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ATLANTIC CLRA | ACRSD

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A Summary of Best Available and Emerging Treatment Technologies for Treating Poly- and Perfluoroalkyl Substances

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November 9, 2016

Agenda

Background

Studied Technologies

Available/Commercial Technologies

Developing Technologies

Summary

Q&A

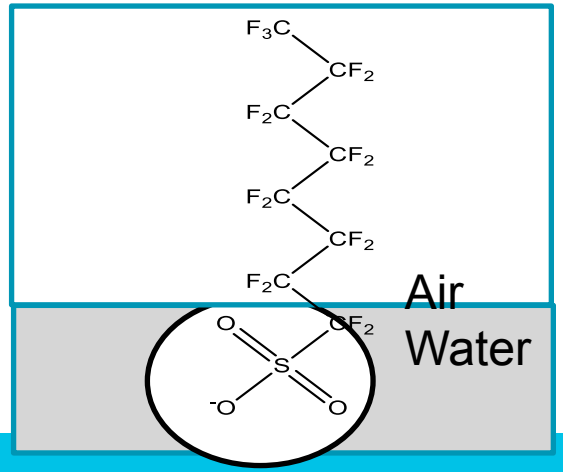
What are PFAS Compounds?

- Class of synthetic chemicals used in manufacturing fluoro-polymers
  - PFOA – perfluorooctanoic acid and its principle salts, manufactured from 1947-present, 8 manufacturers phased out production by 2015
  - PFOS – perfluorooctane sulfonate, manufactured from 1949-2002
- Used in many articles of commerce
  - Typically only a fraction of final product/not an end product
- Aqueous film forming foam (AFFF)

Unique Chemistry

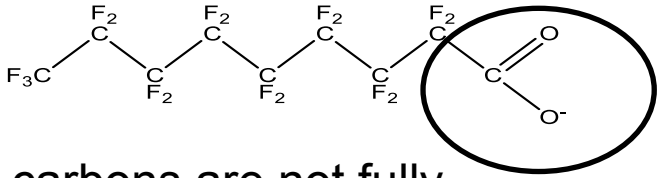
– C-F bond is the shortest and strongest bond in nature

– Few degradation processes: too much energy to break bonds
  - stable in acids, bases, oxidants, heat
  - microorganisms cannot gain energy from breaking the bond



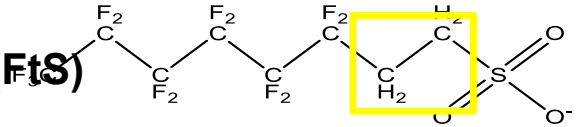
- Perfluorinated = all carbon atoms fully fluorinated (no hydrogen atoms)

PFOA (**per**fluorooctanoate)



- Polyfluorinated = some carbons are not fully fluorinated (have H)

