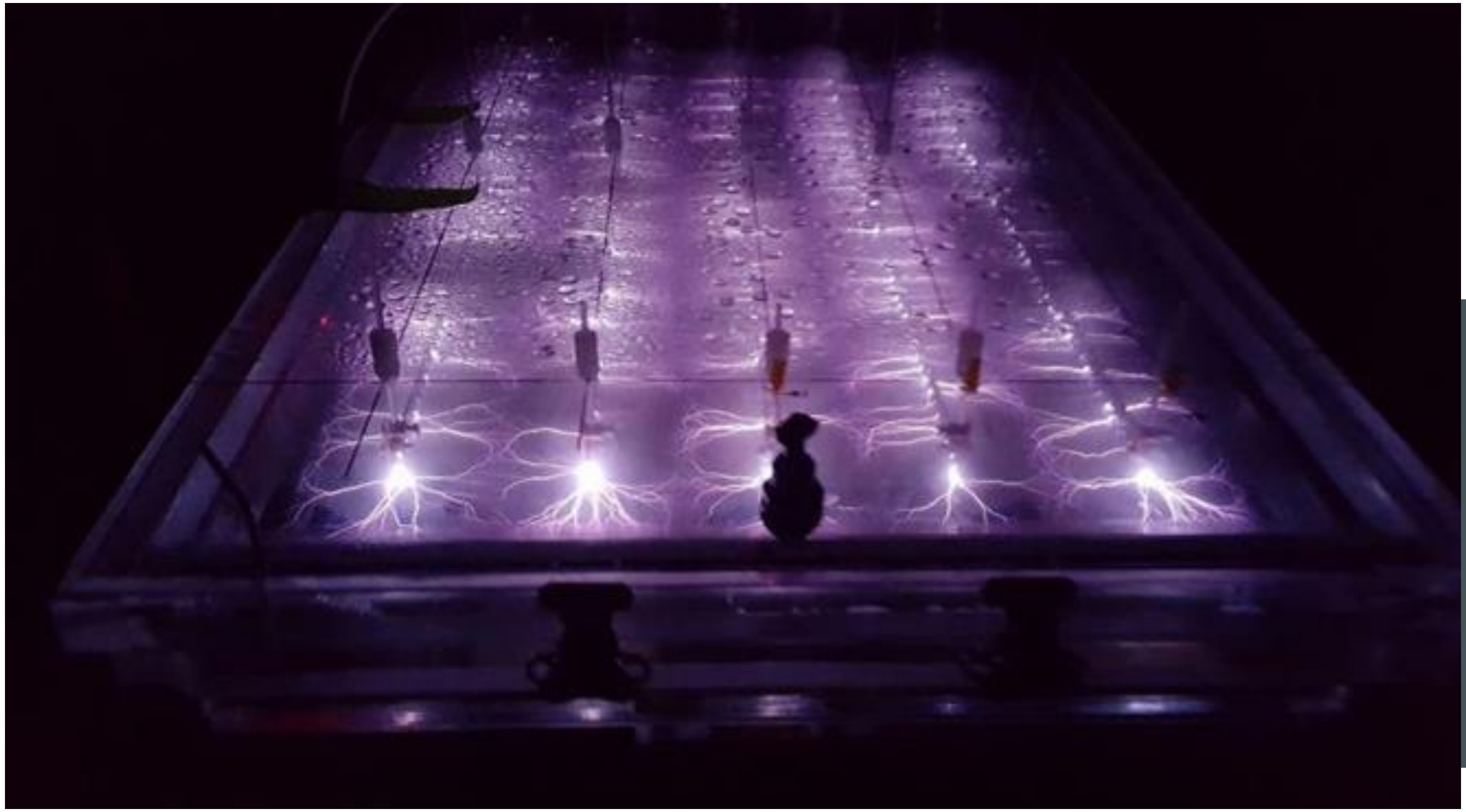
FIELD DEMONSTRATIONS OF ENHANCED CONTACT PLASMA FOR PFAS DESTRUCTION: LESSONS LEARNED



CHASE NAU-HIX

CLARKSON UNIVERSITY

DMAX PLASMA, INC

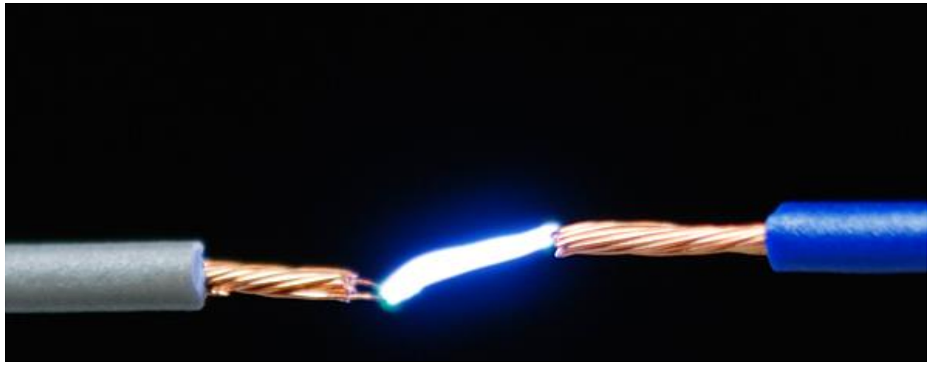
OVERVIEW

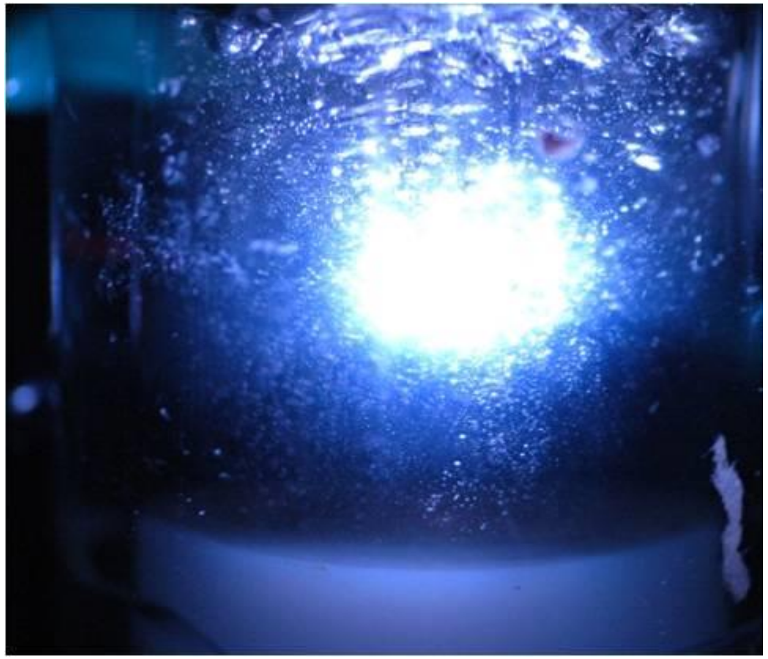
- PLASMA AND PLASMA DESTRUCTION
- FIELD SCALE TREATMENT RESULTS
- CONCLUSIONS AND LESSONS LEARNED

PLASMA

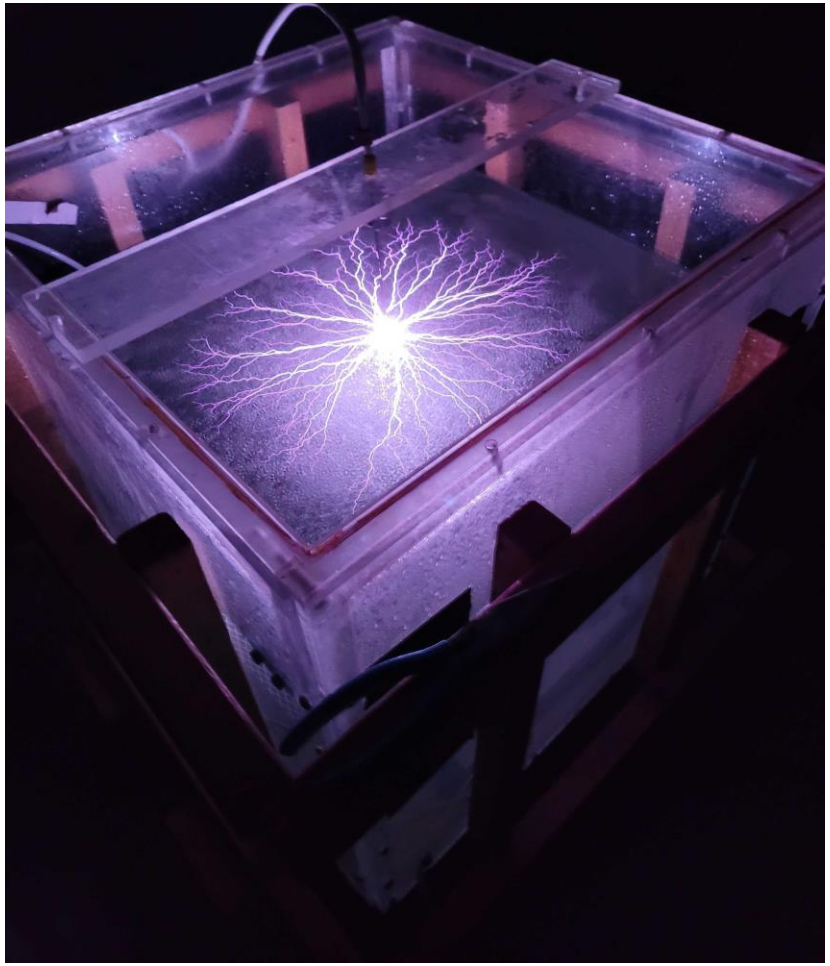
- Plasma is an ionized gas consisting of a quasi-neutral mixture of neutral species, positive ions, negative ions, and electrons.

