g., drinking water)
- 3 **DW Regulated PFAS:** Five of the 6 Regulated PFAS Compounds detected

PFAS Characterization in Leachate - Summary Results



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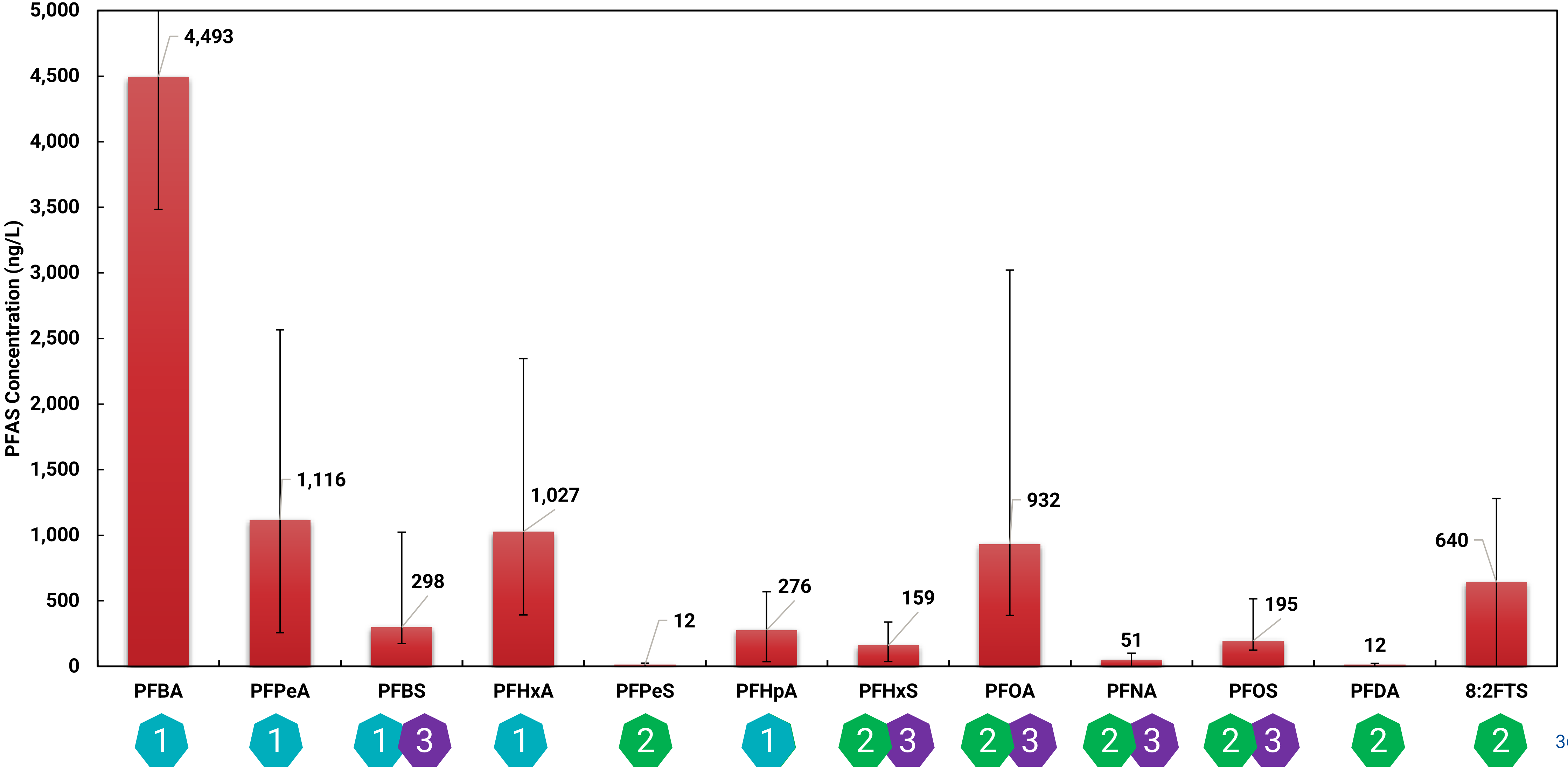
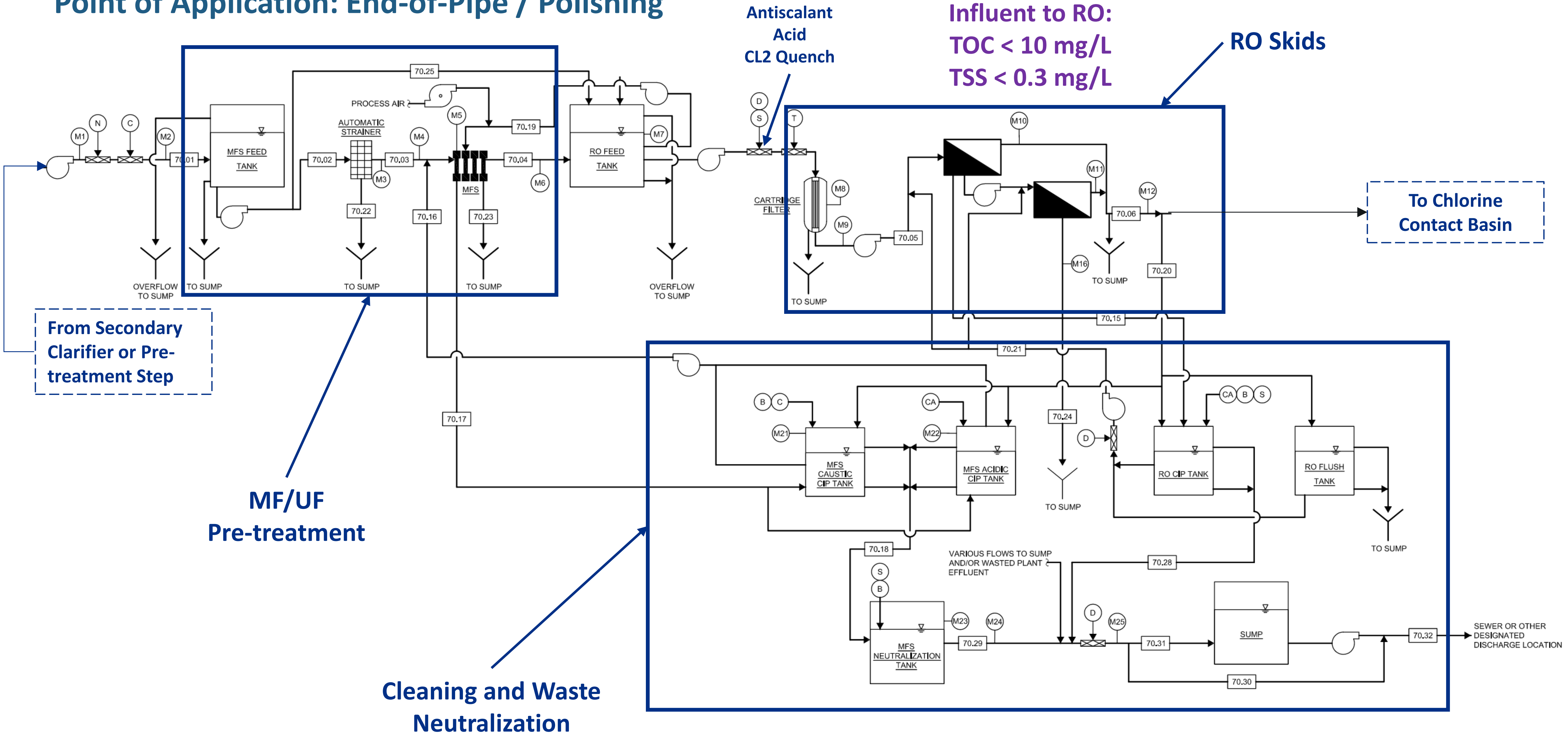


