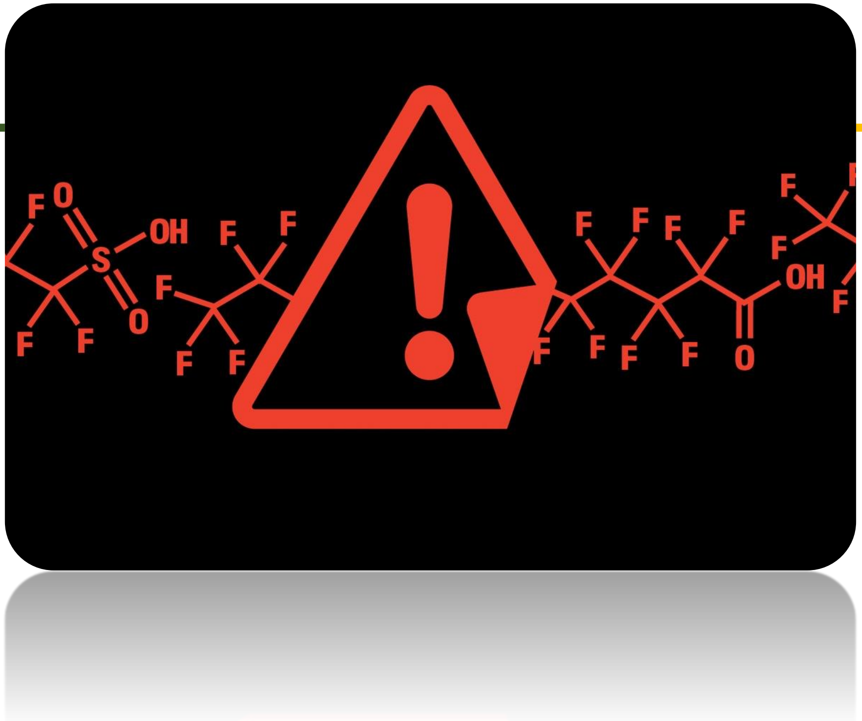


PFAS – the “Forever Chemicals”: Destructive Treatment Technologies

Clarkson
WALLACE H. COULTER
SCHOOL OF ENGINEERING

PFAS TREATMENT CHALLENGES

Several unique properties for environmental contaminants

- Strong C-F bond
- Low volatility
- Charged (high solubility)

EVALUATING DESTRUCTIVE TREATMENT TECHNOLOGIES

- Reactor conditions required
- Effectiveness
  - Chain-length dependence
  - Byproducts produced
  - Effluent treatment required
- Is there a compound specific concentration range (initial and final)
- Ability to scale-up
- Cost

For many technologies some of these are not fully known.

Lots of Advanced Oxidation Processes (AOPs) have been tried.

Most with limited success.

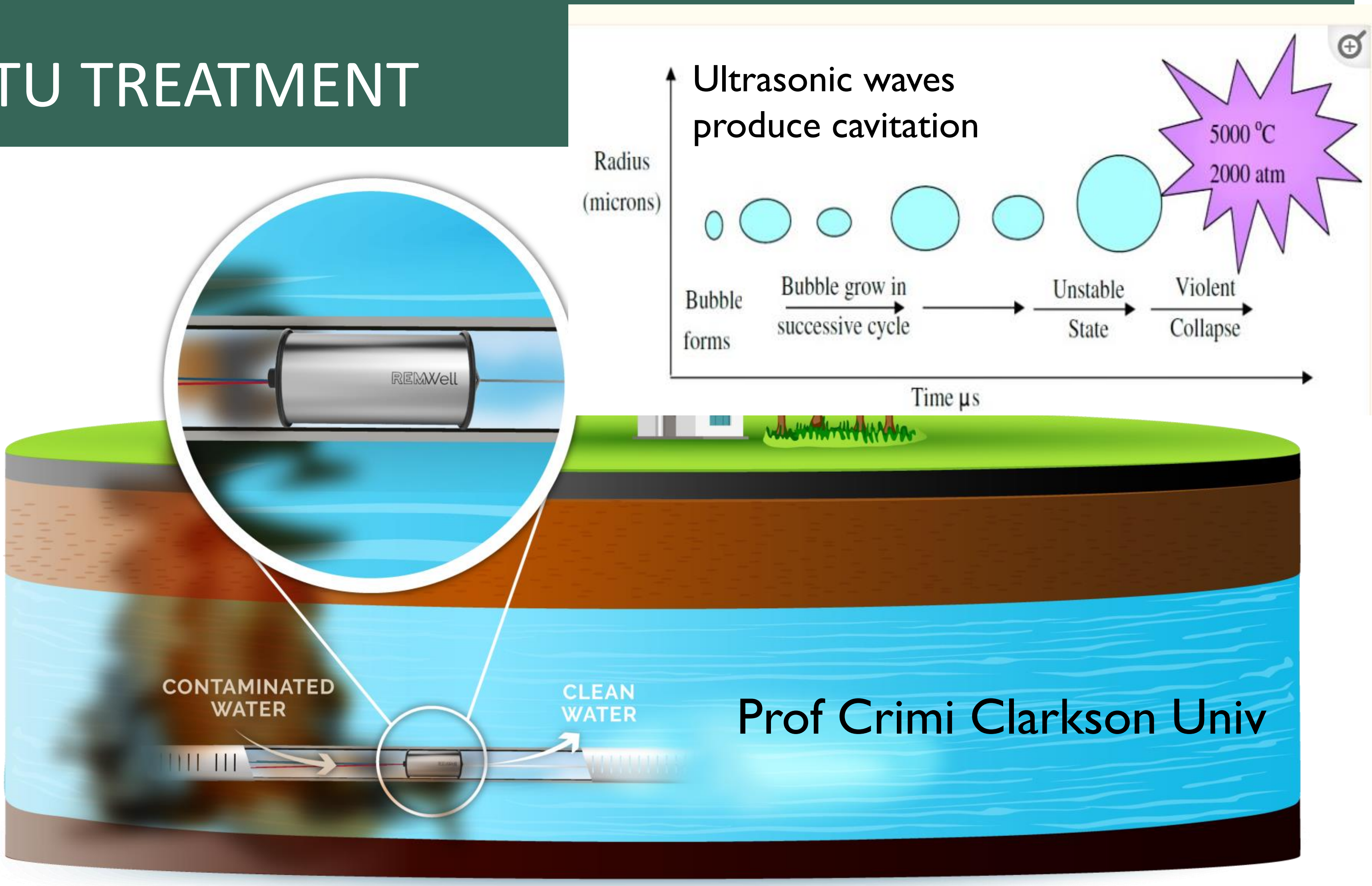
Need new approaches.

