Pacific Northwest
NATIONAL LABORATORY

RemPlex & SURF Seminar

August 19, 2025

The Hidden Costs of PFAS Remediation: Energy, Waste, and Long-Term Viability

SURF SUSTAINABLE REMEDIATION FORUM

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CENTER FOR THE REMEDIATION OF COMPLEX SITES
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U.S. DEPARTMENT OF ENERGY

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Upcoming RemPlex Seminars

Sept. 9th

An Overview of Chalk River Laboratories' Experience in Addressing Legacy Site Liability

Oct. 14th

Moab UMTRA Project: An Update on Progress Toward Closure at a Complex Groundwater Site

For more information and to register for the seminars, go to https://www.pnnl.gov/projects/remplex/seminars

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2025 Global Summit on Environmental Remediation

- Case studies
  - Hanford Pump-and-treat Optimization
  - Port Hope (Canada)
  - Discrete Aquifer Zone Characterization
- Technical sessions and a poster session
- Local geology tour
- Sponsorship/partnership opportunities
- www.pnnl.gov/2025-summit

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ABOUT SURF

SURF is a nonprofit organization dedicated to maximizing the overall environmental, societal, and economic benefits from remediating degraded environmental conditions by:

- Advancing the science and application of sustainable remediation
- Developing best practices
- Exchanging professional knowledge
- Providing education and outreach

www.sustainableremediation.org

Sustainable Remediation Forum

@sustainableremediationforu5730

Go to our website to subscribe to *SURF Break*

SUSTAINABLE REMEDIATION FORUM

UPCOMING SURF ACTIVITIES

- New SURF TI: RESTORE Tool for Remediation Impact Assessment
  - RESTORE = Remedial Evaluation and Screening Tool for Optimization and Resource Efficiency
  - Simple, unbiased interface that gives practitioners the most current quantitative methods for impact assessment
  - Kickoff meeting in late August; more info on website under "News"
- SURF Session at AEHS East Coast Conference
  - AEHS = Association for Environmental Health & Sciences
  - 41st Annual International Conference on Soils, Sediments, Water, and Energy
  - October 20-23, 2025 (Peak Fall Foliage!)
  - University of Massachusetts, Amherst, MA

* Note: Participation in SURF technical initiatives (TIs) is limited to current SURF members. Interested but not a SURF member? Go to www.sustainableremediation.org and click "Join."

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THANK YOU SPONSORS

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Today’s Seminar and Speakers

The Hidden Costs of PFAS Remediation: Energy, Waste, and Long-Term Viability

Emerald Laija
Deputy Director, Federal Facilities Restoration and Reuse Office, U.S. Environmental Protection Agency

Jeffrey Bamer
Discipline Lead for Remedial Design, CDM Smith

Paige Molzahn
Executive Advisor, Federal and Environment business unit, Jacobs

PFAS Regulatory Overview

Emerald Laija, Deputy Director
Federal Facilities Restoration and Reuse Office
August 19, 2025

PFAS RSL Table

- Regional Screening Levels (RSLs) will continue to change and be expanded as new toxicity values are generated
- Next update anticipated in November 2025

State Toxicity/Risk Levels

- States may have their own PFAS risk levels
- ITRC has a good summary of information
  - https://pfas-1.itrcweb.org/
  - https://pfas-1.itrcweb.org/wp-content/uploads/2024/11/ITRCPFASEnvironmentalMediaValuesTables_Nov-Dec-FINAL.xlsx

2024 PFAS National Primary Drinking Water Regulation (NPDWR)

- Announced on April 10, 2024
- Established legally enforceable levels for several PFAS known to occur individually and as a mixture in drinking water.

2025 PFAS NPDWR Update

Chemical	Maximum Contaminant Level Goal (MCLG)	Maximum Contaminant Level (MCL)
PFOA	0	4.0 ppt
PFOS	0	4.0 ppt
PFHxS	10 ppt	10 ppt
HFPO-DA (GenX chemicals)	10 ppt	10 ppt
PFNA	10 ppt	10 ppt
Mixture of two or more: PFHxS, PFNA, HFPO-DA, and PFBS	Hazard Index of 1	Hazard Index of 1

*Compliance with MCLs is determined by running 12-month average at the sampling point

See April 2024 Fact sheet: EPA's Final PFAS National Primary Drinking Water Regulation: Monitoring and Reporting

Rulemaking to Designate PFOA and PFOS as Hazardous Substances

- Effective April 19, 2024
- Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), designated as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Allows cost recovery which can compel cleanup on non-federal sites

Legal Authority

- CERCLA Section 102
- Authorizes the EPA Administrator to designate "hazardous substances" that, when released into the environment, may present substantial danger to the public health or welfare or the environment.

- This is the 1st time EPA has used CERCLA Section 102 authority to designate a hazardous substance
- Currently, there are over **800 CERCLA hazardous substances**
- CERCLA incorporates by reference "hazardous substances" listed or identified under the CWA, CAA, RCRA, and TSCA.

Benefits of CERCLA Designation

- Human health benefits due to reduced exposure to PFOA and PFOS
- Allows EPA to address contamination sooner
  - Earlier responses will reduce risks
  - Cost savings from addressing sooner
  - Incidental cleanup of co-contaminants
  - Increase in property values near cleanup sites.

What The Designation Does NOT Do

Does **NOT**:

- Require any response action
- Impose liability
- Require facilities to proactively sample, test, monitor, or clean up PFOA and PFOS
- Impose requirements on any facility (e.g., how to manage contaminated waste or wastewater)
- Add any site to the NPL or require that EPA reexamine existing sites

Updated PFAS D&D Interim Guidance

- April 2024 PFAS D&D Interim Guidance
- Focuses on options to destroy or dispose of PFAS containing materials, including soil or contaminated media from treating groundwater (ex., GAC)
- Identifies three destruction and disposal technologies that may be effective and are commercially available:
  - thermal treatment (destruction),
  - landfilling (disposal),
  - underground injection (disposal).
- Plan to update this guidance regularly

RPM Technical Bulletins

- Topics that benefit from a "just in time" guidance
- Available on public-facing website (https://www.epa.gov/fedfac/technical-bulletins)
  - Environmental Forensic Tools for Understanding PFAS Fate and Transport (pdf) (2.68 MB, June 2025)
  - PFAS Considerations When Updating Environmental Indicators (pdf) (254.05 KB, April 17, 2025)
  - Considerations when Reviewing Per- and Poly-fluoroalkyl Substances (PFAS) in Five-Year Reviews (pdf) (270.76 KB, April 3, 2024)
  - Developing a Crosswalk between Legacy Chemical and Per- and Polyfluoroalkyl Substances (PFAS) Sites (pdf) (180.97 KB, April 3, 2024)
  - Considerations for PFAS Source Area Investigations (pdf) (343.55 KB, April 11, 2023)

Partnering with Regulators

- Work with your regulators to identify how data will be used in decision-making
- Collaboration allows for identification of flexibilities and non-negotiables
- Existing guidance and templates can be useful

Options and Considerations for Selecting Remediation Technologies for PFAS in Soil and Water

What happens **NEXT** is happening **NOW.**

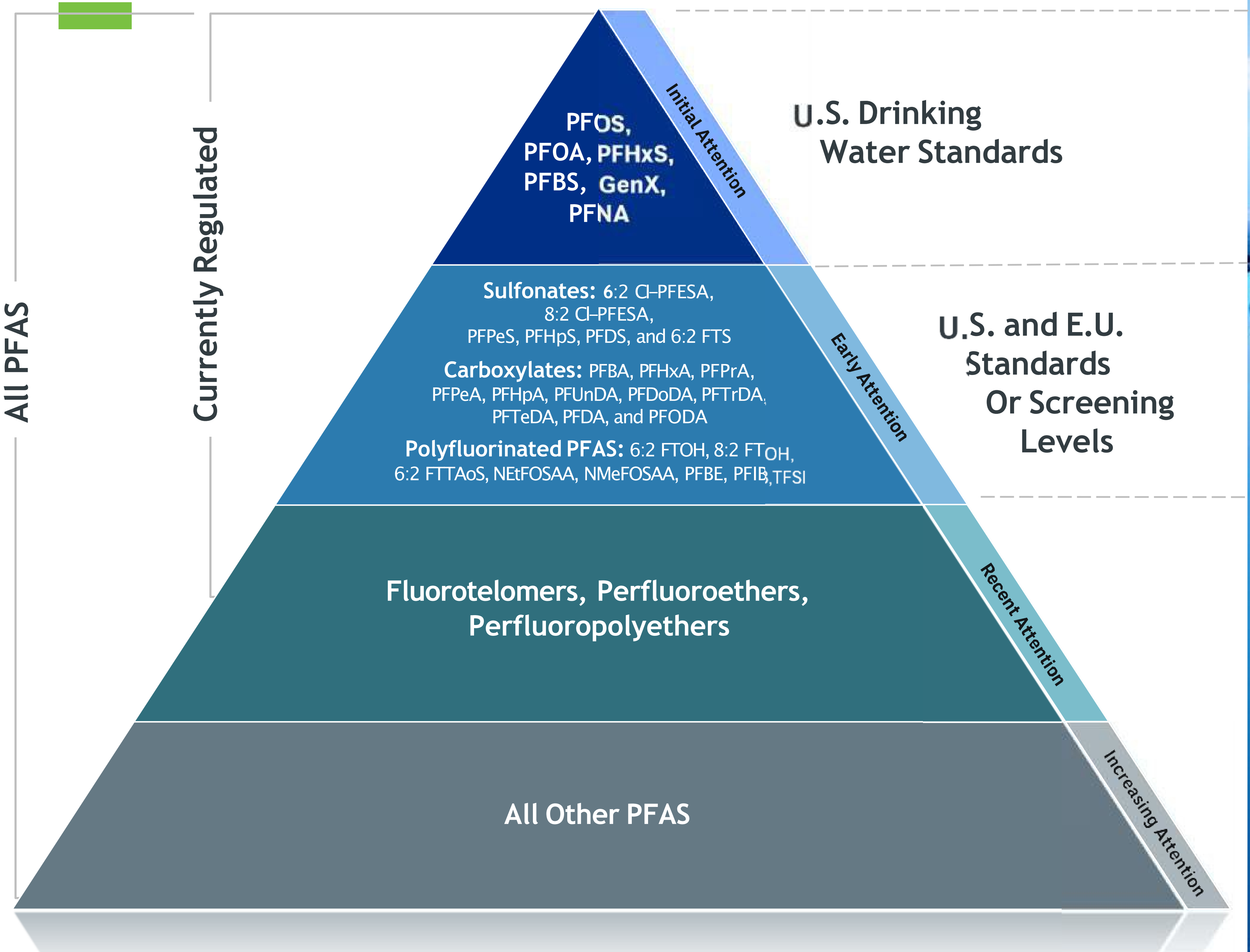
Jeff Bamer, P.E.

August 19, 2025

Agenda

1. Common PFAS Treatment Challenges
2. Water Treatment
3. Soil and Solids Treatment

Thousands of PFAS Chemicals….