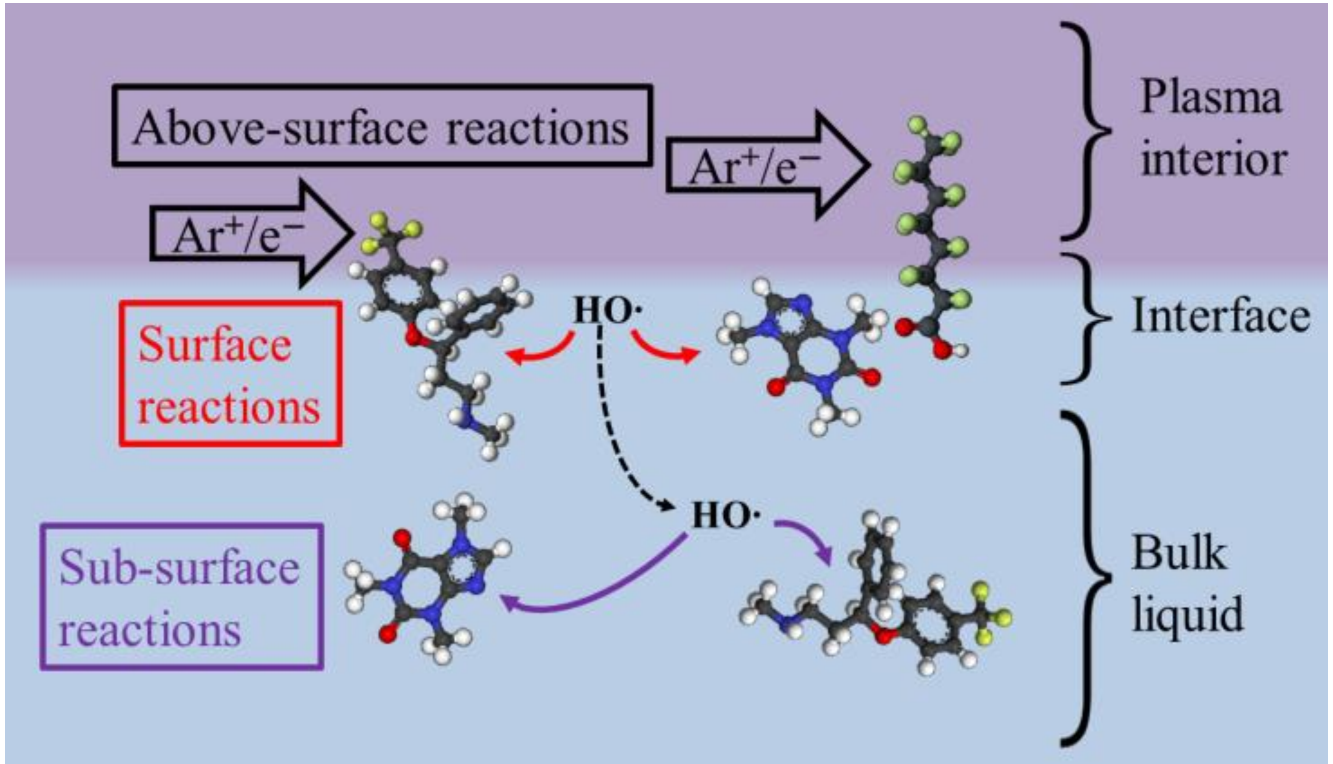
- Plasmas are created by applying a potential difference between two metal electrodes. One of the electrodes can be immersed in a liquid.





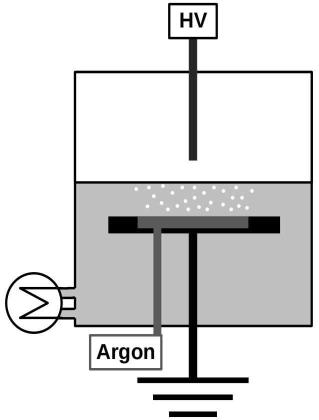
GAS-LIQUID REACTORS: THE BEST PERFORMING PLASMA TREATMENT SYSTEMS

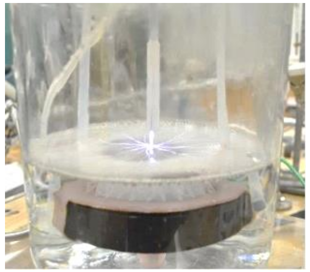




- Plasmas are best suited for degrading surfactant-like compounds!

PLASMA REACTOR SCALEUP FOR PFAS DEGRADATION





Lab, Batch

Lab, Continuous Flow

0.5-2 gpm

Mobile Trailer, Continuous Flow

10 gpm

TREATMENT CAPABILITIES OF ELECTRICAL DISCHARGE PLASMAS

AFFF TREATMENT

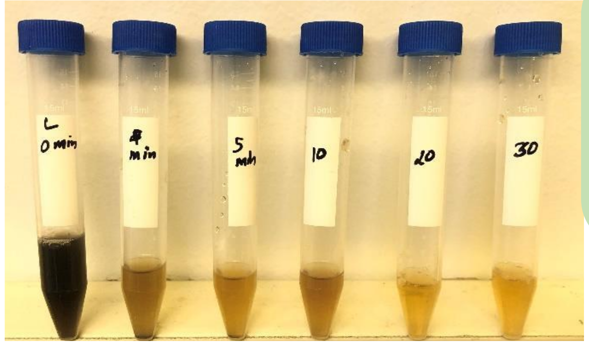
ION EXHANGE

EX-SITU DIRECT GROUNDWATER TREATMENT

PLASMA TECHNOLOGY

CONCENTRATE TREATMENT

LEACHATE TREATMENT

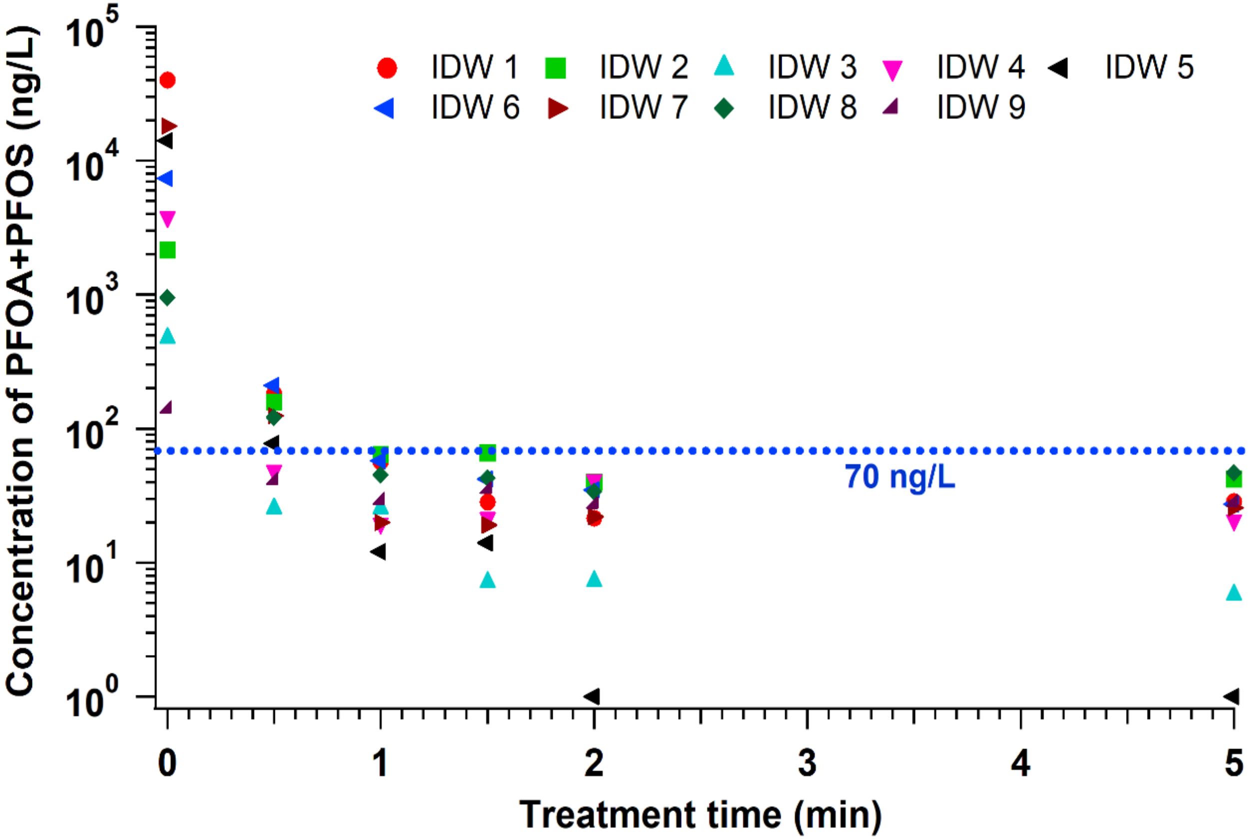


REVERSE OSMOSIS
NANOFILTRATION

Leachate color change following a 30 min treatment

BATCH REACTOR PERFORMANCE: REMOVAL OF PFAS FROM INVESTIGATION-DERIVED WASTE (IDW)

Degradation profiles of combined PFOA and PFOS concentrations in investigation derived waste (IDW) obtained from 9 different Air Force site investigations. Treatment volume is 4 L. No pre-treatment.



