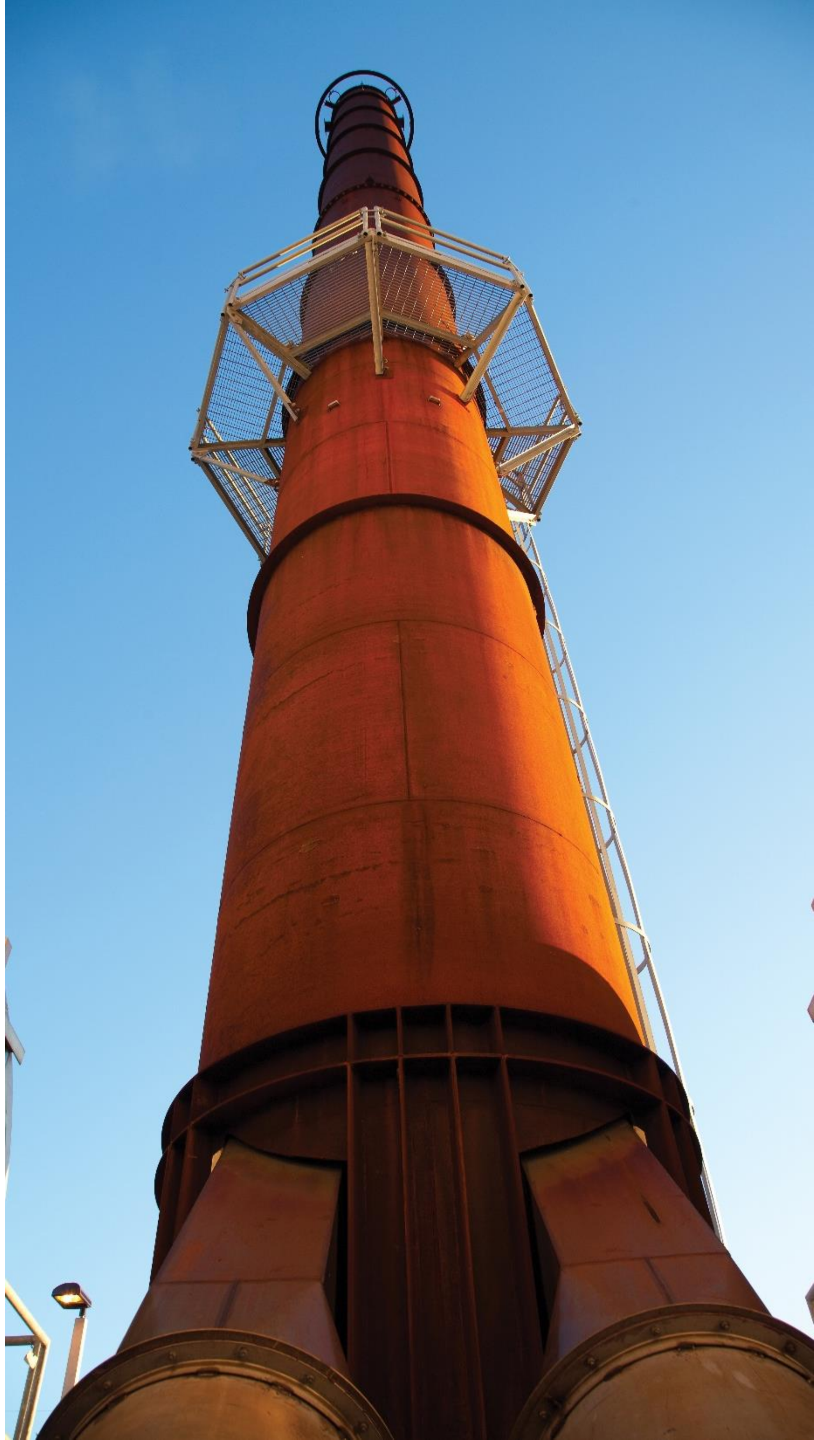


Is it possible to remove PFAS from Biosolids? A review of different PFAS removal technologies

