MINNESOTA POLLUTION CONTROL AGENCY

PFAS Treatment Technologies

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Agenda

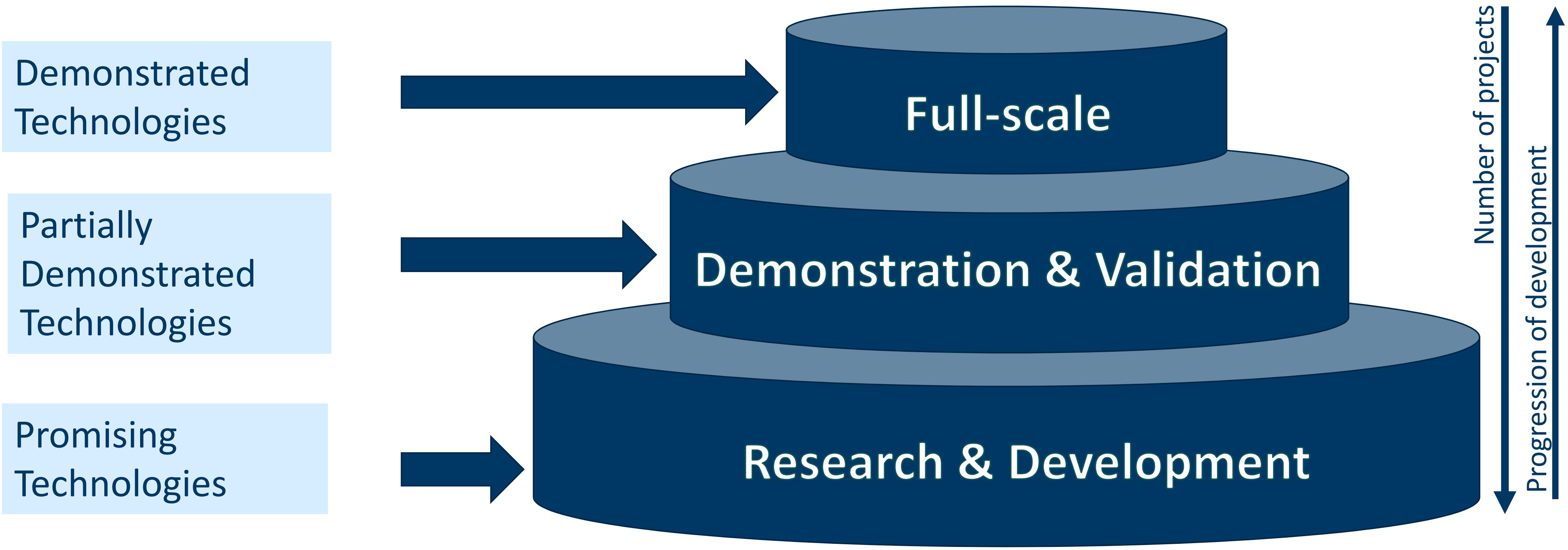
1. Overview of Technology Life Cycle
   - ✓How does a technology move through development?
   - ✓Where are PFAS in the spectrum?
   - ✓Why is this relevant?

2. Defining the Viable Options
   - ✓What are the key variables to consider outside of technology maturity?
   - ✓How can we stay up to speed on new developments?

3. The Drinking water options
   - ✓Full-scale viable technology options

Overview of Technology Life Cycle

How does technology move through development?



