OBJECTIVES:

- Summarize the challenges associated with treatment of PFAS-contaminated soil and groundwater
- Introduce potential viable PFAS remediation approaches
INTRODUCTION

- Perfluorinated Compounds
  - Perfluorinated alkyl acids (PFAAs)
    - PFOA, PFOS
    - PFBA, PFBS
    - PFHxDA, PFHxDA
  - Intermediates or Precursors
    - N-MeFOSE
    - N-EtFOSE
    - 6:2 FTS
  - Range of properties with chain length and functional group(s) – hydrophobicity, electrostatic, reactivity

<table>
<thead>
<tr>
<th>Guidelines (ng/L), EPA 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFOA</td>
</tr>
<tr>
<td>PFOS</td>
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</tbody>
</table>
### INTRODUCTION

<table>
<thead>
<tr>
<th></th>
<th>Formula</th>
<th>Vapor Pressure</th>
<th>Aqueous Solubility</th>
<th>Log $K_{oc}$</th>
<th>Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFOA</strong></td>
<td>$C_8HF_{15}O_2$</td>
<td>0.1 kPa (20°C) 10 mm Hg (25°C)</td>
<td>4.1 g/L (22°C) 9.5 g/L (25°C)</td>
<td>2.06</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>PFOS</strong></td>
<td>$C_8F_{17}SO_3^-$</td>
<td>3.31 x 10⁴ Pa at 20°C</td>
<td>570 mg/L</td>
<td>2.57</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>PFHxS</strong></td>
<td>$C_6F_{13}SO_3$</td>
<td>0.61Pa (25°C)ES</td>
<td>6.2 mg/LES 22 mg/LES</td>
<td>3.5ES</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>PFBS</strong></td>
<td>$C_4F_9SO_3$</td>
<td>0.29 mm Hg at 20°C</td>
<td>8900 mg/LES 344mg/LES</td>
<td>2.2ES 1.9ES</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>6:2 FTS</strong></td>
<td>$F(CF_2)_{6}CH_2CH_2SO_3^-$</td>
<td>0.115Pa(25°C)ES 0.00086 mm Hg (25°C)ES</td>
<td>11 mg/LES 2mg/LES</td>
<td>4.0ES</td>
<td>Biodegradable under specific conditions</td>
</tr>
</tbody>
</table>

ES = estimated from EPISuite (U.S. EPA http://www.epa.gov/opptintr/exposure/pubs/episuite.htm)
REMEDIATION OPTIONS

- Excavation → Incineration
  - Expensive
  - Contaminants must be treated off site
- Immobilization/Stabilization
- Filtration
  - Nanofiltration
  - Reverse Osmosis
- Sorption
  - Granular Activated Carbon (GAC)
  - Carbon nanotubes
  - Biomaterials
- Ion Exchange
  - Resins
  - Mineral materials (e.g., zeolites)
  - Polymers
- Precipitation/Flocculation/Coagulation
- Oxidation/Reduction
  - Chemical oxidation
  - Electrochemical, sonochemical, and photochemical
  - Plasma
  - Customized reductants

TREATMENT TRAINS and COMBINED REMEDIES!
SORPTION BY GAC
SORPTION – GAC

Sorption under site-specific conditions…
ION EXCHANGE
Sustainable Removal of Poly- and Perfluorinated Alkyl Substances (PFAS) from Groundwater Using Synthetic Media

Nathan Hagelin, Amec Foster Wheeler; Steve Woodard, ECT

Media Selection

- Synthetic media (resins) removes various contaminants from liquids, vapor or atmospheric streams
- Isotherm testing to identify potentially effective media
- Potential for indefinite reuse via regeneration

Adsorption and Regeneration of Leading Resins from Column Testing

![Graph showing PFAS Mass Delivered, PFAS Mass Removed, and PFAS Mass Recovered for Resins A, B, and C]
REDOX MANIPULATION

- Sonolytic
- Electrochemical
- Chemical Oxidation and Reduction
- Plasma
- Combinations...
Plasma-based water treatment: Efficient transformation of perfluoroalkyl substances (PFASs) in prepared solutions and contaminated groundwater

Bench-scale enhanced contact plasma reactor

Plasma produces aqueous electrons and H radicals which are capable of chemically degrading PFASs


Major byproducts: fluoride ions, fluorinated gases and shorter-chain PFAs
CHALLENGES AND LIMITATIONS

- Mixtures, precursors, co-contaminants
- Managing materials
  - Sorption
  - Sludge
- Incomplete mineralization
- Energy intensity
- Technical challenges to *in situ* treatment
- Limited field-scale examples
OBJECTIVE: Improve understanding of the similarities and gaps between state of the science and the state of the practice of managing PFAS sites

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