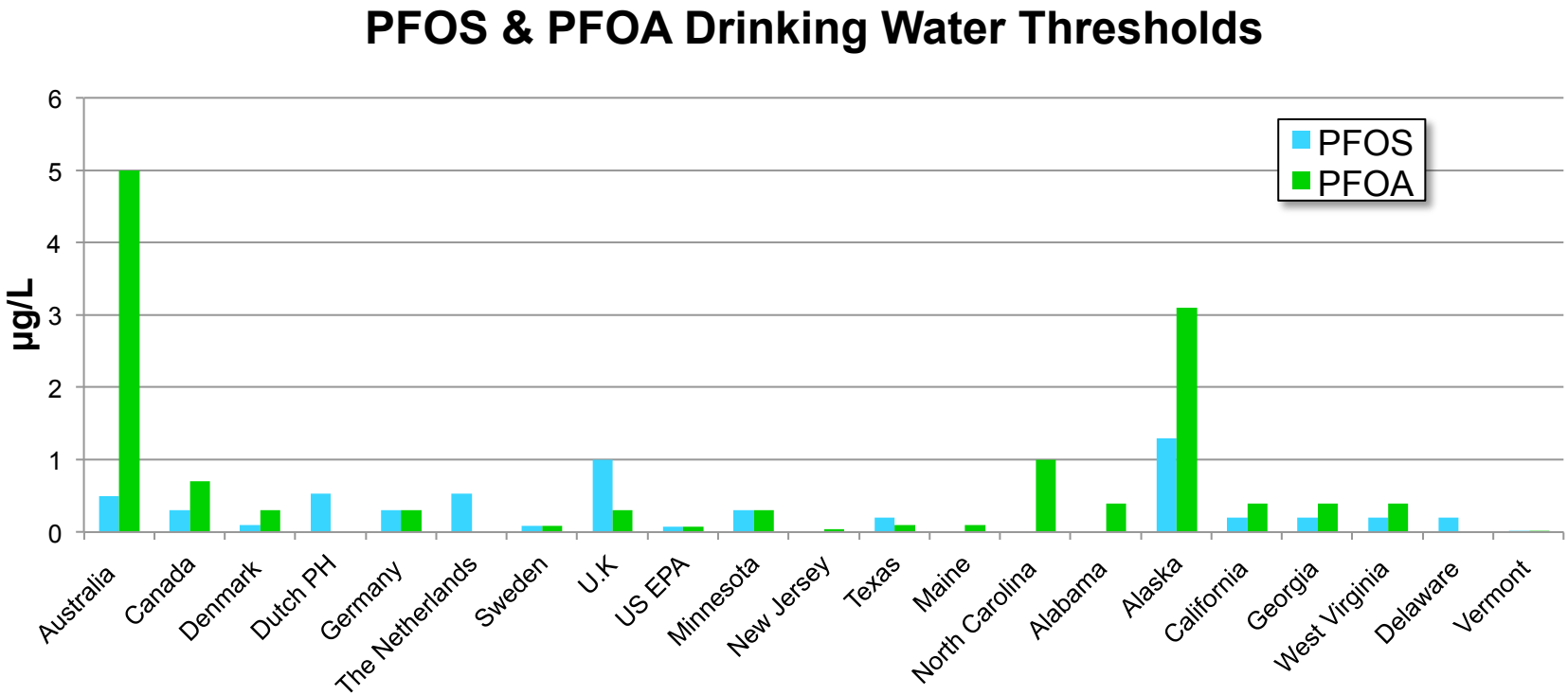
(*Poly*)**fluorotelomer sulfonate (FtS)**



PFAS Properties

Chemical Properties	PCB (Arochlor 1260)	PFOA	PFOS	TCE	Benzene
Molecular Weight	357.7	414.07	538	131.5	78.11
Solubility	0.0027 mg/L @24°C	**3400–9500 mg/L @25°C**	519 mg/L @20°C	1100 mg/L @ 20°C	1780 mg/L @20°C
Vapor Pressure (25°C)	4.05×10^{-5} mmHg	**0.5-10 mmHg**	**2.48×10^{-6} mmHg**	77.5 mmHg	97 mmHg
Henry's Constant	4.6×10^{-3} atm-m^3/mol	0.0908 atm-m^3/mol	**3.05×10^{-6} atm-m^3/mol**	0.0103 atm-m^3/mol	0.0056 atm-m^3/mol
Organic Carbon Part. Coeff. (Log K_{oc})	4.8-6.8	2.06	**2.57**	2.42	2.15

Global Variability in Regulatory Values



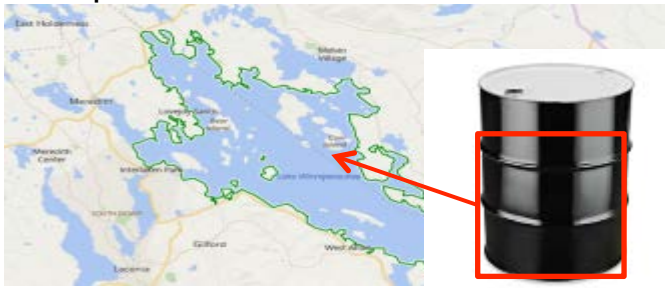
US EPA Lifetime Drinking Water Health Advisories

- 5/19/16 EPA Lifetime Drinking Water Health Advisories
  - 70 parts per trillion PFOS, PFOA, PFOS+PFOA
- Not promulgated/enforceable standards
- 70 ppt = 70/1,000,000,000,000