Oxidation Approach	Intermediates and Byproducts
Persulfate	F^-, PFPrA, PFHpA, PFHxA, PFPA PFPeA , PFBA,TFA
Permanganate	F^-, SO_4^{2-}
UV-Fenton	F^-, Formic acid, PFPrA, PFHpA, PFHeA, PFPeA , PFBA
Fe(III)	F^-, PFPrA, PFHpA, PFHeA, PFPeA
Ferrates	No observed F^-
Fe(III) and Oxalate	F^-, PFPrA , PFBA, PFPeA, PFHxA, PFHpA
Plasma	F^-, TFA PFPrA , PFBA, PFPeA, PFHxA, PFHpA, PFBS
UV-Pb-modified TiO_2	PFHpA , PFHeA, PFPrA, TFA PFPeA, PFBA
Sonolysis	PFHpA, PFHxA, PFPA, TFA and F^- ,PFHpS, PFHxS, PFOA
Photocatalysis with Inidium oxide	F^- ,PFHpA , PFHeA, PFPrA, PFPeA, PFBA
TiO_2 photocatalysis	PFHpA, PFHpA, PFPeA, PFBA
Environmental photolysis	PFBA, PFBS, PFOA
Electrochemical oxidation	F^-, TFA, PFPA, PFBA, PFPeA, PFHxA, PFHpA
Photolysis with persulfate	F^-,CO_2, SO_4^{2-} PFBA, PFPeA, PFHxA, PFHpA
Microwave hydrothermal decomp.	F^-,CO_2, PFBA, PFPeA, PFHxA, PFHpA, PFHeA