Ramola Vaidya

HDR

11/02/2022

01 Background

02 PFAS Treatment and Destruction

03 Thermal Technologies

04 Current PFAS Status

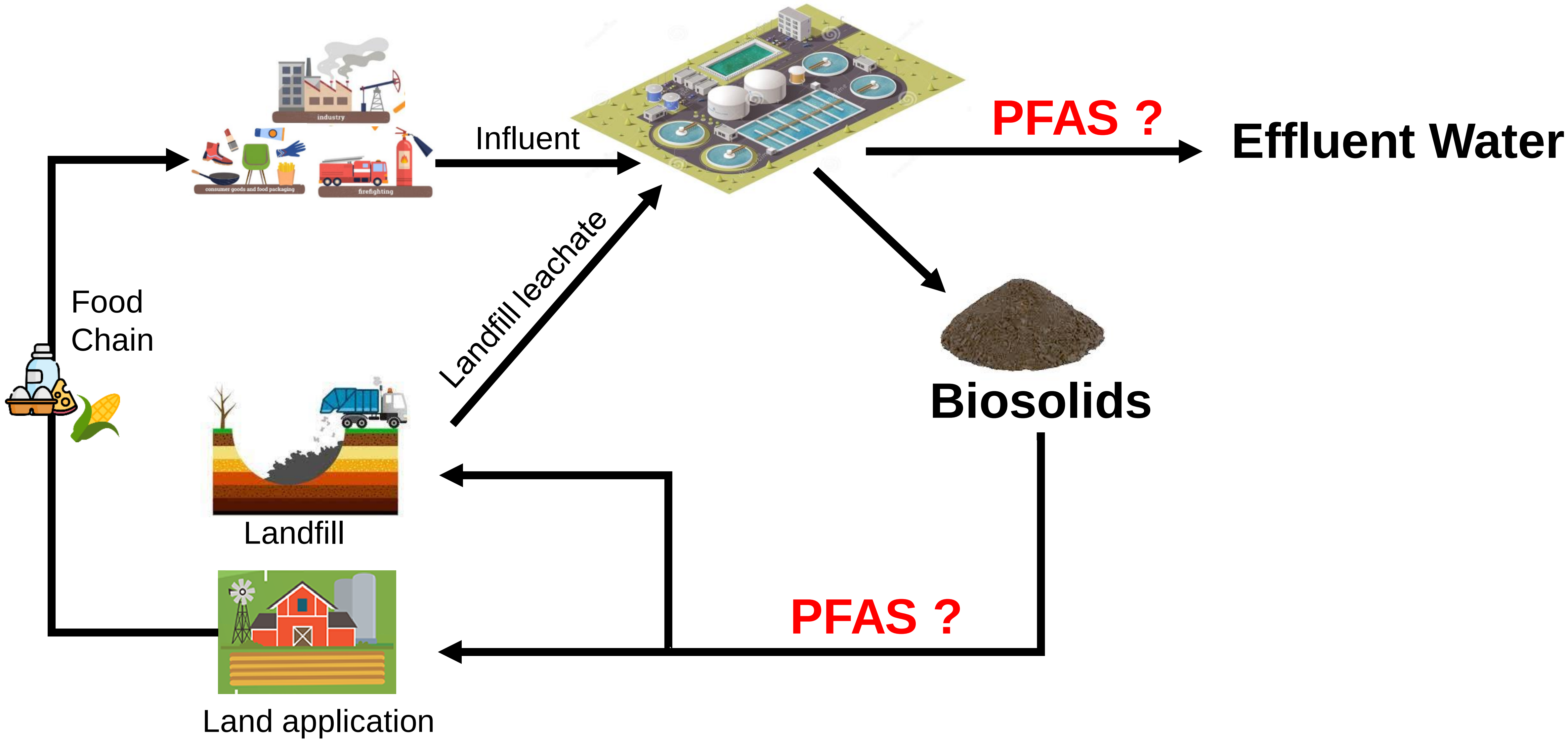
05 Next Steps

06 Conclusion

01

Background

PFAS fate and transport



Currently no federal regulations for PFAS in biosolids, only statewide guidelines