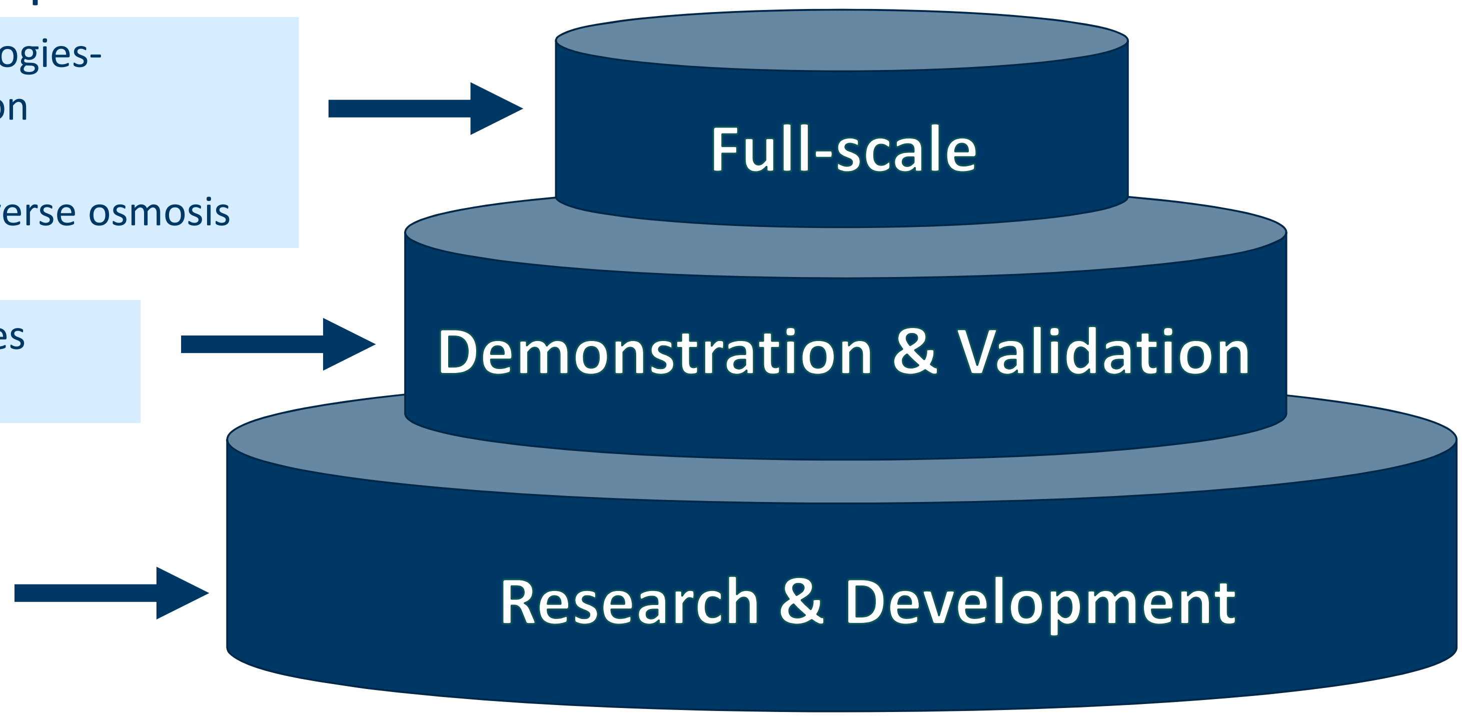
Overview of Technology Life Cycle

Where are PFAS in the spectrum?

Three demonstrated technologies-
1. Granular activated carbon
2. Ion-exchange
3. Membrane filtration/reverse osmosis

Estimate a dozen technologies

Estimate hundreds of projects globally



PFAS Project Spectrum via DoD

PROJECTS OVERVIEW

Projects				
Electrocatalytic (ER2424; CDMSmith)	**In situ coagulants** (ER2425; Minnesota)	**In situ chemical reductive defluorination** (ER2426; Purdue)	Coupled reactive **nanoscale materials & bioremediation**; mixed contaminants (ER2714; Brown)	
In situ chemical oxidation & bioremediation; mixed contaminants (ER2715; UC Berkeley)	**Electrolytic degradation** with electrobiostimulation; mixed contaminants (ER2718; Colorado State)	**Key F&T properties** impacting attenuation & treatment; mixed contaminants (ER2720; Colorado School of Mines)	**Thermally enhanced persulfate** oxidation followed by P&T (ER201729; Navy)	
In situ & ex situ treatment train: **ISCO or amendment, plasma destruction, IX** (1306; Clarkson)	Ex situ treatment train: **pre & post oxidation, adsorption, adsorption material regeneration** (1289; UC Riverside)	**Polymer adsorbents** In or ex situ (1026; Cornell)	Commercially available **regenerable resins** Ex situ (1063; CSM)	**IX resins, electrochemical &/or ultrasonic treatment** for regenerant Ex situ (1027; Aptim)

Proof of Concept (Ex situ/drinking water or pump-and-treat)					
Protein based adsorbents (1417; U.S. Army)	**Electrically enhanced adsorption** onto AC, electrically discharge to regenerate (1395; NCSU)	**Electrochemical oxidation** (1320; Univ of GA)	**Mesoporous organosilica sorbents** Ex situ (1300; Wooster)	**Cationic polyaniline (PANI) & polypyrrole (PPy) polymers** (1052; Univ of AZ)	**Electrocoagulation** (1278; AECOM)