SONOLYSIS – IN SITU TREATMENT

- In situ sonolytic reactor for treatment of PFAS
- Undergoing field trials

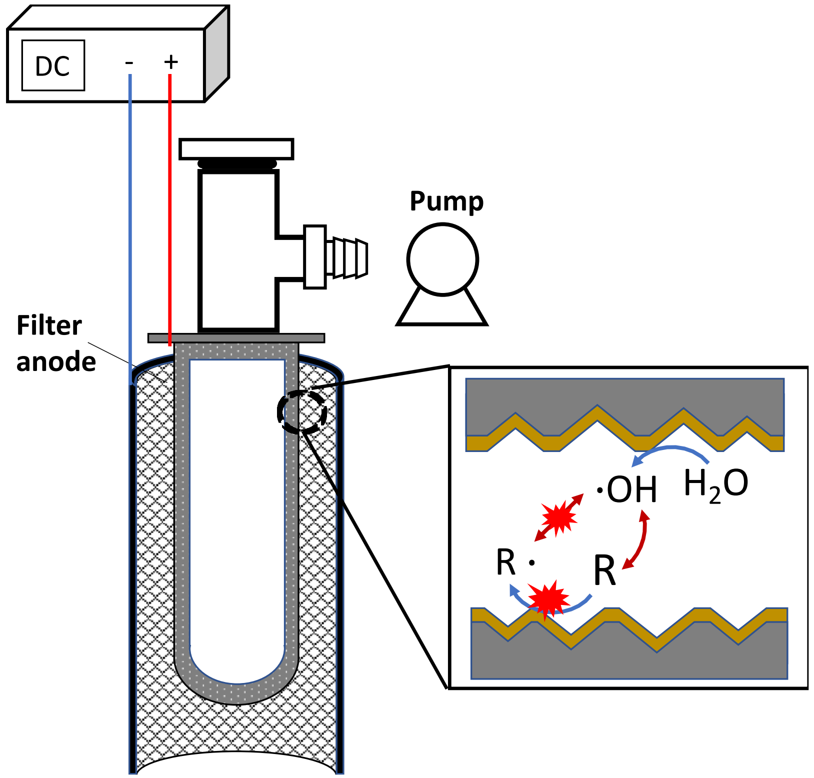
Not scalable for larger flowrates



Prof Crimi Clarkson Univ

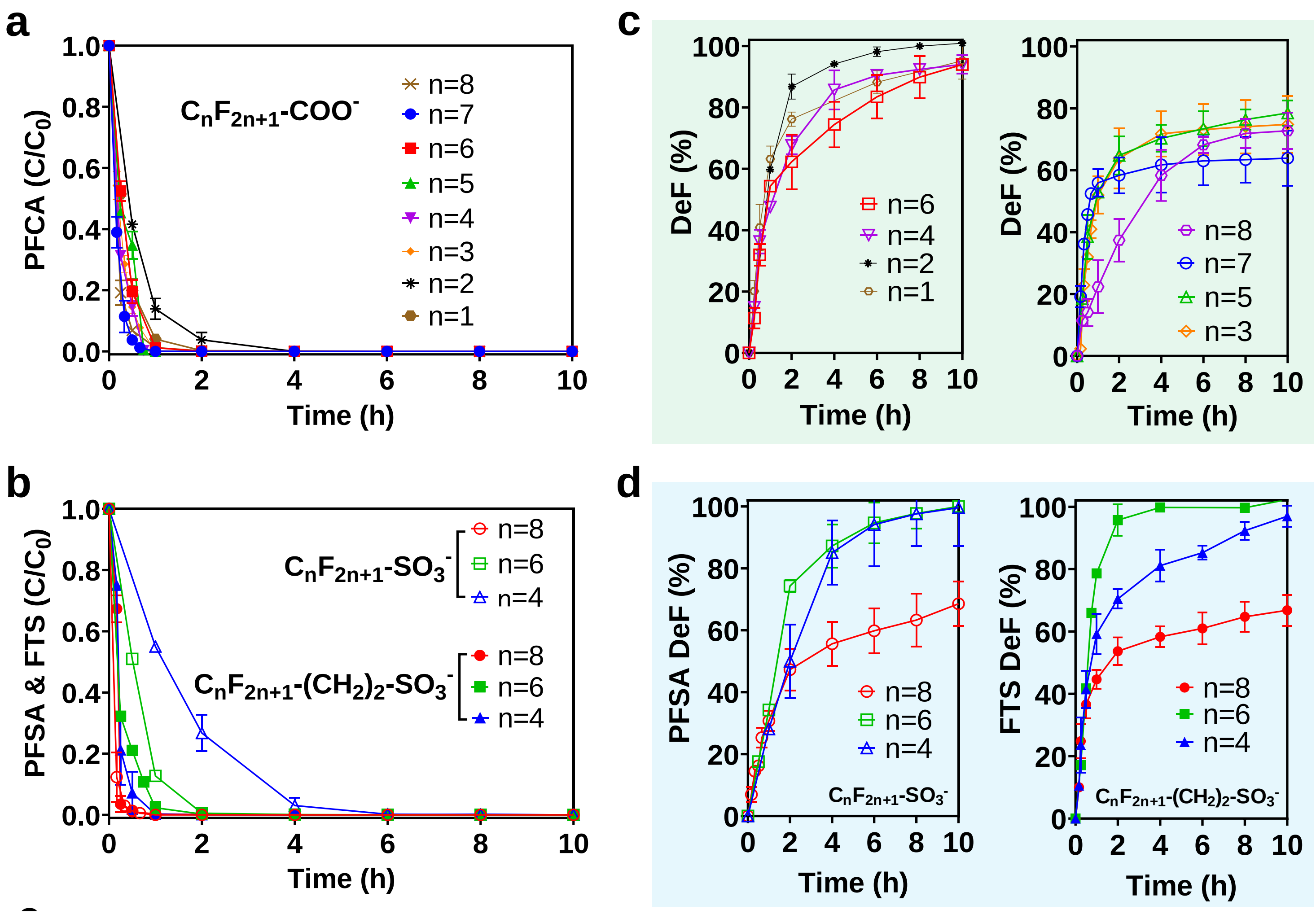
One start-up commercializing this technology

