Can Biosolids Be Cost Effectively Treated?

The Impact of PFAS on Water Reclamation Facilities

2023 NEBRA & NEWEA Fall Residuals Conference   Portsmouth, NH

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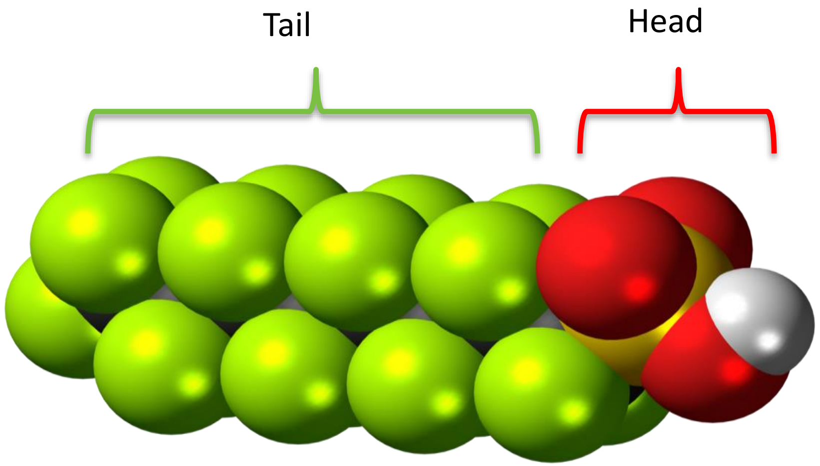
November 2, 2023

CDM Smith

Outline

- Regulatory Updates
- PFAS Destructive Technology Readiness
- Source Identification & Opportunities
- Conclusions



Regulatory Updates

PFAS Regulations – Wastewater

- PFAS in NPDES permits:
  CO, CA, MA, MI, others
- Federal Regulations for biosolids likely 1-2 years away
- State Actions
  - Maine prohibits land application of biosolids
  - Vermont Agency of Transportation (VTrans) disallows use of Biosolids, revoked.
  - Other states taking more measured approach (MI, WA, WI, CO, OK, NH, NY)
  - Arizona biosolids prohibition, revoked

– S-2053 "An Act Establishing a Moratorium on the Procurement of Structures or Activities Generating PFAS Emissions"

- Canadian limits and moratorium

MassDEP

Quarterly reporting of influent, effluent and biosolids

PFHxS
PFNA
PFOS
PFOA
PFHpA
PFDA

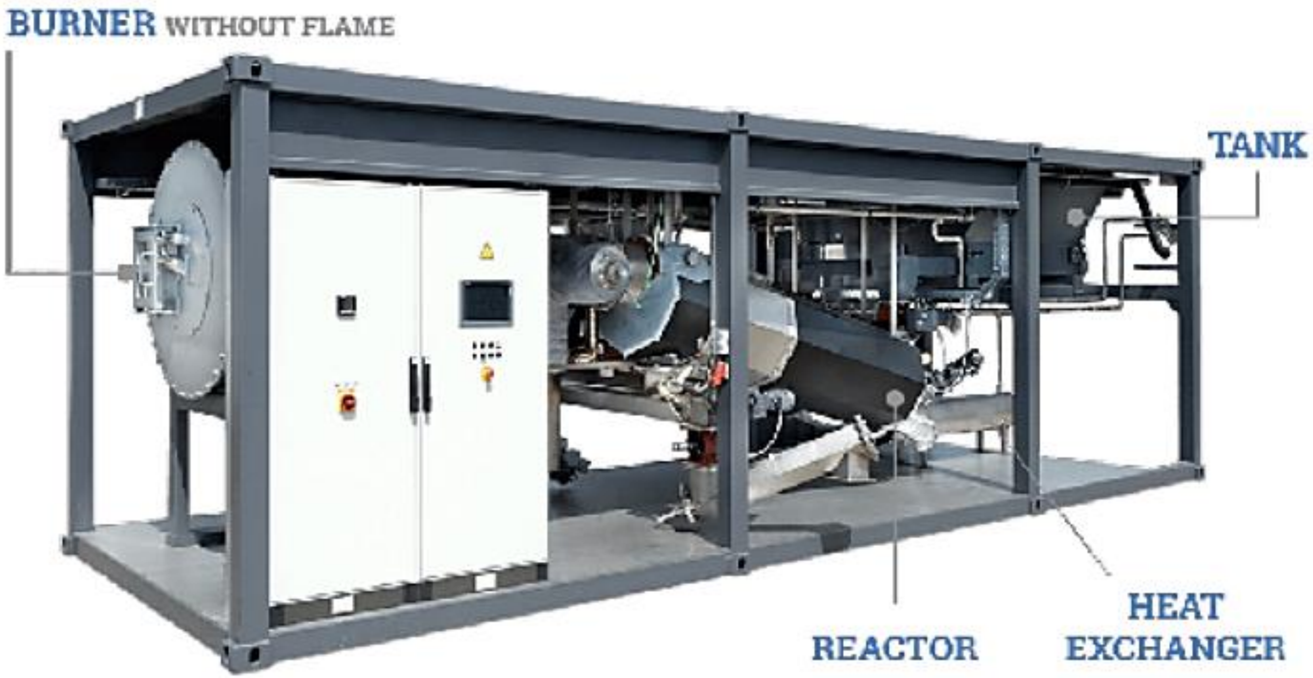
6 months after approved method available

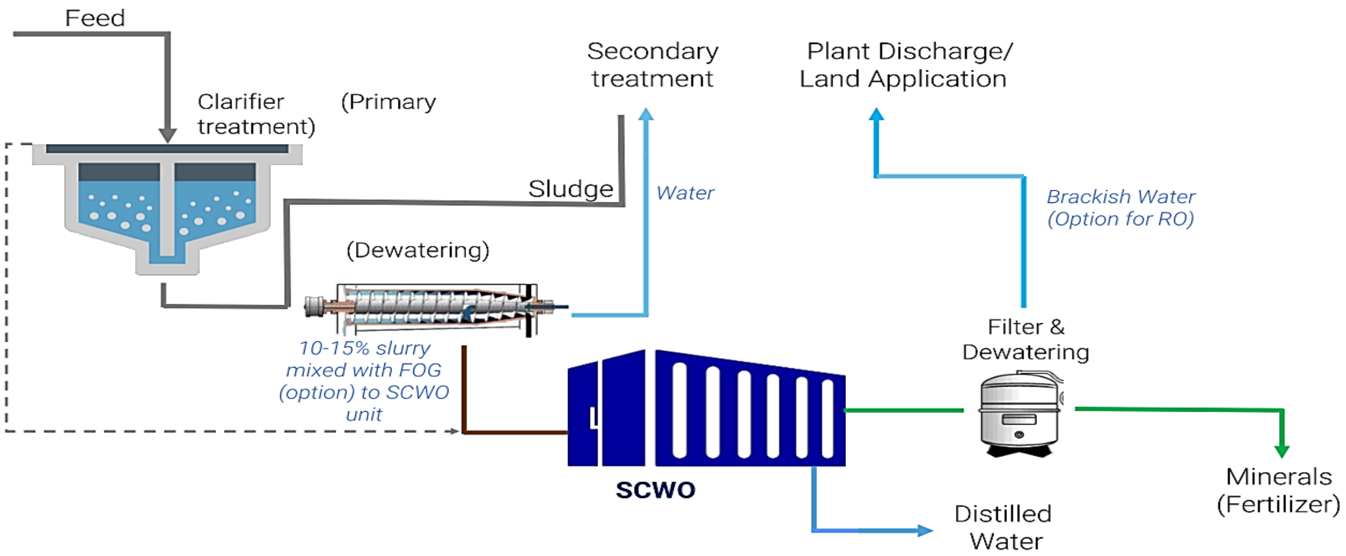
Requiring AOF sampling & not renewing some AOS permits