… With A Variety of Characteristics and Treatability Challenges

Variable Characteristics

Industrial processes/product origins

Molecular weights / chain lengths

Solubility / hydrophobicity

Surfactant properties

Functional groups

Ionic states

Volatilities

Treatability Challenges

Recalcitrant supramolecular structures

Extreme environmental persistence

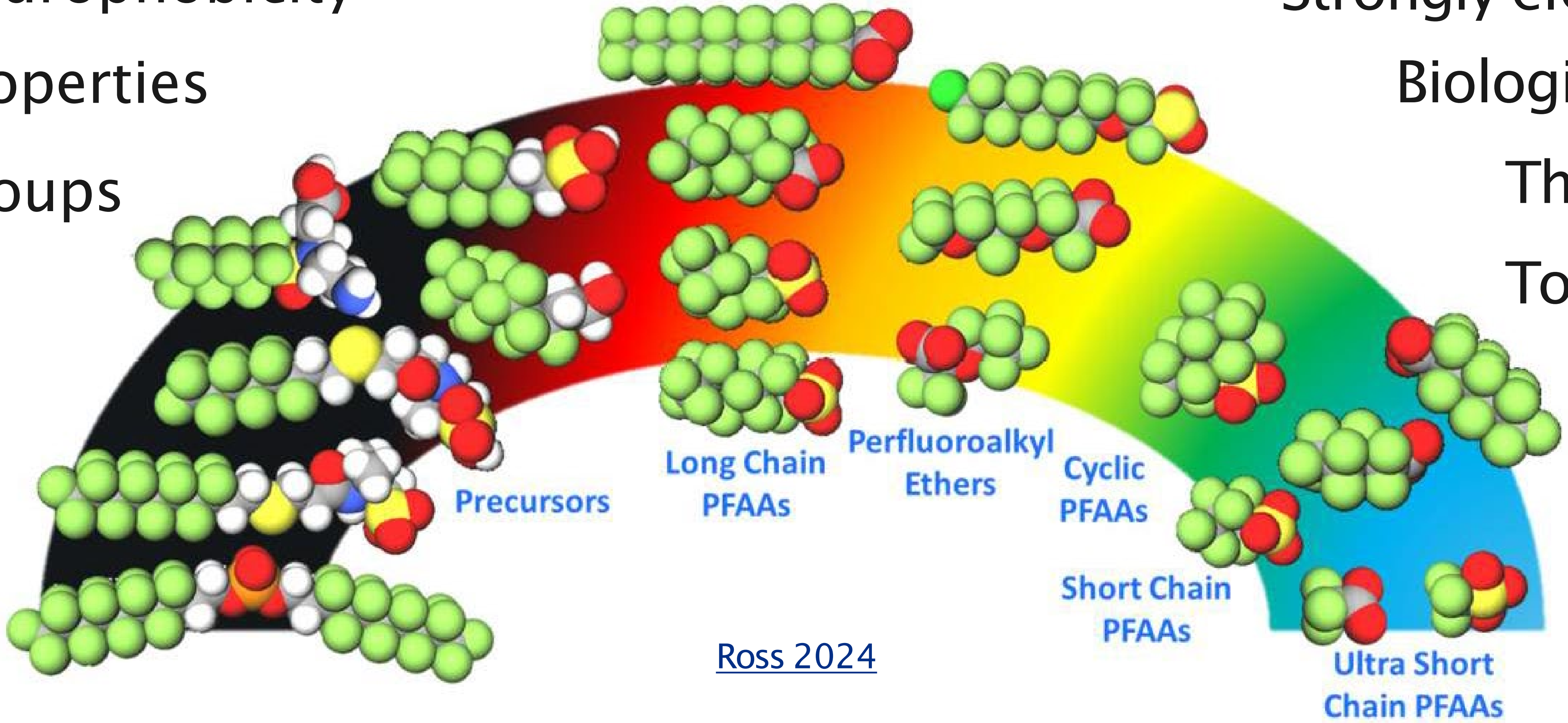
Strongly electronegative

Biologically resistant

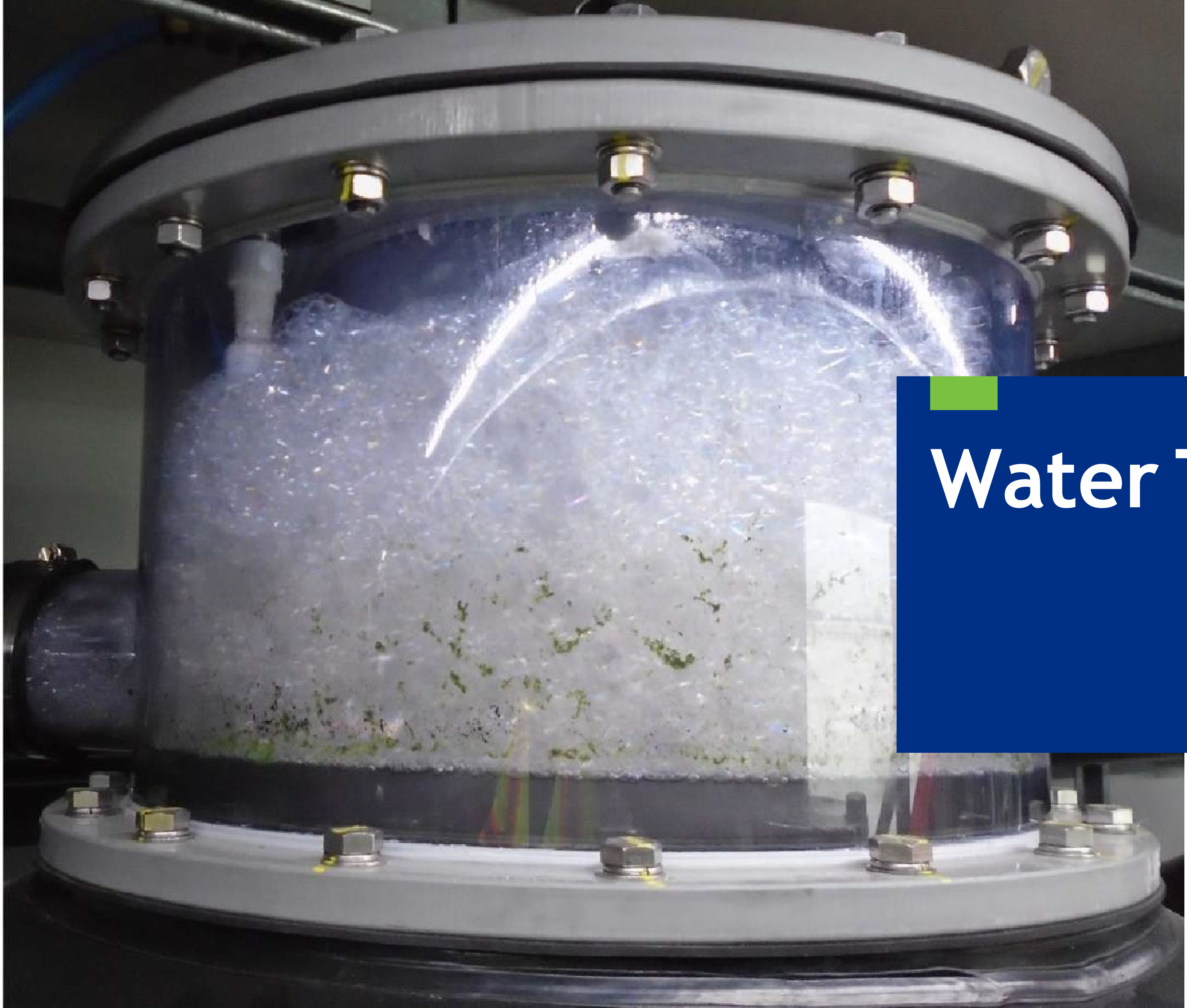
Thermally stable

Toxic (ppt levels)

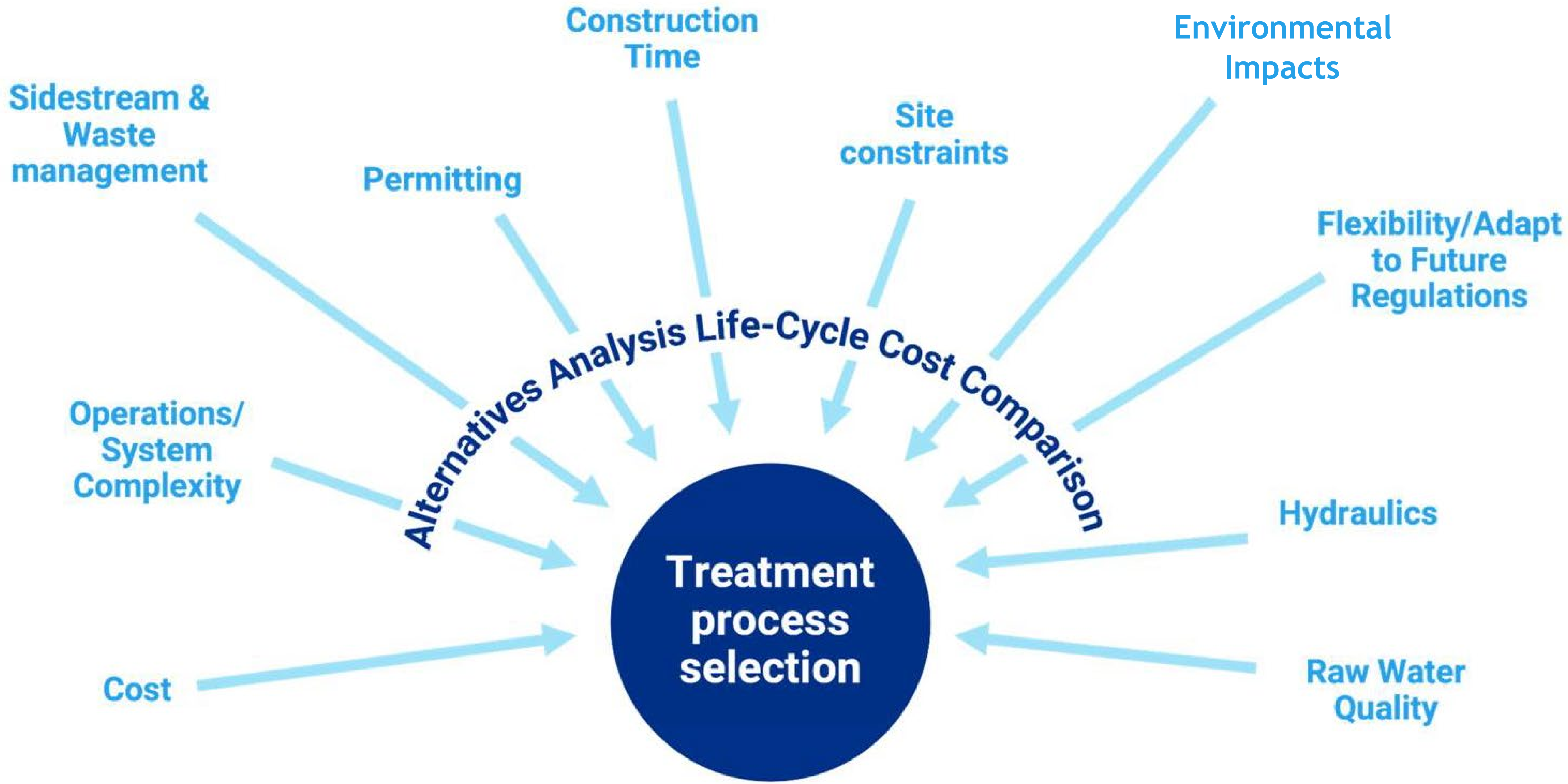
Mobile



Ross 2024



Water Treatment


Construction Time
Environmental Impacts
Sidestream & Waste management
Permitting
Site constraints
Flexibility/Adapt to Future Regulations
Alternatives Analysis Life-Cycle Cost Comparison
Operations/ System Complexity
Hydraulics
Treatment process selection
Cost
Raw Water Quality

Raw Water Quality is Key to Selecting Treatment Technology

PFAS

- *Which PFAS compounds are you treating for?*
- *Where is treated water being discharged?*
- *Changes to future discharge limits?*

Treatment of Other Constituents

- Softening
- Iron/Manganese
- Nitrate
- VOCs
- Perchlorate
- Hexavalent chromium
- 1,4-dioxane
- Radionuclides

Potential Interferences with Treatment Technologies

- Organics
- Radionuclides
- Hardness
- TSS
- Metals / TDS
- Entrained air (GW wells)
- Salinity
- UV Transmittance

Media Treatment for PFAS: It's Not Just GAC and Resin!!!

GAC / Anion Exchange Resin (AER)

- "Go to" sorbents
- Economical, scalable, accepted

Modified clays, biochar

- Fluorosorb®; pyrolyzed cellulose
- Available & competitive

Polymeric Sorbents

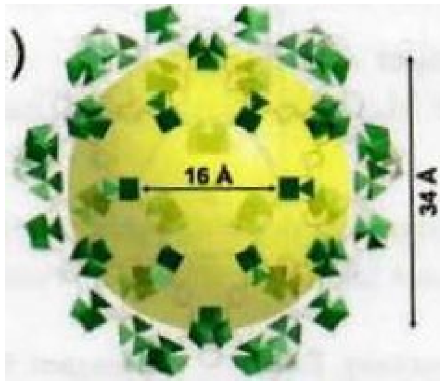
- DEXSORB®; PQ-Osorb®; Puraffinity®
- Promising, improving scalability

Experimental

- MOFs[1]; Hydro/Fluorogels; LDHs[2]; 2-phase composites
- Esoteric, high sorption capacities

DEXSORB (Cyclopure 2025)

FluoroSorb (CETCO, 2023)



MOF Concept
Barpaga et al., 2019

PQ-Osorb (ABS Materials 2018)

[1]*Metallic Organic Frameworks;* [2]*Layered Double Hydroxides*

GAC and IX Resin: Rapid Small Scale Column Testing (RSSCT)

- Examine breakthroughs of short chain and long chain PFAS
- Compare PFAS removal effectiveness between GAC and ion exchange resin
- Evaluate performance of different commercial products
- Evaluate impact of *site-specific parameters* such as co-contaminants (VOCs), geochemical water quality (e.g., TOC, iron, pH), water treatment additives (e.g., chlorination, corrosion inhibitors) on PFAS removal effectiveness
- Evaluate need for pre-treatment

I&EC research
Industrial & Engineering Chemistry Research

Research Note

Cite This: Ind. Eng. Chem. Res. XXXX, XXX, XXX−XXX

pubs.acs.org/IECR

Assessing Rapid Small-Scale Column Tests for Treatment of Perfluoroalkyl Acids by Anion Exchange Resin

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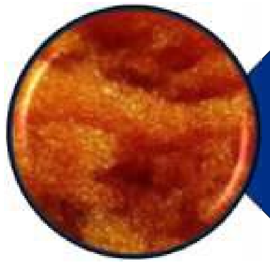
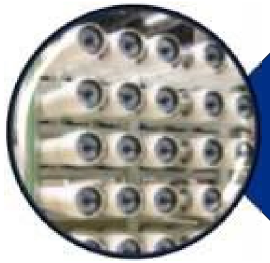
Limitations of "Conventional" PFAS Treatment

1. High volume of spent media/waste stream requiring waste management
2. Significant pretreatment often required to remove competing solutes
3. High concentrations of PFAS can lead to inefficient target compound removal
4. Overall high costs for removing small mass of contamination (down to trace ppt levels)

Granular Activated Carbon (GAC)



Anion Exchange Resin (AER)



NF and RO Membrane Filtration

Commercially Available PFAS Destruction Technologies

- Many technologies not yet proven
- Limited capacity: 100s to 1,000s of gallons per day
- CAPEX: $1.5 M to $4 M each
- Immature understanding of OPEX, e.g., intense reaction conditions +complex waste streams =high cost
- Complete mechanism and mass balance work ongoing
- Benefit from DoD investment (SERDP, ESTCP, DIU)

Electrochemical Oxidation

(Aclarity, 2023)

Hydrothermal

(Aquagga, 2023)

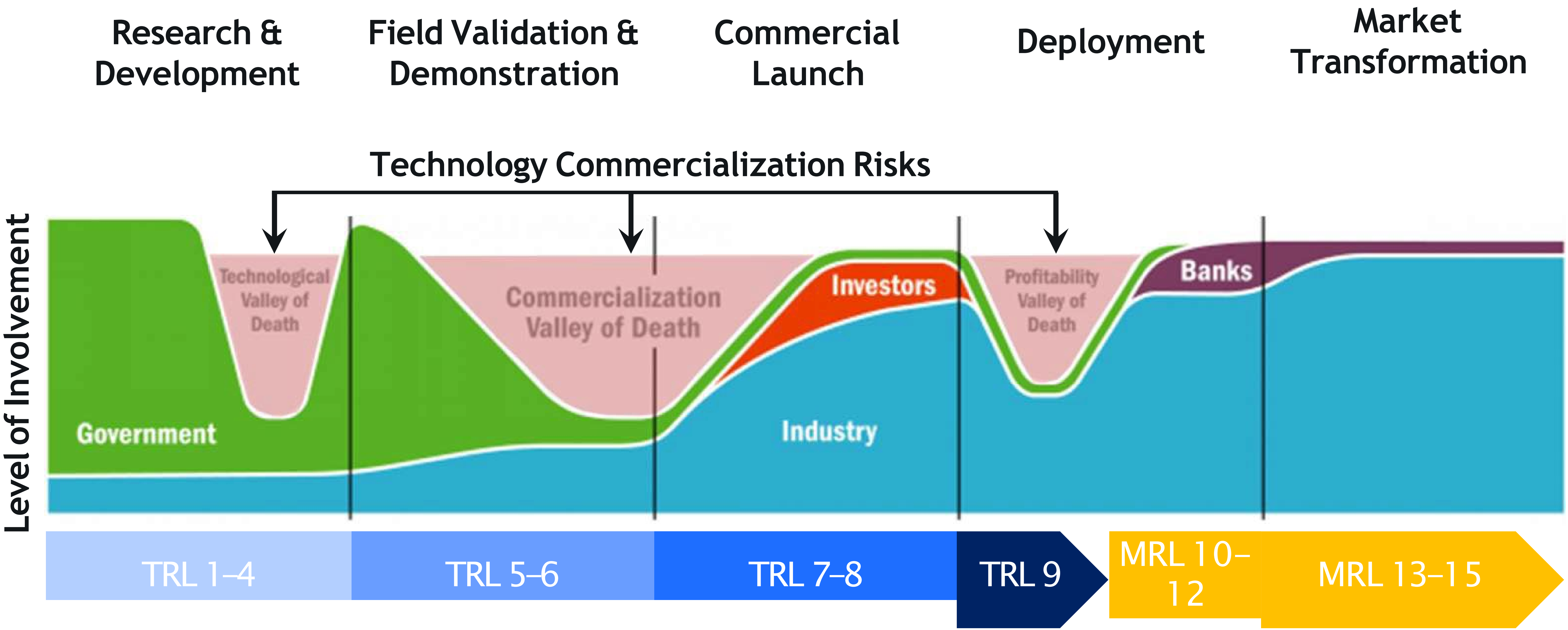
Non-Thermal Plasma

(DMAX Plasma, 2022)

