An Enhanced Contact Electrical Discharge Plasma Reactor:
An Effective Technology to Degrade PFAS

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GSI ENVIRONMENTAL

PFAS REMEDIATION: *What are the Options?*

- **PFAS remediation has focused on ex-situ treatment; mainly sorption**
- **In situ applications are generally unproven and fairly limited (bioremediation; carbon injection; heat activated persulfate)**

EX SITU OPTIONS

Destructive

- Electrochemical
- Photochemical
- Persulfate oxidation
- Reduction processes
- Sonolysis
- Plasma

Sorption

- Activated carbon
- Ion exchange resins
- Novel polymer adsorbents
- Silica coatings
- Zeolites

Filtration

- Nanofiltration
- Ultrafiltration
- Electrodialysis
- Reverse Osmosis

AIR FORCE RESEARCH & DEVELOPMENT

On-Site PFAS Remediation

DoD Challenge: **Active PFAS investigations at hundreds of Air Force bases/installations have generated large amounts of Investigation Derived Waste (IDW)**

1. **Air Force has >400 former fire training areas, many of which are currently assessing the extent of PFAS impacts in groundwater.**
2. **Disposal of PFAS-impacted water is very costly; significant risk of long-term liability.**
3. **Purge water contains a variety of co-contaminants that also require treatment.**
4. **Looking for innovative, cost-effective technologies to treat stored purge water and other PFAS water sources (e.g., AFFF hangars or ARFF vehicles).**

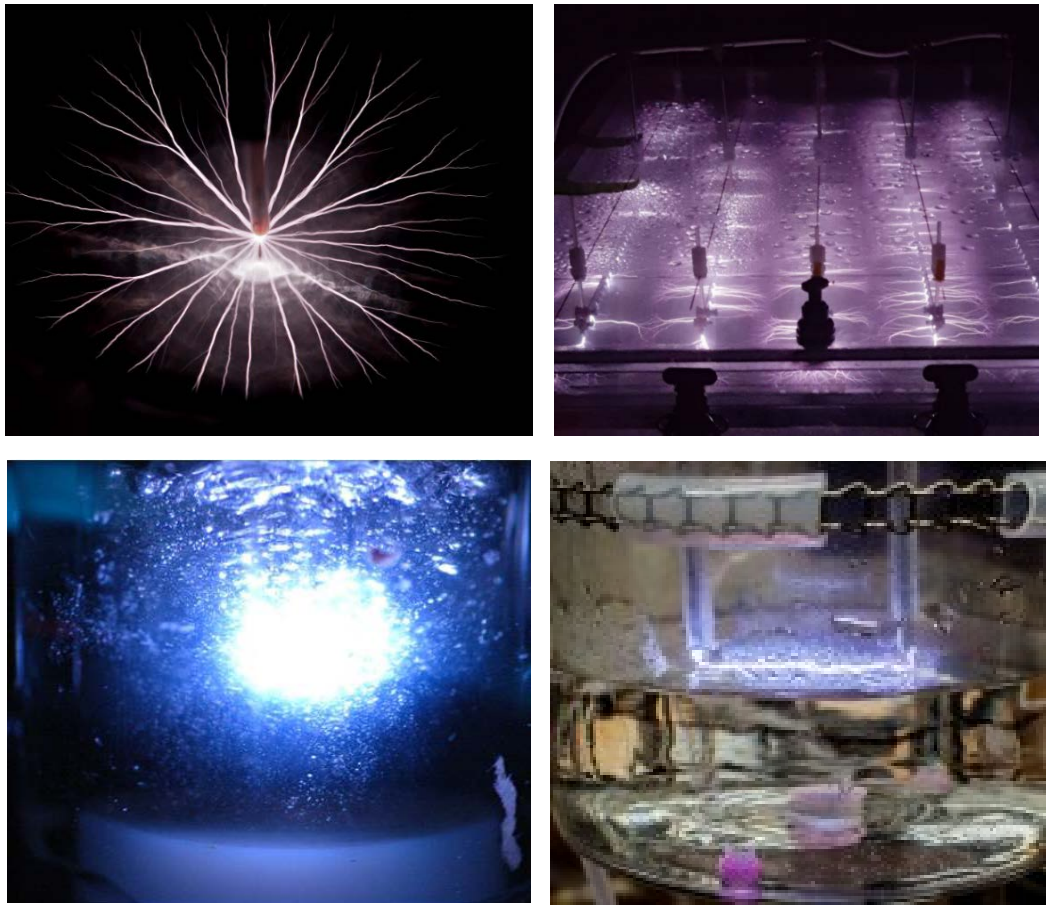
PLASMA-BASED WATER TREATMENT

Plasma-based water treatment uses electricity to convert water into a mixture of highly reactive species (i.e., plasma) that rapidly and non-selectively degrade recalcitrant organic contaminants.