Destruction and Mitigation Technologies

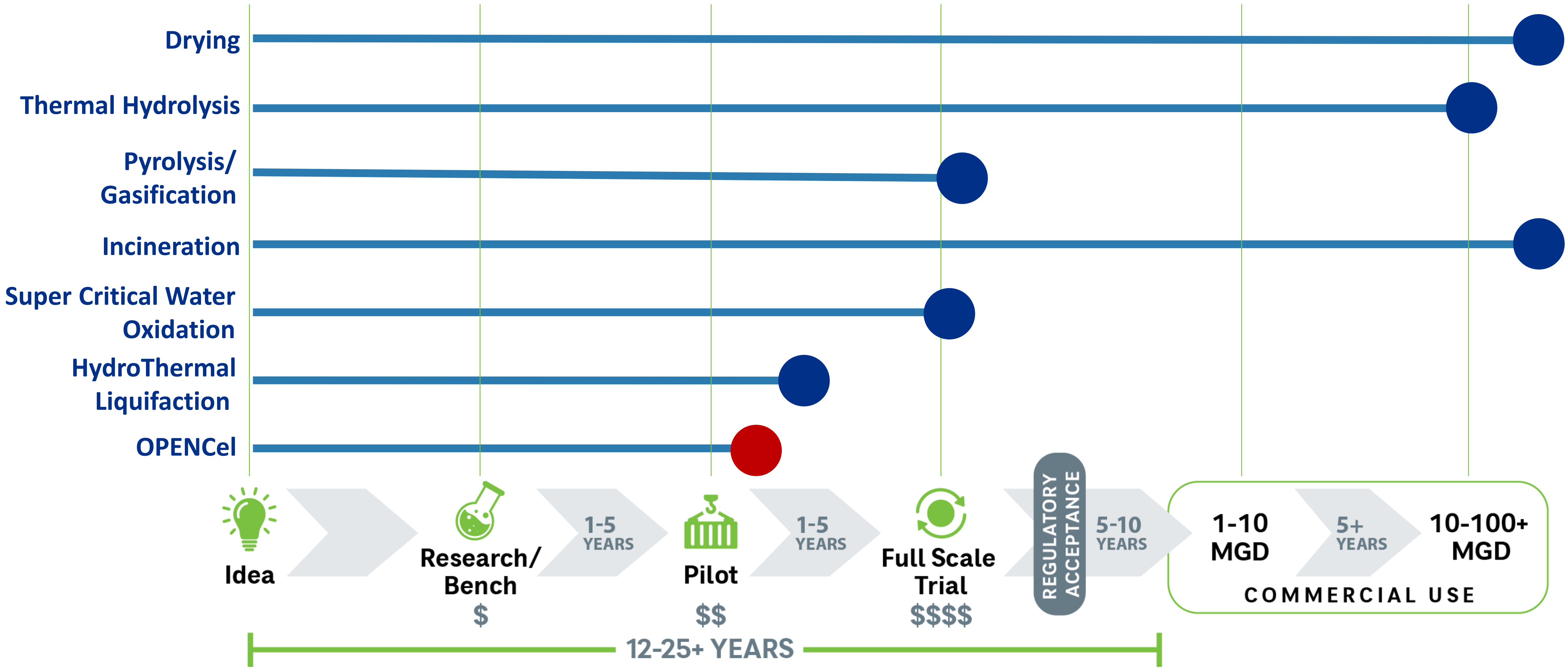
Thermal Processes

- Drying
- Thermal Hydrolysis Process
- Incineration
- Gasification
- Pyrolysis
- Liquid sludge thermal oxidation
  - Supercritical water oxidation
  - Hydrothermal catalytic gasification
  - Deep shaft wet air oxidation
- Hydrothermal Liquefaction
- Plasma



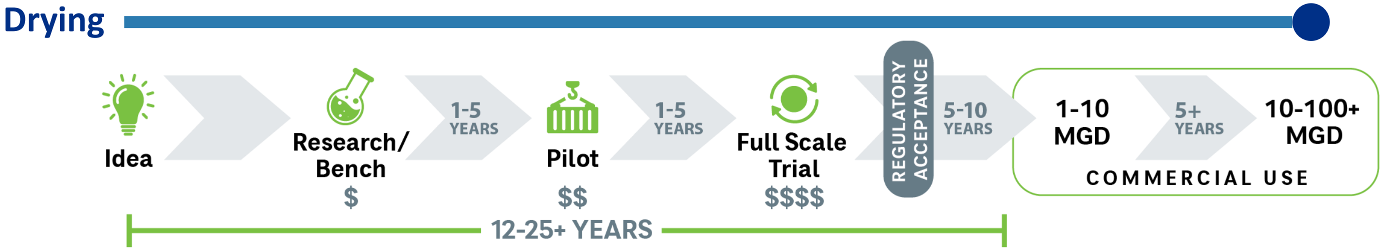


Technology Readiness



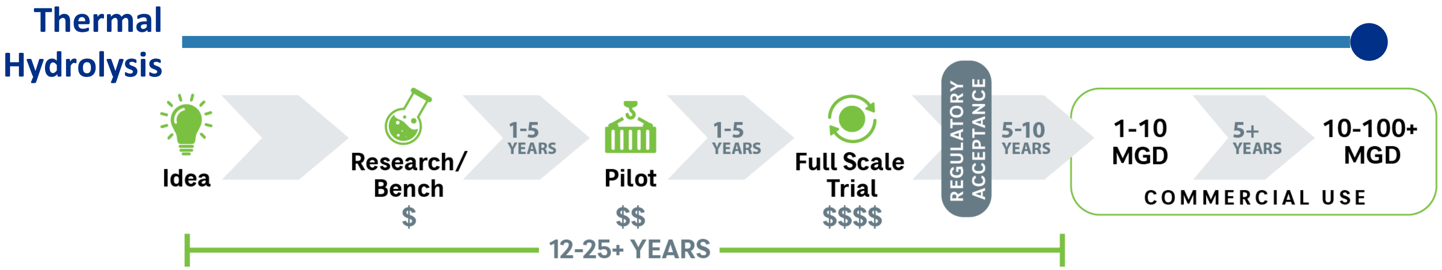
Drying

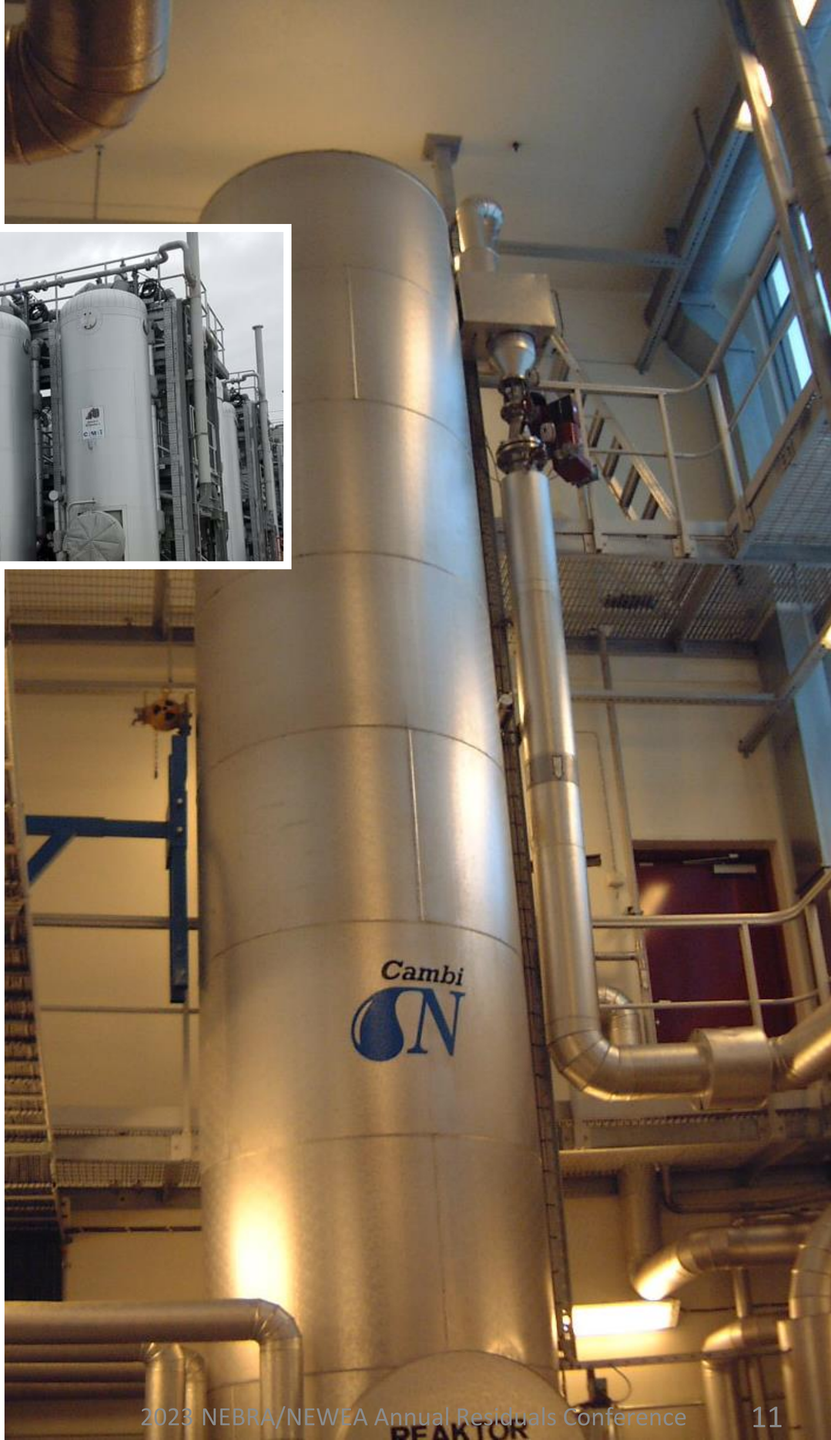
- Class A beneficial reuse
- ~75% mass reduction
- Diverse outlets
  - Compost amendment (dilution)
  - Land app (out of state)
  - Landfill cover
  - Landfill
  - Cement kiln fuel