Proof of Concept (Investigation Derived Waste)				
Advanced oxidation-reduction & membrane concentration (1497; UC Riverside)	**Modified SiiC based catalysts** (1513; Research Triangle Institute)	**Reductive defluorination** by hydrated electrons (1526; Miami)	**Thermal treatment** (1556; Aptim)	**Nonthermal plasma technology** (1570; Drexel)
Combined photo/electrochemical reduction (1595; UCLA)	**Electron beam technology** (1620; Texas A&M)	**Plasma based treatment** (1624; Clarkson)	**Hydrothermal technologies** (1501; Colorado School of Mines)	**Indirect thermal desorption with thermal oxidation** (1572; EA Engineering)

Key Take-away Messages

Why is this relevant?

- PFAS are still considered emerging contaminants, especially in the context of treatment technologies
- There is no "one-size fits all" technology for PFAS- there are many variables to consider
- Not all technologies are effective or applicable to drinking water
- Continuous review of viable technologies is necessary to keep pace with development

Defining the Viable Options

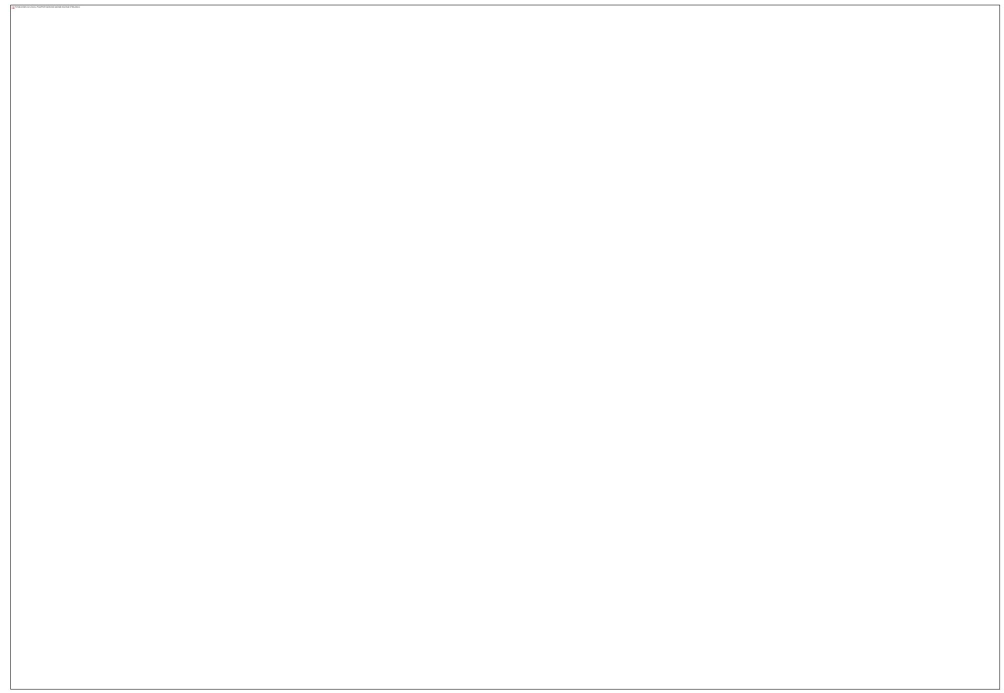
✓How can we stay up to speed on new developments?

1. Track key funding research entities i.e. ESTCP/SERDP
2. Track key researchers
3. Track key collaboration organizations

Defining the Viable Options

✓What are the key variables to consider outside of technology maturity?

1. Technology application/scenario—drinking water to waste
2. Influent concentrations and PFAS characteristics
3. Co-contamination