Electrical discharge plasma formed directly in or above water makes use of OH radicals to oxidize and aqueous electrons to chemically reduce organic and inorganic compounds.

Benefits

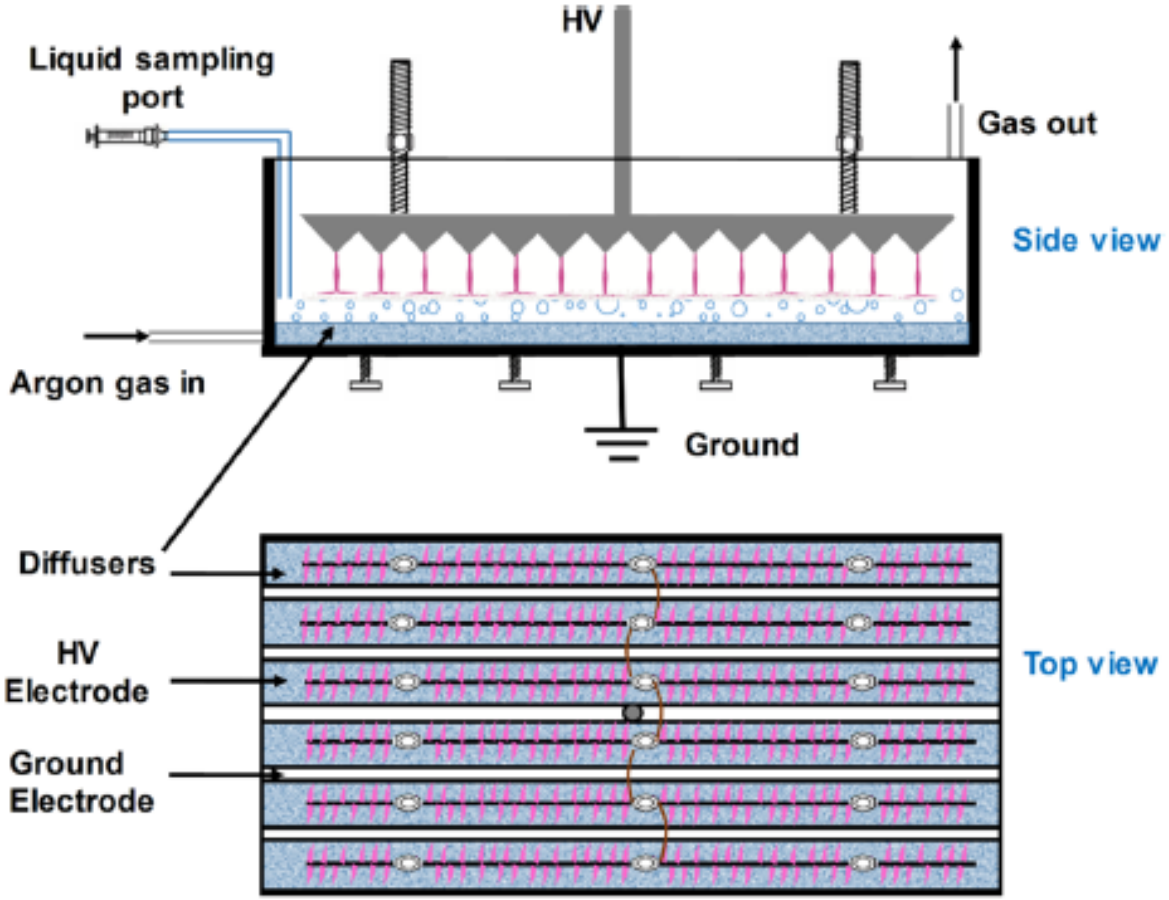
- **Generates a wide variety of reactive chemical species (OH, e_{aq}^-, e^-, O, H, H_2O_2, O_2, HO_2).**
- **Capable of treating a wide variety of compounds including PFAS, 1,4-Dioxane, and VOCs**
- **The plasma process requires no chemical additions and produces no residual waste**