Background: Thermal Hydrolysis (THP) History

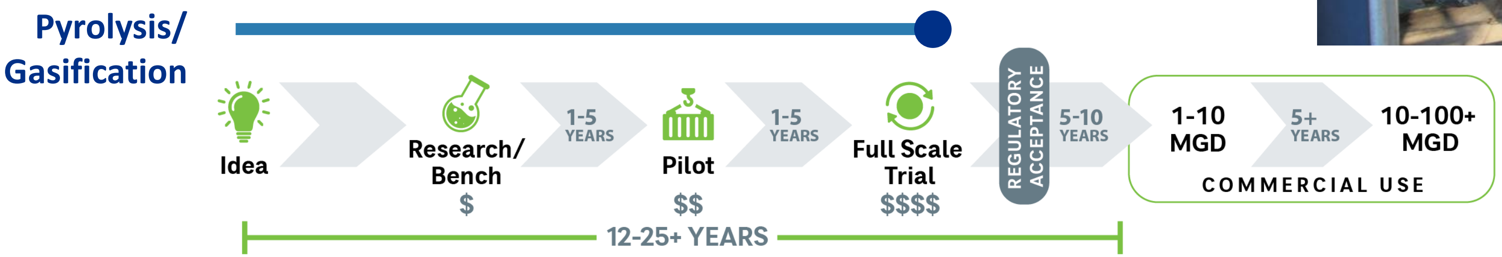
- First steam explosion 1989
- First full-scale THP system commissioned in 1995
- HIAS plant Lillehammer, Norway
- Original vessels are still in operation
- First US Installation – DC Water, Operational October 2014
- TRA Operational 2022
- Veolia Water Technologies purchased THP technologies May 2022





Pyrolysis/Gasification

- Operates at 660 -1,300°F (704°C)
- Recent research[1] has shed light on fate of PFAS
  - Measured PFAS and precursors in biosolids, biochar, and py-liquid
  - PFBA concentrations in py-liquid: 2x higher than in biosolids
  - FOSE compounds 2x higher in py-liquid than biosolids
- Additional research ongoing



[1] McNamara, Samuel, Sathyamoorthy, Moss, Valtierra, Cortes Lopez, Nigro, Somerville, Liu

Note- All Biodryer and Pyrolysis Slides provided by BioForceTech

Pyrolysis and Gasification

- EPA Region 1 classifies gasification as an incinerator. Pyrolysis TBD

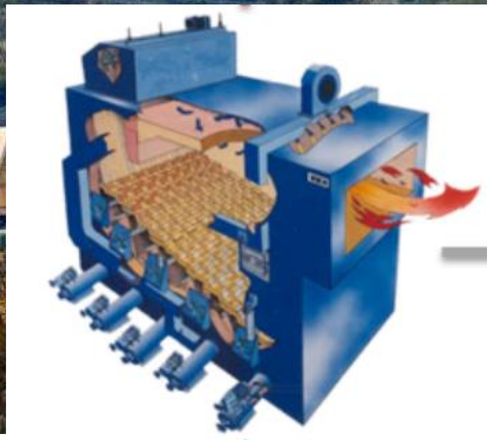
Facility Location	Vendor	Drying/Thermal Processes	Size (wet/ tons/day)	Status	Air Permit/State
Sillicon Valley Clean Water, CA	Bioforcetech	Biodryer & Pyroylsis	20	Operating Since 2017	Southern CA 2 Years to Permit
Ephrata, PA	Bioforcetech	Biodryer & Pyroylsis	20	Unit Delivery Expected February 2023	Ephrata, PA 2 Months to Permit
Schenectady, NY	Biowaste Pyrolysis Solutions	Thermal Drying/ Pyrolysis	100	Commissioning Incomplete	NYS
Rialto, CA	Anaergia	Thermal Drying/ Pyrolysis	300	Shut down	Permit to Construct in CA
Edmonds, WA	Ecoremedy, LLC	Thermal Drying/ Gasification	40	Commissioning Delayed	Edmonds WA
Linden Roselle Sewage Authority, NJ	Aries Clean Energy	Thermal Drying/ Gasification	430	Commissioning Not Completed	NJ
Taunton, MA	Aries Clean Energy	Thermal Drying & Gasification	470	Permitting Hurdles	EPA Region 1 & MassDEP
Lebanon, TN	Aries Clean Technologies	Downdraft Gasification	29 Blended Waste (wood, tires, and biiosolids)	Commissioned 2016	TN
* Morrisville, PA	Ecoremedy	Fluid Lift Gasification	32	Shut down	PA

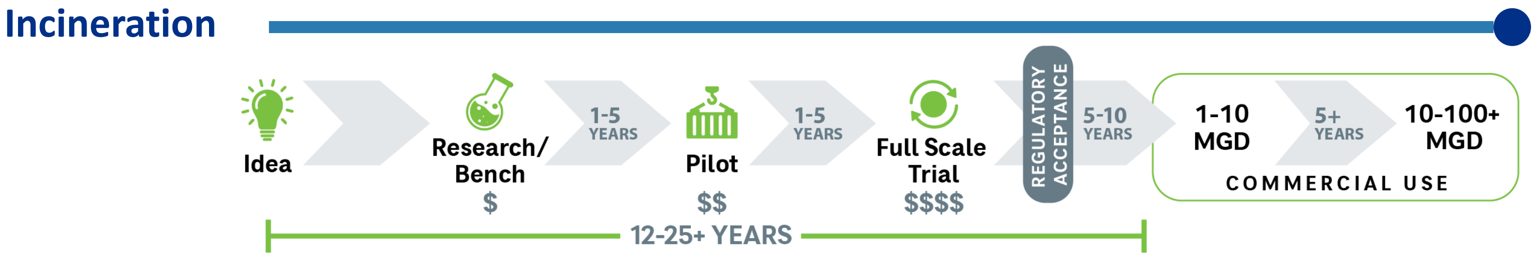
*System demonstration recently completed, and equipment decommissioned.

Incineration

- Technology has been utilized at varying scales for decades
  - No new multiple hearth furnaces (MHFs) in years
  - Fluidized bed incinerators (FBIs) still being permitted and built in the US

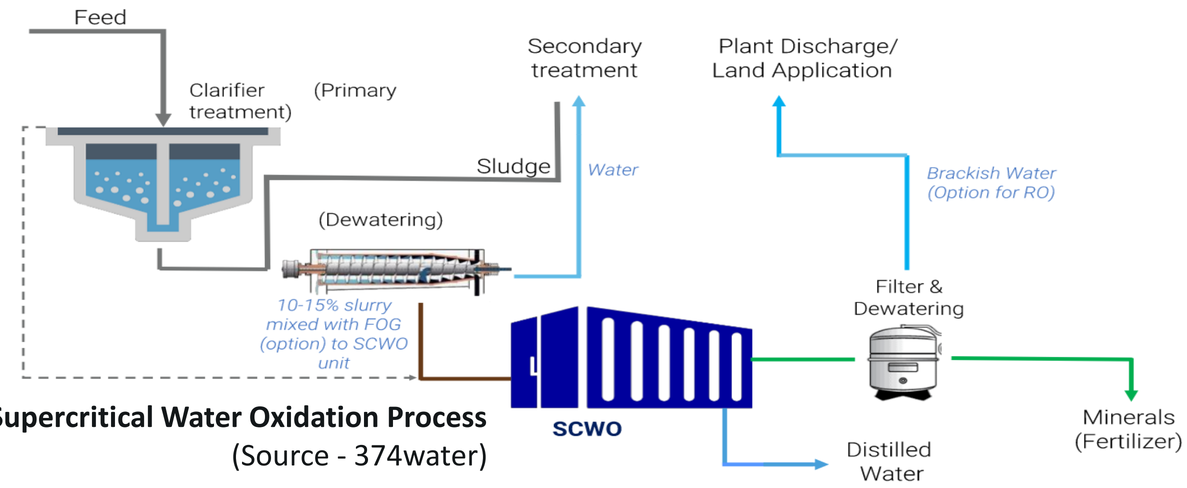
- Advanced Incineration - Veolia/Kruger ERS
  - Compact design
  - Higher operating temperature
  - PFAS Destruction