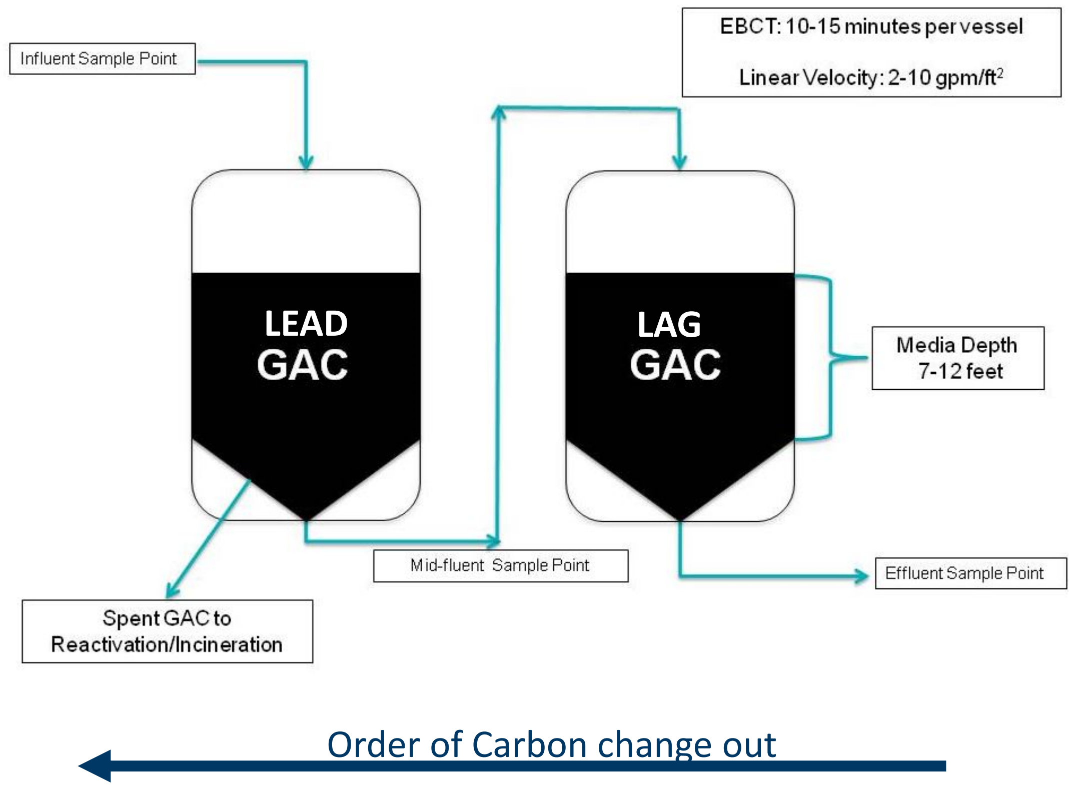


Source: Calgon

The Drinking Water Options

✓Removal with GAC

- Influent GAC vessel, “Lead”
- Second GAC vessel, “Lag”
- Monitoring
  - Influent
  - Mid-point
  - Effluent
- Carbon Change Out
  - Lead to reactivation
  - Lag to lead
  - New to lag



Source: ITRC/Calgon

The Drinking Water Options

✓Removal with GAC

Considerations:

- Public health exposure (balancing risks)
- Environment (waste, energy, available resources, etc)
- Capital costs (immediate and long term)
- Operation and management costs (long term)
- Changing science (flexibility)

