# Treatment Technologies for PFAS in Soil and Water

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# Learning Objectives

- Technologies commercially available for the treatment of PFAS in soil and water
- Innovative technologies for the treatment of PFAS in soil and water
- Highlights of each technology
- Advantages/disadvantages and limitations of each technology
- Economics and costs

# Soil Treatment Technologies for PFAS Available Now

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# Soil Technologies

- Capping
- Excavation with offsite disposal
- Excavation with offsite incineration
- Stabilization/sorption
  - Combination of Activated Carbon and other additives*
  - Activated carbon, activated alumina, kaolin clay
  - Added 5% by weight to soil
  - Fully commercial & demonstrated in Australia

Photo courtesy of: Tersus Environmental, LLC

*RemBind® by Ziltek™ distributed by Tersus Environmental in the US

# Stabilization/Sorption

## How Does it Work?

- Powdered reagent binds to organic contaminants in soil/water to prevent PFAS leaching
- Chemical fixation or immobilization
- Large surface area with mixed charges
- Binds to range of contaminants including TPH, PAH, as well as PFAS

Rembind™ distributed under US Patent 8,940,958 by Tersus Environmental, LLC; Image courtesy of Environmental, LLC

# Sorption in Soil

## In-Situ Example

- Powdered activated carbon (PAC) with a biopolymer
- Widely demonstrated for VOCs
- Can be installed as a treatment barrier
- First several monitoring events positive (show PFAS declining)
- Modeling predicts plume detachment and PFAS retention for > 100 years

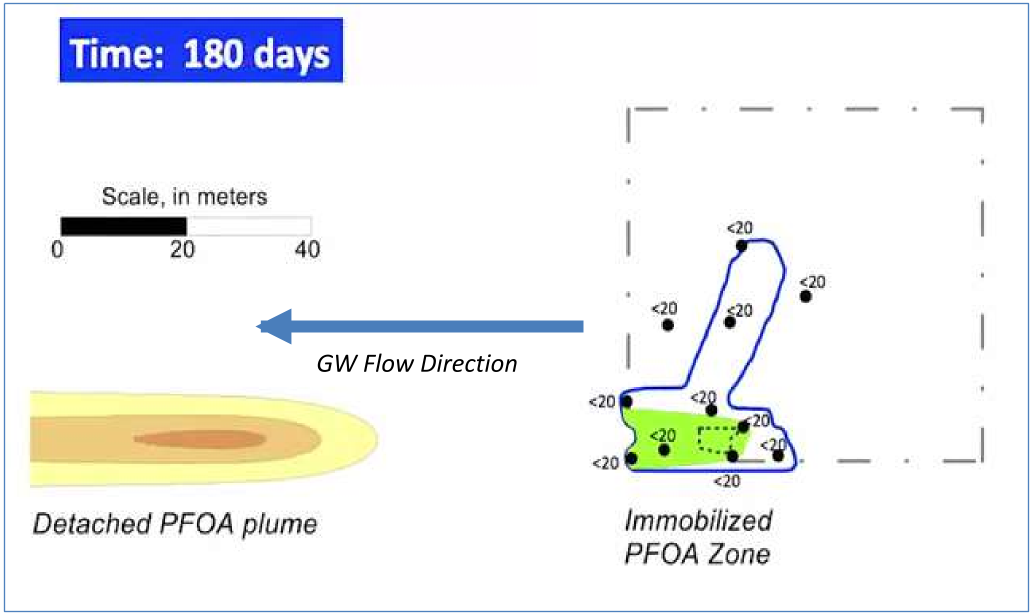



Figure and data on PlumeStop™ courtesy of Regenesis, Inc.