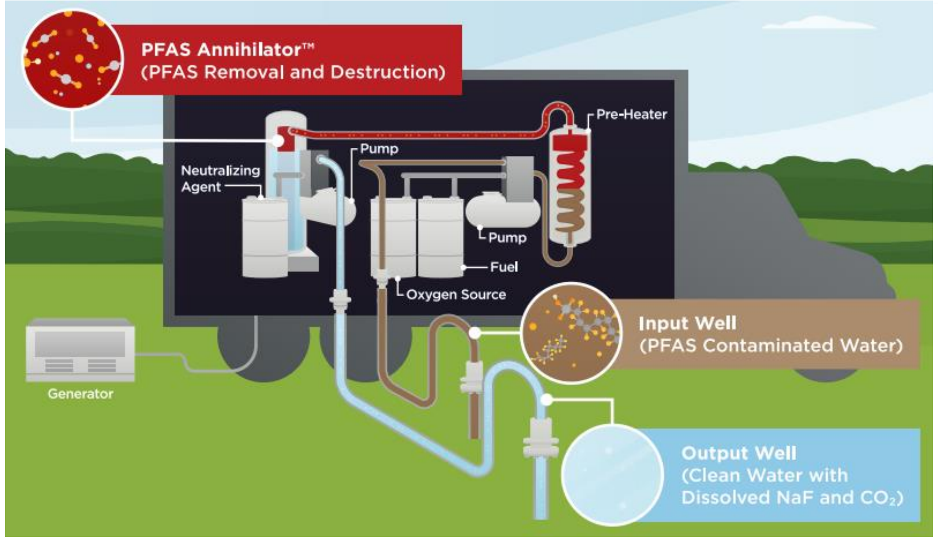



Supercritical Water Oxidation

- 374 Water AirSCWO Nix6 System
  - 706°F @ 3,600 psi
  - 1-6 wet ton/day
- AquaCritox (Hager and Elsasser)
  - 706°F @ 3,208 psi
  - GAC based system
- Battelle PFAS Annihilator
  - 706°F @ >3,200 psi
  - 15 gpm
- General Atomics
- Aquarden Technologies
  - 1094°F @ 3,200 psi
  - Absorbent (IX) based system

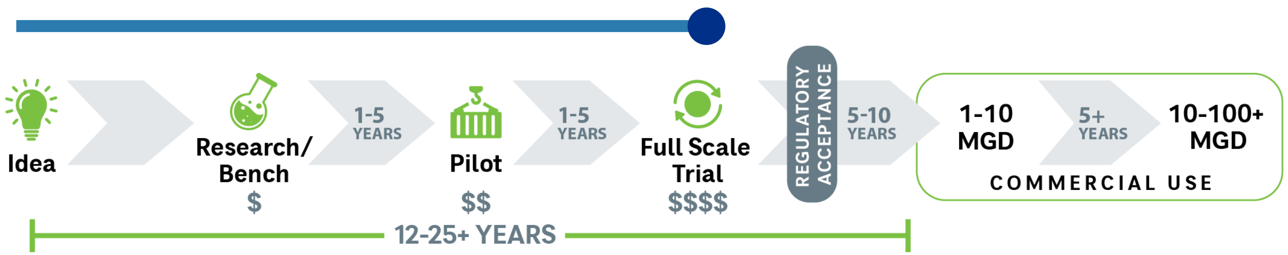


Supercritical Water Oxidation Process
(Source - 374water)



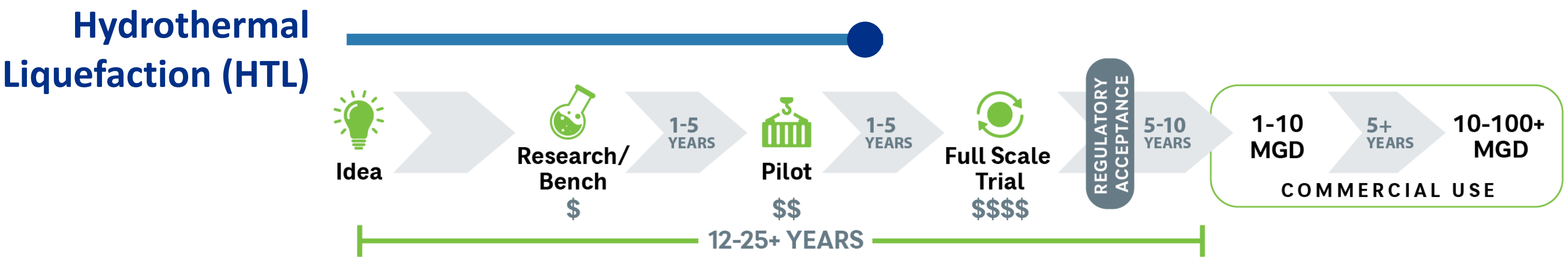
Supercritical Water Oxidation Process
(Battelle's PFAS Annihilator)

Supercritical Water Oxidation



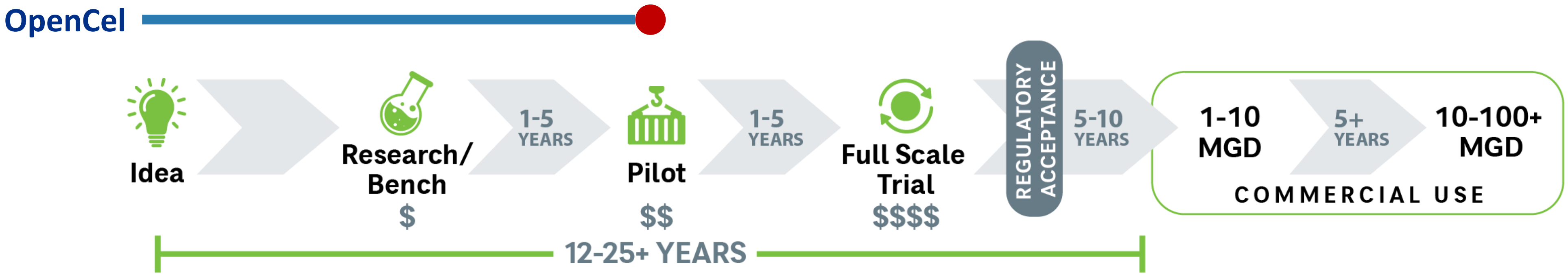
Hydrothermal Liquefaction (HTL)

- Genifuel uses temperature and pressure (660°F @ 2,900 psi) to convert organics to fuels
  - Fossil fuel production in minutes versus millions of years
  - Grind and slurry solid waste
  - Most water is recycled
  - Use oil directly or blended with commercial fuel
  - 99% solids elimination
  - 65% energy recovery