ELECTROCHEMICAL OXIDATION



Production of hydroxyl radicals using electricity

Prof Yang and Grimberg, Clarkson Univ



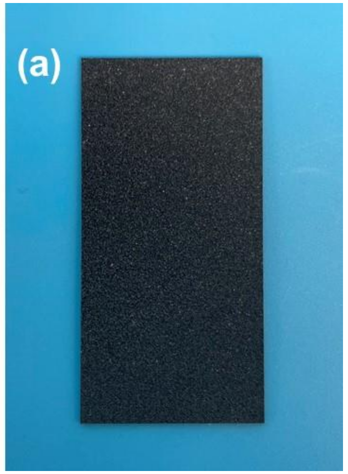
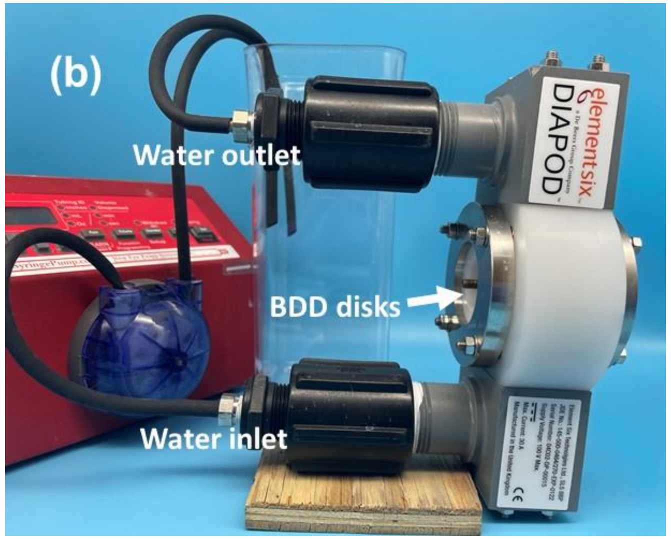