Pictures courtesy of Plasma Research Laboratory, Clarkson University

PLASMA FORMATION: *How Does It Work?*

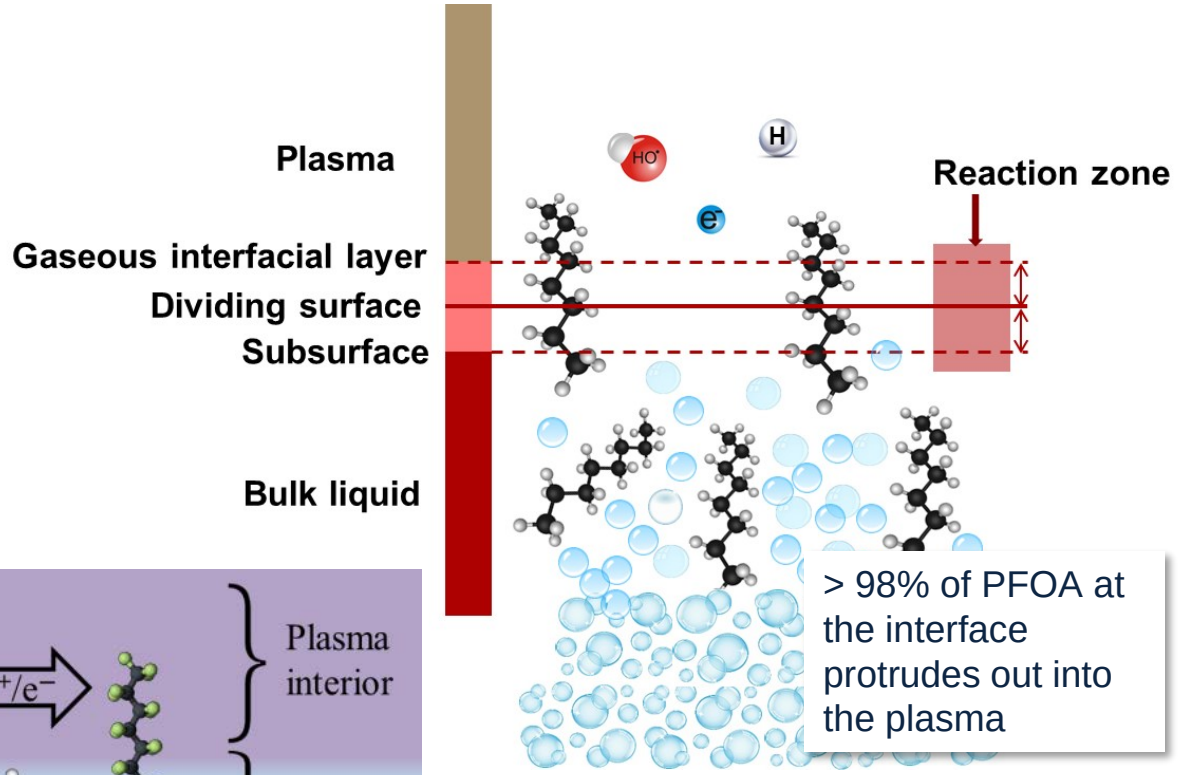
- **Plasma Reactor Components**
  - High voltage electrodes for generation of plasma
  - Stainless steel strips as grounded electrodes
  - Gas diffusers along the bottom of the reactor for bubble formation
- **Plasma Formation:** High voltage is applied between suspended electrodes (above the water surface) and submerged grounded electrodes.



(Singh et al., 2019)

PFAS REMEDIATION: *Mechanism for PFAS Destruction*

- Argon gas is continuously pumped through the diffusers which produce bubbles concentrating PFAS at the argon-water interface
- PFAS molecules are exposed to reactive species in the plasma.
- Dissolved reactive species generated by the plasma drives reactions within the water column