~ 2 teaspoons in 30,000 gal backyard pool

A Sense of Scale

~44 gallons into 625 billion gallon Lake Winnipesaukee



World Population = 7.4 billion
~ 1 person / 2 world populations

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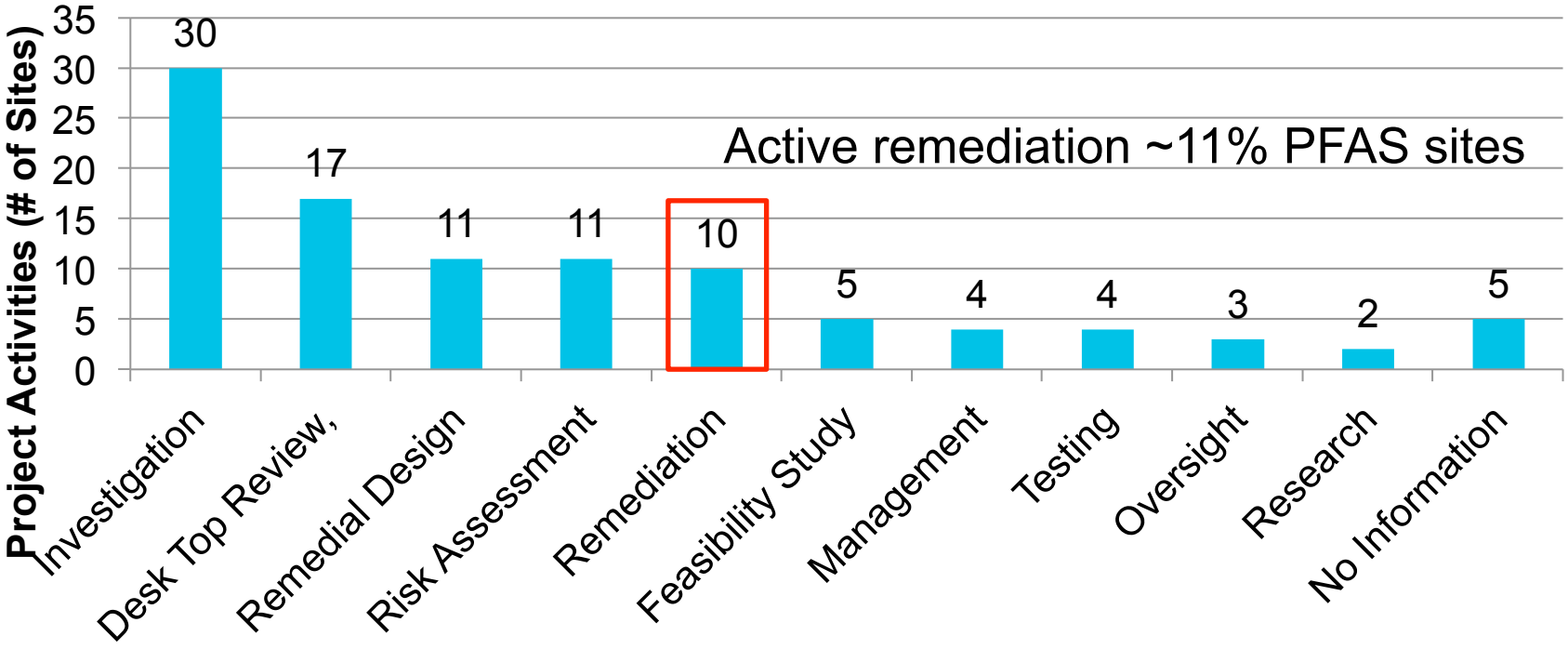
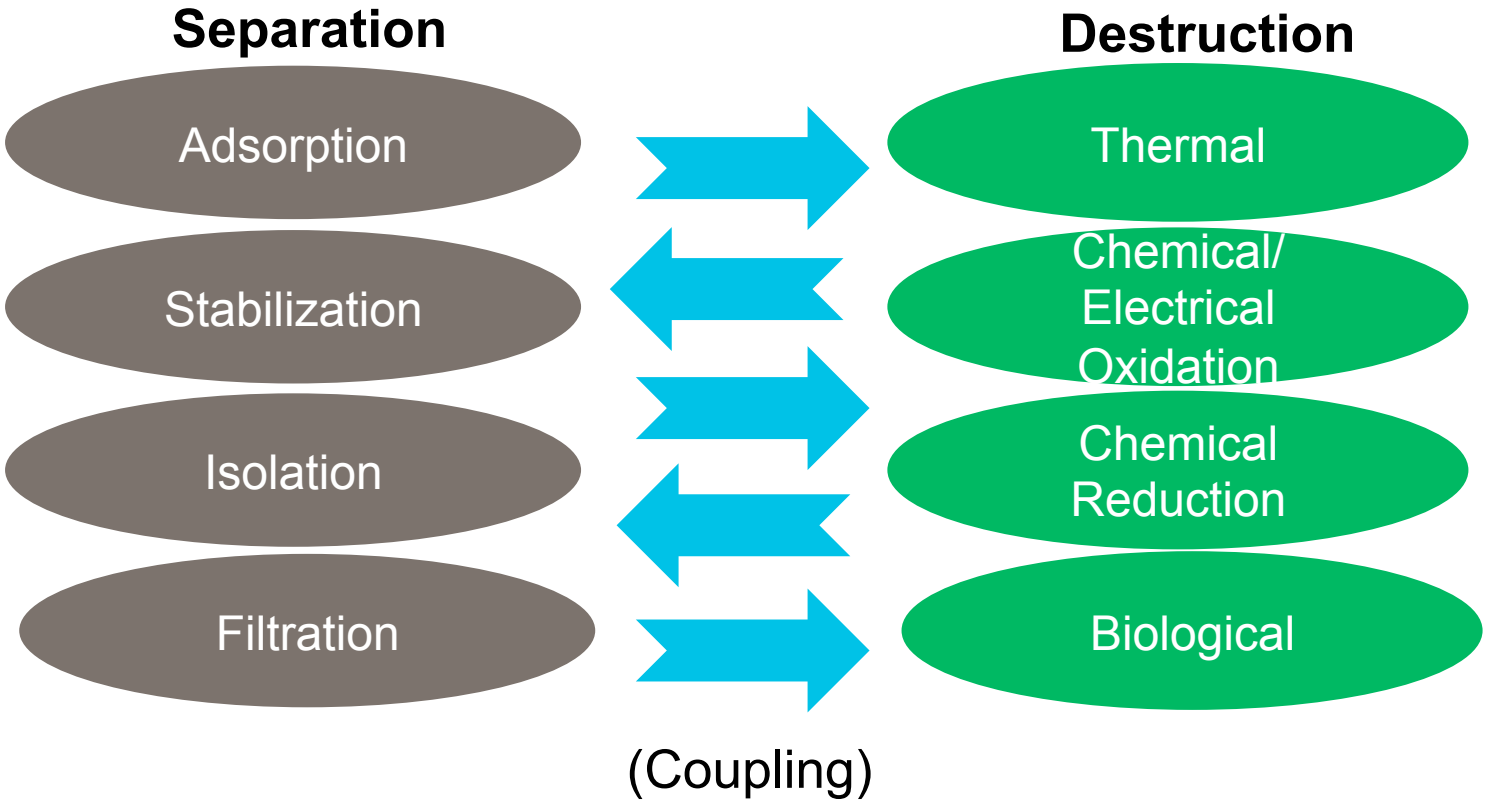
85 PFAS Sites Under Different Project Stages (AECOM, 2015)