- PFAS from WRRFs concentrate in biosolids
- Studies have shown biosolids land application has resulted in PFAS leaching into groundwater and uptake by crops

Maine bans toxic 'forever chemicals' under groundbreaking new law

State is the first to enact a broad ban of PFAS compounds, which are found in everything from cosmetics to cookware

Maine is the nation's first state to enact a broad ban on PFAS. Photograph: Robert F Bukaty/AP

The Colorado Sun

MENU NEWS ELECTION 2022 POLITICS OUTDOORS ENVIRONMENT OPINION NEWSLETTERS PODCASTS ABOUT US

ENVIRONMENT

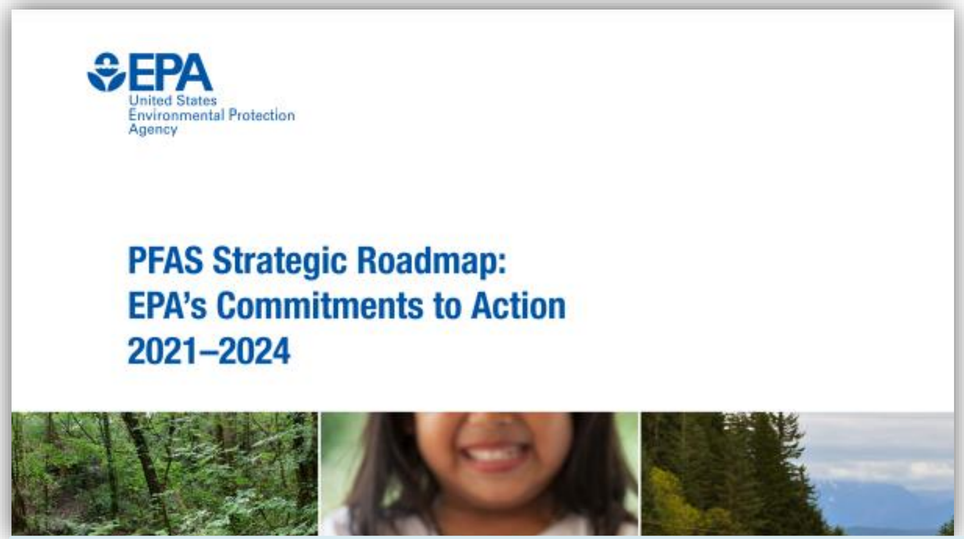
Colorado has been spreading biosolids with "forever chemicals" on farms, records show. How dangerous is it?

Environmental groups say there is no safe level for toxic PFAS chemicals in drinking water or on farm land. State regulators say they are studying it.

Michael Booth 4:08 AM MDT on Jun 20, 2022

PFAS Regulatory Timeline

- No federal regulations, only statewide guidelines
- EPA's PFAS strategic roadmap to finalize biosolids risk by 2024



2003
Phase-out of PFOA/PFOS production

2009
Provisional Drinking Water Health Advisories for PFOA and PFOS (400 ng/L)

2013-2015
Third Unregulated Contaminant Monitoring Rule for six PFAS

2016
Lifetime Health Advisories for PFOS and PFOA (70 ng/L)

2018
PFAS National Leadership Summit

2021
EPA Releases PFAS Roadmap

June 2022
New Lifetime Health Advisories for PFOA, PFOS, PFBS, GenX

Future Timeline

2022
Draft Regulation (PFAS Maximum Contaminant Levels)

2023-2025
UCMR5 PFAS Sampling (29 PFAS)

2023
Final PFAS Regulation

2024-2028
Regulatory Enforcement

EPA to propose designating PFOA & PFOS as hazardous chemicals under CERCLA (Superfund Program).