# Water Treatment Technologies for PFAS Available Now

# Water Treatment Overview

- Ineffective conventional approaches:
  - Air stripping
  - Air sparging
- "Marginally Effective"
  - Bioremediation
  - Chemical reduction (e.g., zero valent iron)
  - Chemical oxidation
- Effective conventional approaches, with limitations:
  - Carbon adsorption
  - Resin adsorption

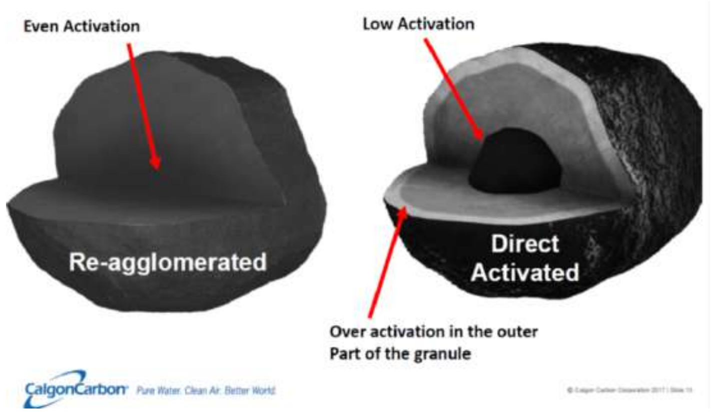
# Carbon Adsorption

- GAC less effective for short chain PFAS
- PFAS 80x less adsorptive than PFOS

Photo courtesy of Jenelle Brewer, Calgon Carbon Corp.

# Carbon Adsorption

- Granular Activated Carbon is the most widely used technology
- Bituminous coal-based GAC out-performs coconut based GAC
- GAC less effective for short chain PFAS
- GAC less effective for PFCAs than PFAS of same chain length

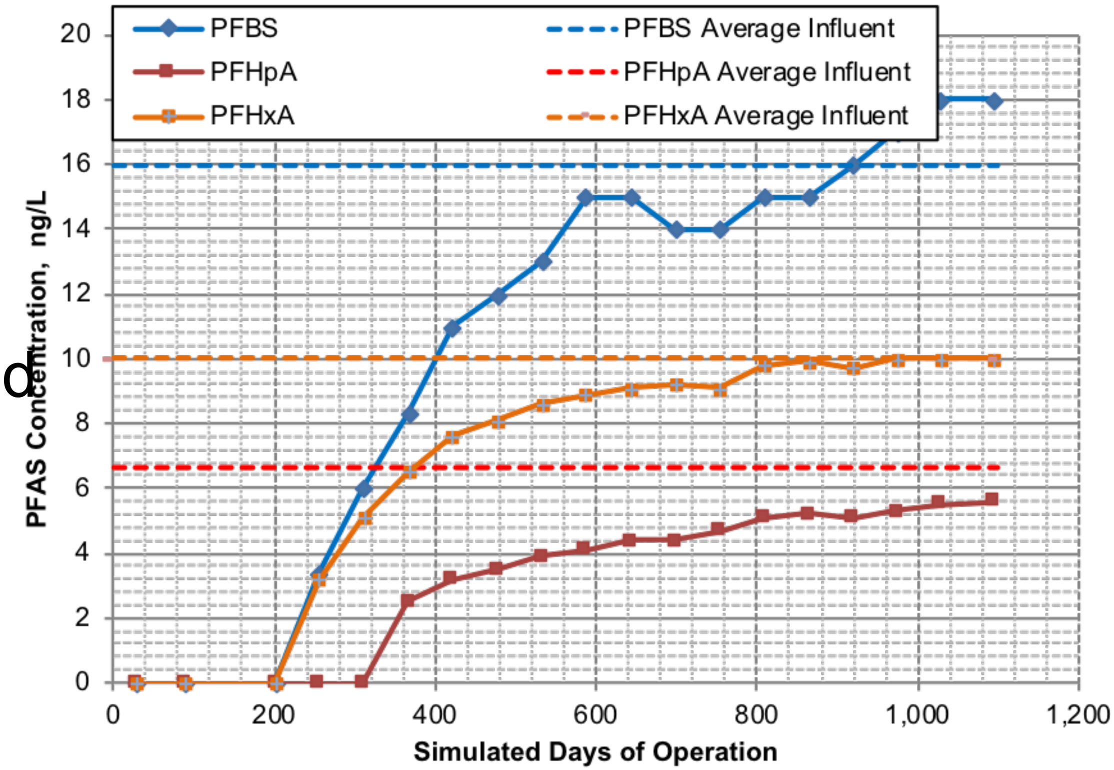




Images courtesy of  Jenelle Brewer, Calgon Carbon Corp.