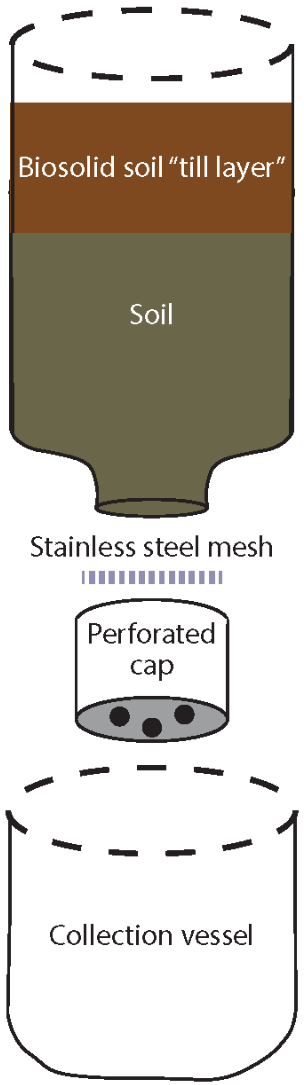
OpenCEL

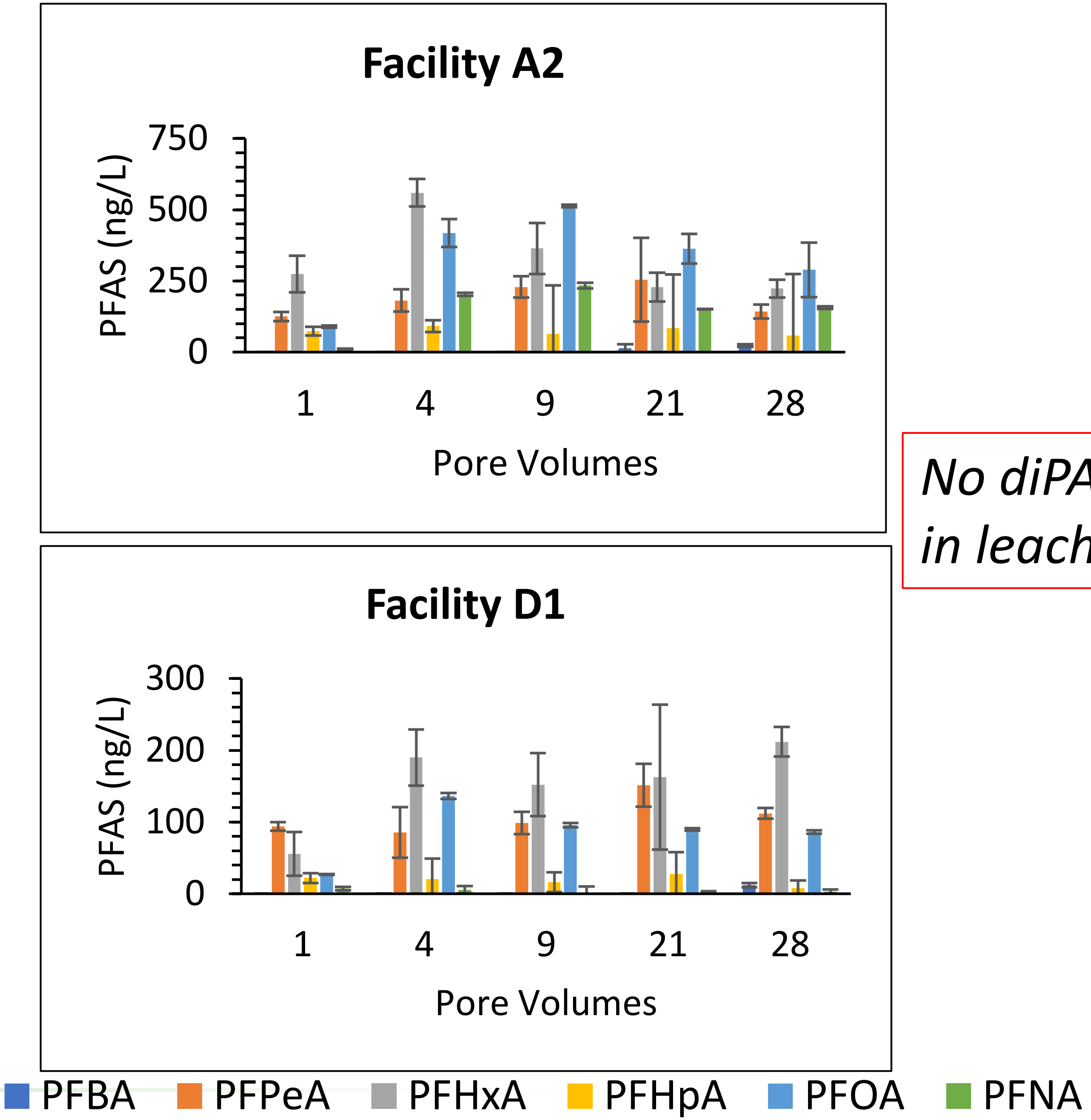
- Sludge electrolysis process. Sludge passes through a small diameter pipe where it is exposed to a high current with the intent of lysing the sludge cells
- Trojan "shelfed" the technology in 2012/2013



Source Identification and Opportunities at WRFs

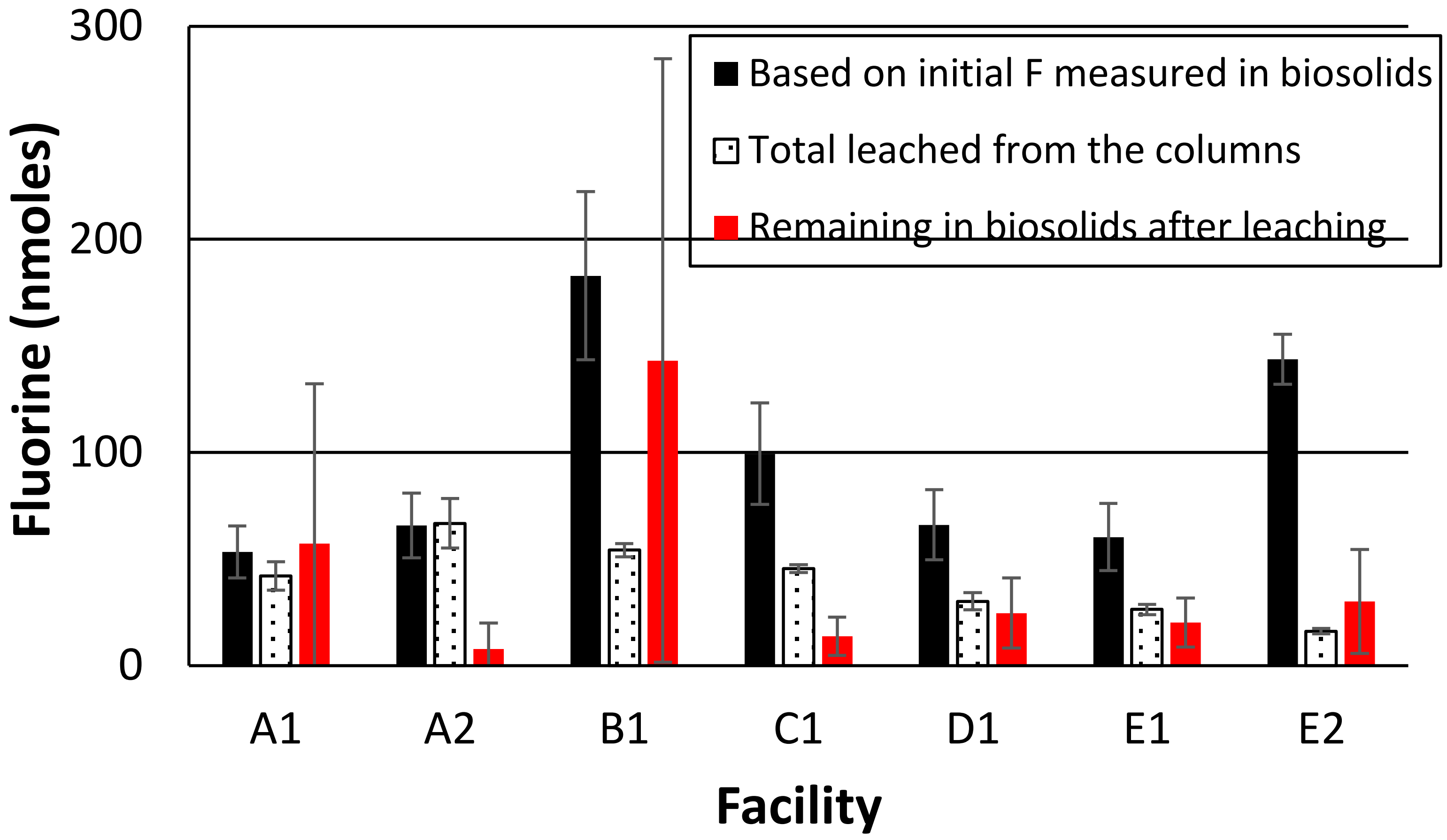
PFAS Leaching from Biosolids: 6 Month Study WRF 5042





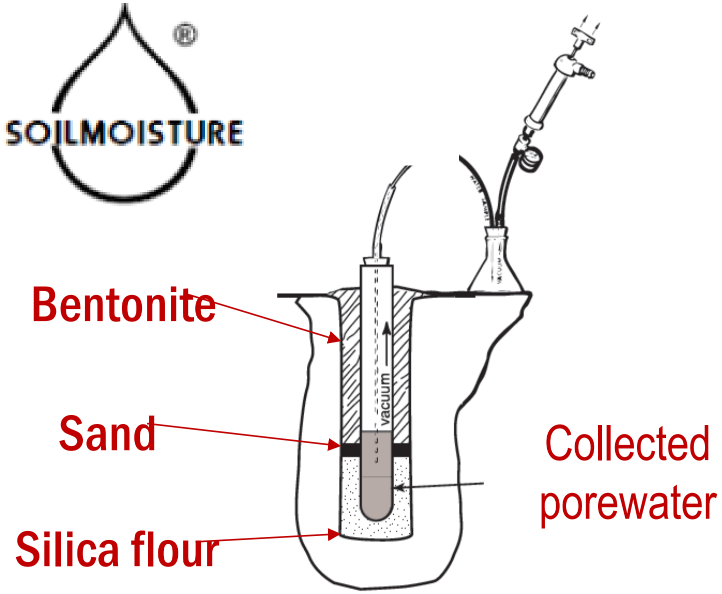
No diPAPs in leachate

PFAS Fluorine Balance



Substantial depletion of diPAPs in biosolids post leaching, but no diPAPs observed in column leachate