UV-Radiated Sensitizers

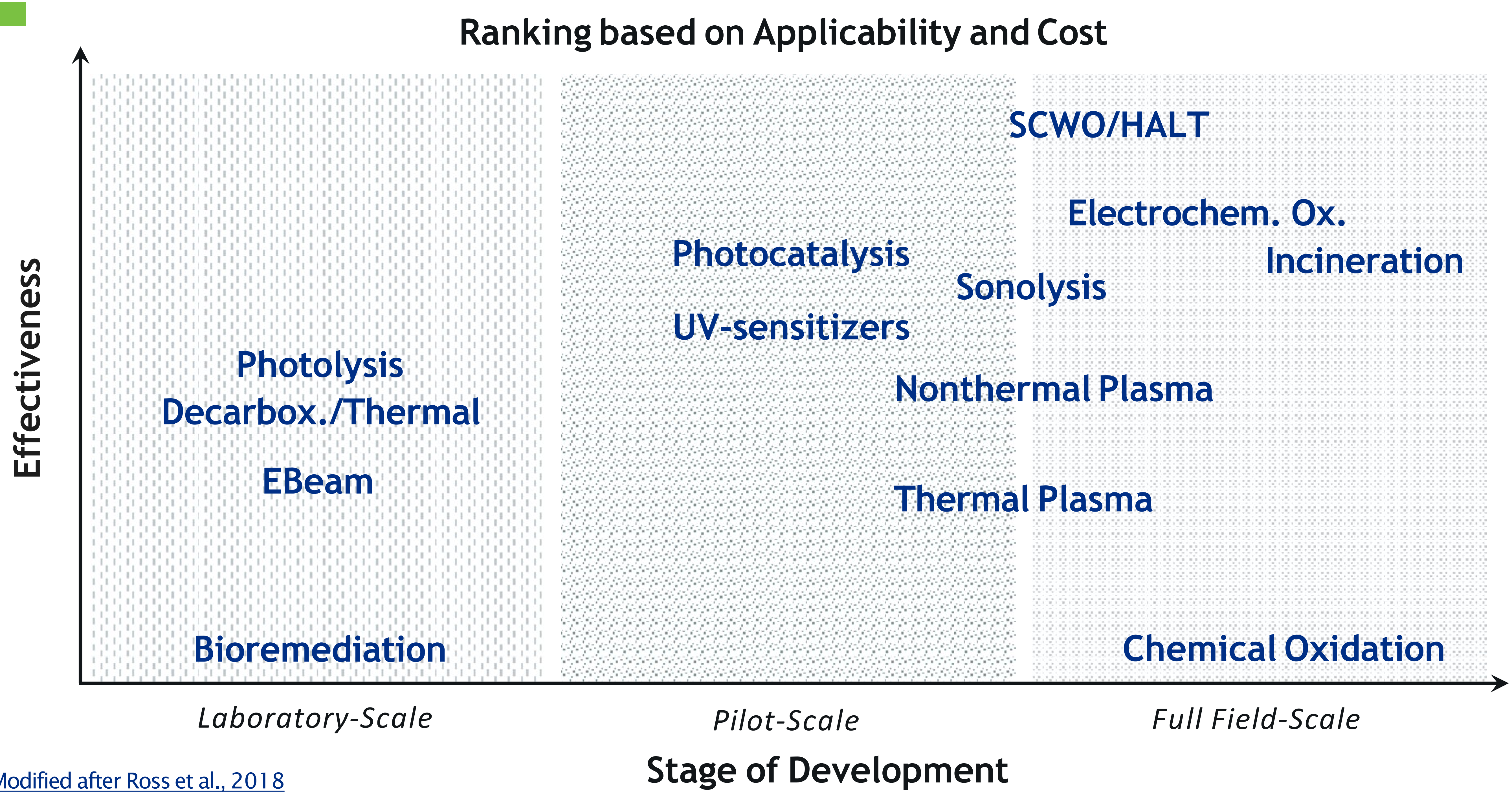
(Claros, 2023)

Technology Readiness Is A Concern…



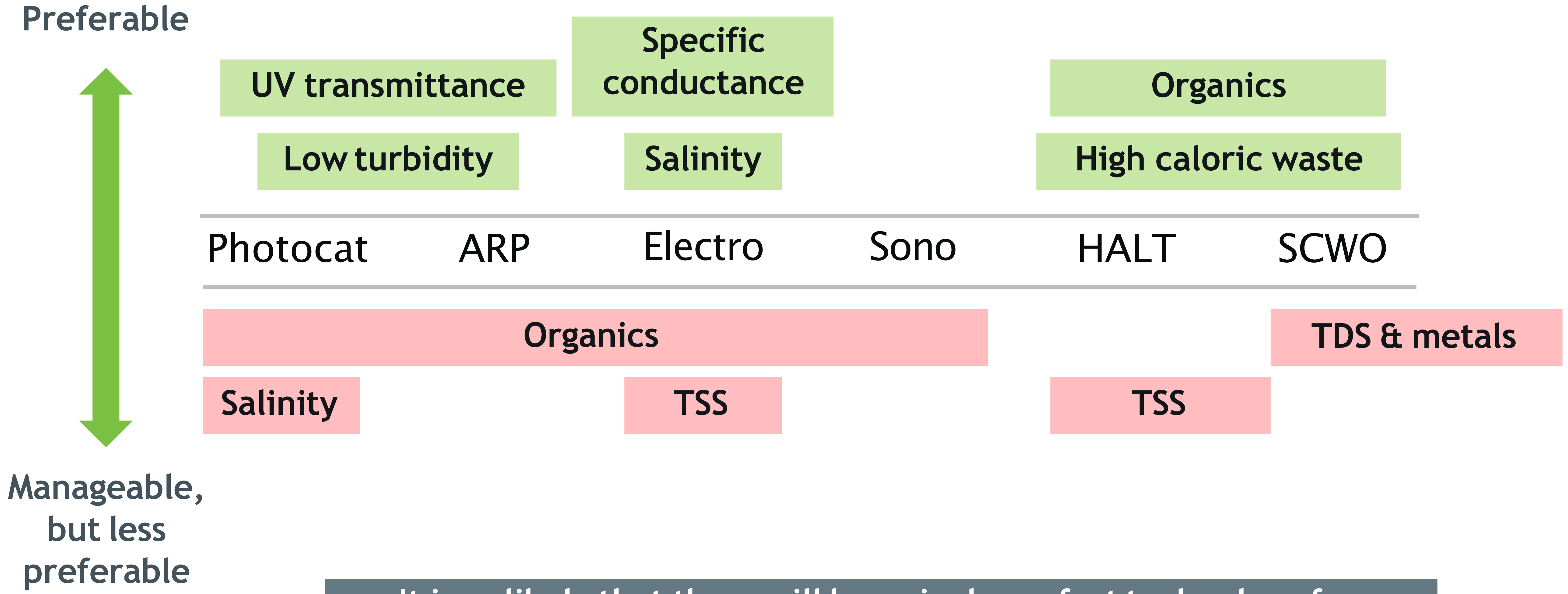
TRL =Technology Readiness Level
MRL =Market Readiness Level

Liquid Phase PFAS Destructive Technologies (Ex Situ)



Modified after Ross et al., 2018

There is No Silver Bullet….



It is unlikely that there will be a single perfect technology for PFAS destruction

TDS = total dissolved solids
TSS = total suspended solids

Treatment Efficiency

where P is the power (kW), t is the treatment time (h), V is the water volume (m^3), and C_0 and C_t are the initial and final concentrations, respectively.

$$E_{EO}\left(\frac{kWh}{m^3}\right) = \frac{P\,t}{V\,\log\left(\frac{C_0}{C_t}\right)}$$

System	PFAS	Volume (L)	OOM	Time (hr)	E_{EO} (W-h/L)	Defluorination (%)	Source
				8	46–140		Chaplin, 2020
				0.1–1	9–84		
				8	15–50		
				0.5	127		
				8	250–1500		

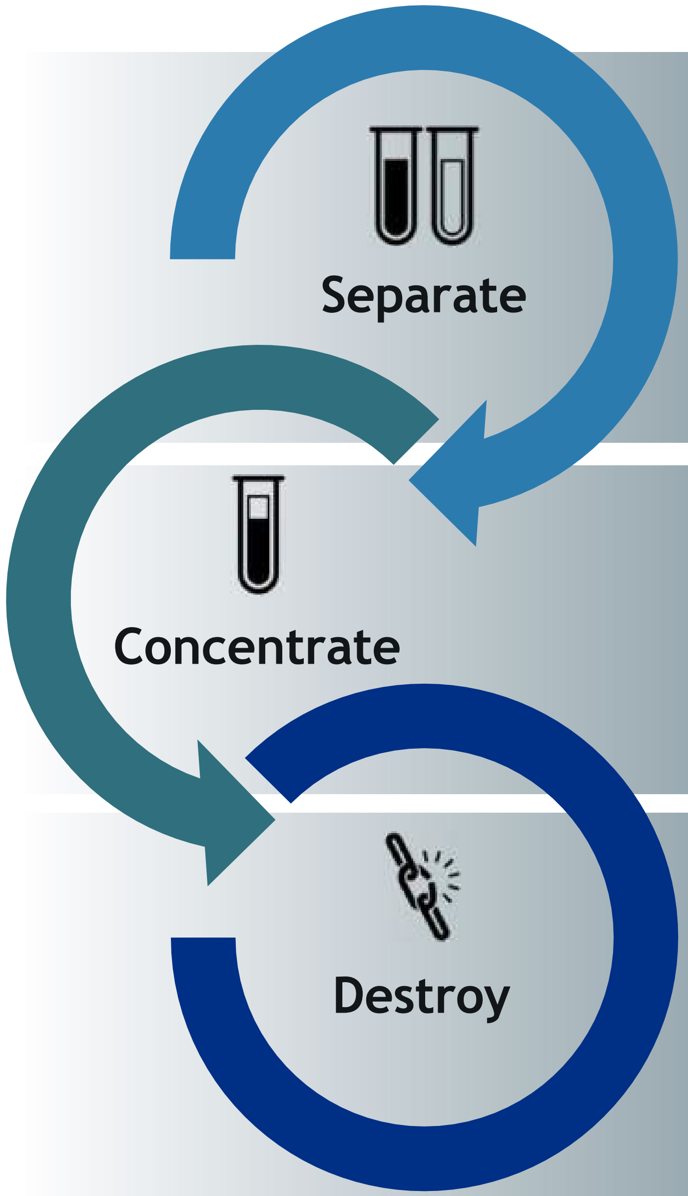
Separation Technologies:
Reverse Osmosis - 0.4 W-h/L
Ion Exchange - 0.01 W-h/L

1 MGD = 160 kL/h
If E_{EO} is 10 W-h/L, that's 1.6 MW of power per MGD (~1,300 average US homes)

E_{EO} is only useful for intra-technology comparisons

If part of a treatment train, energy per mass is a more useful metric

Present and Future of PFAS Treatment



Focused Technologies

- **Media separation:** GAC, AER, and novel adsorbents
- **Liquid-liquid separation:** Membrane filtration, Foam fractionation

- Foam fractionation
- Regenerable IX resin
- Coagulants/flocculants

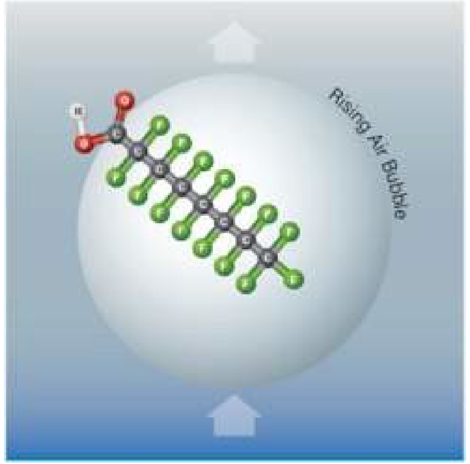
- Hydrothermal (HALT, SCWO)
- Electrochemical oxidation
- UV-ARP
- Photocat
- Sonolysis

SERDP DOD · EPA · DOE
ESTCP
WORLD ECONOMIC FORUM
AUSTRALIAN DEFENCE FORCE
THE Water Research FOUNDATION
NGWA The Groundwater Association
AIR FORCE CIVIL ENGINEER CENTER
INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

Many technical challenges remain for application of PFAS concentration and destruction.