Field Demonstrations Completed

Location	Water Type	Water volume	Partners
Wright Patterson Air Force Base	Groundwater from Fire Training Area	325 gallons; up to 2 gpm	GSI Environmental (Steve Richardson lead) Funded by AFCEC
Pease Air Force Base	Ion Exchange Still Bottoms	35 gallons; batch	Wood (Nate Hagelin lead) ect_2 (Steve Woodard lead) Funded by DoD - ESTCP
Industrial Site	Ion Exchange Still Bottoms, Groundwater	Confidential	Confidential
Tyndall Air Force Base	Pit water from Fire Training Area	2900 gallons; Up to 8 gpm	GSI Environmental (Steve Richardson lead) Funded by NDCEE (through Battelle)

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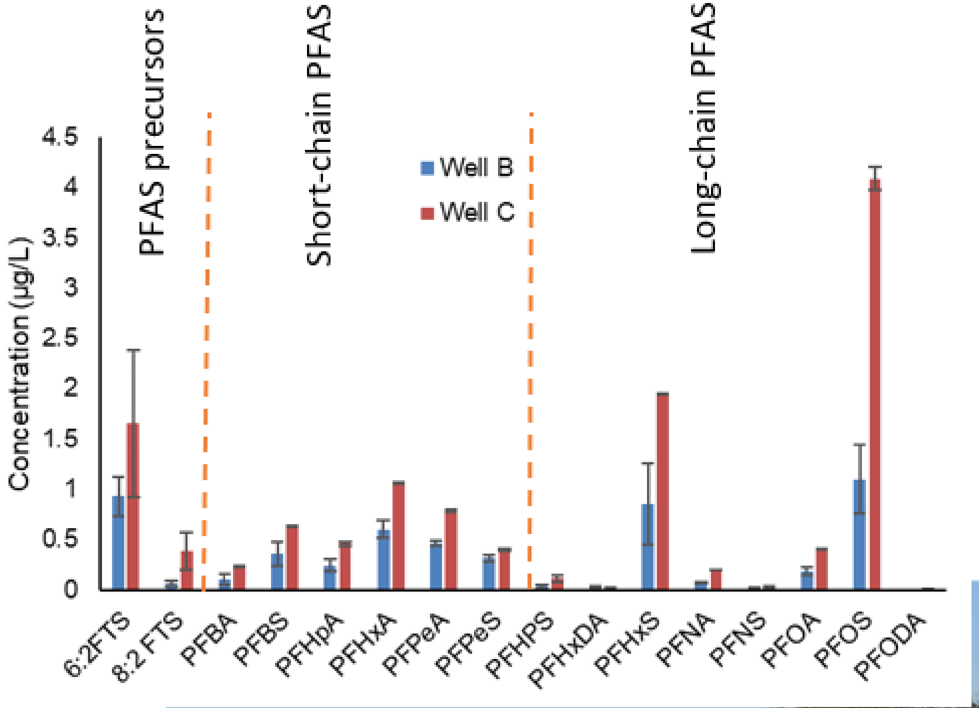
September 16-27, 2019 at former Fire Training Area 2, Wright-Patterson AFB

Partnered with GSI Environmental (Steve Richardson, Poonam Kulkarni)

- Influent PFOA and PFOS concentrations:

	PFOA (ppt)	PFOS (ppt)
FTA2-MW02B	185	1100
FTA2-MW02C	416	3944



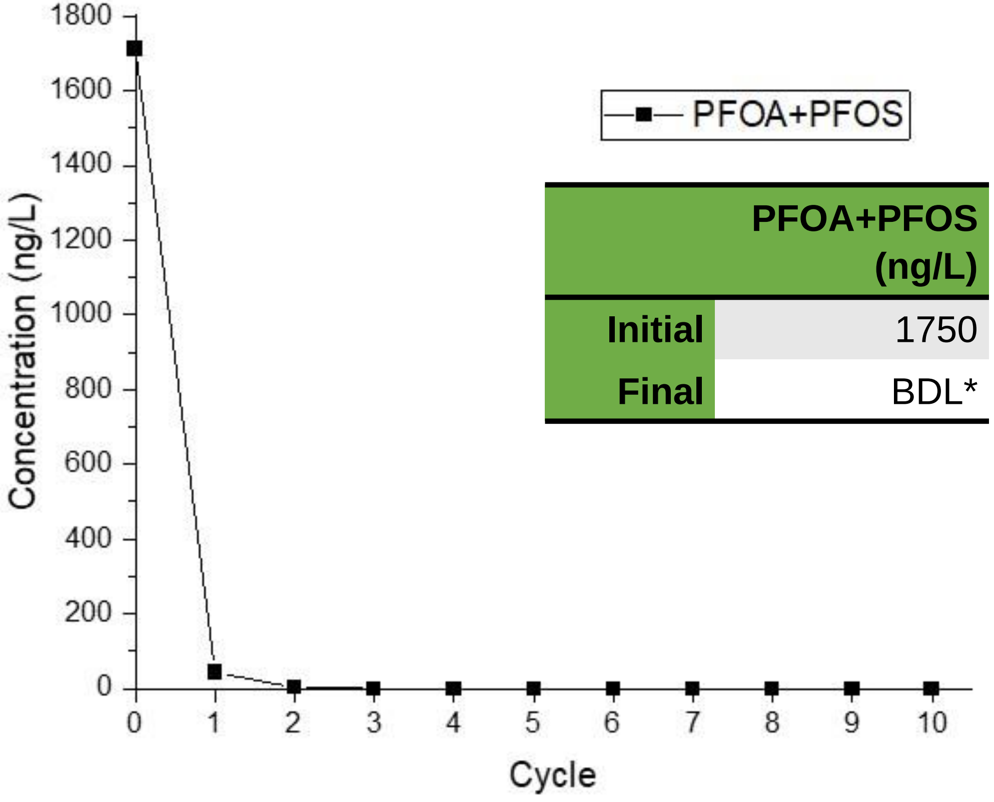
~350 gallons of PFAS-impacted groundwater were treated at various reactor operating conditions:

- flowrates: 0.3 -1.1 GPM per reactor
- number of recycle events* up to 10 cycles

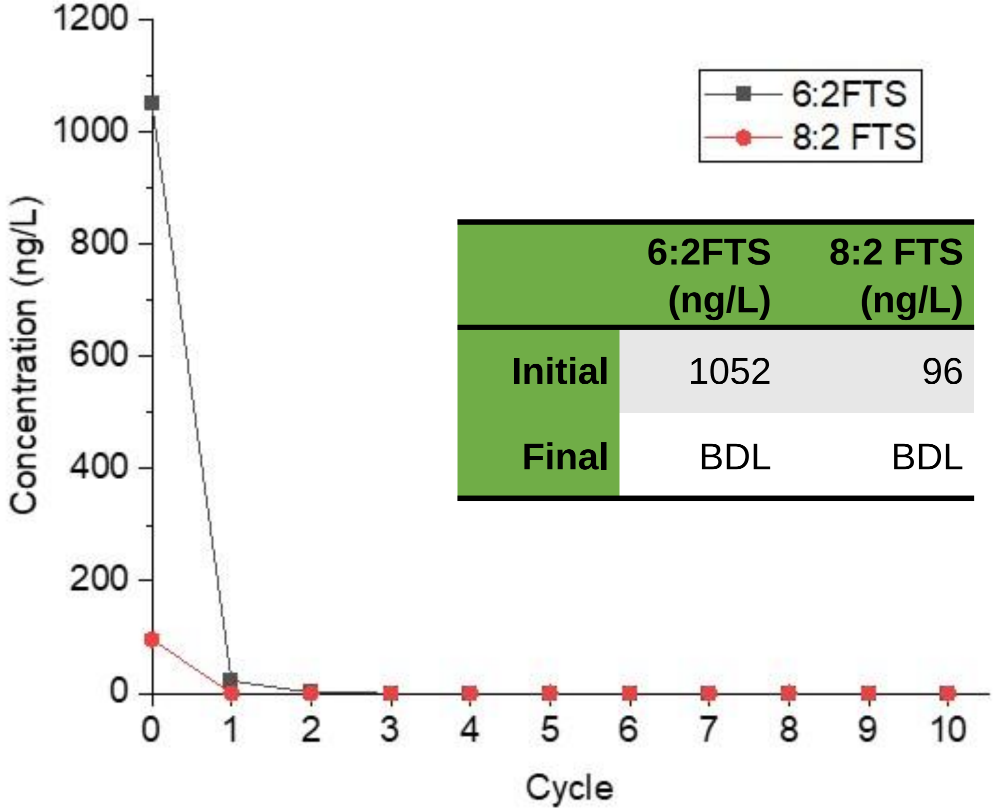
**One cycle (18 gal of water) is defined as a single pass through the reactor from the influent tank.*