WRF 5214: PFAS Leaching through Soil

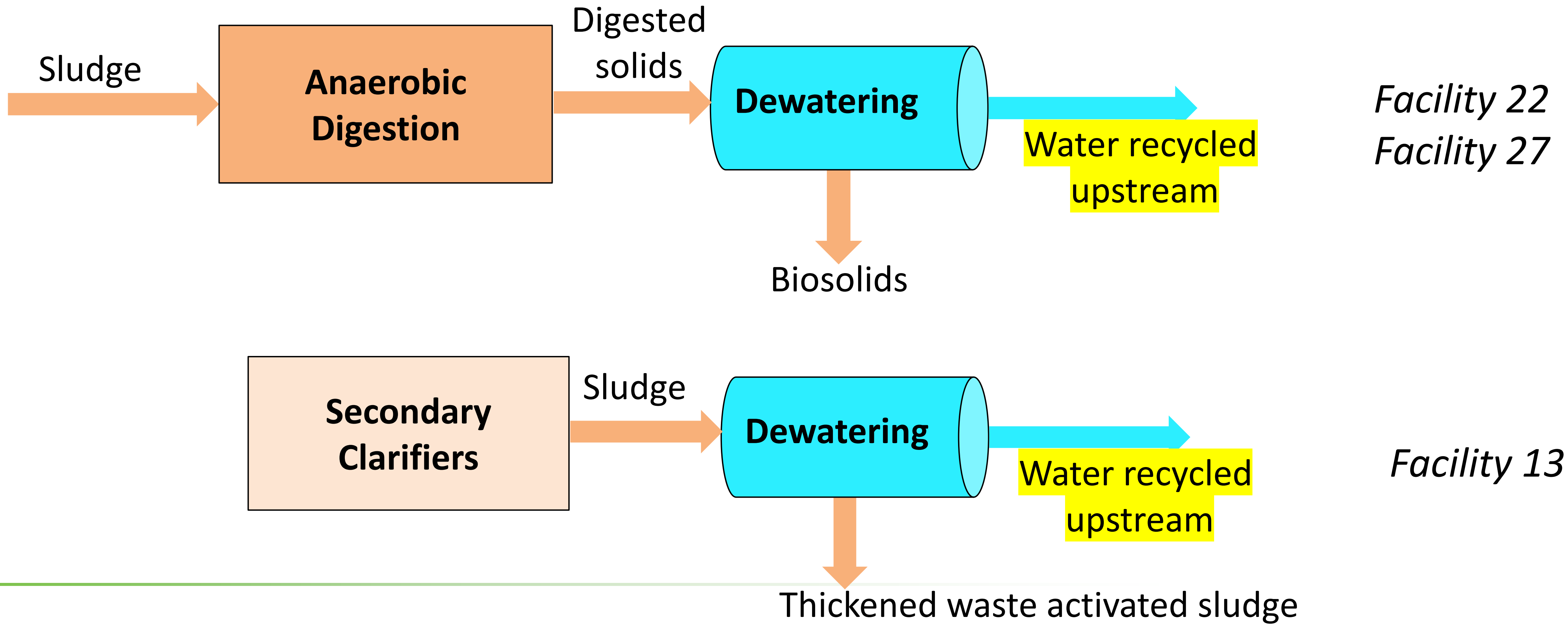


WRF 5031: Solids Dewatering

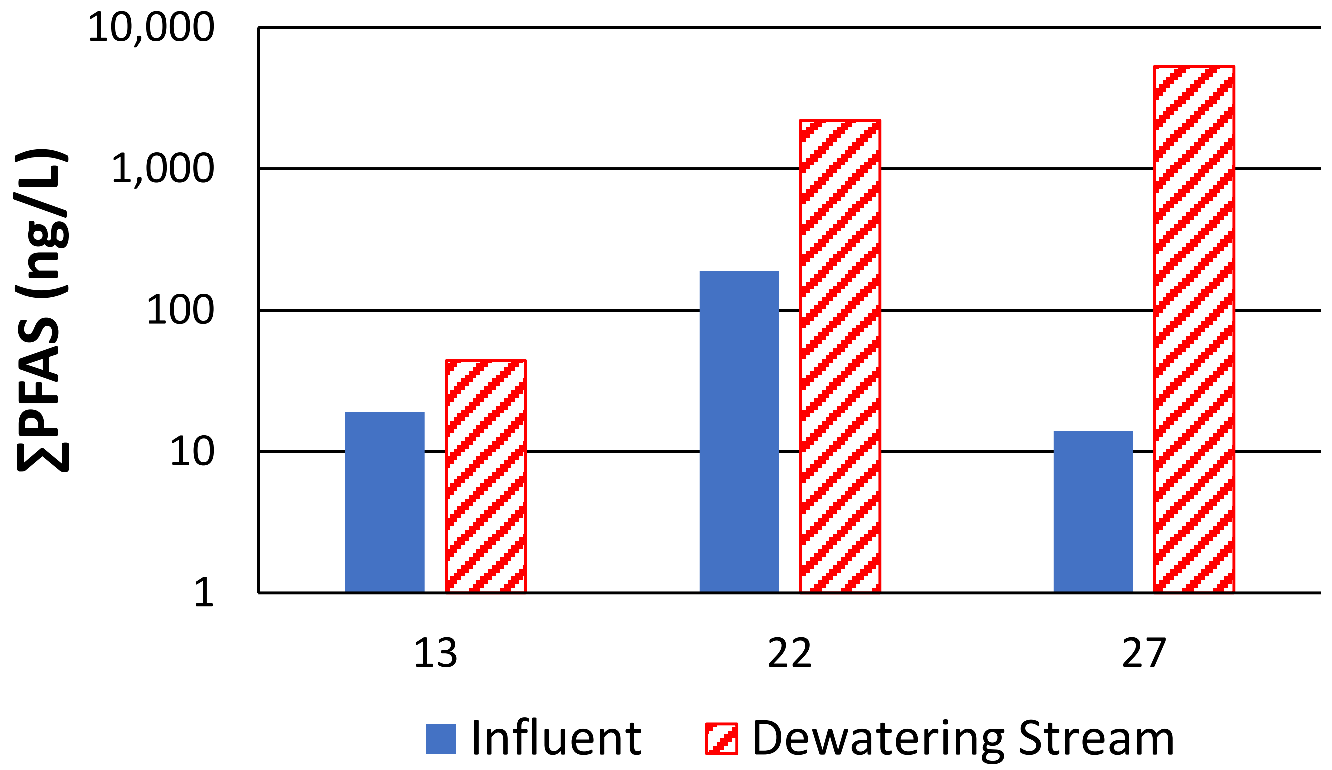
AWWA WATER SCIENCE
Theory and Practice of Safe, Sustainable Water

"PFAS in Foam and Dewatering Streams at Wastewater Treatment Plants"

C.E. Schaefer, J.L. Hooper, L.E. Strom, K. Wu, J.L. Guelfo



PFAS Phase Behavior

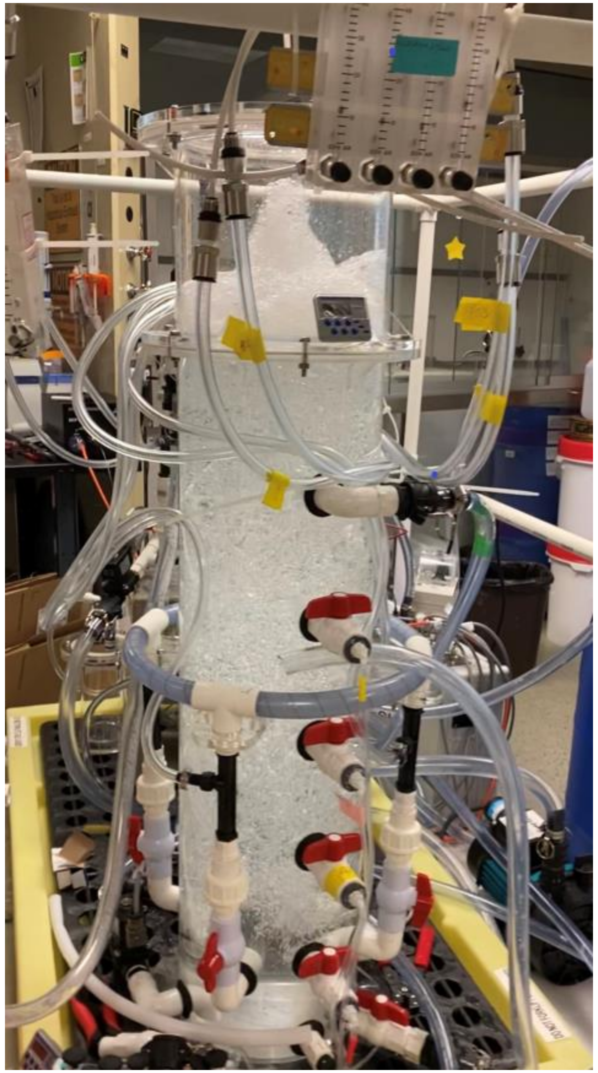


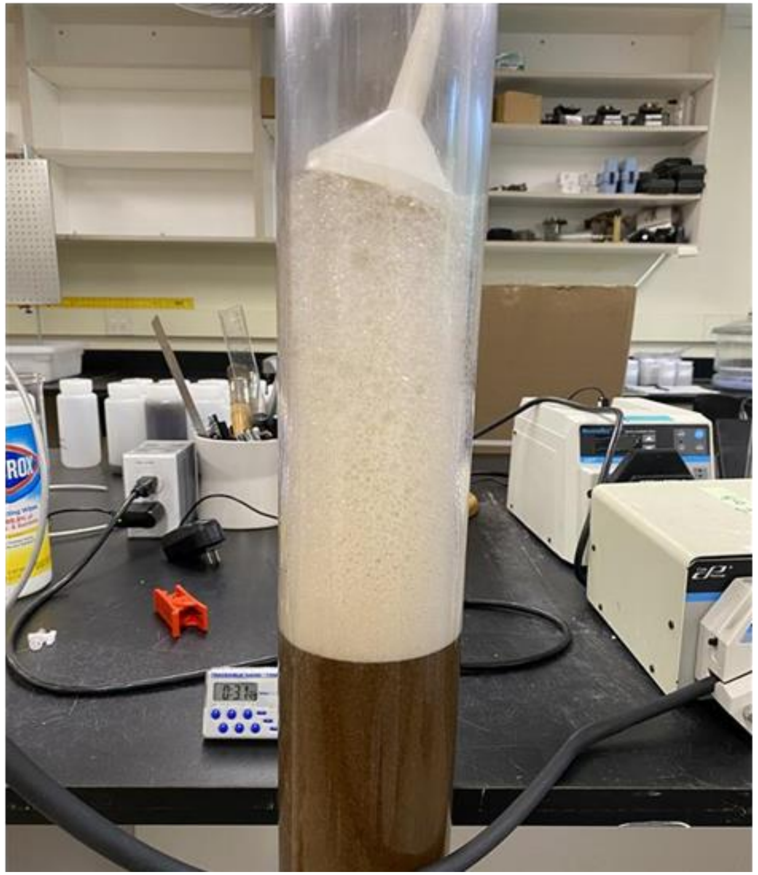
- For facilities 22 and 27, PFAS in dewatering streams primarily FTCAs *(diPAP transformation product)*
- *diPAPs in facility 27 biosolids 5-times greater than in facility 22*