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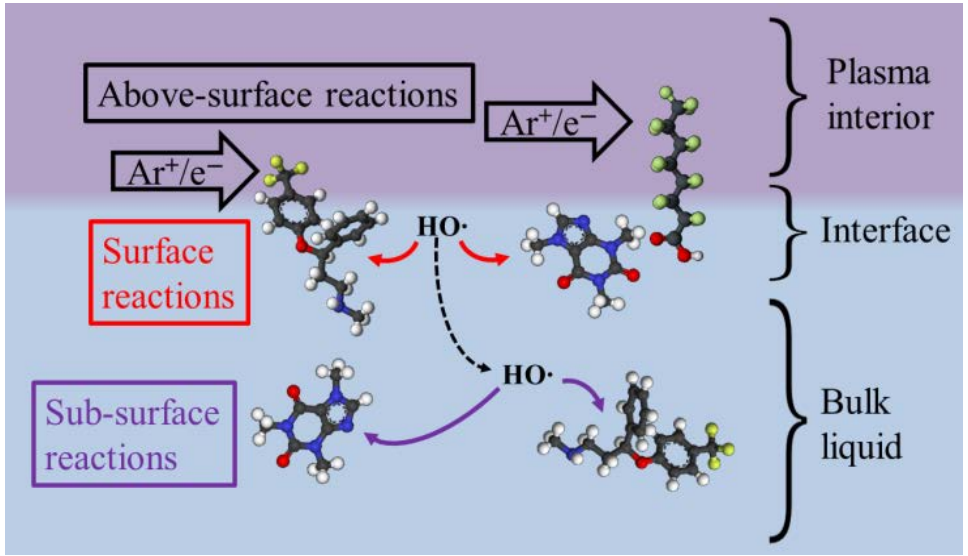
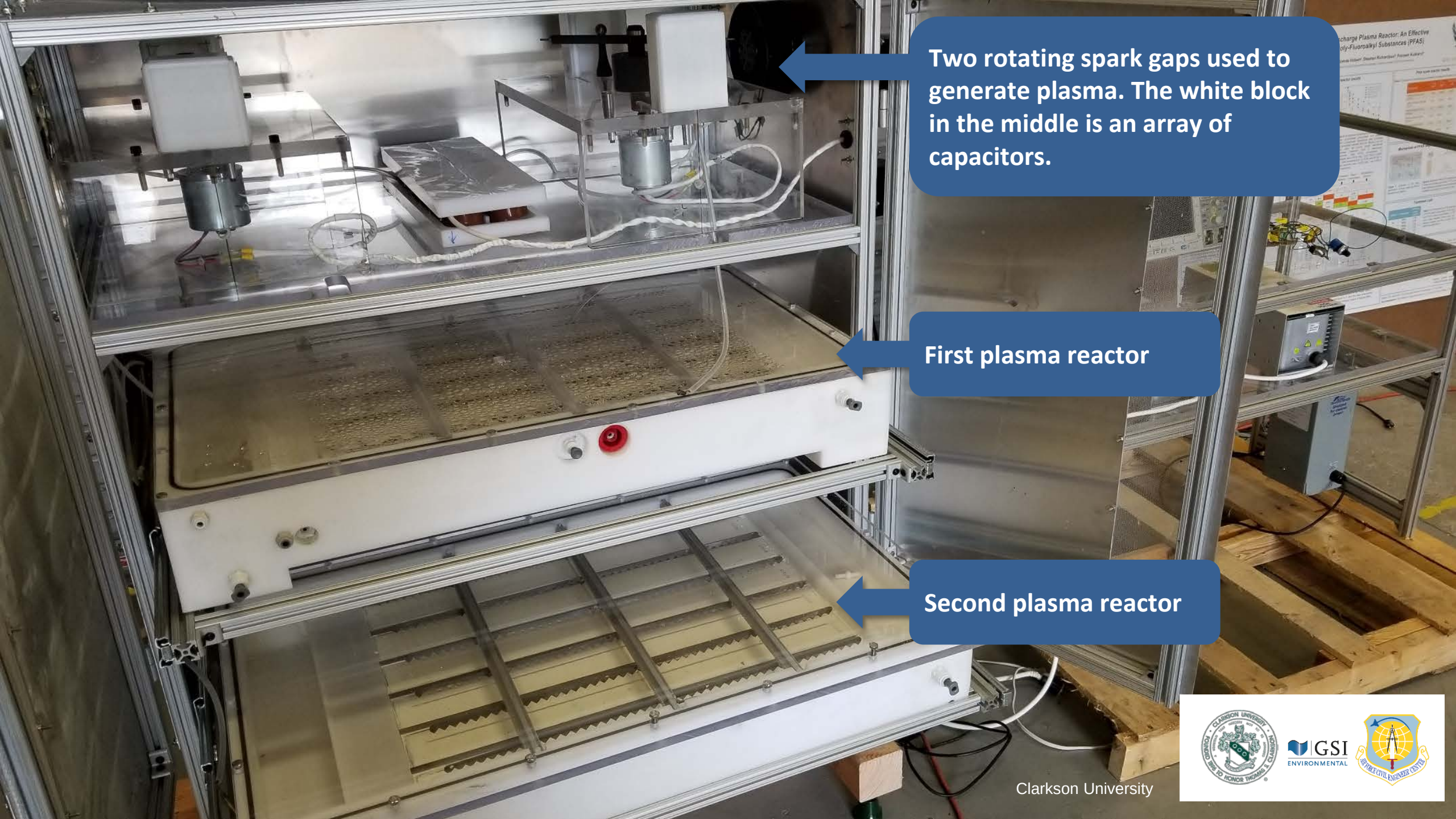
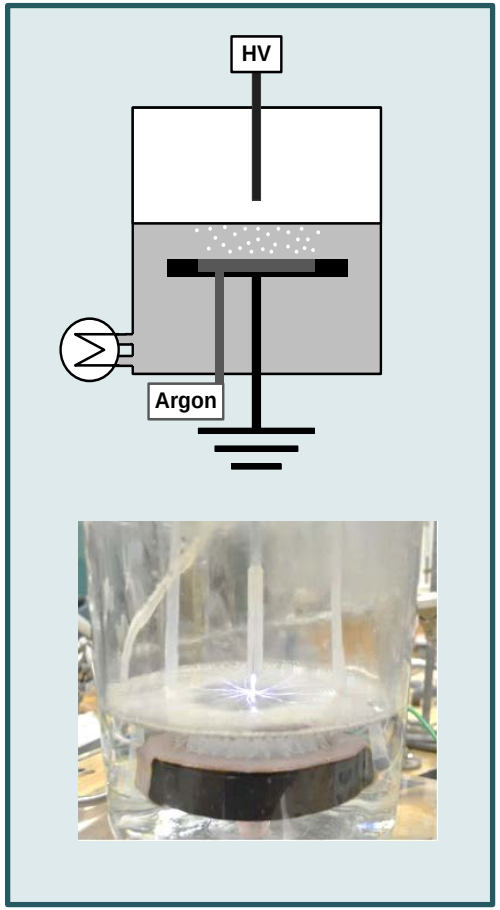