TRAILER PERFORMANCE: WELL B AT 0.9 GPM FOR 10 CYCLES

1 cycle ~ 2 mins of treatment time



	PFOA+PFOS (ng/L)
Initial	1750
Final	BDL*



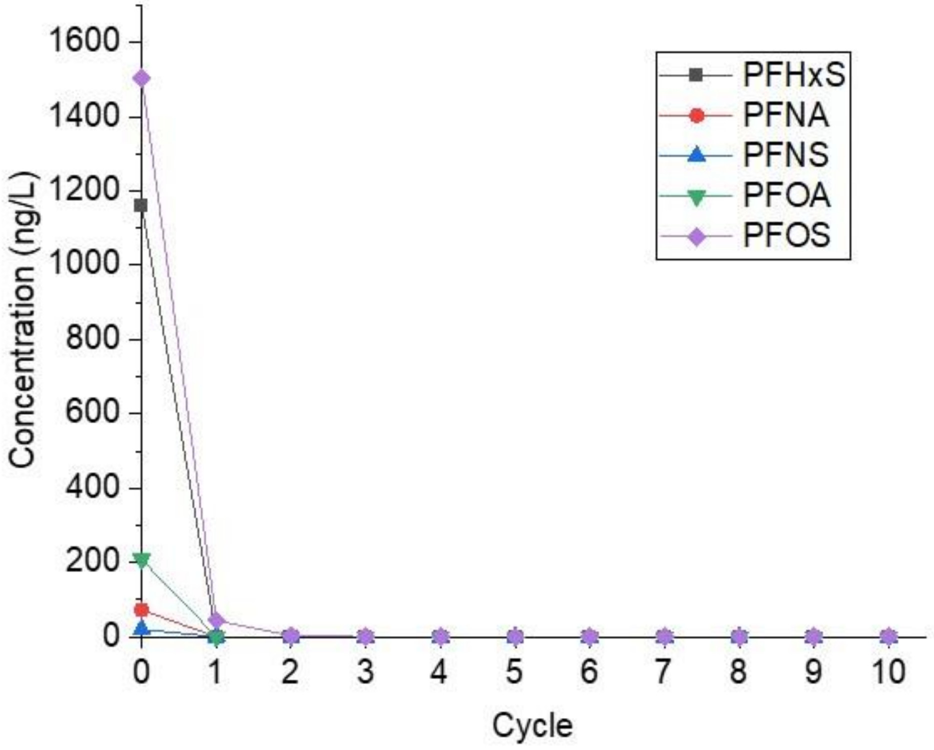
	6:2FTS (ng/L)	8:2 FTS (ng/L)
Initial	1052	96
Final	BDL	BDL

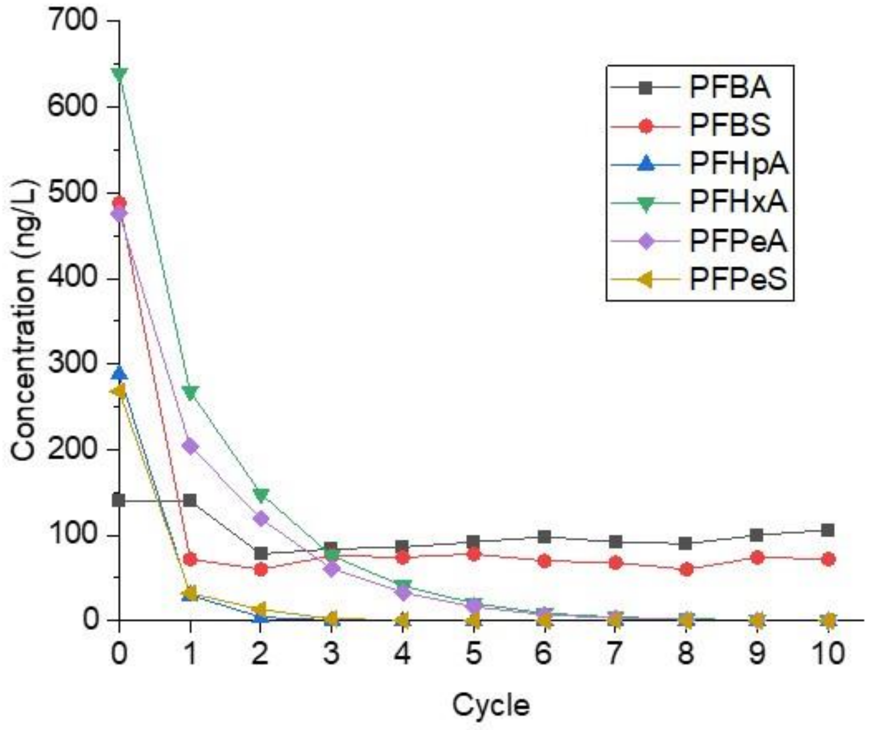
*BDL=Below Detection Limit (< 9 ng/L)

TRAILER PERFORMANCE: WELL B AT 0.9 GPM FOR 10 CYCLES

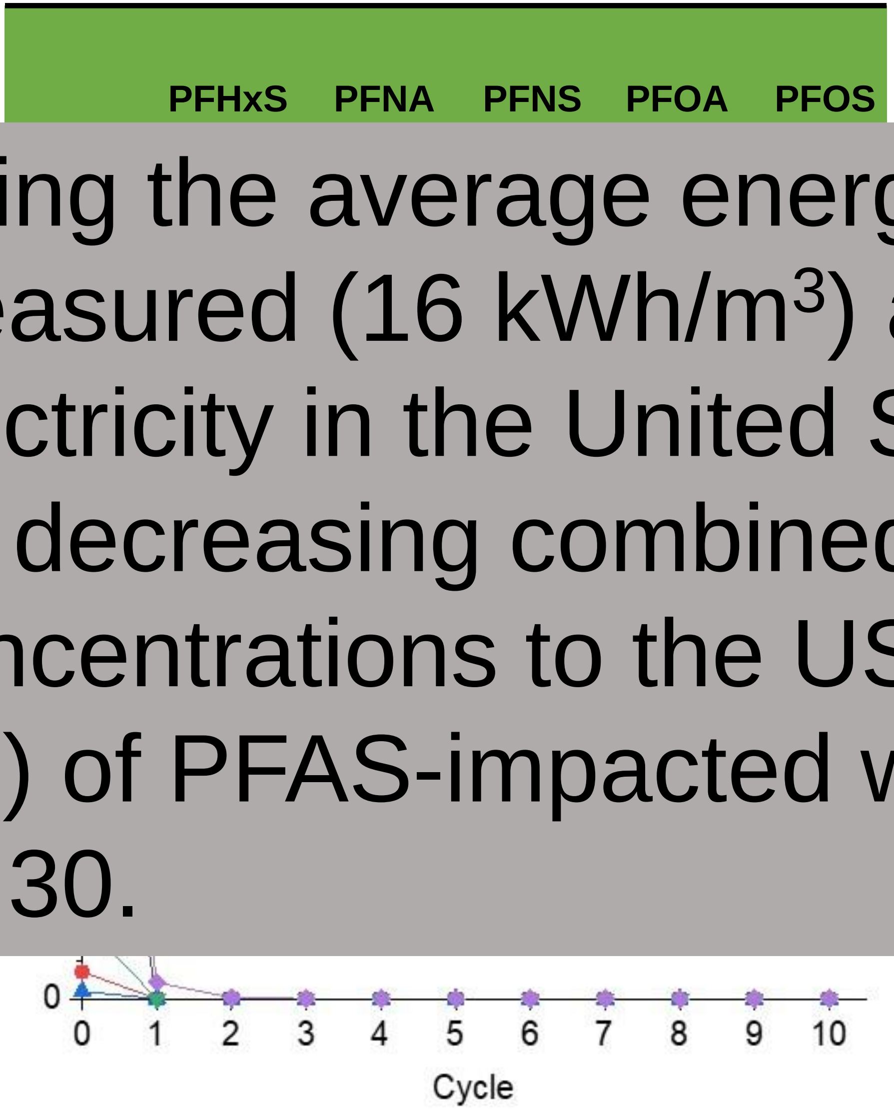
	PFHxS (ng/L)	PFNA (ng/L)	PFNS (ng/L)	PFOA (ng/L)	PFOS (ng/L)
Initial	1160	72	20	208	1504
Final	BDL	BDL	BDL	BDL	BDL