Foam Fractionation

- Applicable for groundwater, surface water, wastewater and leachate treatment
- Separates PFAS using bubble formation
- Concentrates PFAS at the bubble-water interface → PFAS foam concentrate
- Capable of removing PFAS to low levels
- Short chain PFAS takes longer to remove (lower K_{aw})
- Multiple offerors:
  - EPOC Enviro/Allonnia (SAFF®)
  - ECT2
  - WCG



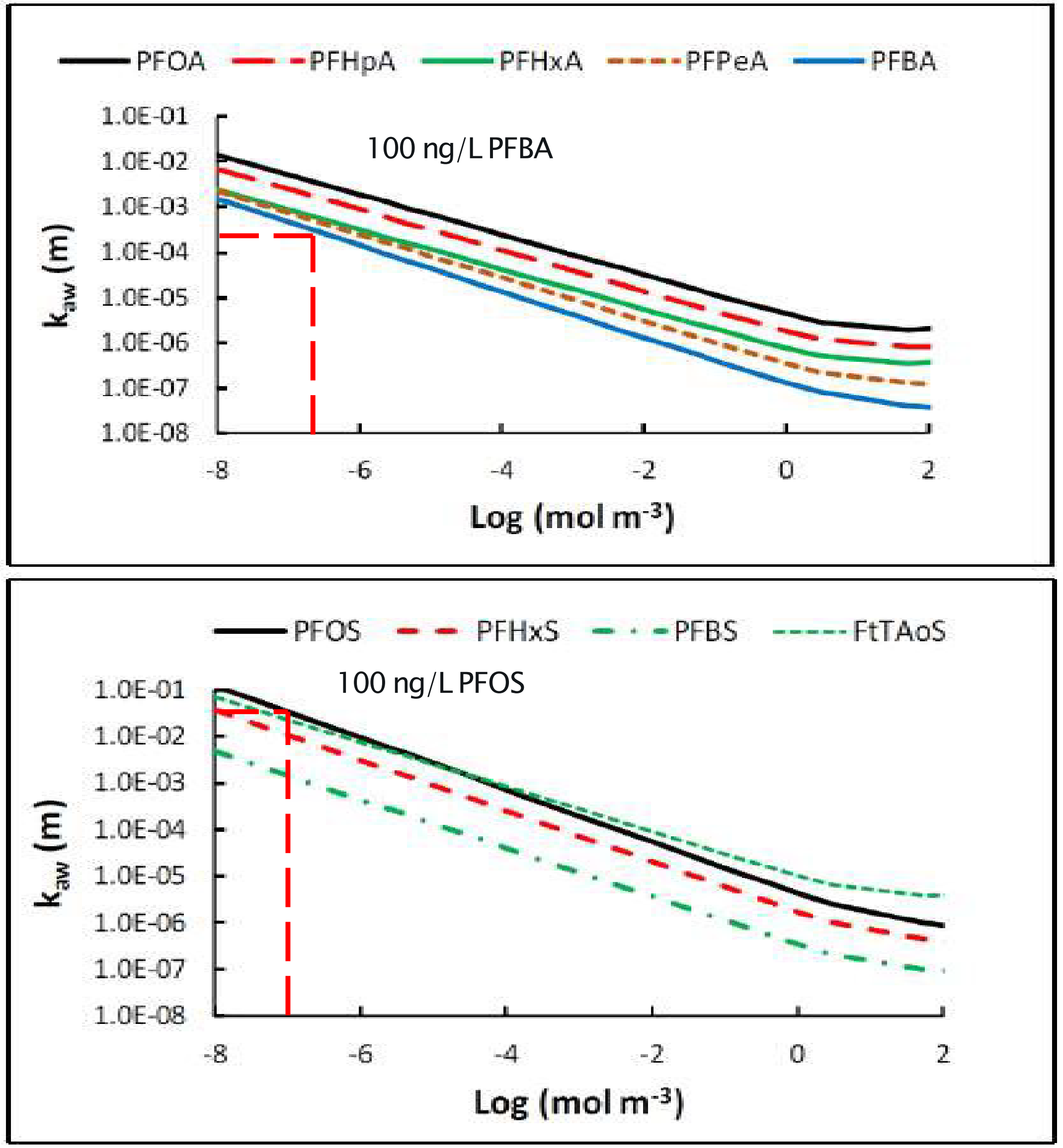
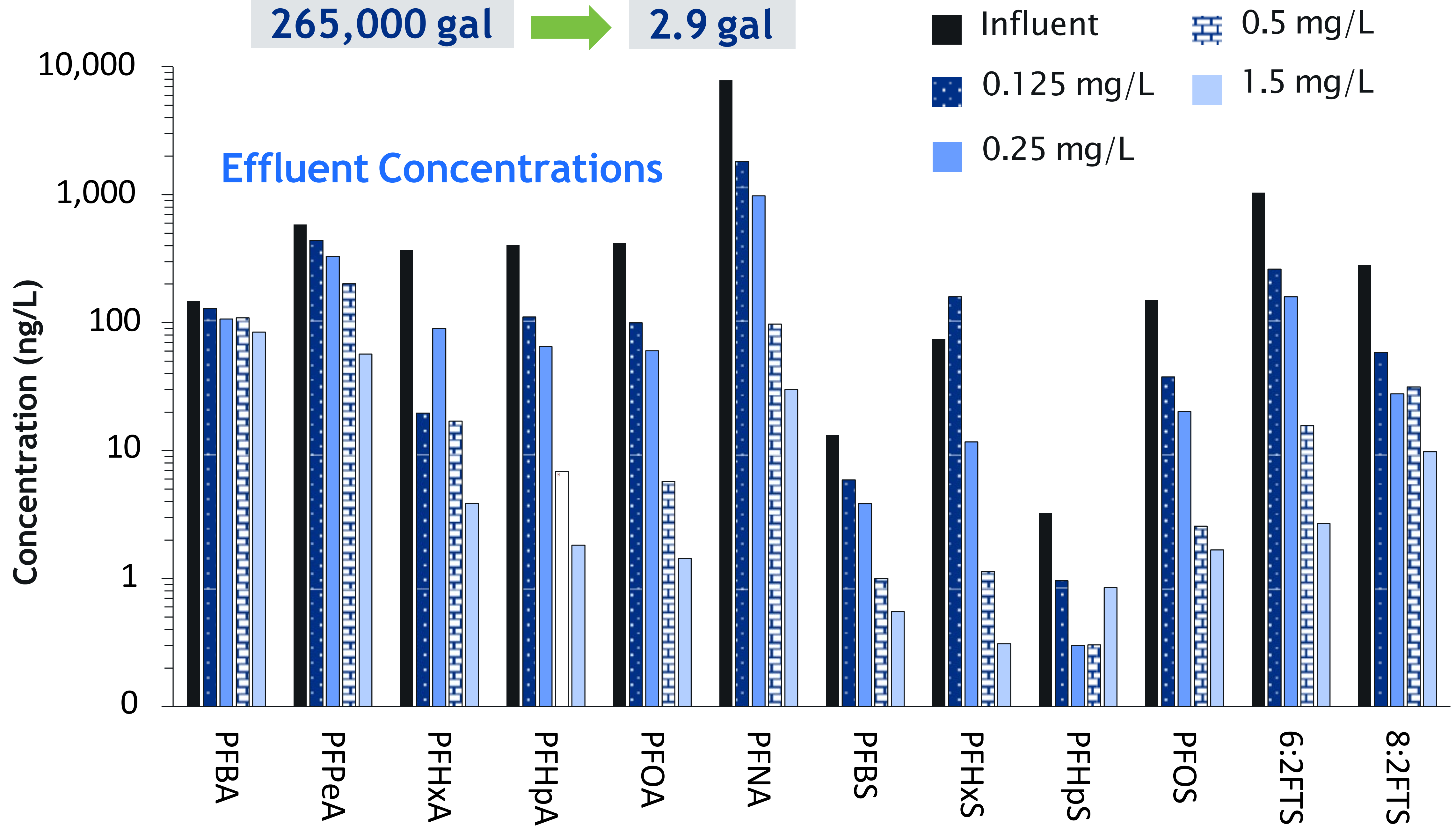
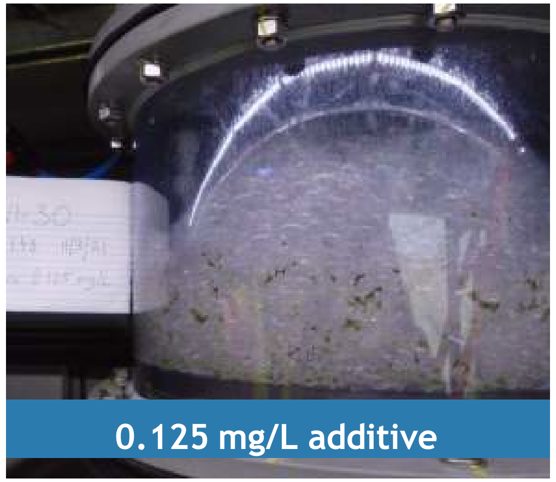


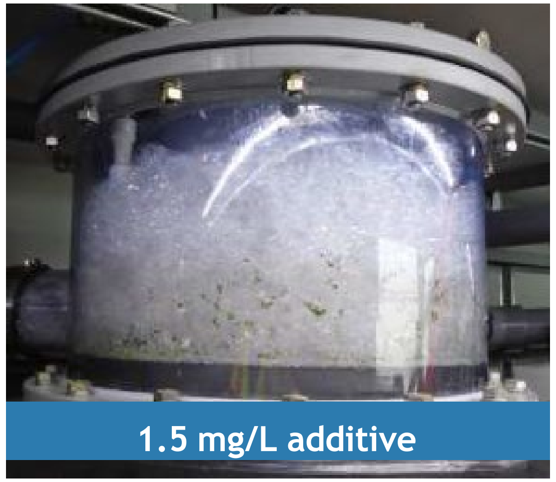
Figure courtesy of Schaefer et al., 2019

Field-Scale Optimization of Foam Fractionation

265,000 gal → 2.9 gal





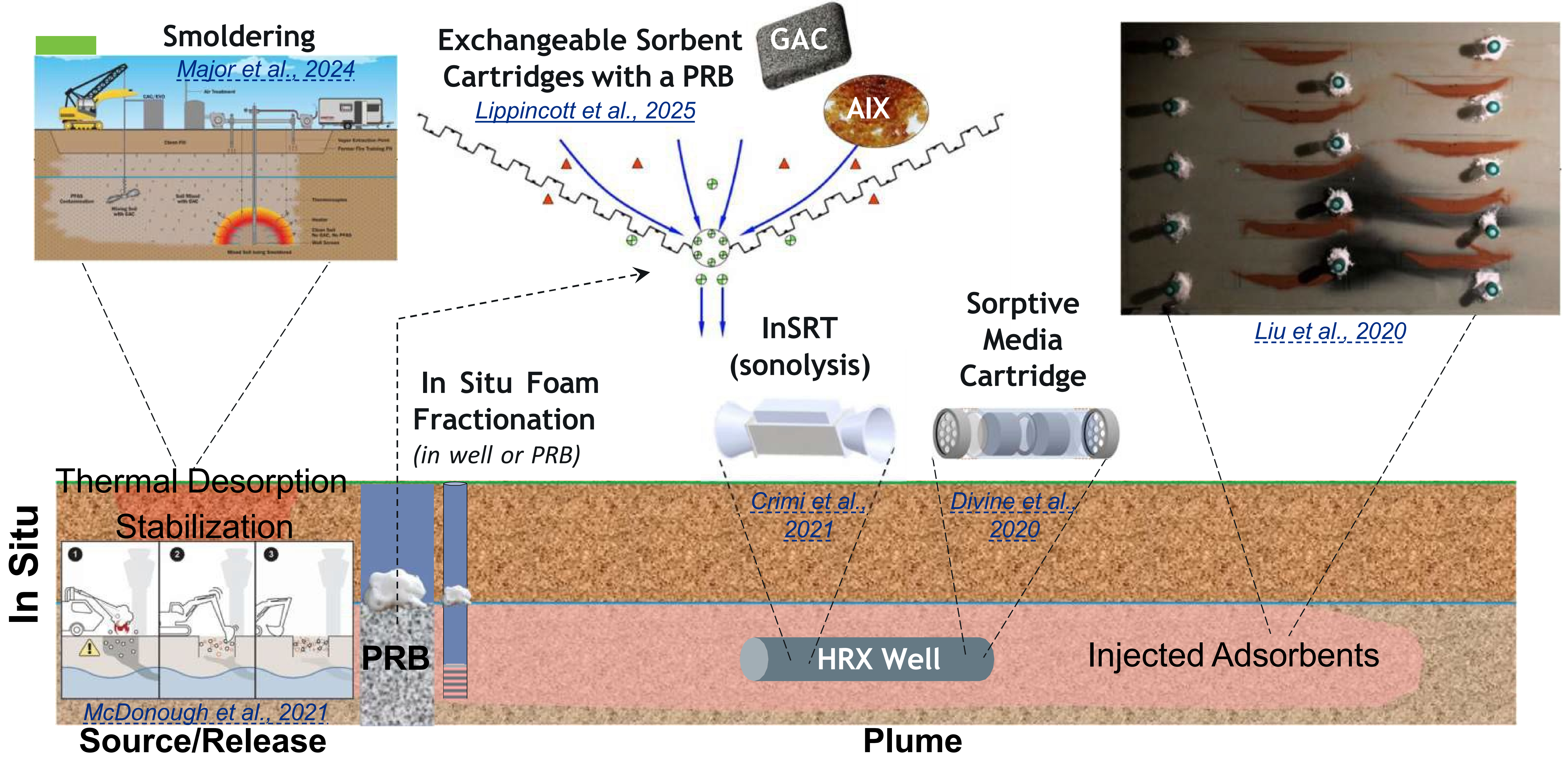


Salvetti 2022 Beattie et al., 2023

FF Takeaways and Progress

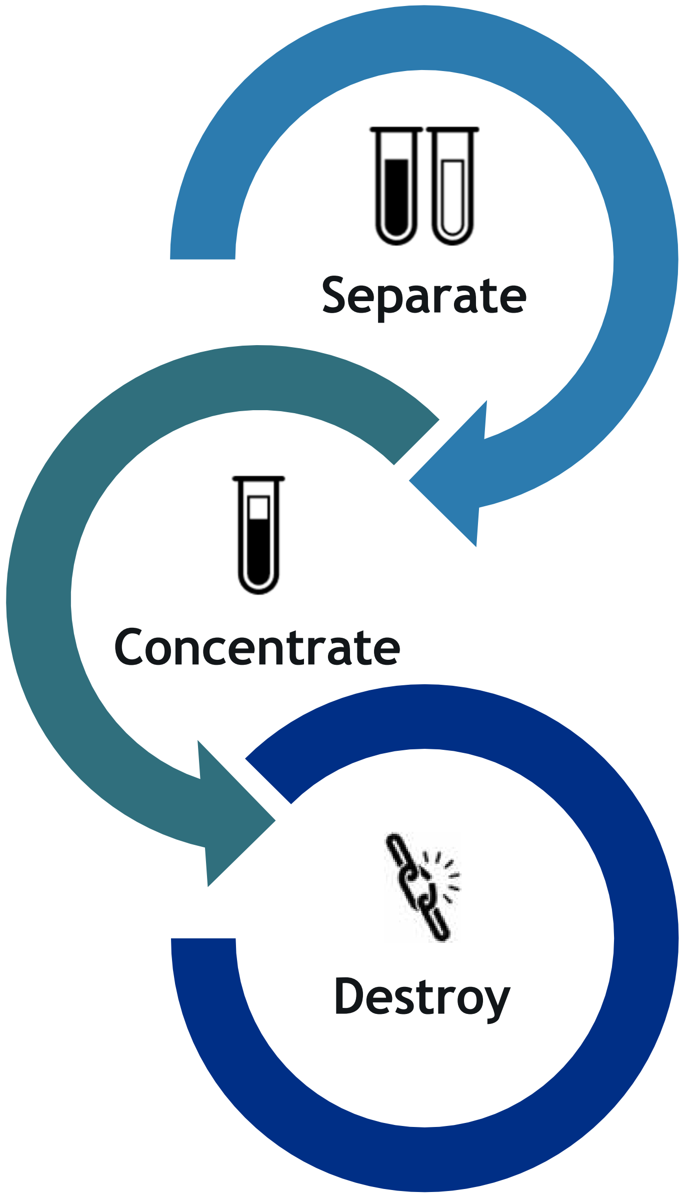
- Less treatment of short-chain PFAS
- Foaming is required!
- Optimization is necessary to maximize removal and volumetric reduction factor
- Not limited to toxic cationic surfactants
- Applicable to multiple water types (including landfill leachate)
- Aerosolization → PFAS loss