Plate-type electrode

750 mL reactor volume

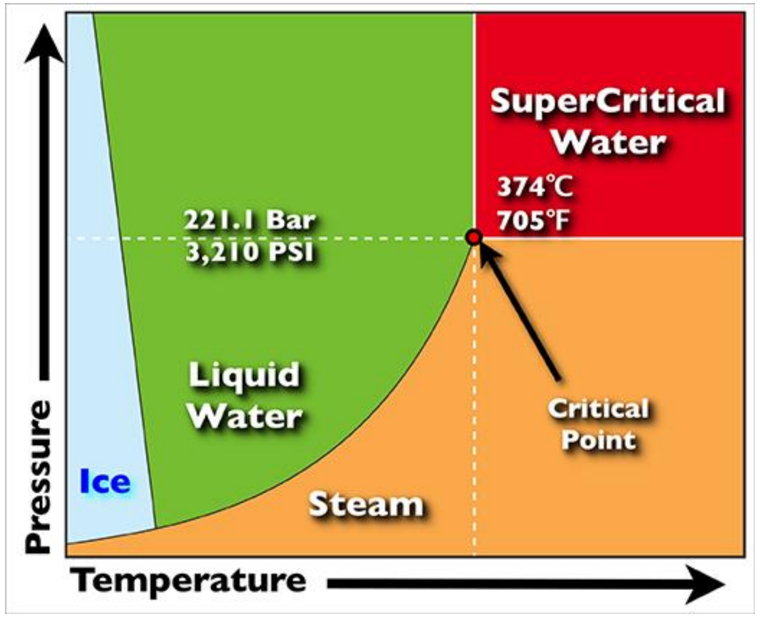


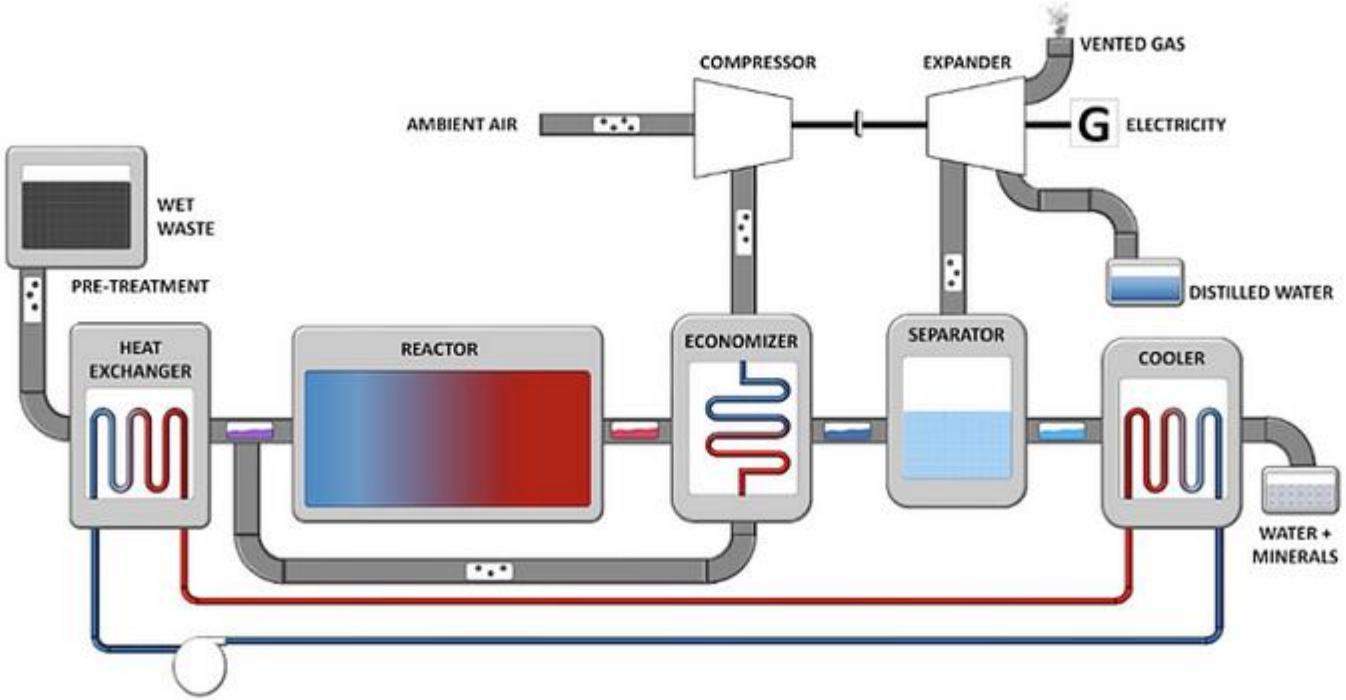
Flow-cell electrode

High defluorination efficiency, challenges with scale-up since surface contact is required, energy intensive, potentially toxic byproducts produced

(Manuscript under review)

SUPERCRITICAL WATER OXIDATION





Good removal, independent of chain length, susceptible to corrosion particularly if salts are present, pH adjustment and control needed, energy and infrastructure intensive

Several companies involved in commercializing this technology

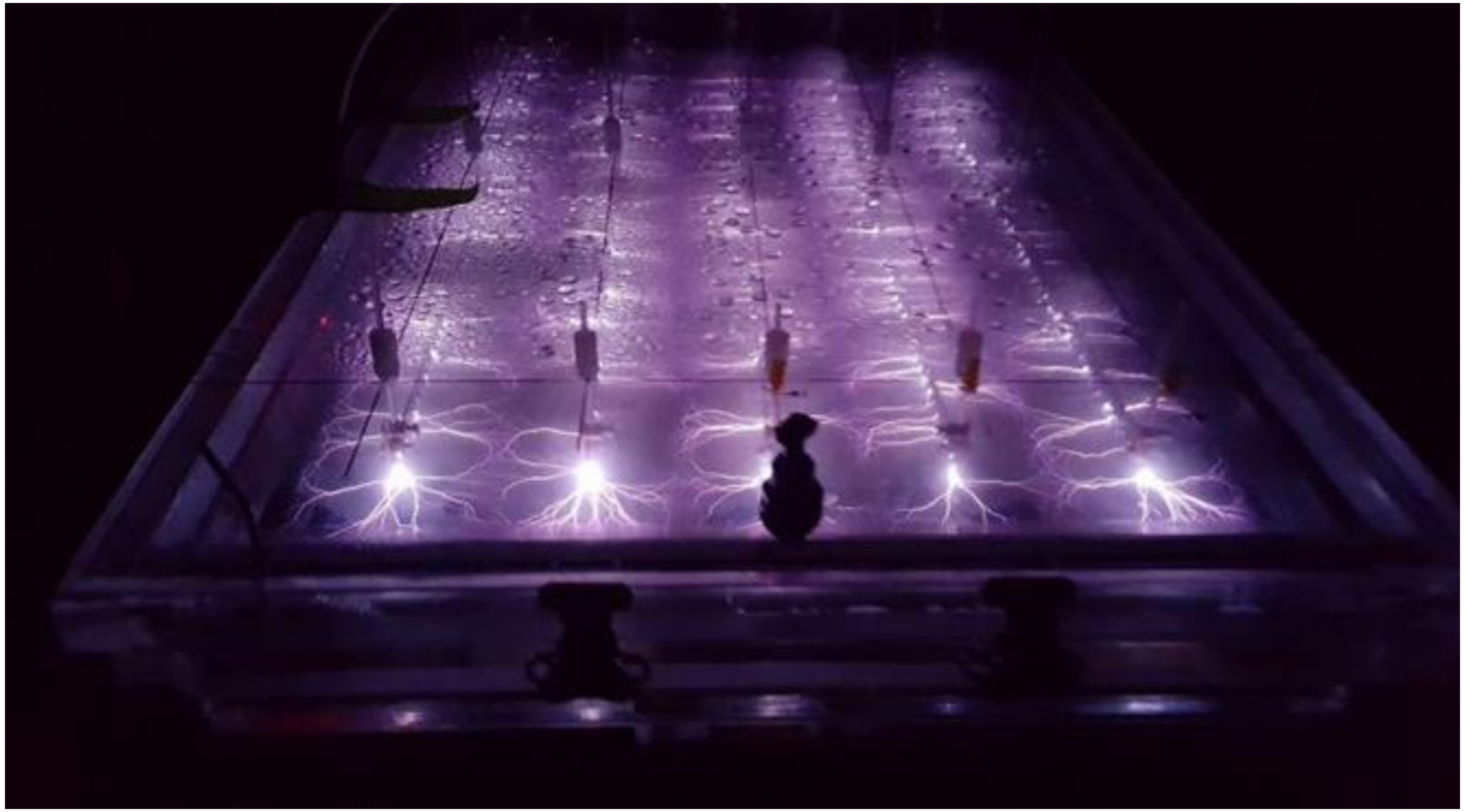
HYDROTHERMAL ALKALINE TREATMENT (HALT)

Requires alkaline amendment (typically sodium hydroxide [NaOH] to pH >14), high-pressure (~25 MPa) and high-temperature (~350 °C)