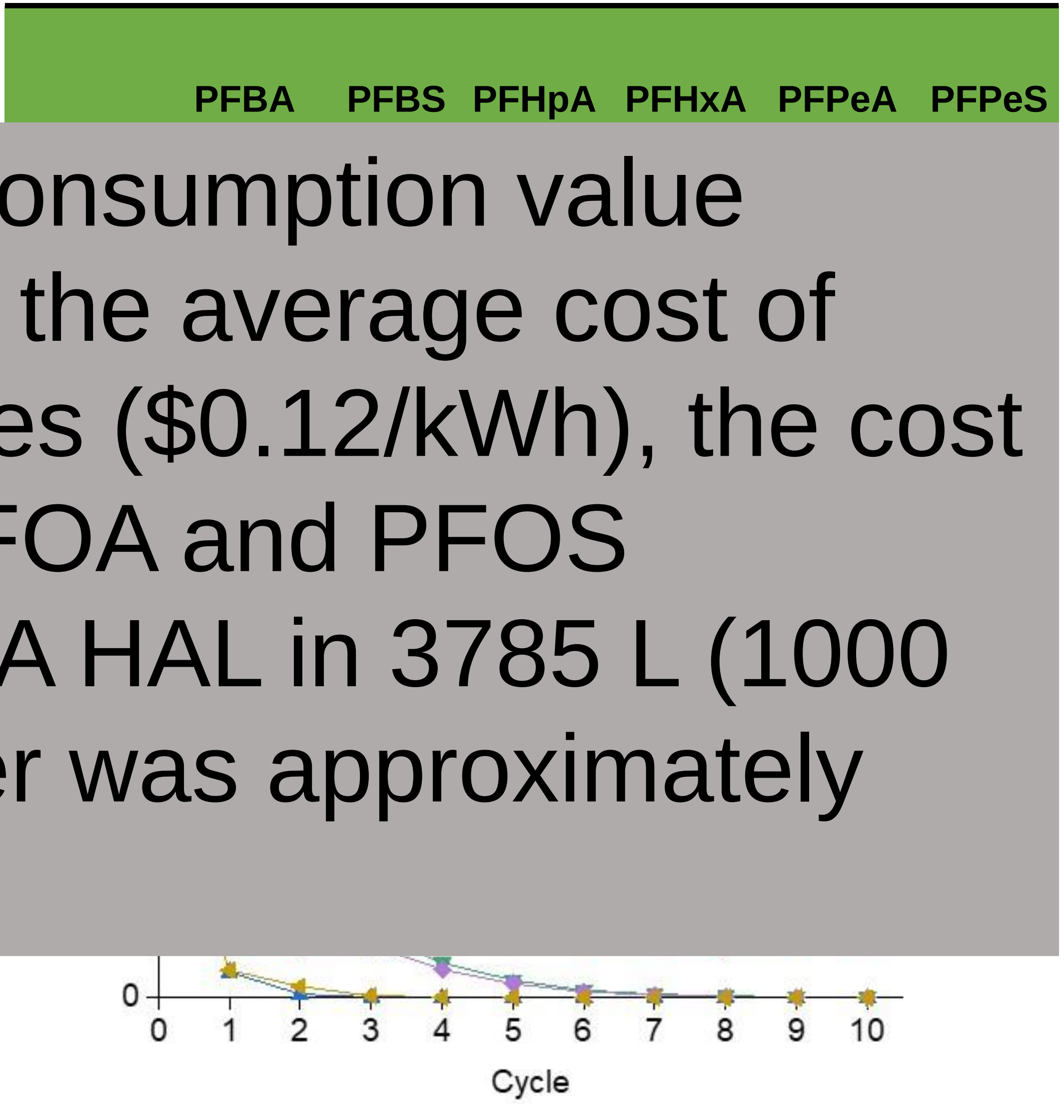
	PFBA (ng/L)	PFBS (ng/L)	PFHpA (ng/L)	PFHxA (ng/L)	PFPeA (ng/L)	PFPeS (ng/L)
Initial	140	488	288	640	476	268
Final	102	93	BDL	BDL	BDL	BDL





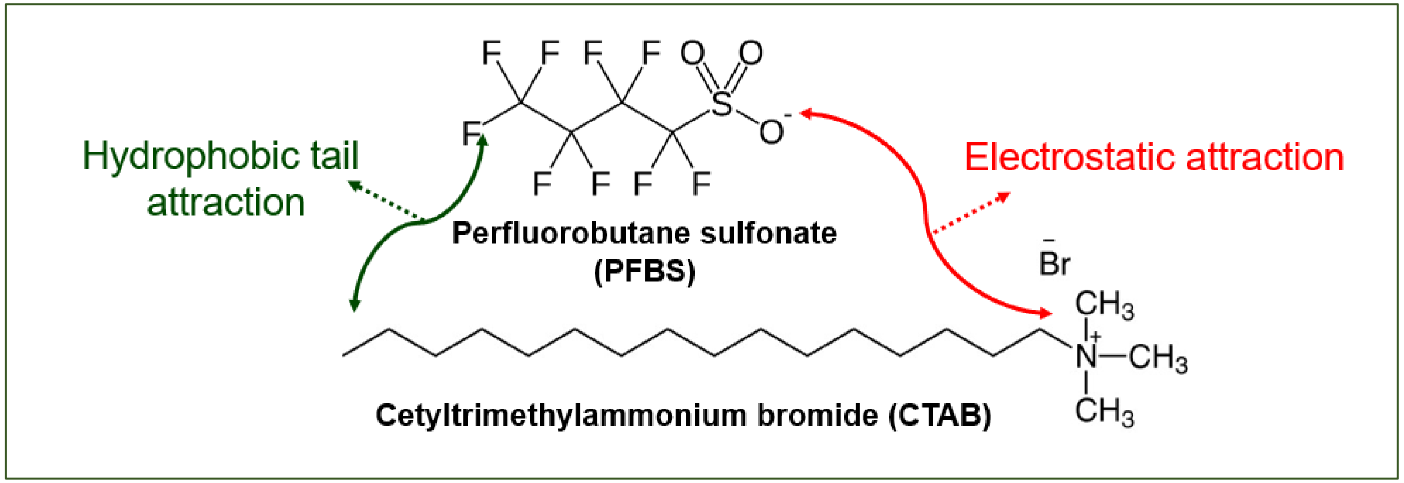
TRAILER PERFORMANCE: WELL B AT 0.9 GPM FOR 10 CYCLES

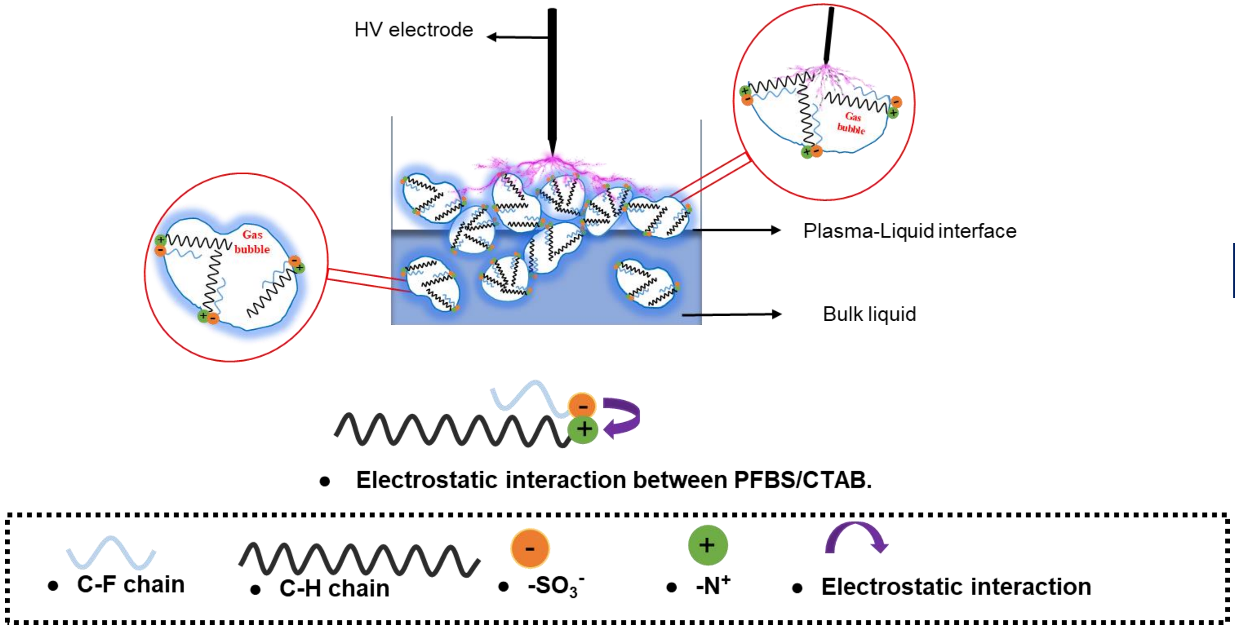


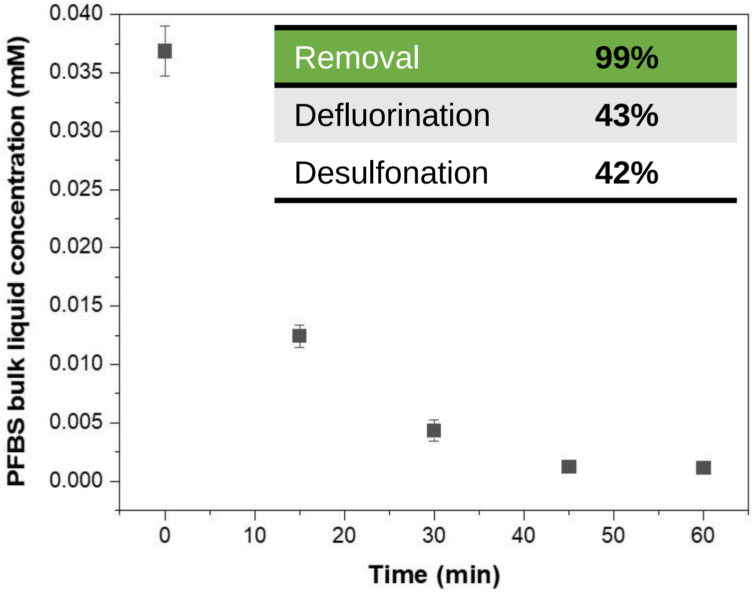


Using the average energy consumption value measured (16 kWh/m^3) and the average cost of electricity in the United States ($0.12/kWh), the cost for decreasing combined PFOA and PFOS concentrations to the USEPA HAL in 3785 L (1000 gal) of PFAS-impacted water was approximately $7.30.