Updated Evaluation of ~165 Sites in progress

Treatment Technology Approaches



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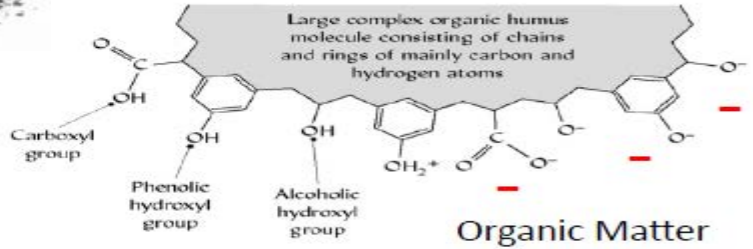
Short List of Technologies that Have Been Studied

Ex-Situ		In-Situ
GAC RemBind Ion Exchange Resin Modified Zeolites Coagulation/Electrocoagulation Reverse Osmosis Nano-/Ultra- Membrane Filtration	Separation	Isolation (e.g., capping) PlumeStop Phytoremediation
Thermal Oxidation Advanced Oxidation Sonochemistry Electrochemical	Destruction	Chemical Oxidation Chemical Reduction Microbial biodegradation Fungal Degradation Enzymatic Catalyzed Oxidation

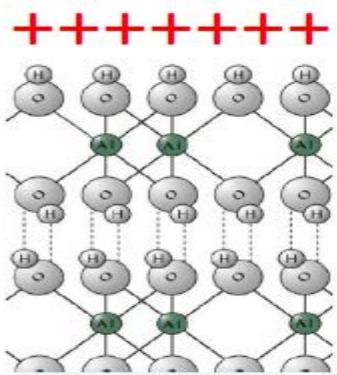
Full Scale Soil Treatment - RemBind®

Electrostatic interactions



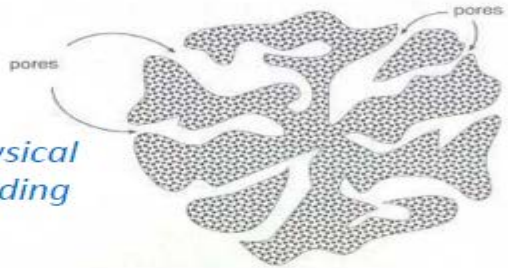
Organic Matter

Point of zero charge > pH 7.7



Aluminium Hydroxide (Amorphous)

Hydrophobic Interactions



Physical Binding

Van der Waals

Activated Carbon

ziltek

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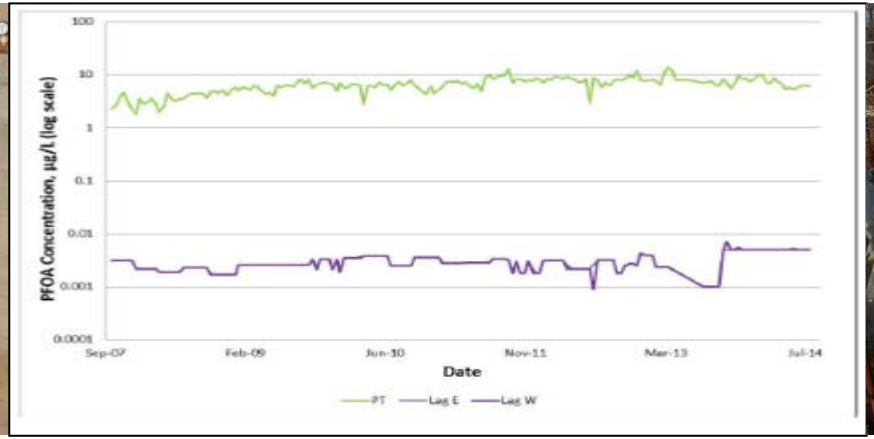
Full-Scale GAC Treatment for PFOA

- Remedial decision based on detailed CSM, EPC determination and annual average PFOA intake by the residents
- GAC is proven effective for PFOA treatment
- Probably not as effective for short chain PFAS

150 Private GAC Systems



Full-scale PFOA GAC Treatment System

9 Public Water Supply GAC Systems

Ion Exchange Resin for PFAS

- Synthetic resins remove various contaminants from liquids, vapor or atmospheric streams
- Combined ion exchange/adsorption mechanism
- Potential for indefinite reuse via regeneration
- Regeneration with solvent-brine solution
  - High concentration salt dislodges PFAS molecules
  - High concentration solvent desorbs PFAS molecules
  - Waste disposal – high PFAS in solvent, brine paste
- Advantage over GAC – effective on short chain PFASs that are of increasing potential concern

Technologies/Innovation Development by AECOM

- Introducing the concept of “ambient/background” levels into the current and future debates on PFAS
- Plant uptakes of PFAS
- New low-cost sorbents
- Optimize GAC effectiveness
- New PFAS destruction technologies