In Situ Treatment Technology Development for PFAS



Soils and Solids Treatment

Treatment Options and Trains for Soils / Solids



Treatment Goals	Focused Technologies
• Protect human health and the environment • Prevent leaching to groundwater and other exposure pathways	• Soil Excavation, Landfilling • Capping • Thermal Desorption (350-400°C) • Stabilization/Solidification • Concrete/Asphalt Sealing
• Reduce waste stream volume	• Soil Washing (volume reduction)
• Zero PFAS waste discharge	• Incineration • SCWO (spent GAC or AER) • Pyrolysis

Base Case: Incineration

- Massive head start vs everyone else
- Minimum requirements: >1,000℃, >2 seconds, adequate mixin hydrogen
- DoD moratorium?
  - Repeal under 2026 NDAA and change to “adequate destruction”
- Uncertainty remains regarding complete destruction
  - Studies suggest products of incomplete destruction (PIDs)
  - Insufficient conditions ➔PFAS in gas, scrubber condensate, ash
  - Hydrogen fluoride is expected, dangerous, but manageable
  - Data from new USEPA Methods OTM–45, –50, & –55 forthcoming
- Providers: Clean Harbors, Clean Earth, Veolia, Kruger ERS

Conclusions

No “best” technology for all sites

Current PFAS destruction technologies are very energy intensive

Volumetric concentration can pay for itself

Be careful with energy efficiency (E_{EO}) statistics

Several promising new technologies are emerging

Incineration has a big head start

Thank you!

Jeff Bamer, PE
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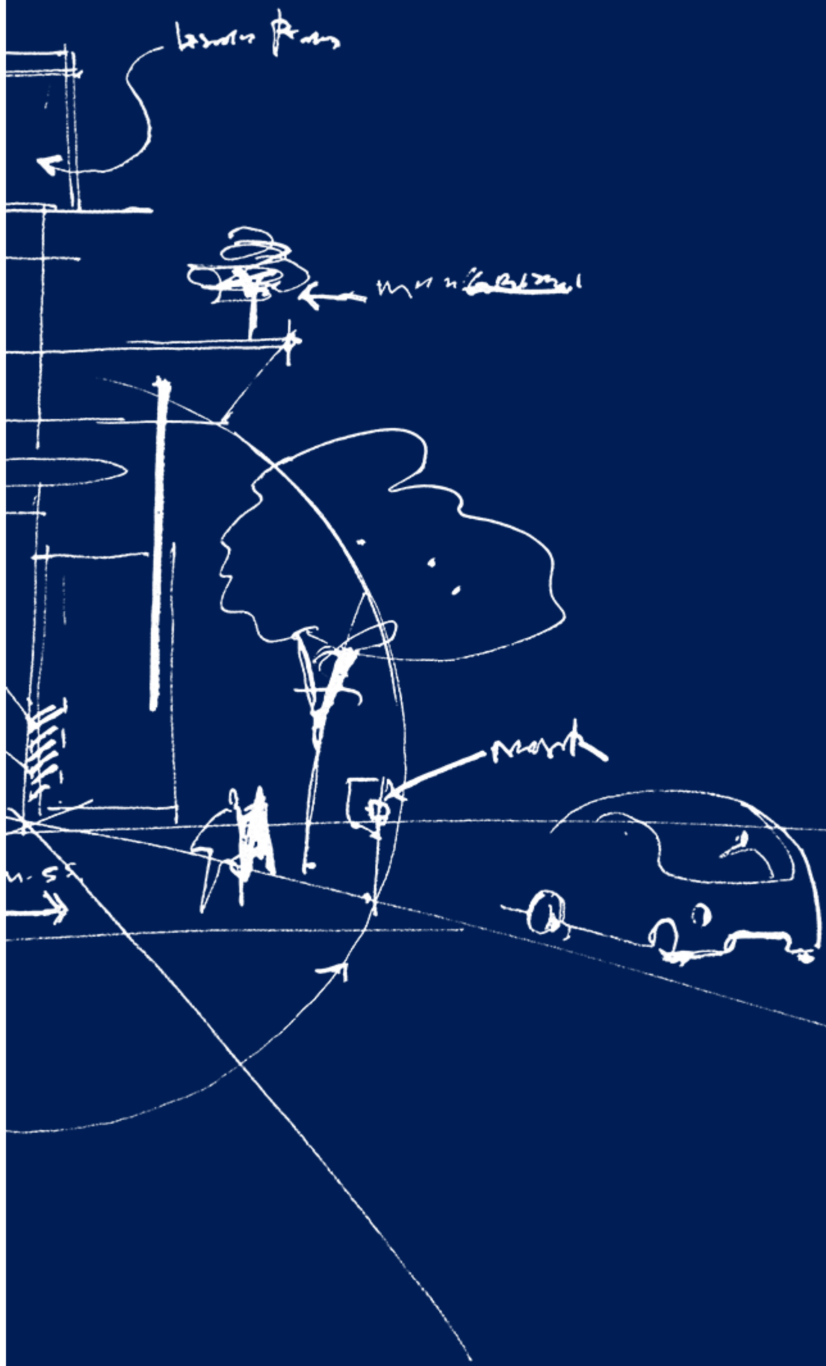
Challenging today.
Reinventing tomorrow.

Assessment of Environmental Footprints for Per- and Polyfluoroalkyl Substances (PFAS) Treatment Technologies for Liquids and Solids

Betsy Collins, Jacobs
Bill DiGuiseppi, Jacobs
Paul Favara, Jacobs
Nikki Fitzgerald, Jacobs
Paige Molzahn, Jacobs paige.molzahn@jacobs.com

Agenda

- Why consider the environmental footprint of PFAS treatment?
- Methodology
  - Develop Scenarios
  - Gather Data
  - Calculate Environmental Footprint
- Results
  - Liquid Scenarios
  - Solid Scenarios
- Conclusions and Opportunities



Why consider the environmental footprint of PFAS treatment?

- Remediation ≠ Sustainability
- PFAS cleanup levels are low
- Long term operations are required
- There will be an environmental impact

➡ How will we reduce that impact?

https://pfas-1.itrcweb.org/

Methodology

Develop Scenarios → Gather Data → Calculate Environmental Footprint

	Volume	Initial Concentration (PFOA+PFOS)	Target Concentration (PFOA+PFOS)
Liquid Scenario 1	1,000 gallons	50,000 ng/L	10 ng/L
Liquid Scenario 2	50,000,000 gallons	500 ng/L	10 ng/L
Solid Scenario 1	Five 55-gallon drums	10,000 µg/kg	1 µg/kg
Solid Scenario 2	10,000 cubic yards	10,000 µg/kg	1 µg/kg

	Volume	Initial Concentration (PFOA+PFOS)	Target Concentration (PFOA+PFOS)
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High concentration, low volume sources: monitoring well IDW, thermal treatment condensate, soil washing waste streams, IX regenerant liquids, etc.

Develop Scenarios → Gather Data → Calculate Environmental Footprint

	Volume	Initial Concentration (PFOA+PFOS)	Target Concentration (PFOA+PFOS)
Liquid Scenario 1	1,000 gallons	50,000 ng/L	10 ng/L
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Solid Scenario 2	10,000 cubic yards	10,000 µg/kg	1 µg/kg

<u>High volume, low concentration sources</u>: potential pump and treat groundwater hydraulic containment system, contaminated site dewatering system, etc.

	Volume	Initial Concentration (PFOA+PFOS)	Target Concentration (PFOA+PFOS)
Liquid Scenario 1	1,000 gallons	50,000 ng/L	10 ng/L
Liquid Scenario 2	50,000,000 gallons	500 ng/L	10 ng/L
Solid Scenario 1	Five 55-gallon drums	10,000 µg/kg	1 µg/kg
Solid Scenario 2	10,000 cubic yards	10,000 µg/kg	1 µg/kg