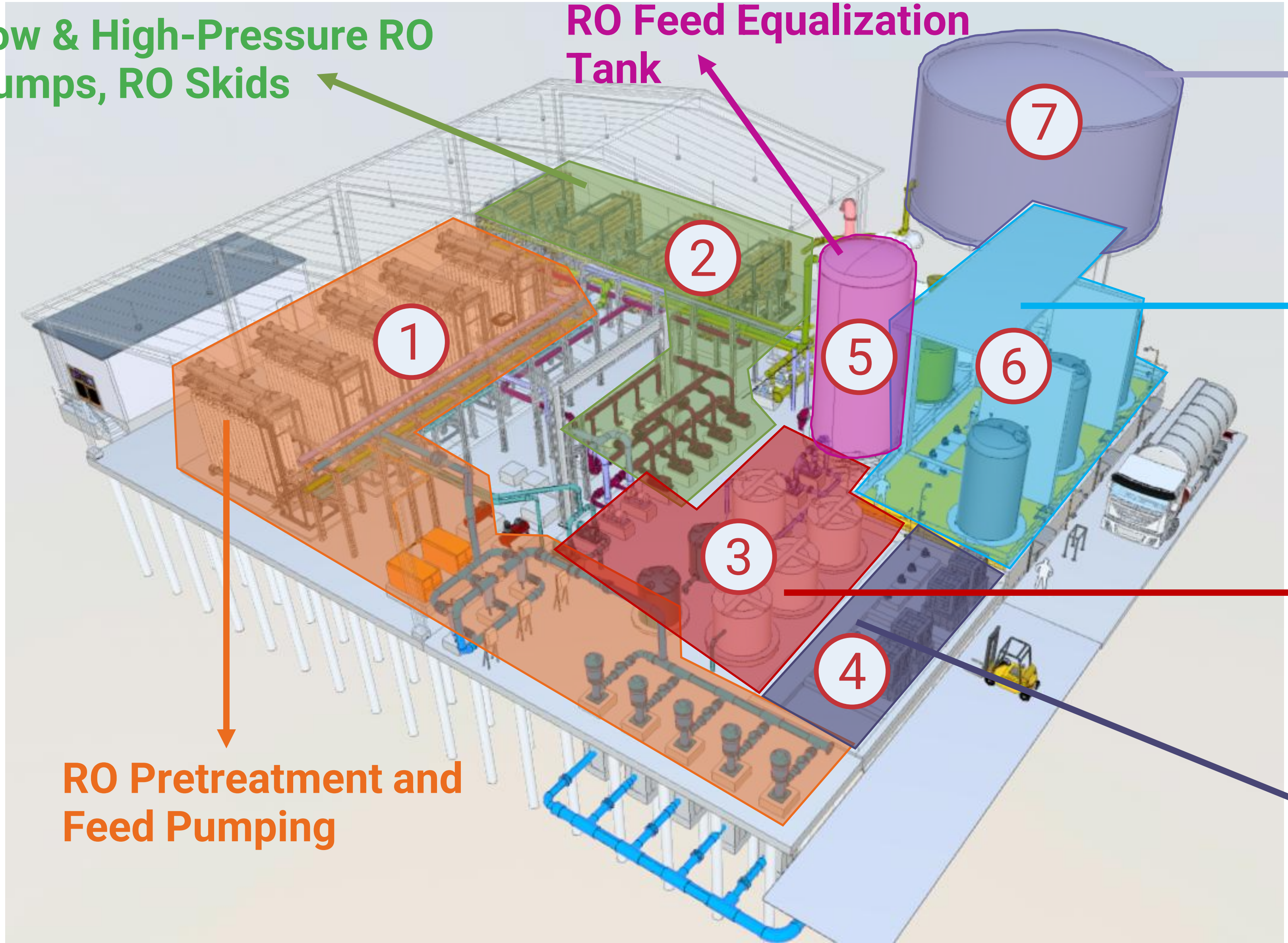
Reverse Osmosis (RO)/Nanofiltration (NF) - PFD