Source: ITRC/Calgon

The Drinking Water Options

✓Removal with ion-exchange resins

PFAS in water

Treated water

PFAS loaded resin

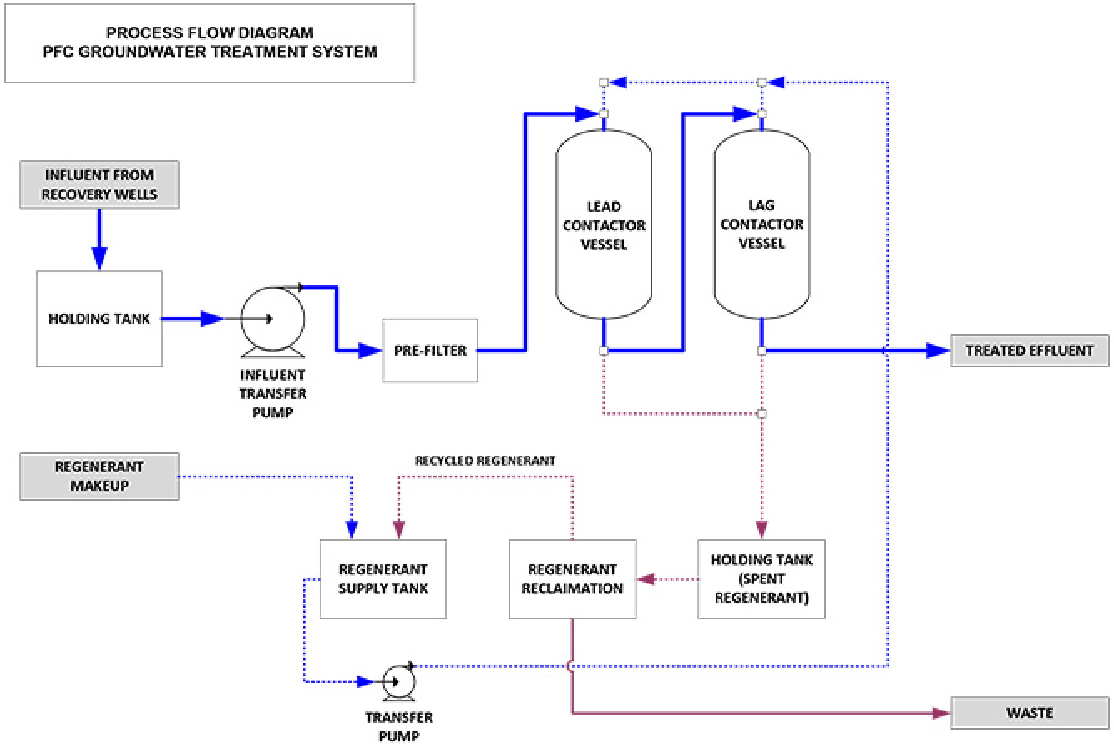
Short Contact Time ~3 mins
Simple & Effective - Operator Preferred

Incineration or other disposal alternative

Source: ITRC/Purolite

The Drinking Water Options

- ✓Removal with "regenerable" ion-exchange resins
  - ✓ Treatment process: Particle filters, GAC, sorbent media, in-place regeneration
  - ✓ Construction completed April 2018
  - ✓ On-going optimization
  - ✓ NOT CURRENTLY APPROVED FOR DRINKING WATER IN THE US



Source: ECT2

The Drinking Water Options

✓Removal with ion exchange resins

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- Public health exposure (balancing risks)
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Source: ITRC/Calgon

The Drinking Water Options

- ✓ Extraction and membrane filtration/reverse osmosis
  - ✓ Membrane Processes
  - ✓ Effective for PFAS
    - High pressure membrane
    - High energy usage
    - Reject water disposal
    - Typically used on lower flow rates
  - ✓ Removes a wide range of constituents:
    - Including hardness, dissolved solids, as well as VOCs and PFAS
  - ✓ Costly
    - Capital
    - Operating

Photo courtesy of Agape Water Solutions, Inc.

Source: ITRC

The Drinking Water Options

✓Removal with membrane filtration/reverse osmosis

Considerations:

- Public health exposure (balancing risks)
- Environment (waste, energy, available resources, etc)
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Source: ITRC/Calgon

Drinking Water Options Comparison

Granular Activated Carbon

✓Pros

- ✓ Good removal of PFOS/PFOA and most long chain PFAS
- ✓ Readily available network of GAC vendors and reactivation facilities
- ✓ NSF Approved for drinking water
- ✓ GAC Media is less expensive
- ✓ Used for Point of Entry Systems (POET)

✓Cons

- ✓ Less effective on short chain PFAS
- ✓ Virgin GAC (>$) significantly outperforms reactivated GAC (<$)
- ✓ Requires significant footprint (i.e. larger systems)
- ✓ Organic co-contaminants compete for sites
- ✓ Potential concerns regarding effectiveness of reactivation process
- ✓ POET systems require replacement annually (typical)

IX Resins

✓ Pros

- ✓ higher capacity than GAC (> removal of PFOS/PFOA, short, and long chain PFAS vs. GAC)
- ✓ Requires smaller footprint than GAC
- ✓ May allow for onsite PFAS destruction (Regen IX only)
- ✓ Single use resin NSF approved for drinking water
- ✓ Point of Entry Treatment (NSF Media)
  - ✓ Long life for POET systems

✓ Cons

- ✓ Larger pumps that use more power required
- ✓ Regenerable IX uses flammable solvent for regeneration
- ✓ Co-contaminants may result in media fouling
- ✓ Regenerable system not NSF approved
- ✓ Media more expensive than GAC

Key Take-away Messages

Reminder

- PFAS are still considered emerging contaminants, especially in the context of treatment technologies
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- Not all technologies are effective or applicable to drinking water
- Continuous review of viable technologies is necessary to keep pace with development

Thank you!

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