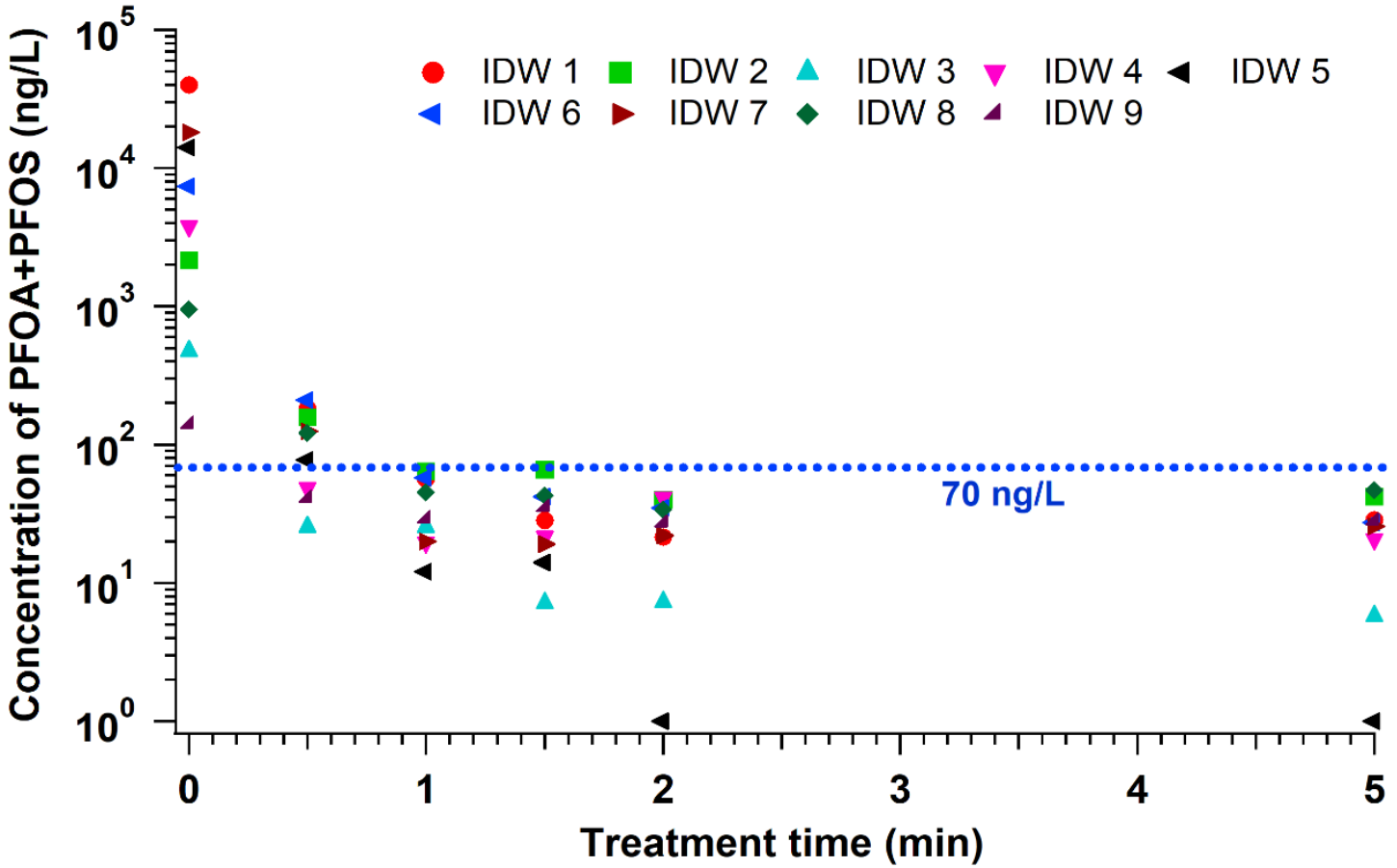

Two rotating spark gaps used to generate plasma. The white block in the middle is an array of capacitors.
First plasma reactor
Second plasma reactor