Chain length independent, few byproducts
Scale-up unknown
High pH effluent
Energy intensive

One start-up commercializing this technology

ENHANCED CONTACT PLASMA FOR PFAS DESTRUCTION



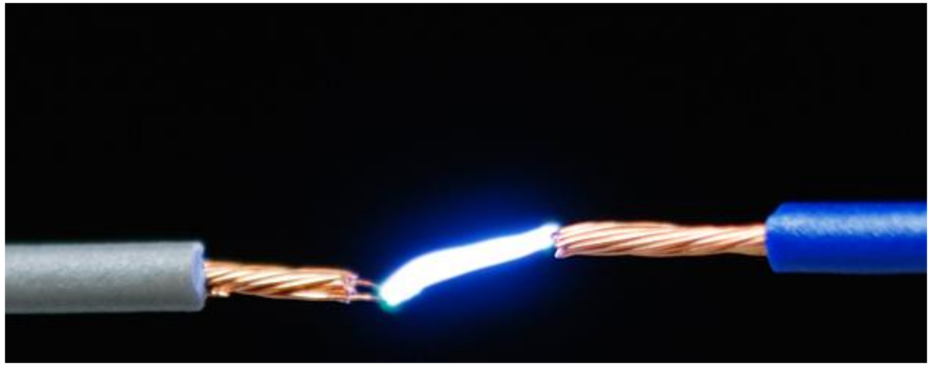
Professors Mededovic Thagard and Holsen

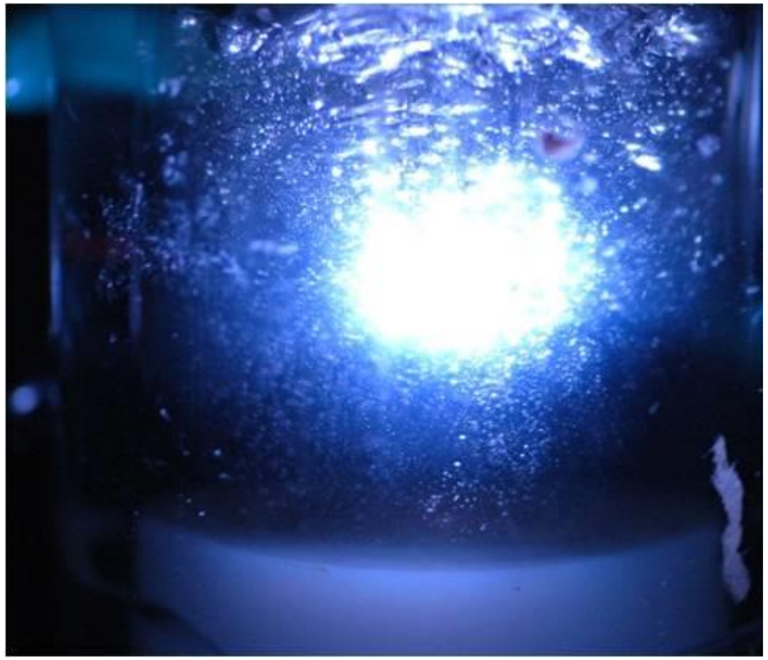
Start-up company DMAX Plasma Inc

Video of one of the plasma reactors in operation

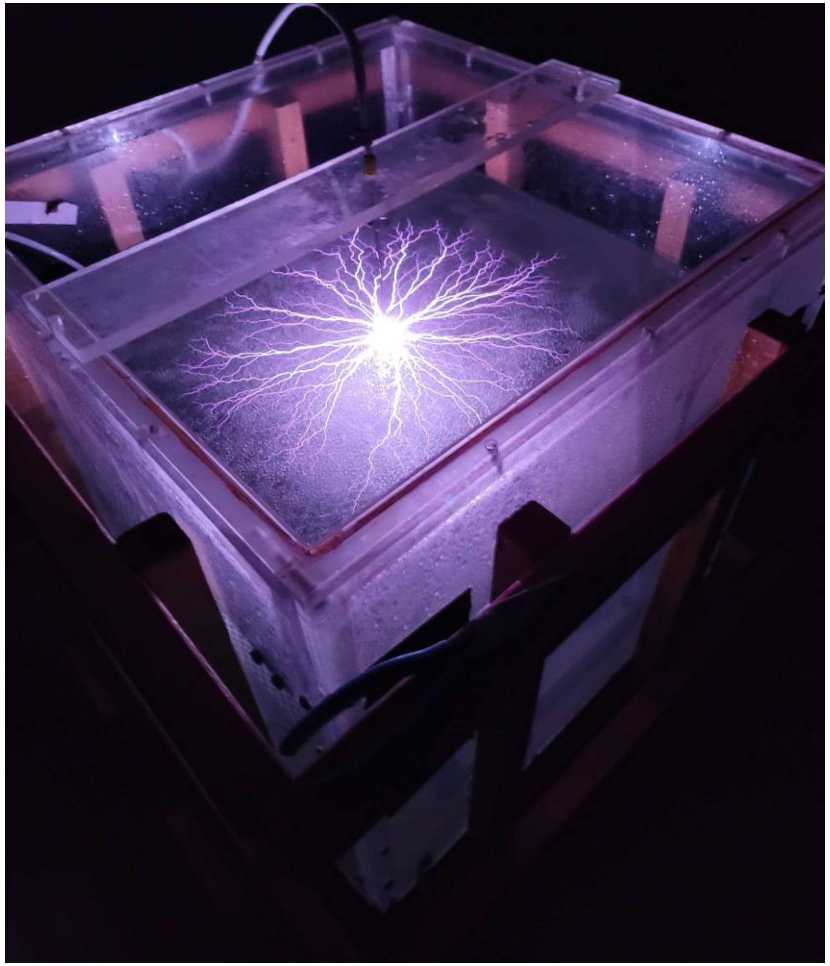
PLASMA

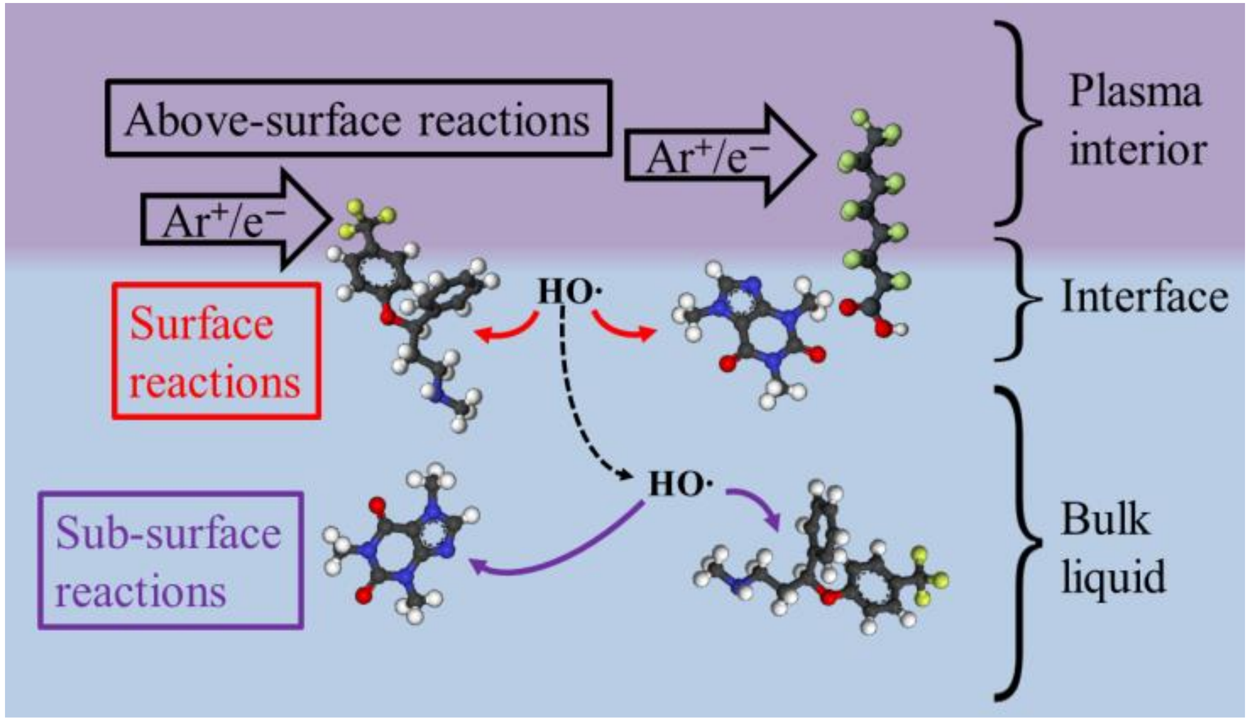
- Plasma is an ionized gas consisting of a quasi-neutral mixture of neutral species, positive ions, negative ions, and electrons.
- Plasmas are created by applying a potential difference between two metal electrodes. One of the electrodes can be immersed in a liquid.
- Plasma-based water treatment uses electricity to convert water into a mixture of highly reactive species (i.e., plasma) that rapidly and non-selectively degrade recalcitrant organic contaminants.