SURFACTANT ADDITION INCREASES REMOVAL RATES OF SHORT-CHAIN PFAS







LIMITATIONS OF CTAB ADDITION

1. CTAB inhibits the interfacial adsorption of long chain PFAS, in particular, PFOS.

<u>CTAB can only be added after long-chain PFAS are degraded!</u>

2. In highly electrically conductive solutions, ions interfere with binding of ultra-short chain PFAS to CTAB.

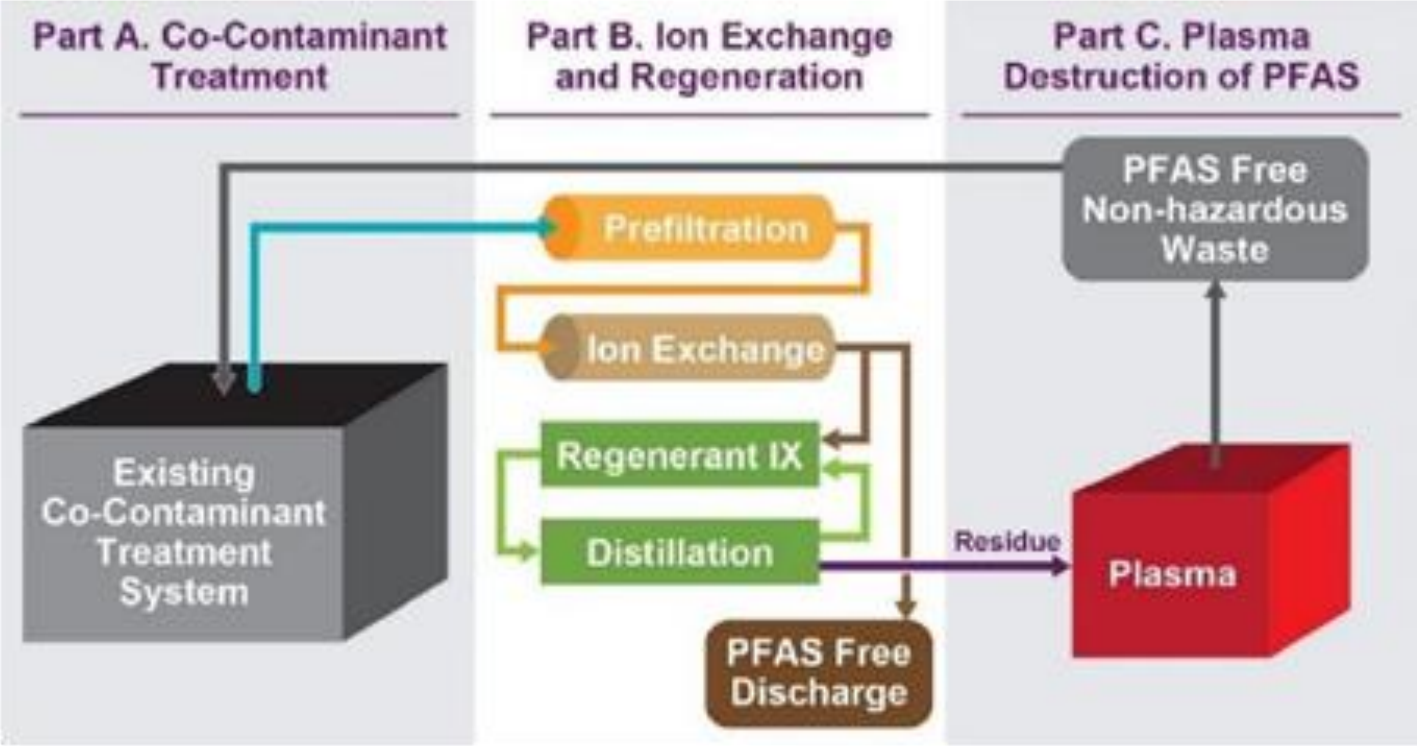
3. CTAB is a chemical (oxidized by plasma to nitrate ions).

WITHOUT PLASMA

WITH PLASMA

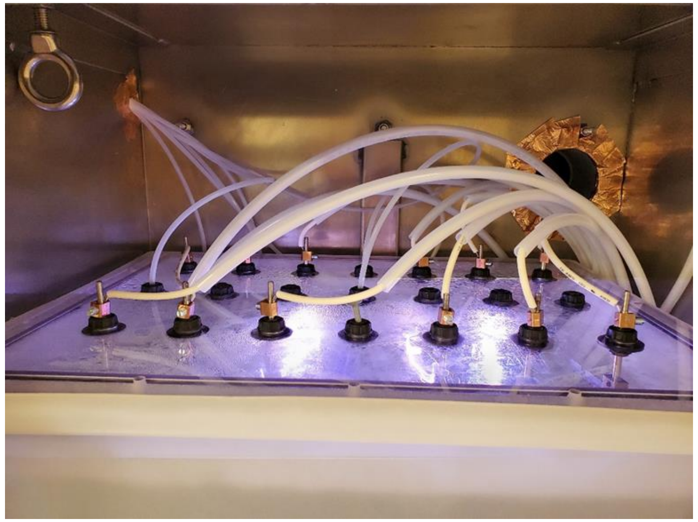
Treatment of Still Bottoms – Pease Air Force Base

Partnered with WOOD (Nate Hagelin, Eric Thompson) and ect$_2$ (Steve Woodard, John Berry, Mike Nickelsen)

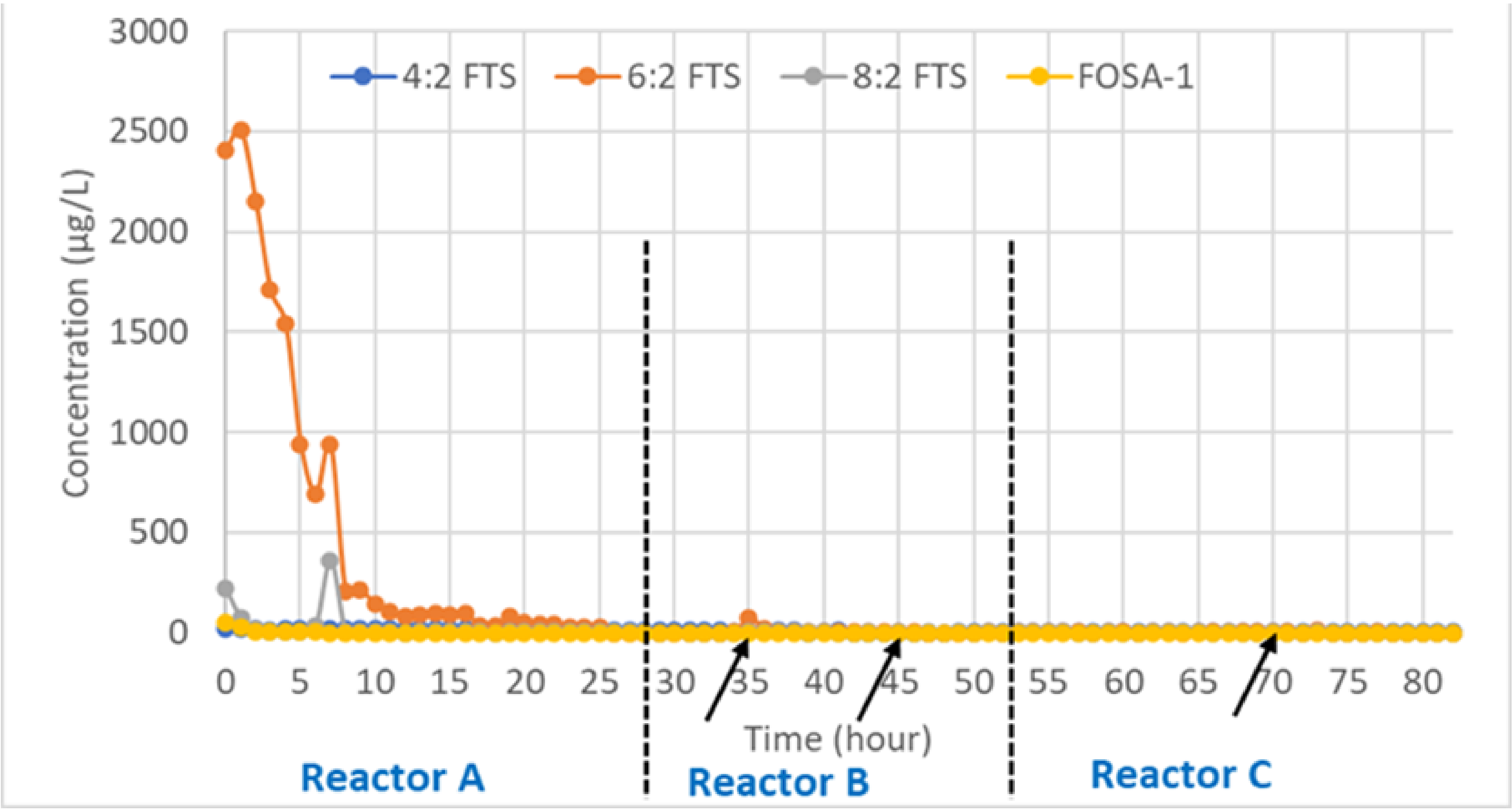


- Plasma treatment of distilled ion exchange regenerant solution (still bottoms)
- High conductivity and high concentration
- Diluted 10x