Point of Application: End-of-Pipe / Polishing



Reverse Osmosis (RO)/Nanofiltration (NF) - PFD

8 MGD AWP Facility, AZ



Low & High-Pressure RO Pumps, RO Skids

RO Feed Equalization Tank

RO Permeate Storage Tank (+ Permeate Transfer Pumping)

Process Chemicals

- Sodium Hydroxide
- Sulfuric Acid
- Liquid Ammonium Sulfate
- Antiscalant
- Sodium Hypochlorite

MF & RO CIP Tanks and Pumps

RO Pretreatment and Feed Pumping

MF & RO CIP Chemical Feed & Storage

Summary Table - 60,000 GPD Facility - Lvl 5 estimate

	FF-1	FF-2	FF-3	FF-4
Total Project Cost Estimate	**$6.8M to $8.3M**			
Annual O&M Cost Estimate	**$70K to $125K**			
20-Year Life Cycle Cost	**$8.4M to $9.2M**			
Footprint	50’x20’	20’x40’ (40’x80’)	40’X8’ (40’ X 32’)	20’x40’ (40’x80’)
Max Flow (gpm)	110	42	80	42
Concentration Factor	600X-4,000X	500X-1,000X	500X-1,000X	200X-1,000X

Available Destruction Technologies

Electrochemical Oxidation

axine WATER TECHNOLOGIES

Aclarity

e2metrix

LUMMUS TECHNOLOGY

Supercritical Water Oxidation

Aquarden TECHNOLOGIES

Because Water Is Supercritical.

374WATER

RENEW. RESTORE.

Revive environmental

Hydrothermal Alkaline Treatment

Aquagga

Plasma Treatment

SYNERGENMET

ONVECTOR

UV-Based Treatment

Claros Technologies

ecoSPEARS

INNOVATION THAT CLEANS THE WORLD

ENSPIRED SOLUTIONS

Conventional Water Quality