PFAS in Recycled Dewatering Stream May be the Primary Contributor of PFAS in Aqueous Effluent

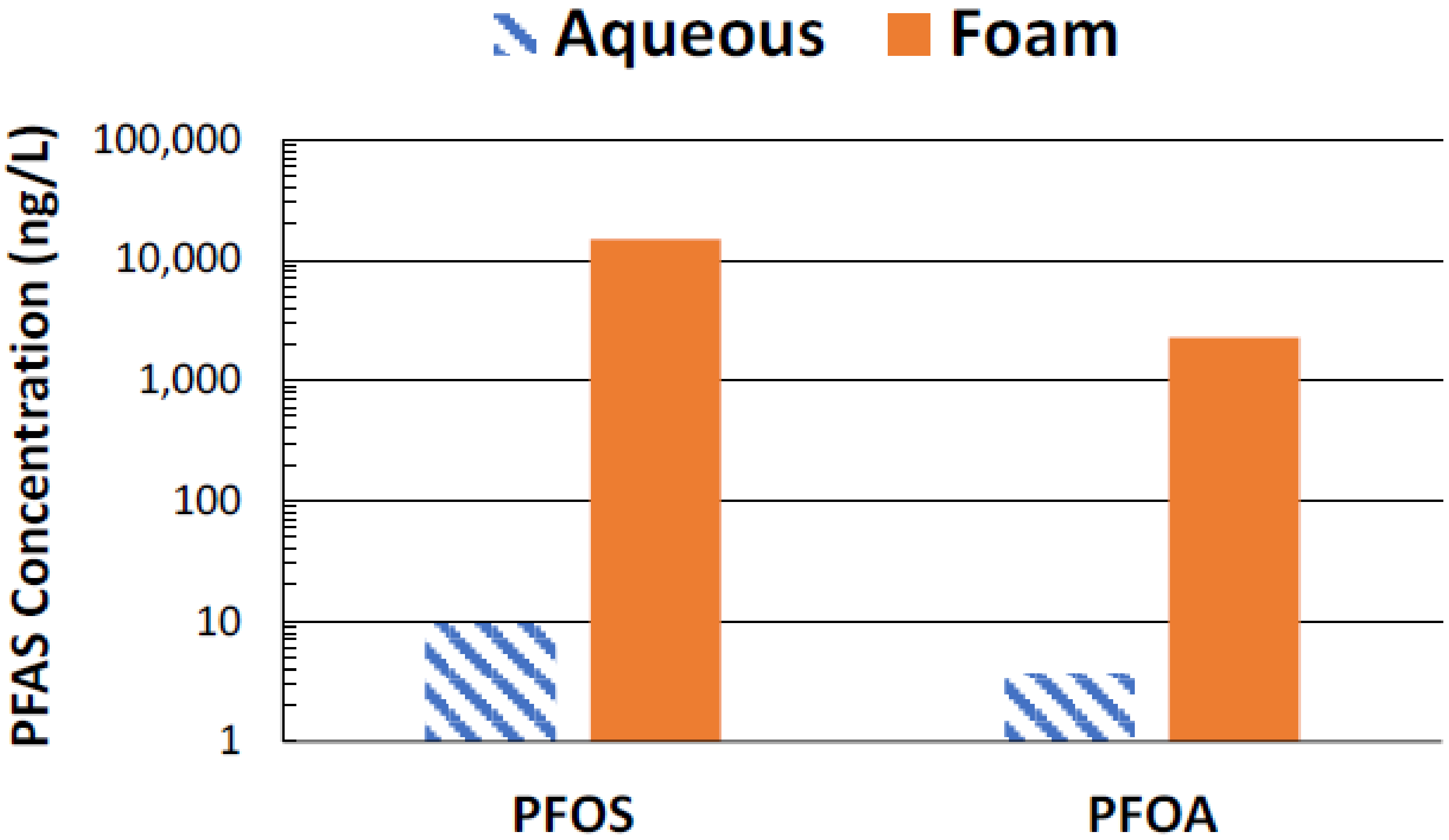
Facility	∑PFAS mass flow in dewatering stream (g/day)	∑PFAS mass flow in WWTP aqueous influent (g/day)	
13	0.063 ± 0.084	6.9 ± 0.087	(0.1%)
22	1.1 ± 0.06	25 ± 1.4	(4.4%)
27	1.1 ± 0.12	0.38 ± 0.04	(290%)