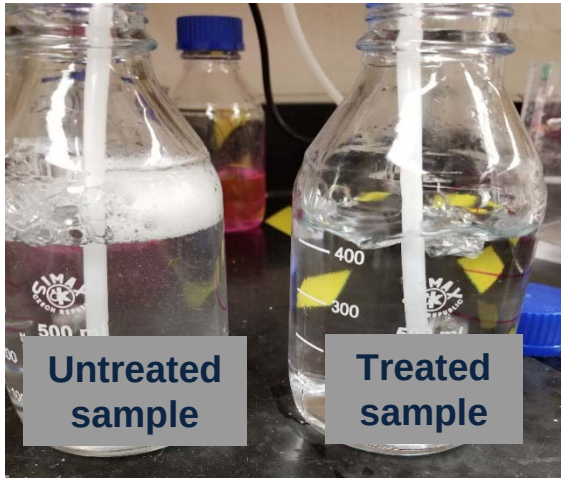
PROJECT OBJECTIVES

Demonstrate operation of an *enhanced contact (EC) electrical discharge plasma reactor* for the treatment of PFAS-contaminated groundwater at an Air Force site.



LABORATORY TESTING: *PFAS Samples*





Both PFOS and PFOA concentrations were reduced to less than 70 ppt within 1 min of treatment for the majority of samples

Singh, R.K. et al. (2019) Rapid Removal of Poly- and Perfluorinated Compounds from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor, *Environ. Sci. Technol,* 53, 11375−11382