Low volume: potential IDW or drill cuttings from environmental investigation

Develop Scenarios → Gather Data → Calculate Environmental Footprint

	Volume	Initial Concentration (PFOA+PFOS)	Target Concentration (PFOA+PFOS)
Liquid Scenario 1	1,000 gallons	50,000 ng/L	10 ng/L
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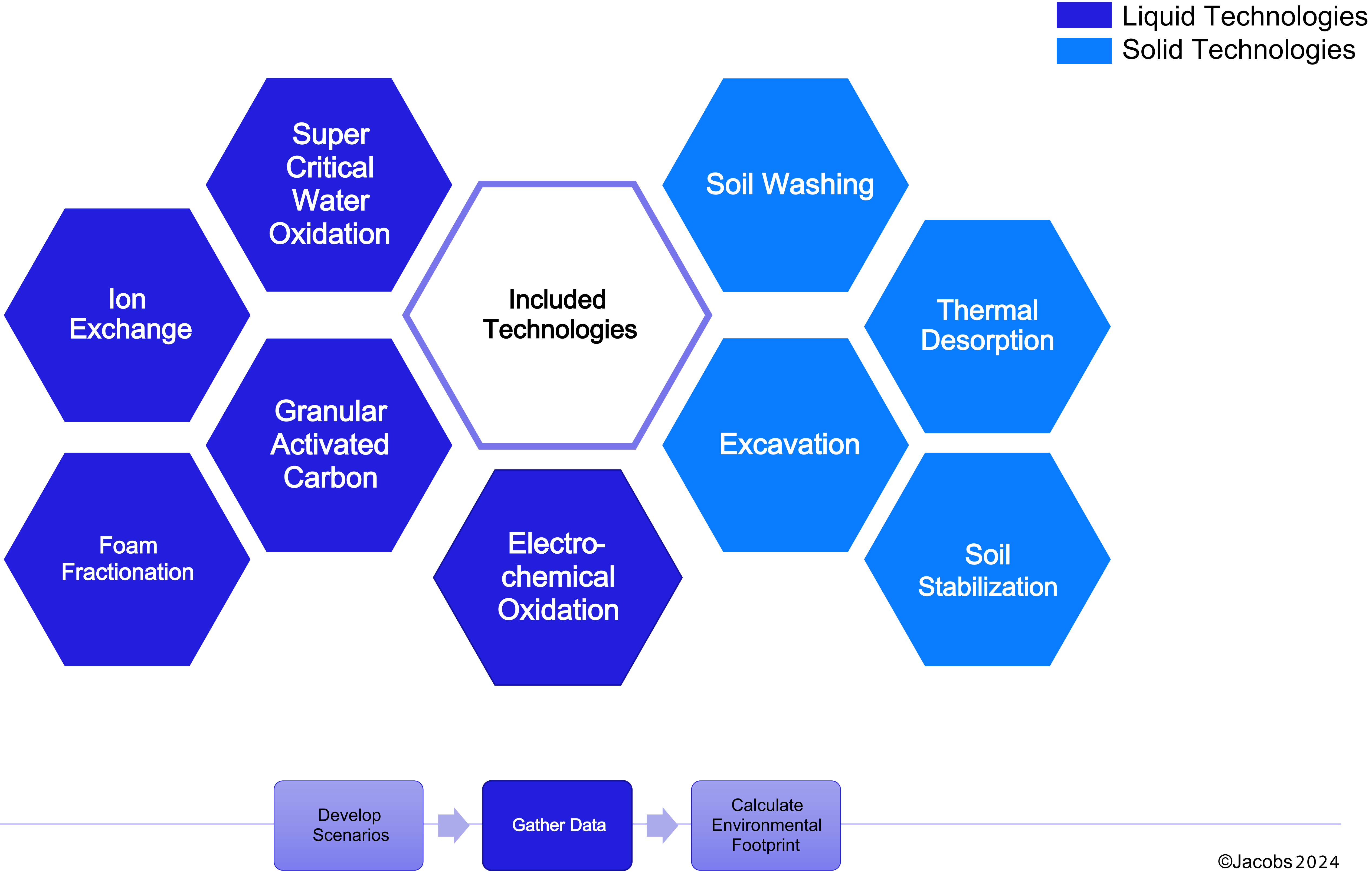
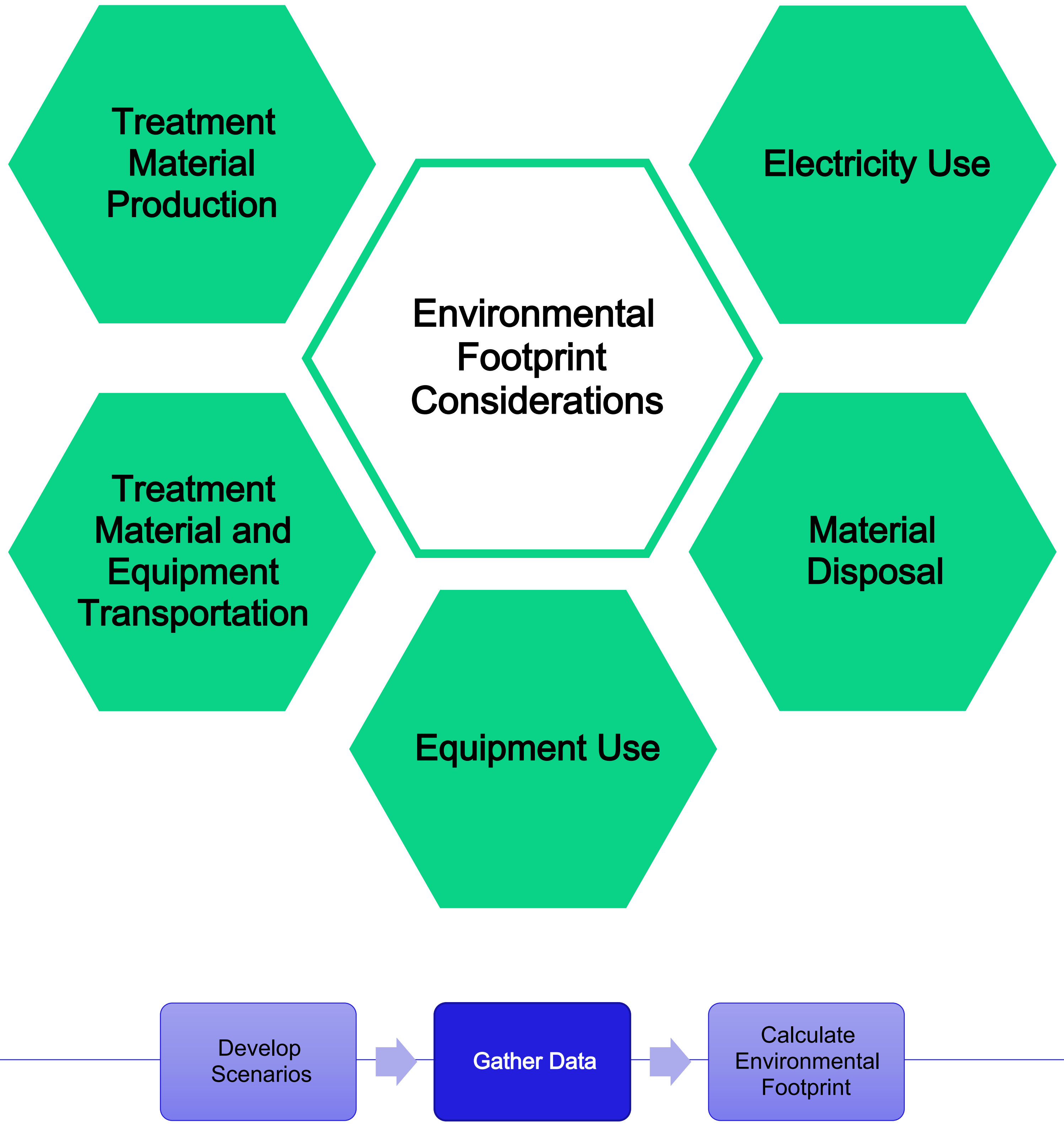
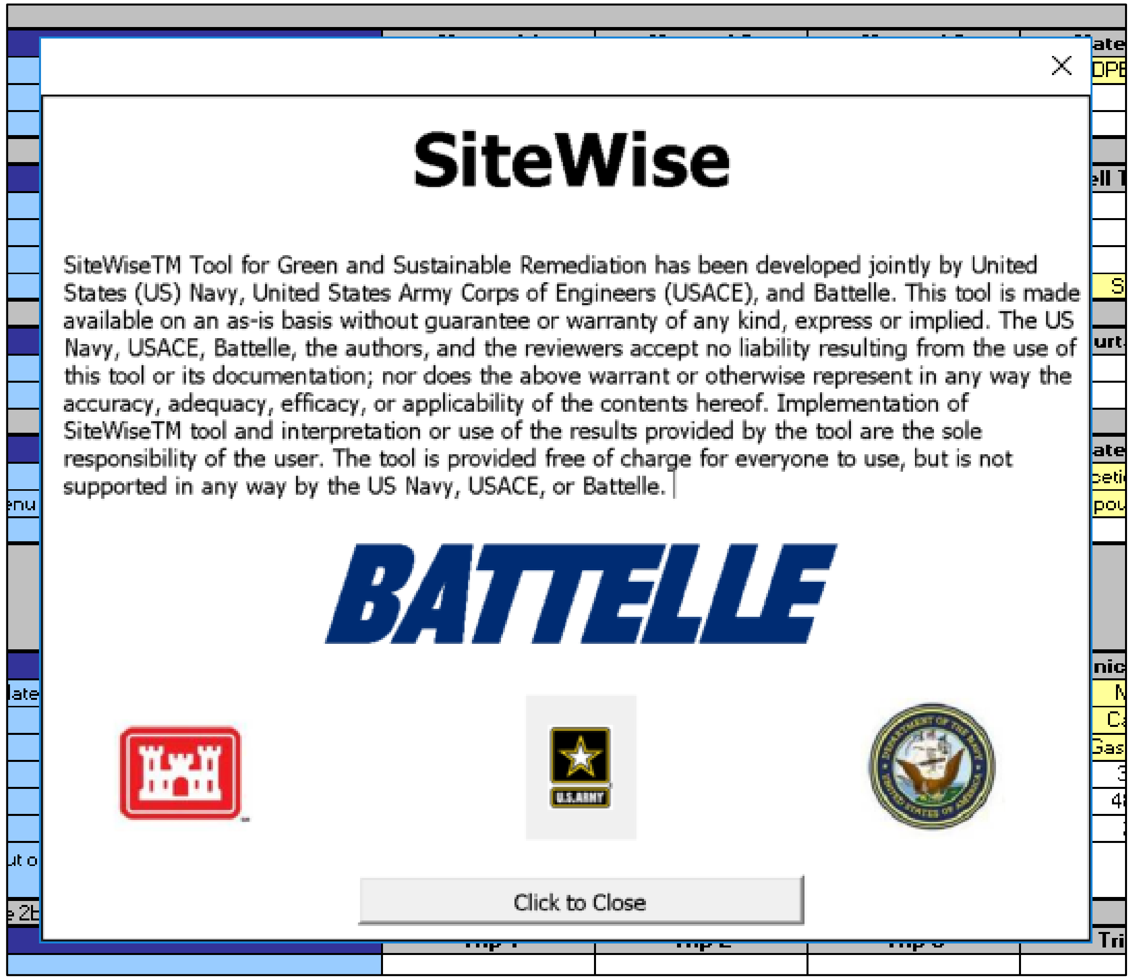
Solid Scenario 2	10,000 cubic yards	10,000 µg/kg	1 µg/kg

<u>High volume</u>: potential source area contamination on a site

Develop Scenarios → Gather Data → Calculate Environmental Footprint


Liquid Technologies
Solid Technologies
Super Critical Water Oxidation
Ion Exchange
Granular Activated Carbon
Foam Fractionation
Included Technologies
Electro-chemical Oxidation
Soil Washing
Thermal Desorption
Excavation
Soil Stabilization
Develop Scenarios
Gather Data
Calculate Environmental Footprint


Treatment Material Production
Electricity Use
Environmental Footprint Considerations
Treatment Material and Equipment Transportation
Material Disposal
Equipment Use
Develop Scenarios
Gather Data
Calculate Environmental Footprint



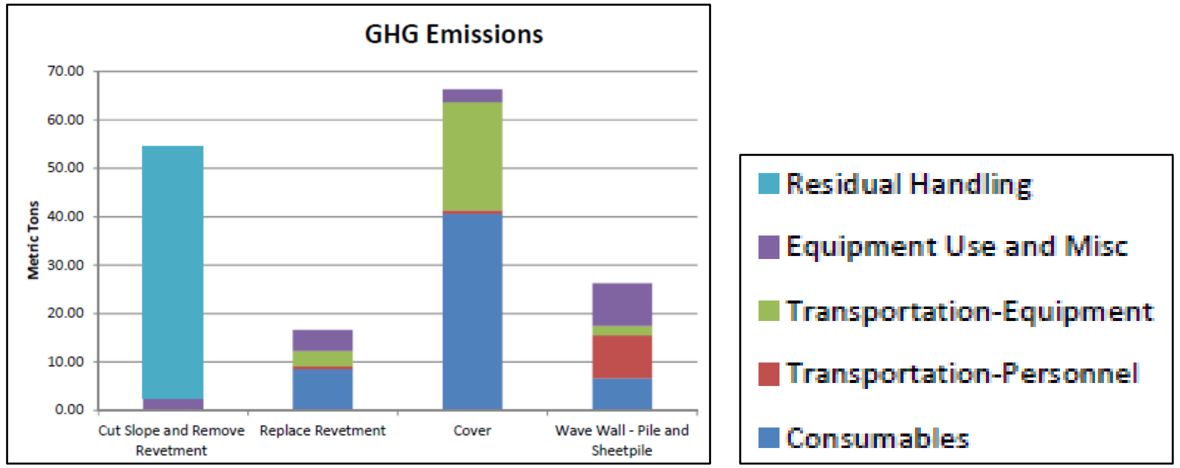
Inputs

BULK MATERIAL QUANTITIES	Material 1	Material 2
Choose material from drop down menu	Bentonite	Virgin GAC
Choose units of material quantity from drop down menu	pounds	pounds
Input material quantity	165,000	300

DRILLING	Event 1	Event 2
Input number of drilling locations	5	25
Choose drilling method from drop down menu	Sonic Drilling	Direct Push
Input time spent drilling at each location (hr)	5.00	5.00
Choose fuel type from drop down menu	Diesel	Diesel

RESIDUE DISPOSAL/RECYCLING	Soil Residue	Residual Water
Will DIESEL-run vehicles be retrofitted with a particulate reduction technology?	No	No
Input weight of the waste transported to landfill or recycling per trip (tons)	20.0	16.0
Choose fuel used from drop down menu	Diesel	Gasoline
Input total number of trips	4.0	2.0
Input number of miles per trip	100.0	300.0

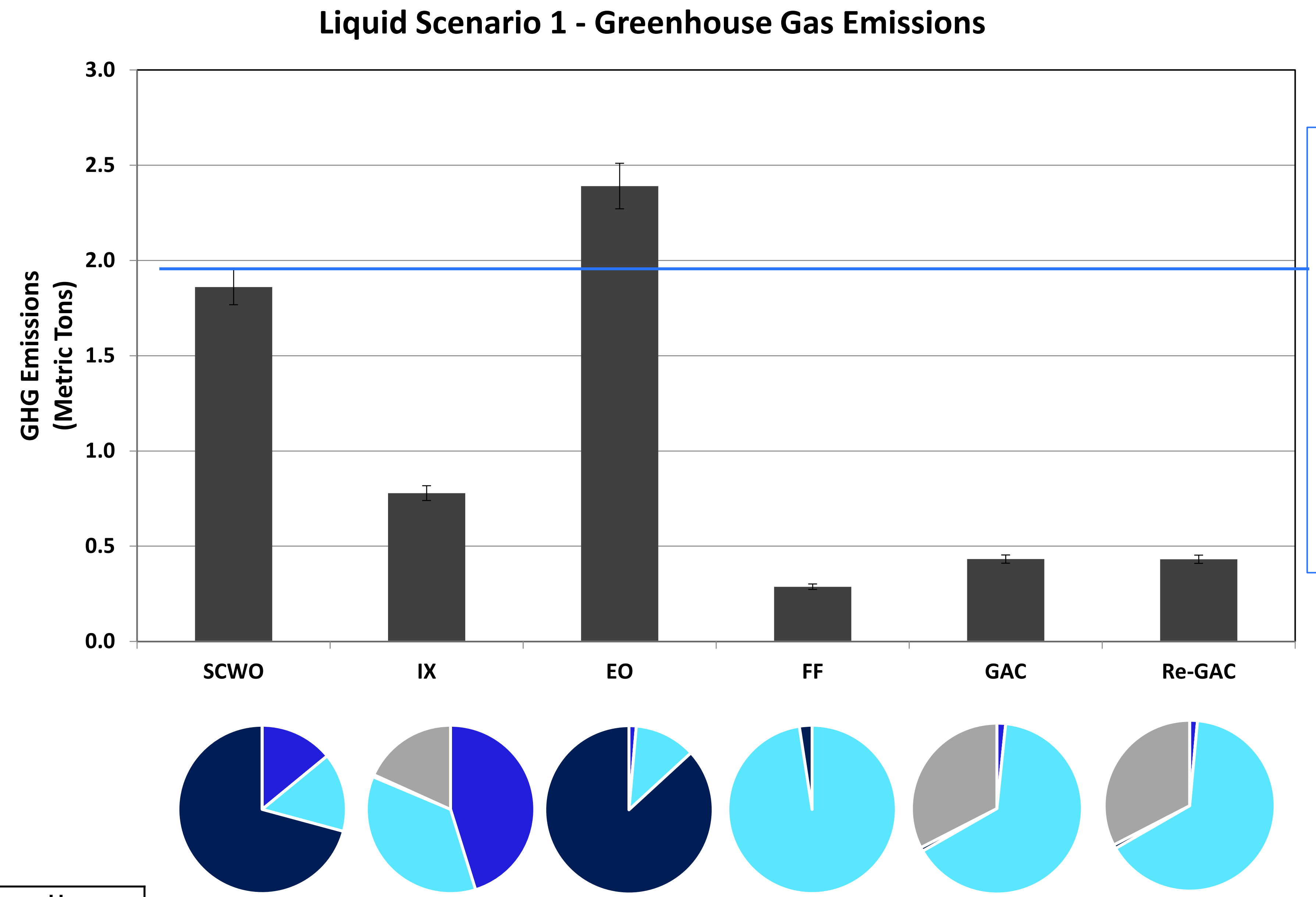
Outputs



Remedial Alternatives	GHG Emissions	Energy Usage	Water Usage	Electricity Usage	Onsite NOx Emissions	Onsite SOx Emissions
Alternative 1	High	High	Low	High	Medium	Medium
Alternative 2	Medium	Medium	Low	Low	High	High
Alternative 3	Medium	Medium	High	Low	High	High