Enzyme Catalyzed Oxidative Coupling

- Enzyme Catalyzed Oxidative Coupling (ECOC) is a process inspired by how natural organic matters are broken down naturally through enzyme catalyzed oxidation process
- ECOC to treat PFASs was originally developed for treatment of other persistent organics (PCBs, PAHs)
- White rot fungi are unable to survive in subsurface, not applicable for in-situ remediation, but fungi-produced enzyme can be concentrated and engineered for remediation
- Common enzymes:
  - Lignolytic enzymes
    - Peroxidases
    - Phenoloxidases
    - Laccase

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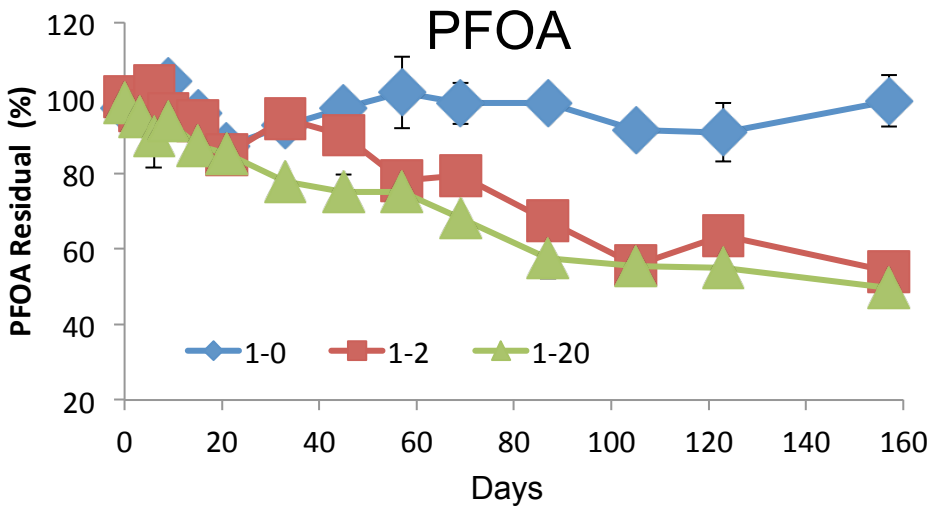
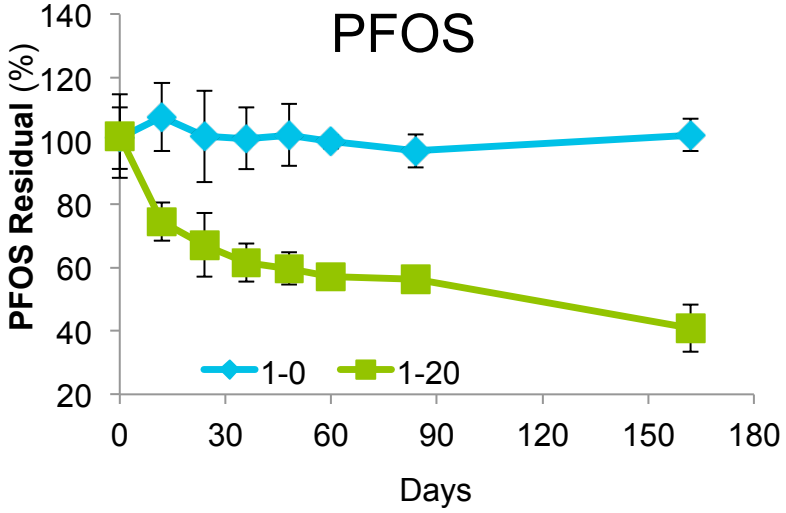
Enzyme Catalyzed Oxidative Coupling





ENVIRONMENTAL Science & Technology LETTERS
Letter
pubs.acs.org/journal/estlcu

Laccase-Catalyzed Degradation of Perfluorooctanoic Acid

Qi Luo,[†] Junhe Lu,[‡] Hao Zhang,[§] Zunyao Wang,[∥] Mingbao Feng,[∥] Sheau-Yun Dora Chiang,[⊥] David Woodward,[#] and Qingguo Huang[*,†]