# Carbon Adsorption

## Column Testing Results

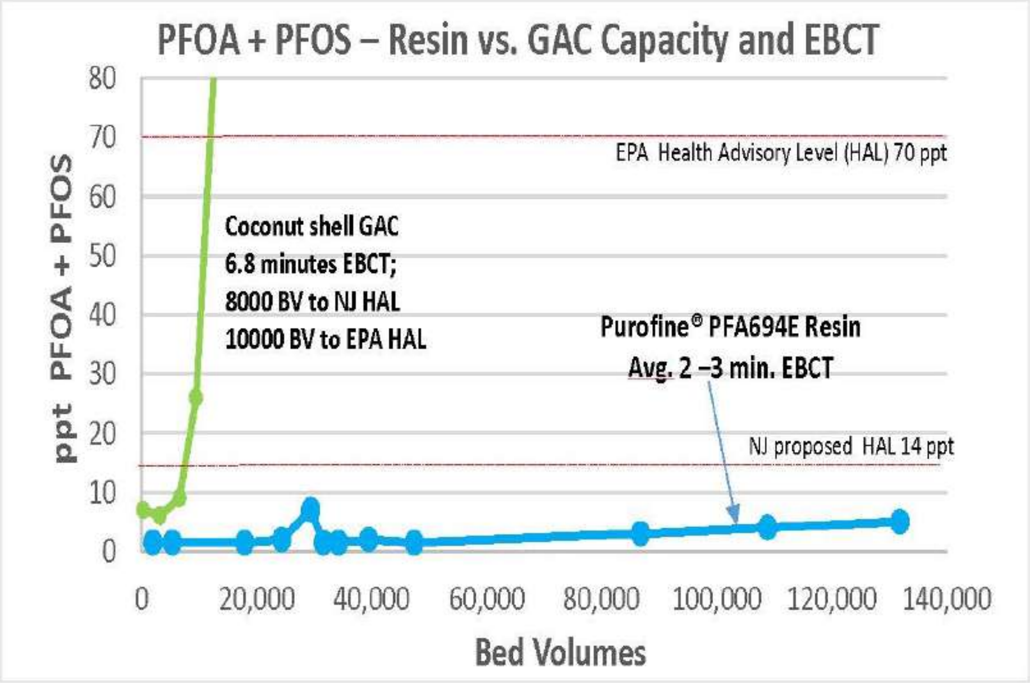
- GAC showed less removal efficacy for shorter chain carbon compounds (PFBS and PFHxA).
- Initial breakthrough:
  - PFBS at 256 days.
  - PFHxA at 311 days.
  - PFHpA at 367 days.




Graph courtesy of Langan, with permission of client.