Develop Scenarios → Gather Data → **Calculate Environmental Footprint**

Results



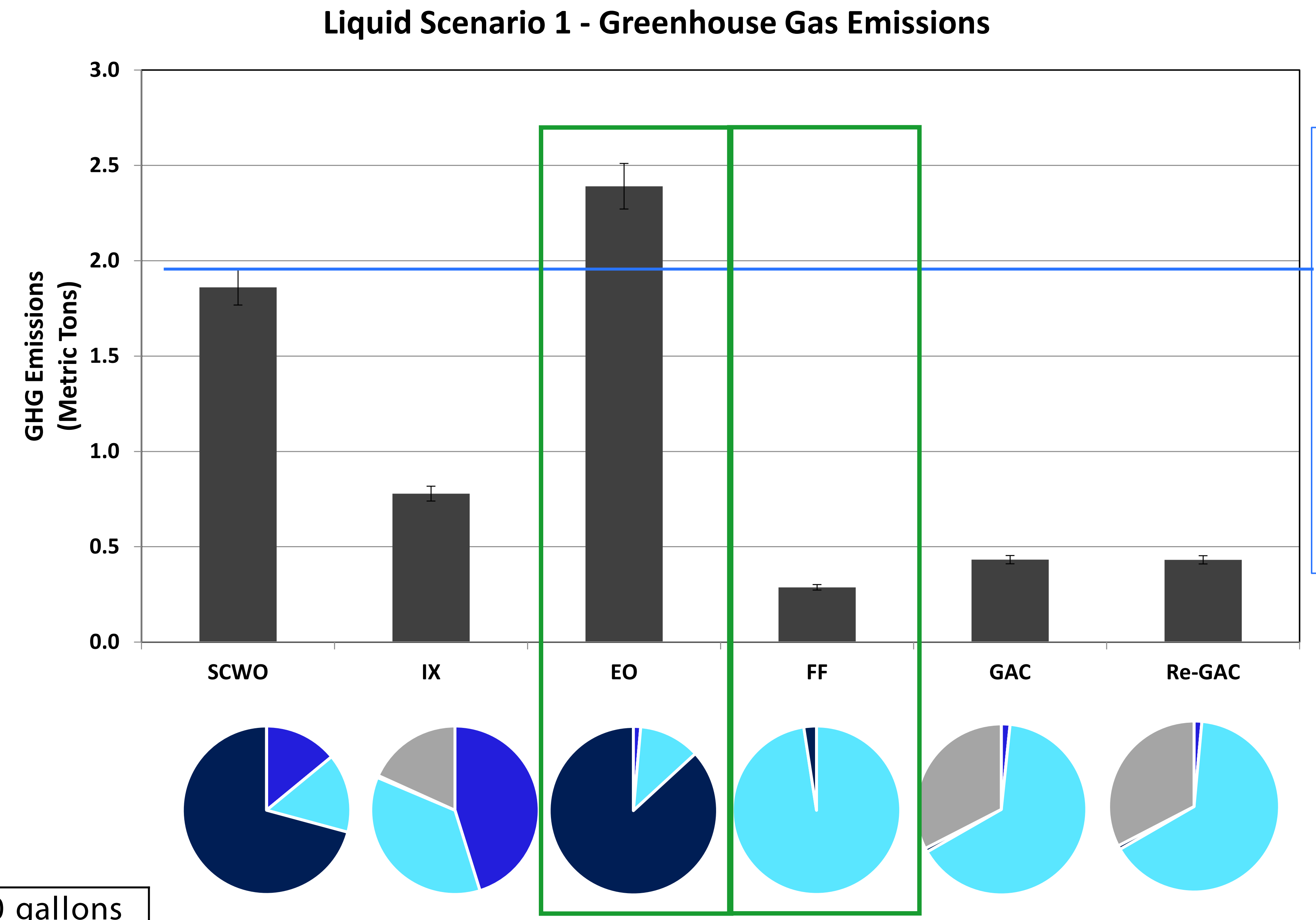
Equivalent to ~5,000 miles driven by an average gasoline powered passenger vehicle

Volume	1,000 gallons
Initial Concentration (PFOA+PFOS)	50,000 ng/L
Target Concentration (PFOA+PFOS)	10 ng/L

SWCO = supercritical water oxidation
IX = ion exchange
EO = electrochemical oxidation
FF = foam fractionation
GAC = granular activated carbon
Re-GAC = regenerated granular activated carbon

- Treatment Material Production
- Treatment Material and Equipment Transportation
- Equipment and Electricity Use
- Material Disposal

Results



Equivalent to ~5,000 miles driven by an average gasoline powered passenger vehicle

Volume	1,000 gallons
Initial Concentration (PFOA+PFOS)	50,000 ng/L
Target Concentration (PFOA+PFOS)	10 ng/L

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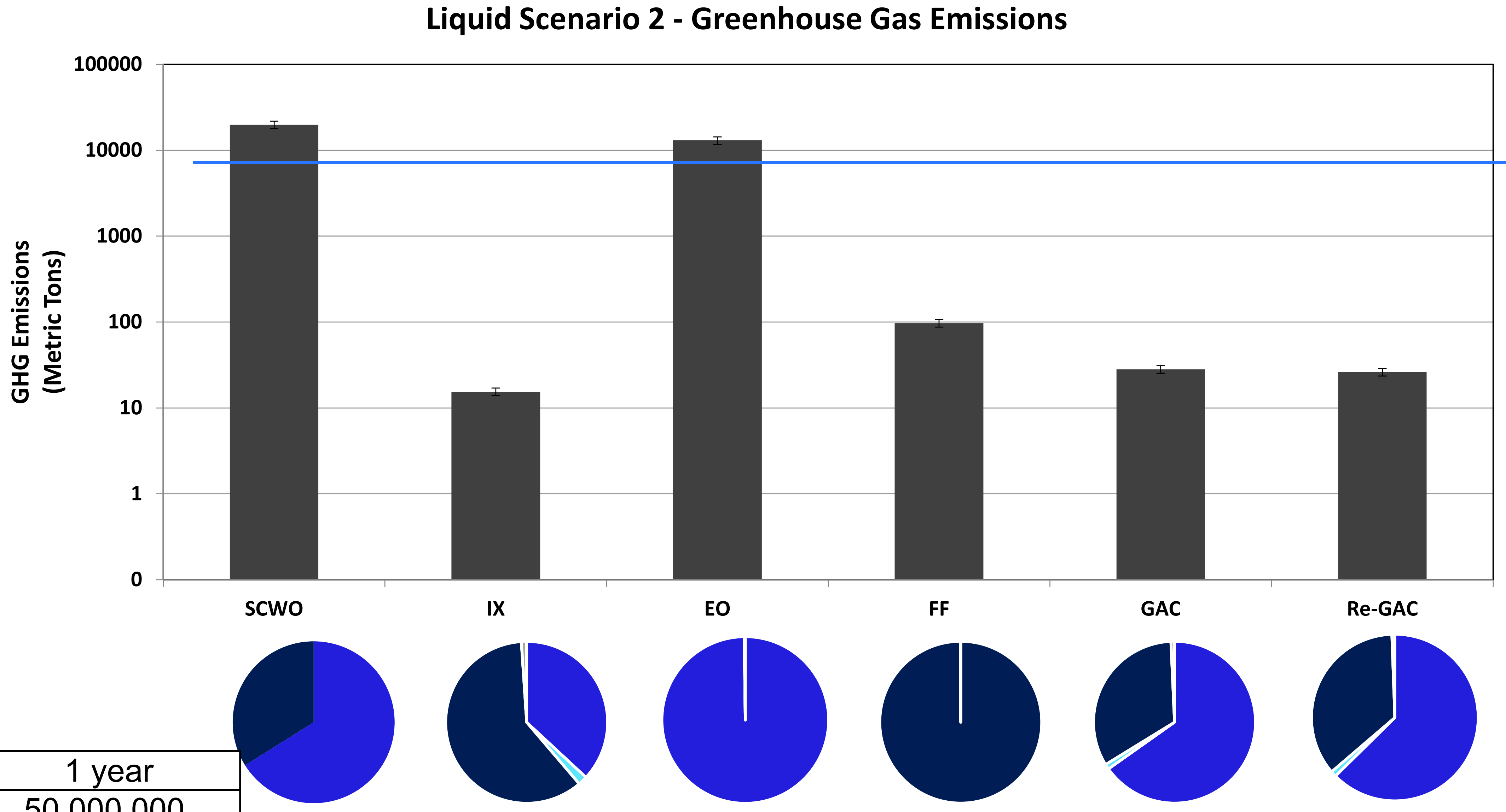
Results



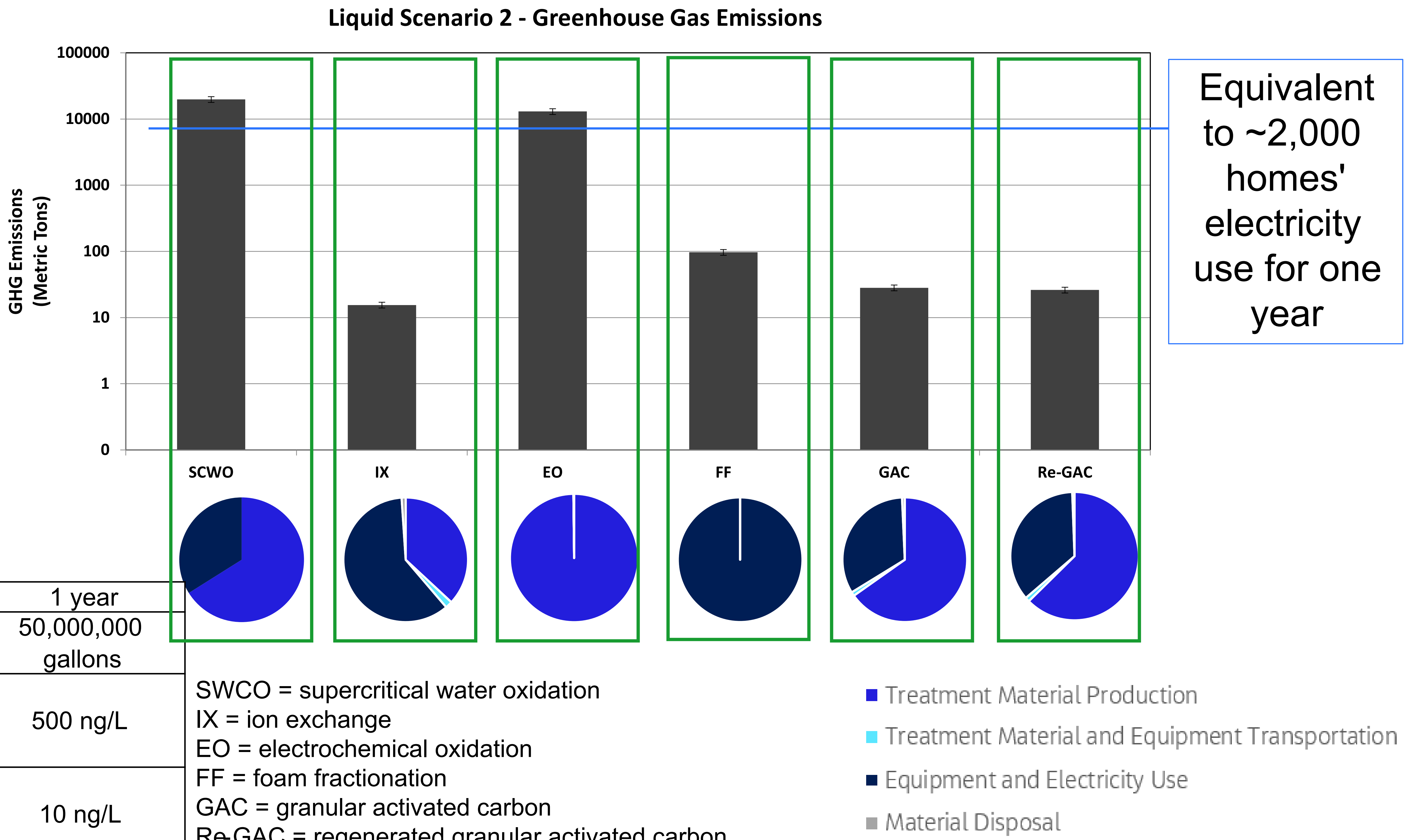
Equivalent to ~2,000 homes' electricity use for one year

Duration	1 year
Volume	50,000,000 gallons
Initial Concentration (PFOA+PFOS)	500 ng/L
Target Concentration (PFOA+PFOS)	10 ng/L

SWCO = supercritical water oxidation
IX = ion exchange
EO = electrochemical oxidation
FF = foam fractionation
GAC = granular activated carbon
Re-GAC = regenerated granular activated carbon

- Treatment Material Production
- Treatment Material and Equipment Transportation
- Equipment and Electricity Use
- Material Disposal

Results



Duration	1 year
Volume	50,000,000 gallons
Initial Concentration (PFOA+PFOS)	500 ng/L
Target Concentration (PFOA+PFOS)	10 ng/L

SWCO = supercritical water oxidation
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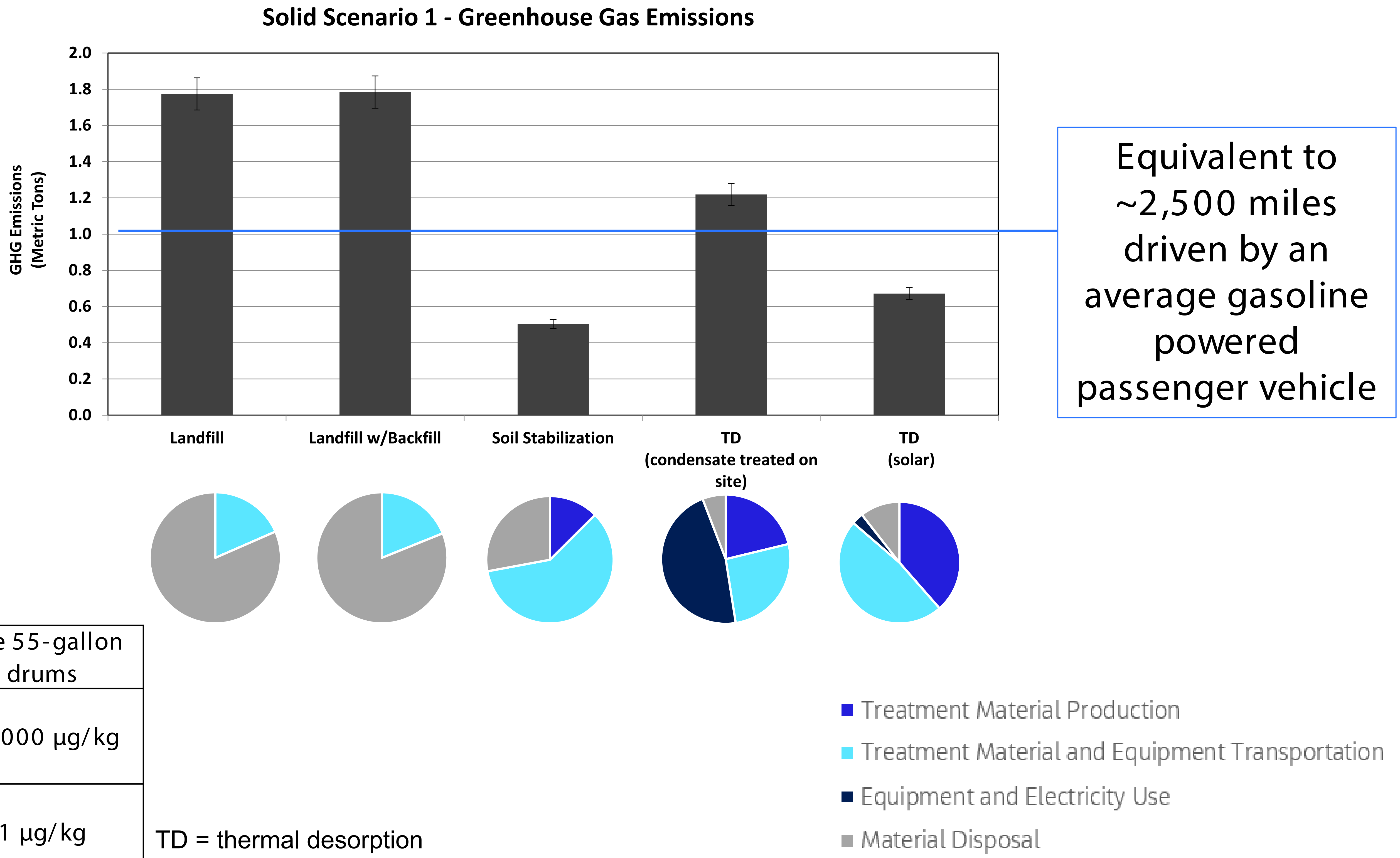
Results