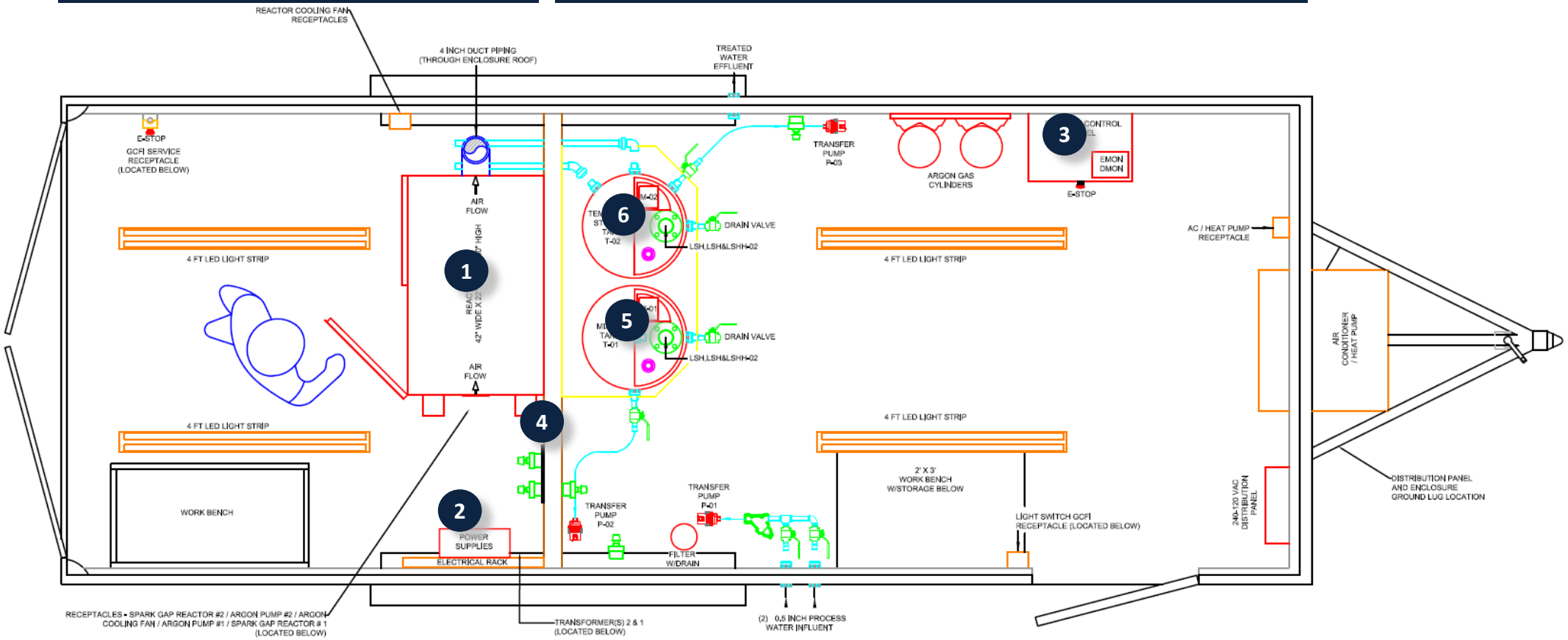
FIELD DEMONSTRATION

- Designed as a mobile unit for treatment of PFAS-impacted groundwater, stored IDW purge water, or other sources of PFAS-impacted water
- The trailer houses two plasma reactors; operated in parallel or series to accommodate different reactor conditions (e.g., flowrate, argon recirculation rate) and minor system shut-downs
- Field demonstration conducted at Wright Patterson AFB (September 2019)
- Samples collected at ports before and after each reactor
- Monitor system parameters
  - Flowrates
  - Pressures
  - Voltage; Energy use
  - No. of Recycling Events

MOBILE PLASMA TREATMENT TRAILER

Plasma Side of the Trailer

Sample Collection Side of the Trailer



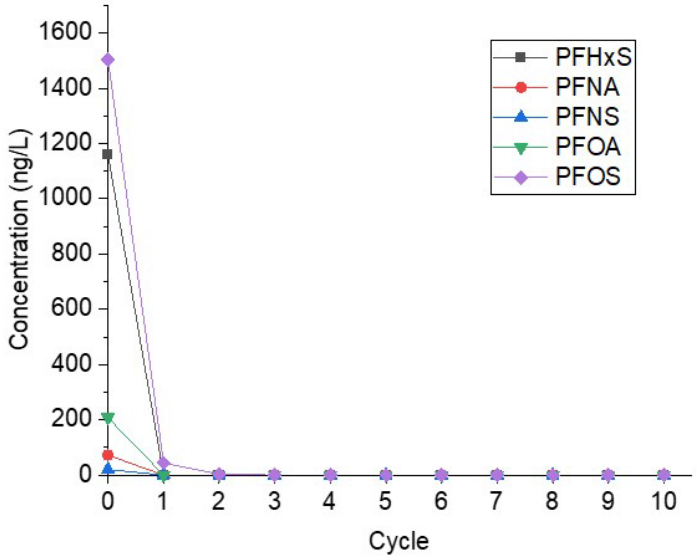
1. Plasma reactor rack
2. Power supplies
3. Control panel
4. Partition
5. Influent Mixing Tank
6. Effluent Mixing Tank

Sample Collection Side of the Trailer

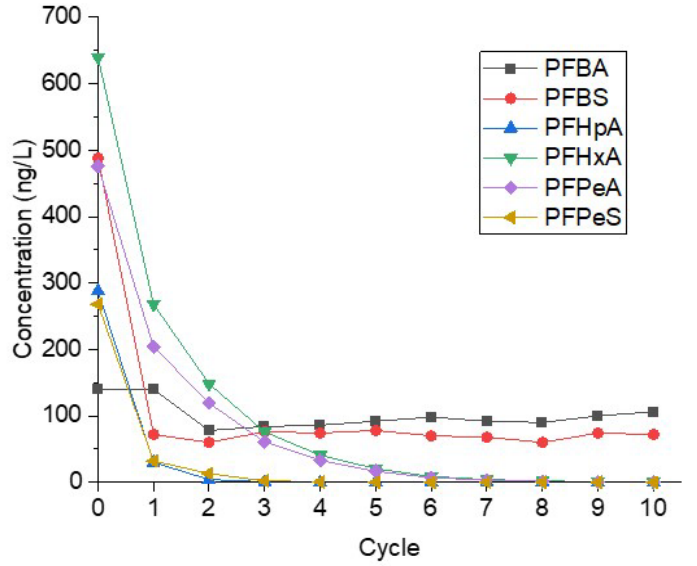
Plasma Side of the Trailer

PRELIMINARY RESULTS

- ~350 gallons of PFAS-impacted groundwater were treated at various reactor operating conditions.
  - **Flowrates**: 0.3-1.1 gpm
  - **Recycle events:** up to 10 cycles (1 cycle = 18 gal; single pass through reactor from influent tank)
- Significant removal of PFOA, PFOS, and other long-chain PFAS after 1-2 cycles; similar results for precursors (fluorotelomer sulfonates).
- Longer removal times (3-6 cycles) for some short-chain PFAS required.
- Limited removal of PFBA and PFBS likely due to inadequate transfer of molecules to interface.