Leachate and Aeration Tank Foam Collection and Analysis



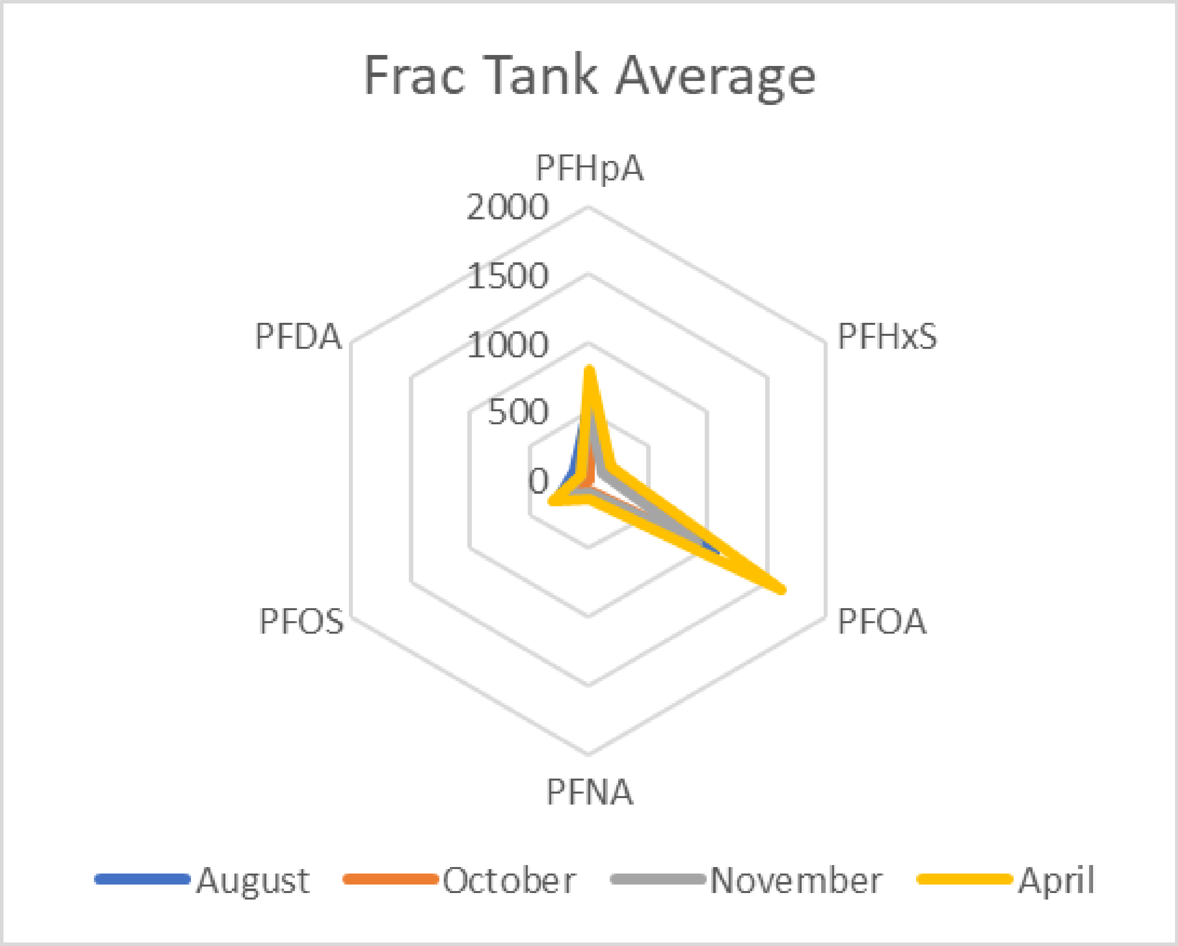


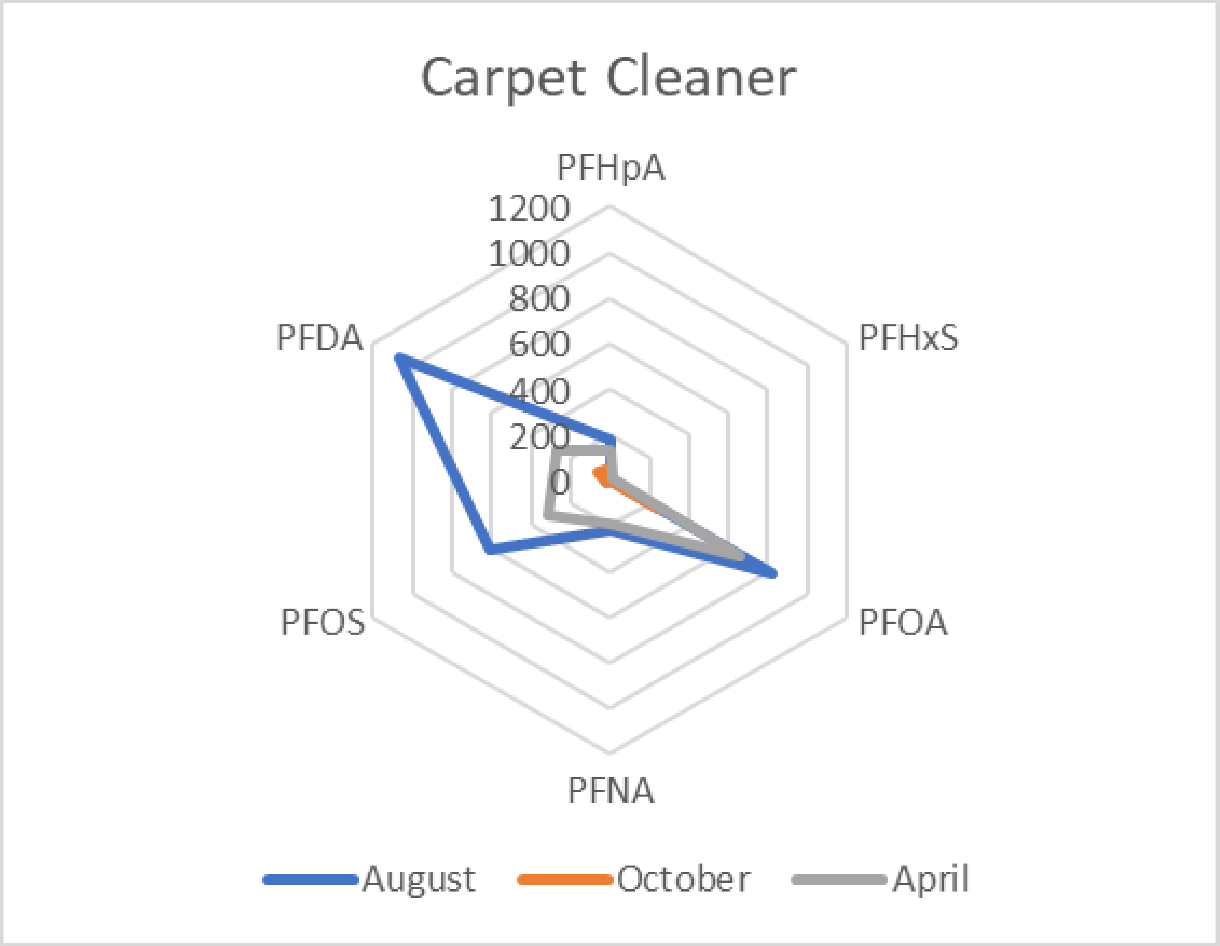
PFAS in Foam vs Aqueous Phase



PFOS and PFOA concentrations measured in the aqueous phase and foam/scum during biological aeration.

Fingerprinting – Radar Plots





Minnesota Study*

Table 11-1 Estimated cost per mass of PFAS removed from targeted waste streams over 20 years[1]

	Size/Production		
Municipal WRRF facility size[3]	0.1 MGD	1 MGD	10 MGD
Municipal WRRF effluent capital	$7,300,000	$32,000,000	$120,300,000
Municipal WRRF effluent annual O&M	$500,000	$1,400,000	$6,400,000
Total 20-year cost for municipal WRRF effluent[2]	$12,600,000	$46,900,000	$188,200,000
Cost per lb PFAS removed over 20 years[5]	$18,100,000	$6,800,000	$2,700,000
Municipal WRRF biosolids production[4]	On-site biosolids management for facilities smaller than 1 dtpd is not expected to be economical.	1 dtpd	10 dtpd
Municipal WRRF biosolids capital		$24,600,000	$85,200,000
Municipal WRRF biosolids annual O&M		$200,000	$800,000
Total 20-year cost for municipal WRRF biosolids		$26,800,000	$93,700,000
Cost per lb PFAS removed over 20 years[5]		$2,700,000	$1,000,000
Mixed MSW landfill facility size[3]	1 GPM	10 GPM	100 GPM
Mixed MSW landfill leachate capital	$300,000	$800,000	$4,800,000
Mixed MSW landfill leachate annual O&M	$400,000	$400,000	$700,000
Total 20-year cost for mixed MSW landfills	$4,600,000	$5,100,000	$12,300,000
Cost per lb PFAS removed over 20 years[5]	$12,000,000	$1,400,000	$400,000
Composting facility size[3]	1 GPM	10 GPM	100 GPM
Compost contact water capital	$300,000	$800,000	$4,800,000
Compost contact water annual O&M	$300,000	$300,000	$600,000
Total 20-year cost for composting facilities	$3,500,000	$4,400,000	$11,200,000
Cost per lb PFAS removed over 20 years[5]	$39,300,000	$4,500,000	$1,300,000

MGD = million gallons per day, dtpd = dry tons per day, and gpm = gallons per minute

[1] Costs presented here reflect estimated project cost (Class 5 per AACE) developed with an associated uncertainty of +50%/-30% for both capital and annual O&M cost estimates. Costs are based on design basis concentrations selected to be typical of those reported in WRRF effluent (Helmer, Reeves, and Cassidy 2022; Coggan et al. 2019; Thompson et al. 2022), biosolids (Venkatesan and Halden 2013; Helmer, Reeves, and Cassidy 2022), landfill leachate (Lang et al. 2017), and compost contact water (Wood Environment & Infrastructure Solutions Inc. 2019). All costs are rounded up to the nearest $100,000.

[2] 20-year costs reflect present value calculations using an interest rate of 7%.

[3] Upgrade costs for liquid-phase treatment in WRRF effluent, mixed MSW landfill leachate, and compost contact water are for PFAS separation and destruction using GAC adsorption with high-temperature incineration of media (at flows below 10 MGD) or GAC reactivation (at 10 MGD or higher). These include approximate costs for tertiary treatment retrofits (at WRRFs) or pretreatment processes (at mixed MSW landfill leachate and composting sites) likely needed at most facilities to provide the water quality required for GAC feed.

[4] Upgrade costs are for PFAS destruction in WRRF biosolids using pyrolysis or gasification with thermal oxidation of produced gasses. Costs include centrifuge dewatering to provide 25% solids material for process feed for each facility.

[5] Mass PFAS removed reflect the sum of assumed concentrations of PFAS targeted in this study (PFOA, PFOS, PFHxA, PFHxS, PFBA, PFBS, 6:2 FTS, PFOSA, N-EtFOSAA, and N-MeFOSAA) as previously documented in Sections 2.3, 6.1.2, 7.1.2, 8.1.2, 9.1.2 multiplied by the flow rate or solids production rate shown.

Cost per pound of PFAS removed

- Effluent treatment $2.7 – $18.1M/lb
- Biosolids Treatment: $1.0 – $2.7M/lb
- Leachate Treatment: $400,000/lb
- Small/Mid WRF :
  - Effluent $14,450,000/year
  - Biosolids $2,133,117/year
  - Leachate $44,000/year
    - Leachate represents ~5% of the total PFAS load to this WRF

*Minnesota Pollution Control Agency (Barr Engineering Co.) – May 2023

Final Thoughts

- Piloting is needed to evaluate efficacy and cost effectiveness of destruction technologies

- More than standard analysis is needed to evaluate PFAS leaching from biosolids and transformation reactions

- We can achieve PFAS reduction “cost effectively” by utilizing processes already occurring within WRFs

- There are some readily implementable approaches that can mitigate PFAS discharges before entering WRFs

- **Source Reduction** remains the most economical mitigation strategy!

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