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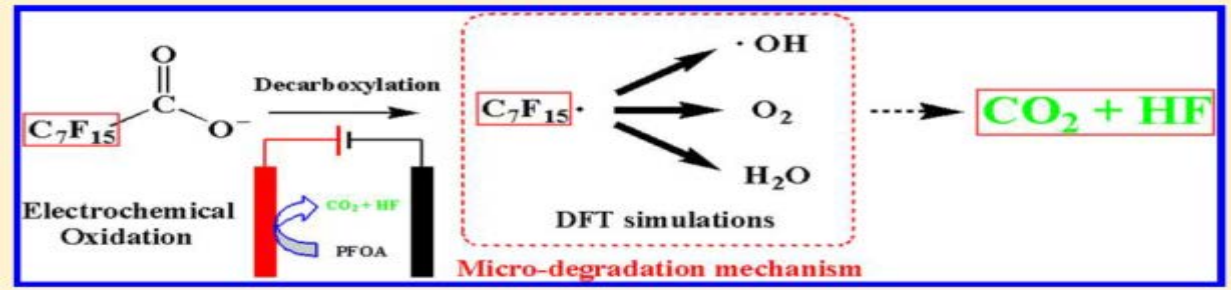
Electrical Oxidation



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– Electrodes
  - SnO_2
  - $Sb\text{-}SnO_2$
  - PbO_2
  - $Ce\text{-}PbO_2$

  Not effective for PFOS
  - Ti/RuO_2
  - Boron Doped Diamond (BDD) – Effective for PFOS and PFOA, but results are not consistent or repeatable, not cost effective for scale up applications
  - Electrode T – Effective for PFOS/PFOA, cost effective scale-up applications available

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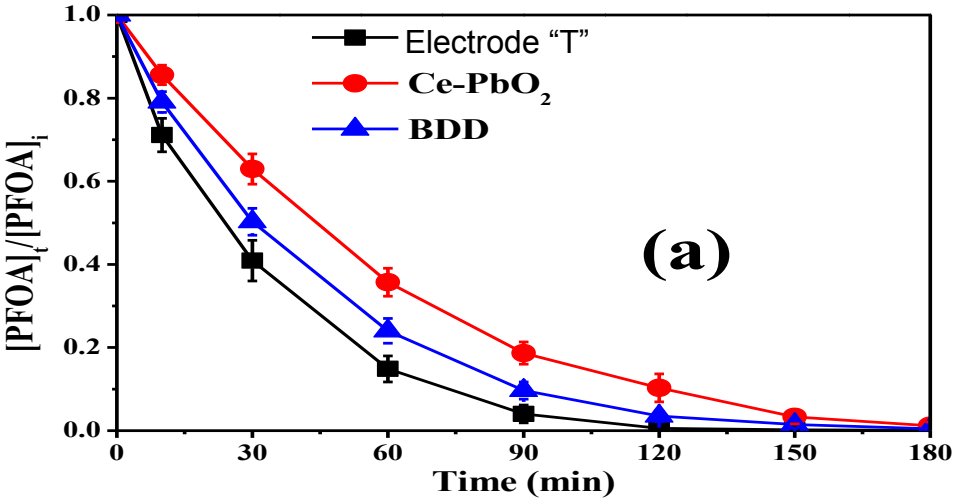
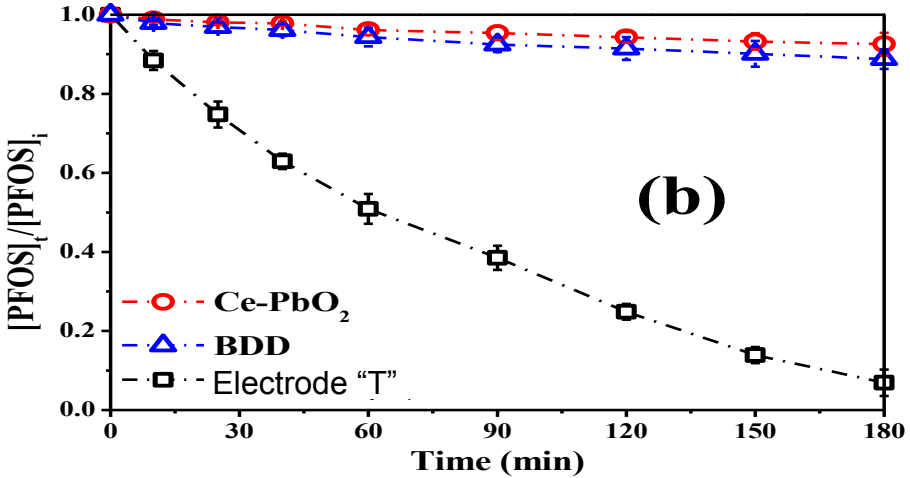
Electrode “T” for Destruction of PFOA and PFOS in Water