GAS-LIQUID REACTORS: THE BEST PERFORMING PLASMA TREATMENT SYSTEMS

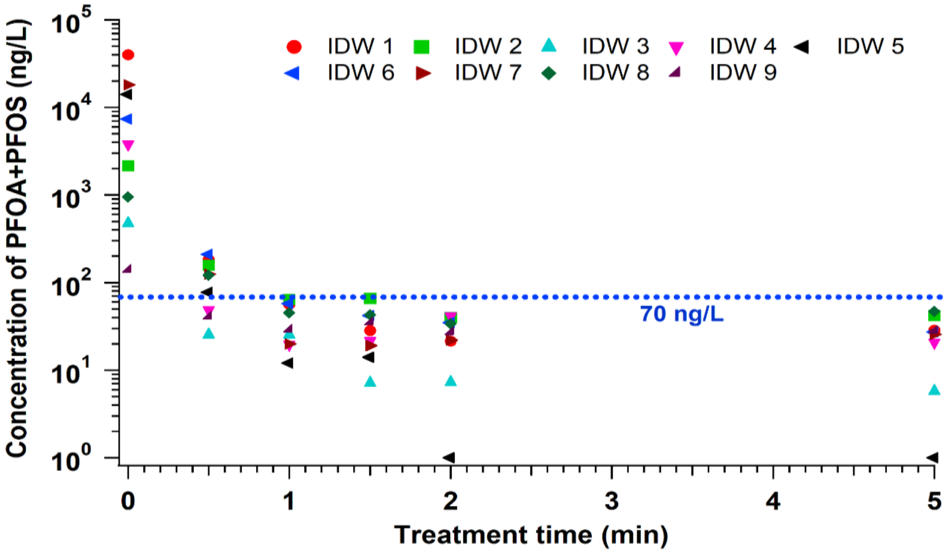




- Argon gas bubbles bring the PFAS to the gas-water interface near to where the plasma is generated (argon is recycled).
- Reductive species like solvated electrons and argon radicals play a key role in PFAS destruction (breaking the C-F bond).

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

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.



AFCEC funded project partnered with GSI Environmental

Removal of PFOA+PFOS to < 70 ng/L in 2 minutes

Several successful field trials treating 1000's of gallons each

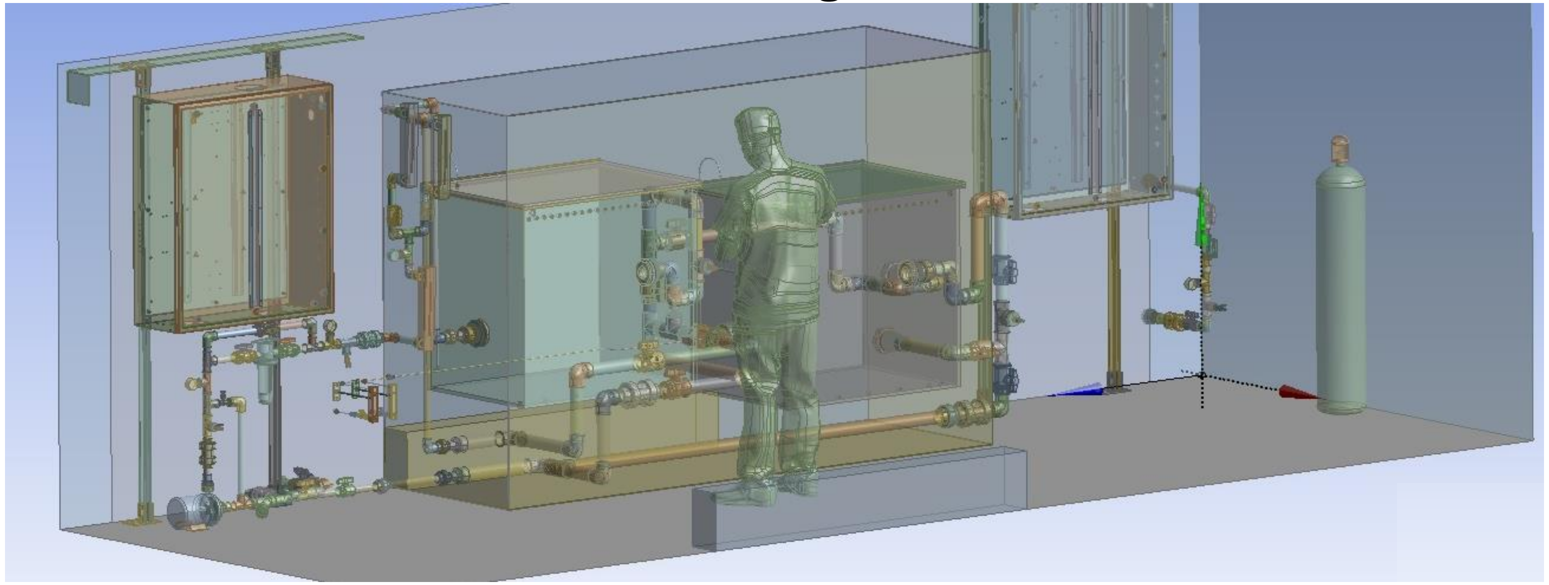
Short-chain removal slow – can be improved with the addition of a surfactant

Energy costs low – fractions of a penny/gallon

DMAX PLASMA ECo-PRe™

- ✓ ONLY field proven PFAS "Degradation and Destruction" solution
- ✓ Cost Effective – Low Energy & Operating Expense
- ✓ High Scalable Throughput
- ✓ Treat Any PFAS mix, Anywhere (mobile available)
- ✓ No Hazardous By-Products
- ✓ Safe & Durable Operation

DMAX Plasma 4th generation mobile treatment trailer



Newest trailer with automated controls

Treating membrane concentrate at Wright Patterson Air Force Base this week

QUESTIONS ABOUT DESTRUCTIVE TECHNOLOGIES

- Can you verify destruction with fluoride recovery? Are the compounds truly destroyed?
- What intermediates or byproducts may form?
- What impact do precursors have on mass balance?
- What is the energy cost?
- What are the implementation challenges?