Pease Air Force Base – Reactor configuration

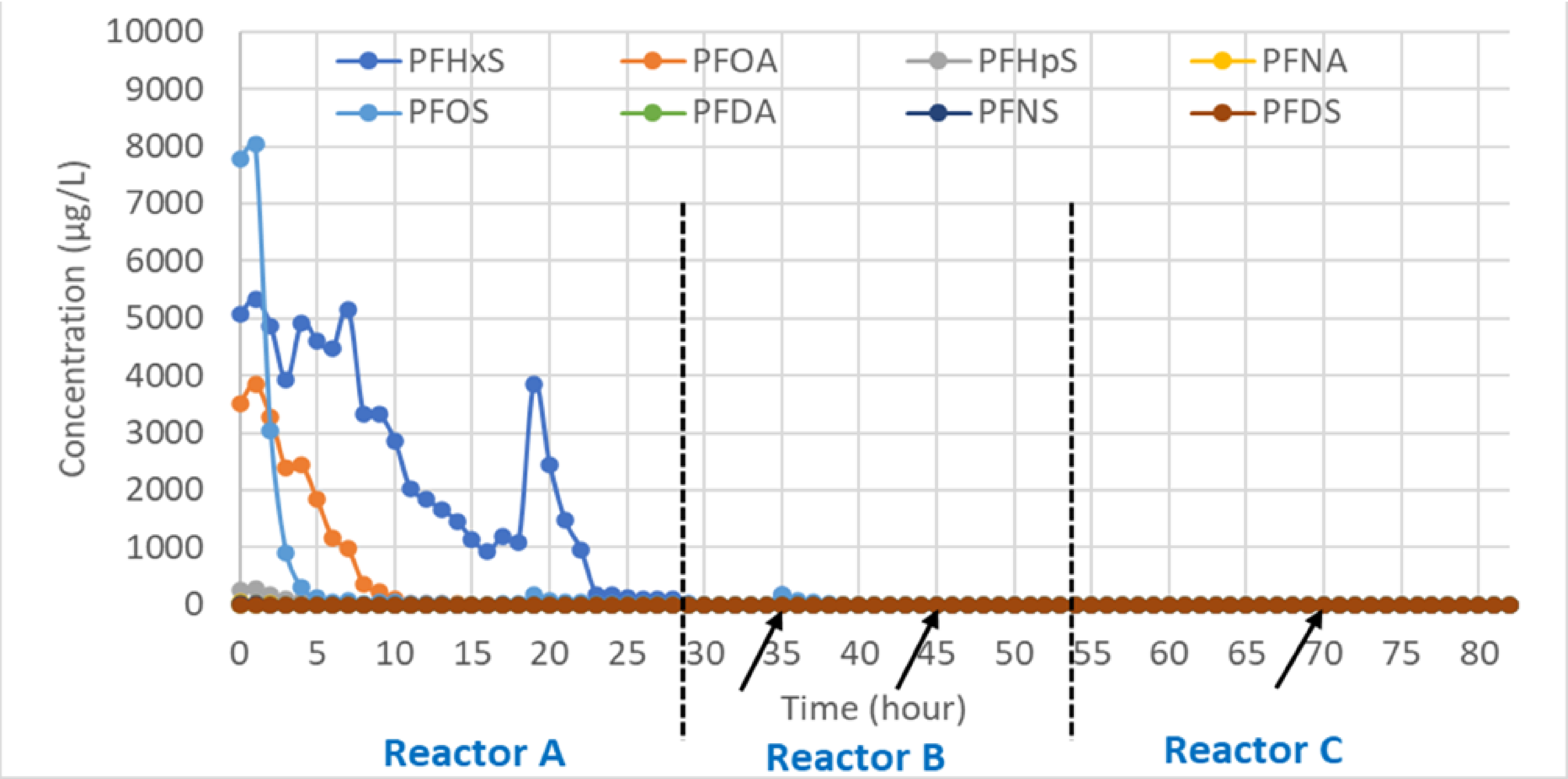


Pease Air Force Base – Precursor Treatment



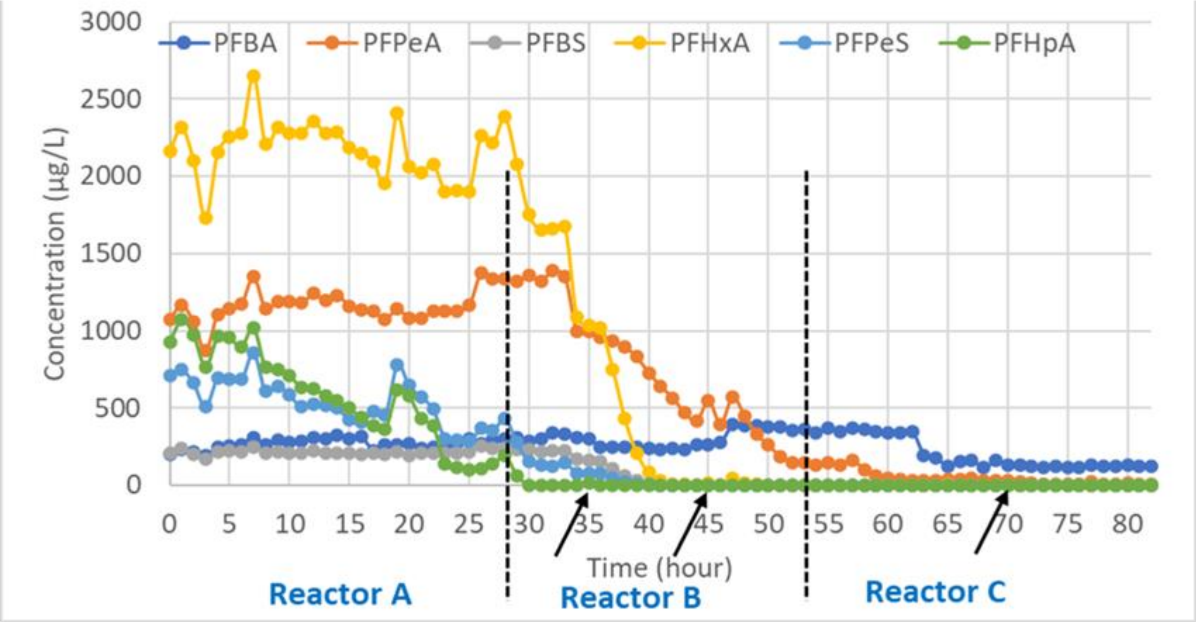
CTAB added at times indicated by arrows

Pease Air Force Base - Long-chain PFAAs treatment



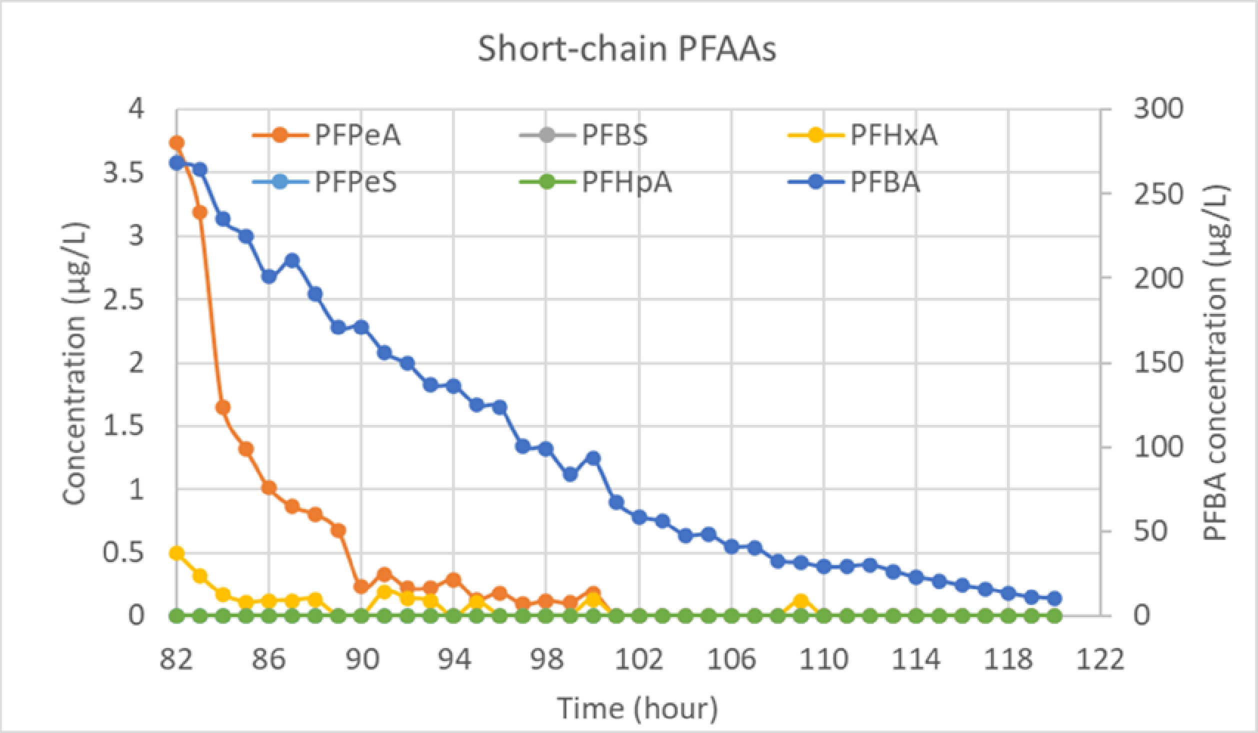
CTAB added at arrows

Pease Air Force Base - Short-Chain PFAAs treatment



CTAB added at arrows

Additional treatment at Clarkson with CTAB addition as needed to maintain foam layer



Conclusions/Lessons Learned

- Enhanced contact plasma technology is effective at removing long and short chain PFAS from a variety of media at field scale.
- Bench-scale treatment of water being treated before getting into the field is a must.
- Sample turn-around time is a challenge for short field demonstrations - need for real-time measurements.
- Industrial sites are going to provide additional challenges in terms of concentrations and compounds encountered.
- Treating standard PFAS compounds likely not be sufficient – precursors and ultra-short chains will become more important.