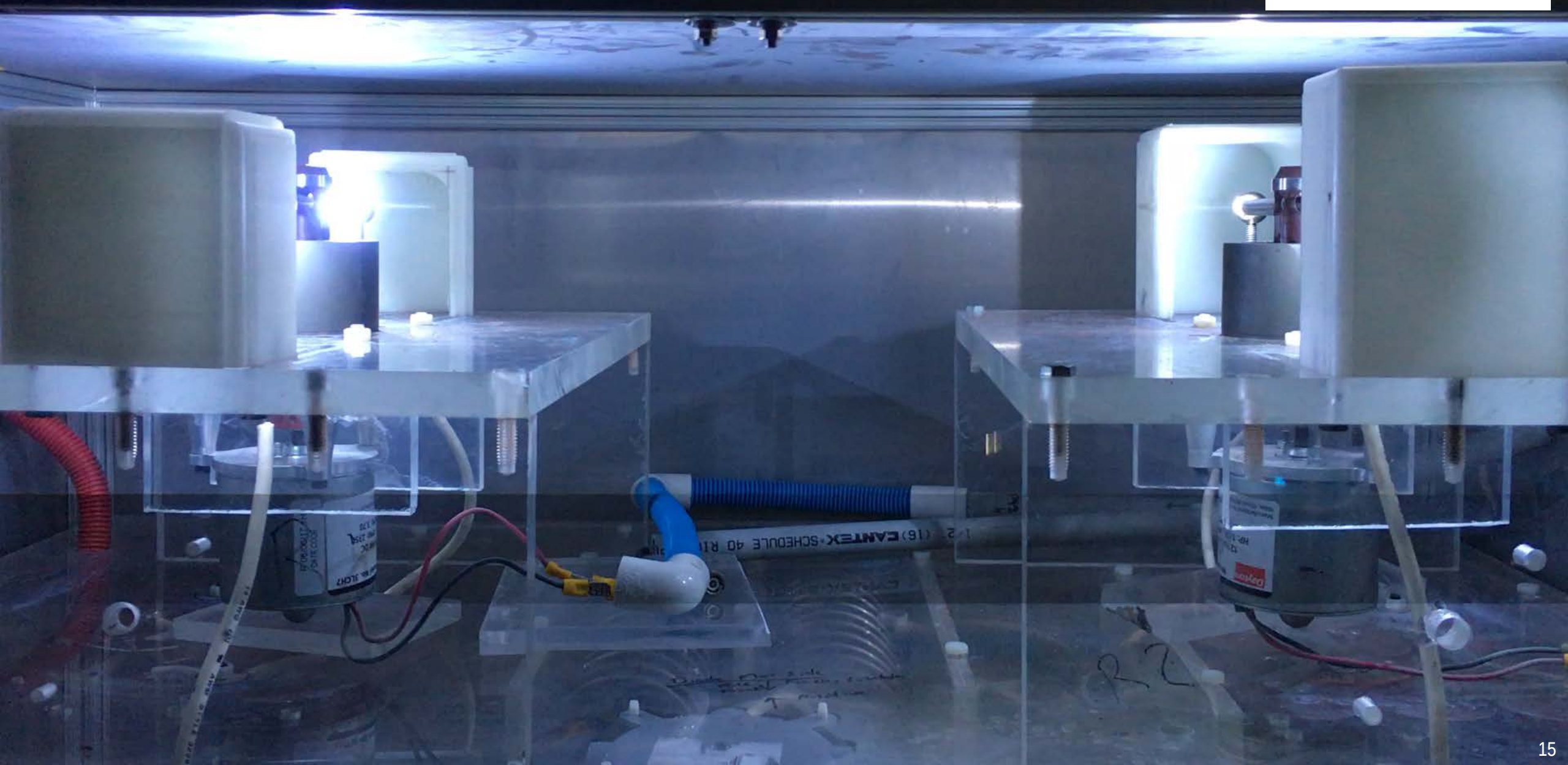


	Initial (ng/L)	Final (ng/L)
PFOS	1504	< 9
PFOA	208	< 9
PFHxS	1160	< 9
PFNA	72	< 9
PFNS	20	< 9



	Initial (ng/L)	Final (ng/L)
PFBA	140	106
PFBS	488	72
PFHpA	288	< 9
PFHxA	640	< 9
PFPeA	476	< 9
PFPeS	268	< 9

Video of the Plasma Trailer in Action!



TAKE HOME MESSAGES

- Plasma-based water treatment is an effective technology for the treatment of various sources PFAS-impacted water.
- Cost-effective relative to current treatment technologies and disposal methods
- Capable of treating a wide variety of compounds including PFAS, 1,4-Dioxane, and VOCs
- The plasma process requires no chemical additions and produces no residual waste
- Co-contaminants have no effect on the PFAS treatment efficiency
- The technology is highly scalable and is more efficient than leading alternative processes for treatment of PFAS-contaminated water

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