# Resin Sorption

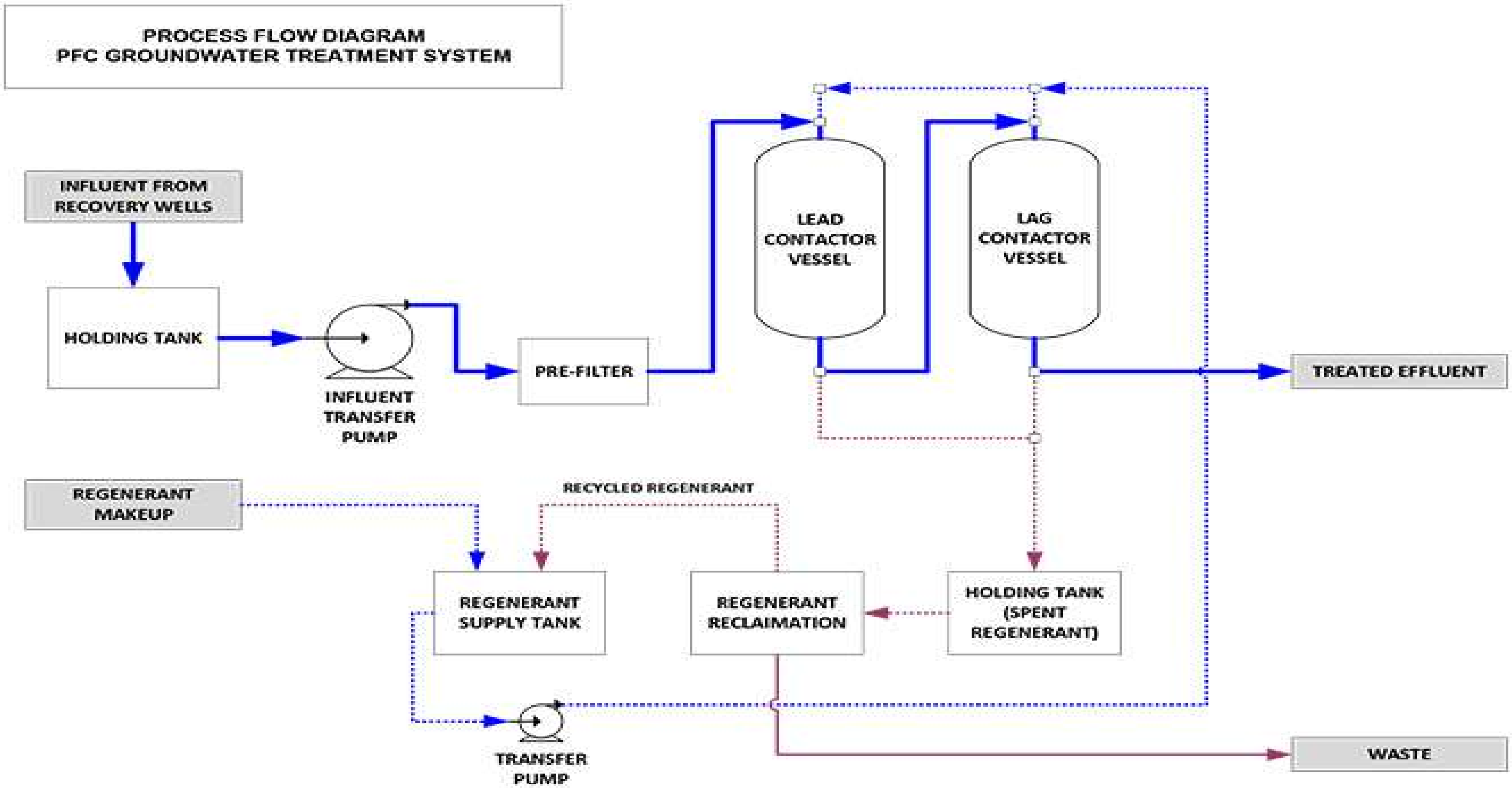
- Synthetic Resins
  - Regeneration is necessary
  - Shown to be equally effective after multiple regeneration cycles
  - Regeneration solution is solvent-based and solvent is recovered and reused
  - Distilled brine is loaded on IX media for incineration
  - Overall result is 99.9998% volume reduction for a "typical" site




Data courtesy of Purolite

# Resin Adsorption

## Regenerable Resin Process




Courtesy ECT2

# Resin Adsorption

## Single-Use Selective Resin + Incineration

PFAS in water

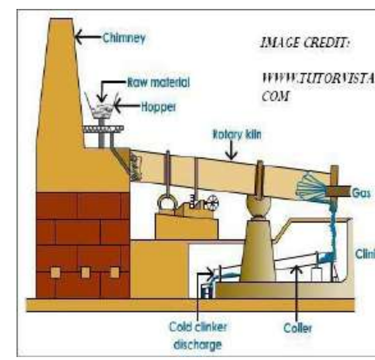

PFAS –free water

Illustrations courtesy of Purolite, Inc.

Short Contact Time ~3 mins
Simple & Effective - Operator Preferred.