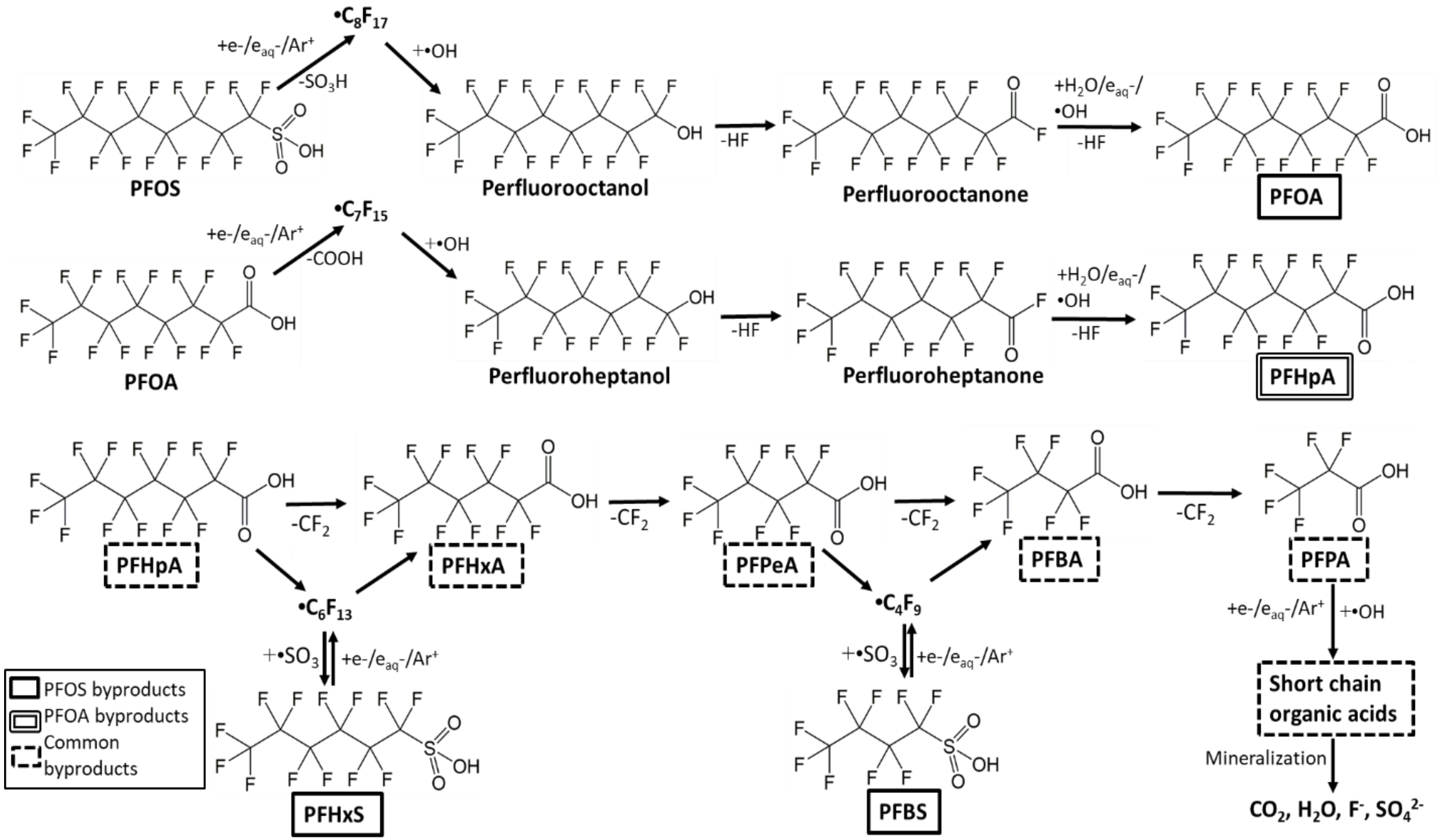
Field Demonstrations Upcoming

- Hill Air Force Base - groundwater
- Leavenworth Army Base - groundwater
- Solid Waste Landfill leachates and membrane concentrate
- TBD - membrane reject
- Sugar Grove Naval Base – still bottoms
- Navy – oily bilge water

ACKNOWLEDGMENTS

- Dr. Thomas Holsen
- Dr. Selma Mededovic Thagard
- Postdoctoral researchers and graduate students
- Clarkson’s CAARES and CAMP
- ISE
- NYS Center of Excellence in Healthy Water Solutions
- Clarkson’s Ignite Program
- The Shipley Center for Innovation

MECHANISM OF PFOA AND PFOS DEGRADATION: LIQUID-PHASE BYPRODUCTS



PFOS (C8)

PFOA (C8)

n-1

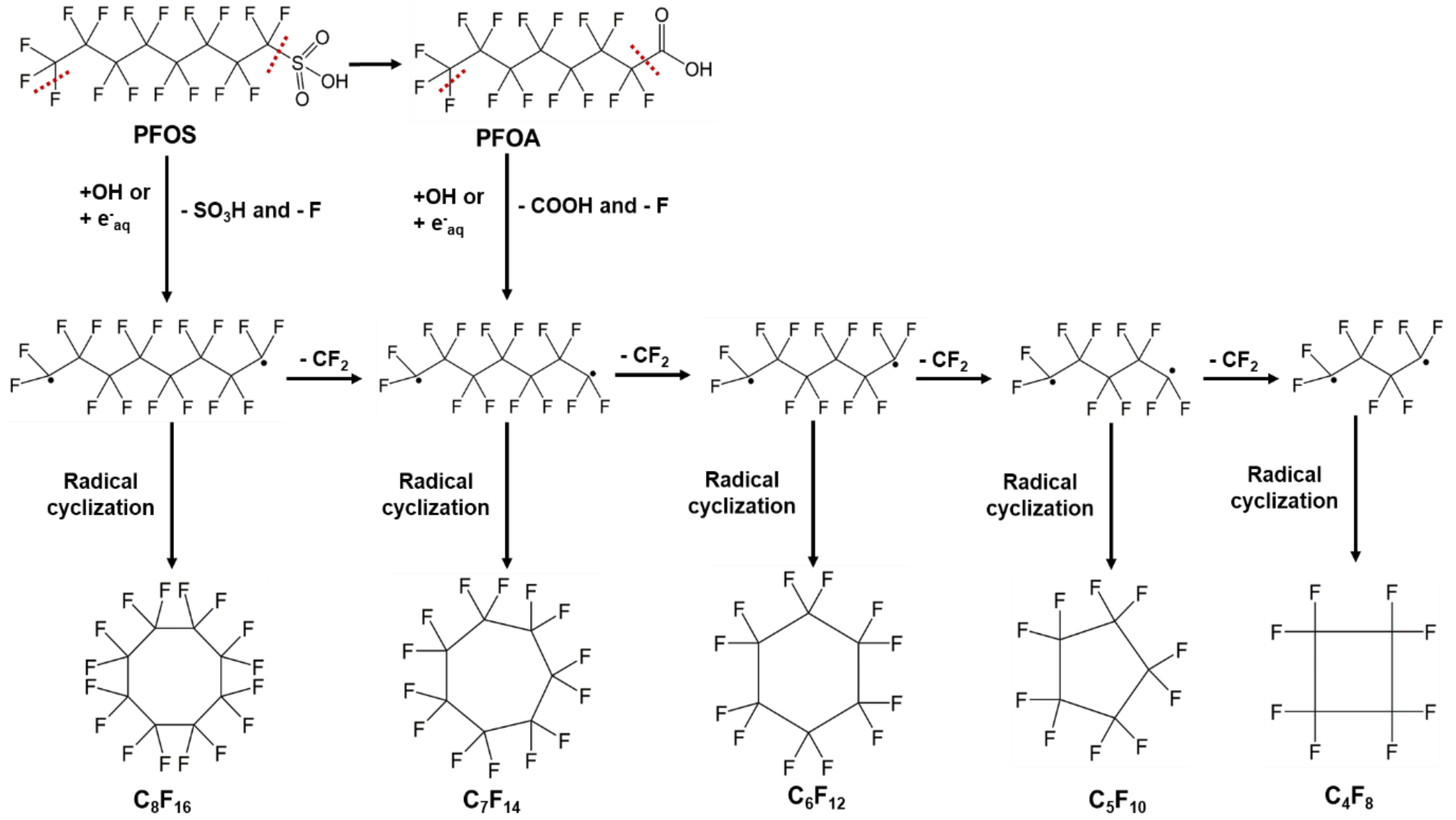
PFHpA (C7)

n-2

n-6

Trifluoroacetate (C2)

MECHANISM OF PFOA AND PFOS DEGRADATION: GAS-PHASE BYPRODUCTS



PFOA

Liquid byproducts – 74%,
Gas-phase byproducts – 2.5%
Sorption – 22%

PFOS

Liquid byproducts – 57%
Gas-phase byproducts – 1%
Sorption – 38%