PFOA



PFOS



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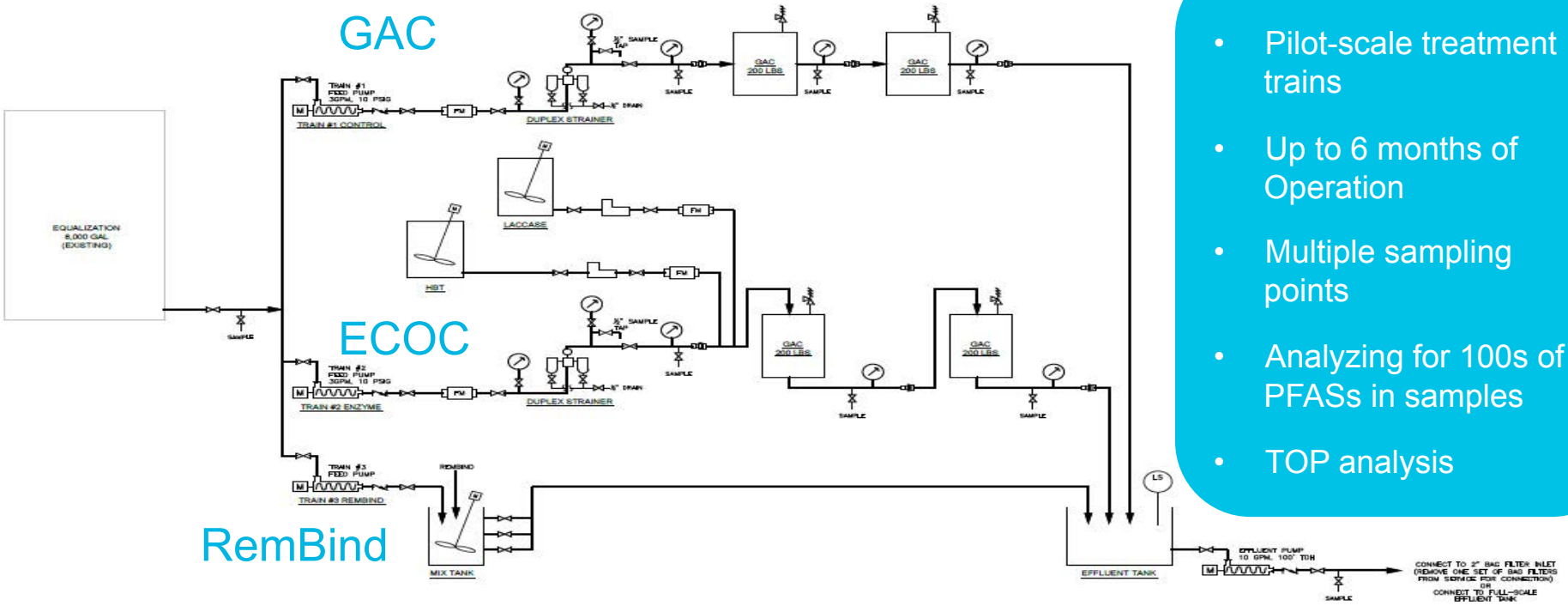
Pilot Testing Multiple Technologies – AFFF Impacted Site



- Pilot-scale treatment trains
- Up to 6 months of Operation
- Multiple sampling points
- Analyzing for 100s of PFASs in samples
- TOP analysis

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Summary – Take Home

- PFASs are soluble, recalcitrant and may form large dilute plumes
- Rapidly evolving science & regulatory environment
- Limited commercially available/demonstrated technologies
- Stabilization, capping or excavation/disposal are best soil options
- GAC or Ion exchange resins are best water options
- Significant R&D ongoing – promising and challenging
- PFAS Water treatment success will likely be ex-situ and require expensive treatment trains and long term pump and treat

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Thank You!

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