**Cement Kiln Incineration 1400°C to 2000°C**

PFAS loaded resin




**Complete Destruction of PFAS**

# Resin Adsorption

## Benefits of Single-Use Selective Resin

- Field Demonstrated/Commercially Available
- Simple Operation
- Greater than 99.99% reduction (to non-detect) for short & long chain PFAS
- Reduced footprint /headspace
- High operating capacity (100,000 to 350,000 BV)
- Competitive operation costs ($0.15 to $0.40 / Kgal)

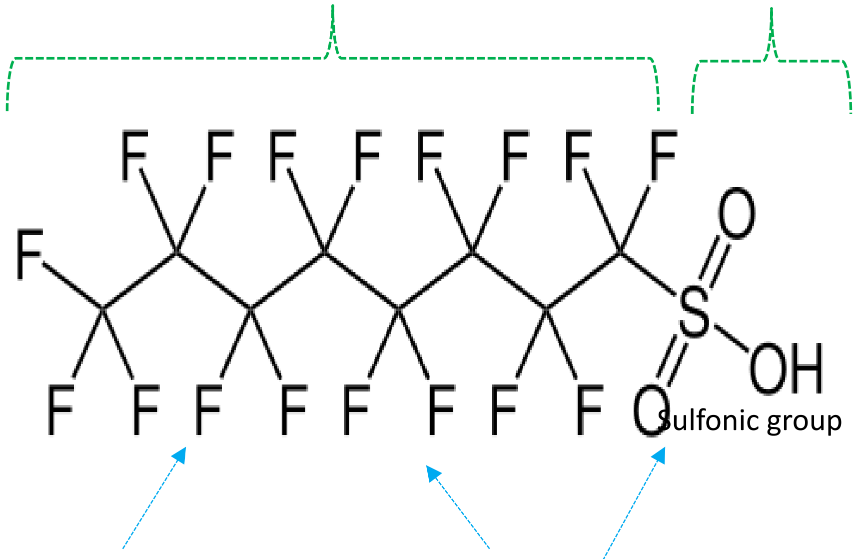
# Carbon vs. Resin Adsorption

## Mechanisms for ion exchange and GAC

PFOS – Perfluoroalkyl Sulfonic Acid

Hydrophobic "Tail"

Ionized/(-) Charged "Head"




GAC
removes by adsorption using hydrophobic "Tail"

Selective IX Resins
removes by both ion exchange and adsorption using both "Head" & "Tail"

# Reverse Osmosis/Ultrafiltration

- Effective for PFOA & PFOS
  - High pressure membrane
  - High energy usage
  - Reject water disposal
  - Typically used on lower flowrates
  - Questions about sustainability
- Costly
  - Capital
  - Operating

Photo courtesy of Agape Water Solutions, Inc.

# Innovative Treatment Technologies for PFAS

# Innovative/Developing Soil Technologies

- Soil/Solids
  - Sorption and Stabilization
    - Carbon Nanotubes
    - Natural Minerals
    - Modified Minerals
  - Thermal Desorption/ Destruction
    - High Temp (>700$^o$C)
    - Moderate Temp (<500$^o$C)
  - Soil Washing

# Innovative/Developing Water Technologies

Liquids/Water

- Flocculation/Coagulation
  - Chemicals
  - Electrocoagulation
- Ex Situ and In Situ Sorption
- Redox Manipulation
  - Oxidation
  - Reduction
- Fractionation
- Biodegradation
  - Bacteria
  - Fungus


Photo courtesy of CH2M/Jacobs.

# FY2018 SERDP PFAS Technologies Funded: Remediation of PFAS Contaminated Water

- Combination of regenerable resin sorbents
- Treatment train using AEX with electrochemical or ultrasonic destruction
- Novel polymer adsorbents
- Electrochemical oxidation
- Electrocoagulation onto activated carbon
- Cationic hydrophobic polymers
- Oxidation-organoclay adsorption-defluorination treatment train
- Electrically enhanced adsorption onto activated carbon
- Treatment train of in situ oxidation followed by direct plasma treatment/AEX
- Mesoporous organosilica sorbents
- Adsorption onto proteins

# Takeaways

- There are a lot of technologies with promise to treat PFAS and a lot of people indicating their technology works
- There are only a few things that have been fully demonstrated:
  - Excavation and incineration or sorption/stabilization for soil
  - Pump and treat with GAC, membrane filtration or anion exchange
- Field tested but minimally commercialized approaches include:
  - Thermal desorption or soil washing for soil
  - Injectable sorbents, coagulants, fractionation
- Technologies that still need work include:
  - Biological treatment
  - Destructive chemical treatment


Thank you!