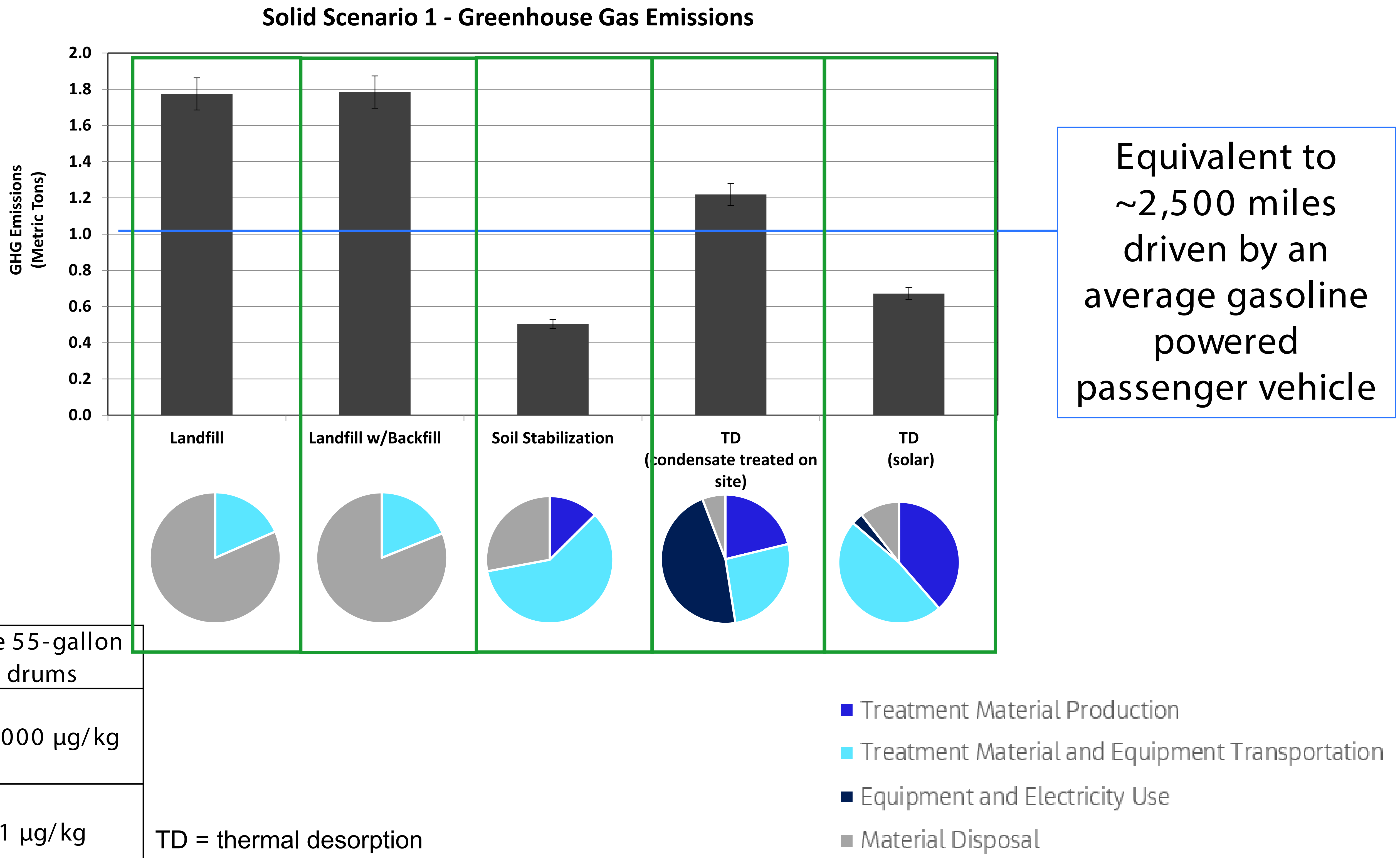


Equivalent to ~2,500 miles driven by an average gasoline powered passenger vehicle

Volume	Five 55-gallon drums
Initial Concentration (PFOA+PFOS)	10,000 µg/kg
Target Concentration (PFOA+PFOS)	1 µg/kg

TD = thermal desorption

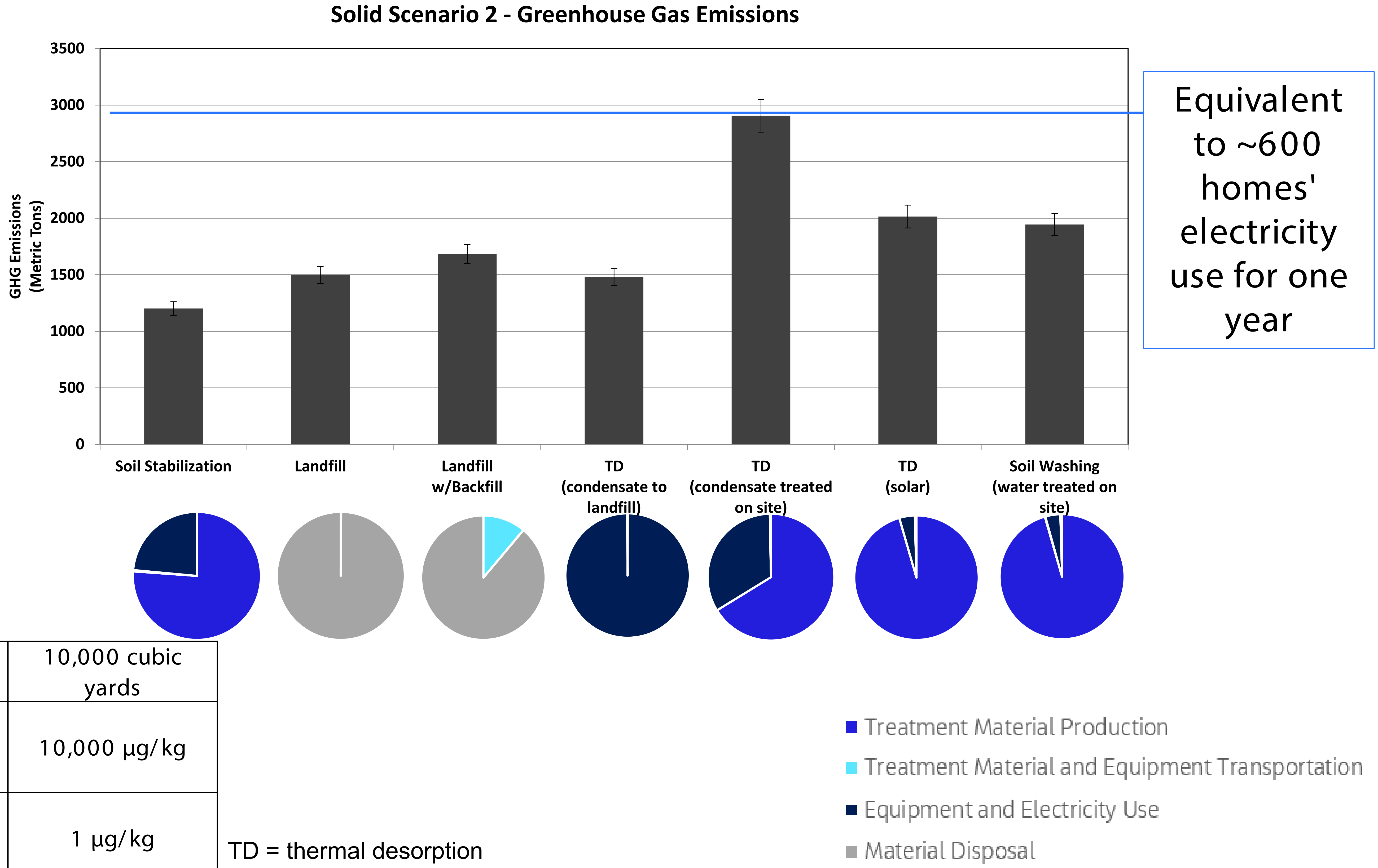
Results



Volume	Five 55-gallon drums
Initial Concentration (PFOA+PFOS)	10,000 µg/kg
Target Concentration (PFOA+PFOS)	1 µg/kg

TD = thermal desorption

Results

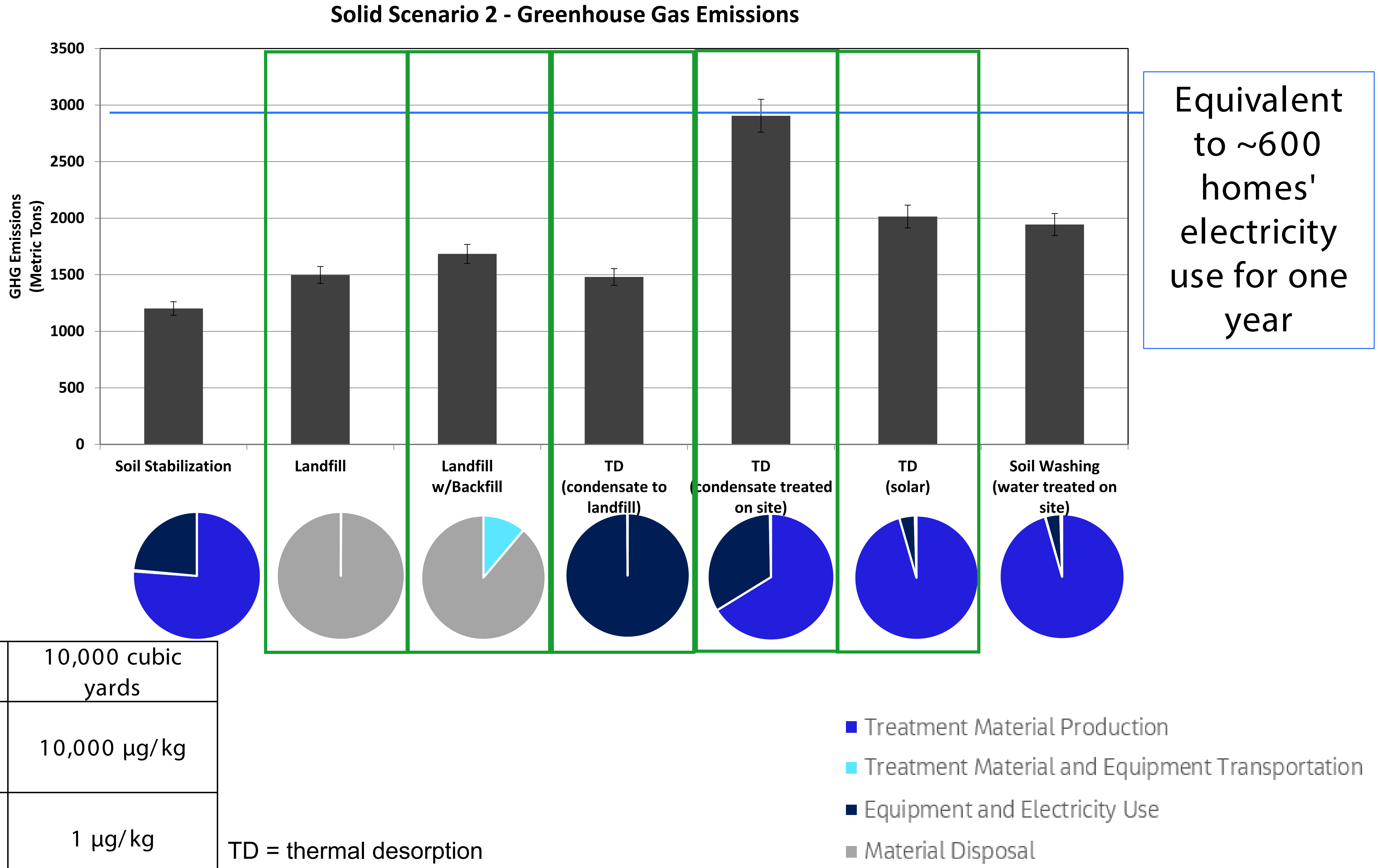


Equivalent to ~600 homes' electricity use for one year

Volume	10,000 cubic yards
Initial Concentration (PFOA+PFOS)	10,000 µg/kg
Target Concentration (PFOA+PFOS)	1 µg/kg

TD = thermal desorption

Results



Equivalent to ~600 homes' electricity use for one year

Volume	10,000 cubic yards
Initial Concentration (PFOA+PFOS)	10,000 µg/kg
Target Concentration (PFOA+PFOS)	1 µg/kg

TD = thermal desorption

Considerations and Opportunities

- Long-term resiliency
  - Risk mitigation vs. destruction of PFAS
- Main contributors: electricity use and transportation
  - Solar panels
  - Higher percentages of renewables
  - Electric vehicles
- Treatment Trains
  - Combine technology types
  - Create efficiencies, reduce overall environmental footprint
- Consideration of additional sustainability factors in future evaluations
- PFAS treatment will have an impact, consider opportunities for reductions

Thank you!

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