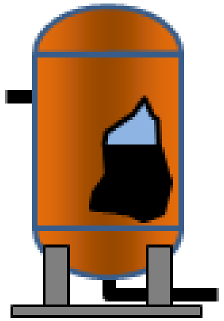
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act

02

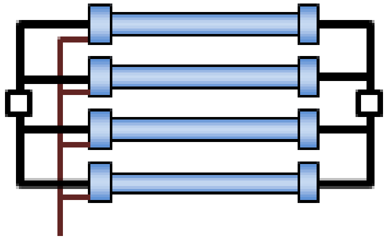
PFAS Treatment and Destruction

Quick peak at PFAS treatment and destruction options

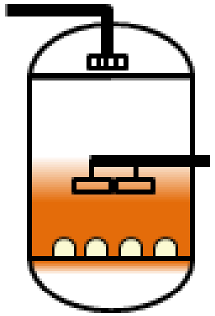
PFAS Treatment Technologies



GAC



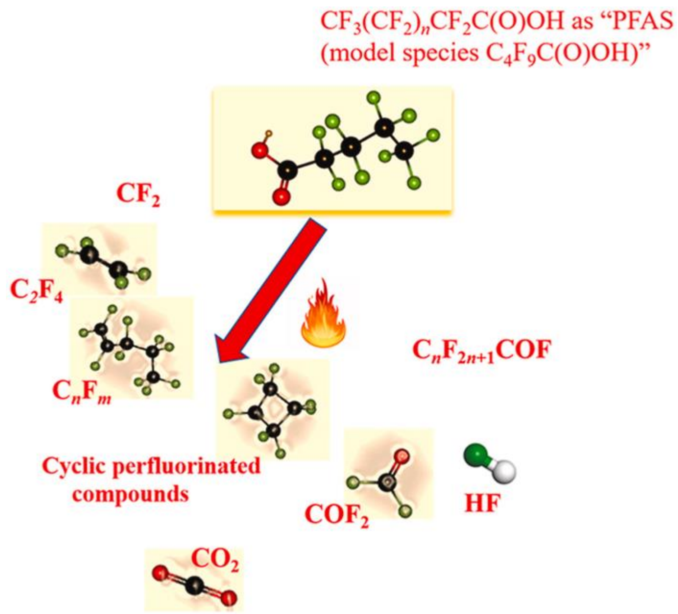
Reverse Osmosis



Ion Exchange

- GAC, IX and RO can remove PFAS from water but do not destroy PFAS

PFAS Destruction



Altarawneh et al., 2022

- PFAS destruction may require temperatures >600-1400^{o}C

Need to review thermal technologies for PFAS destruction

03

Thermal Technologies

Thermal Technologies Overview

Incineration
End products: Ash & flue gas

Pyrolysis
End products: BioChar & syngas

Gasification
End products: BioChar & syngas

Supercritical Water Oxidation
End products: CO_2, N_2, distilled water

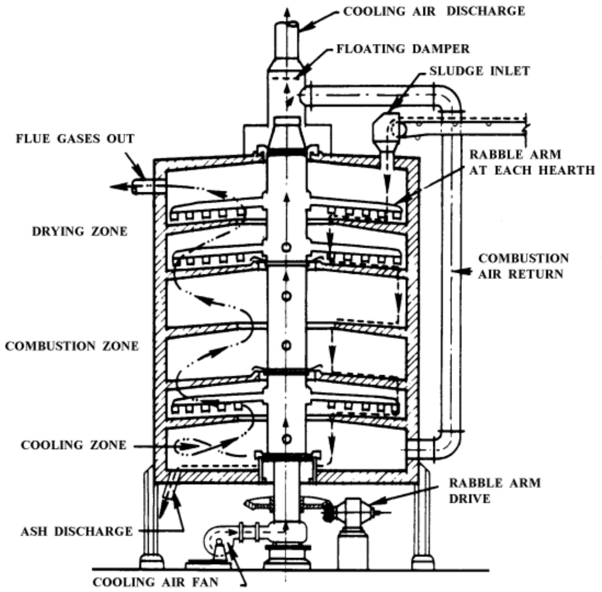
Hydrothermal Liquefaction
End products: Biocrude oil & flue gas

Hydrothermal Carbonization
End products: HydroChar & Nutrient rich effluent

Incineration

- Operating temperature: 150-1300°C
- Excess air required for combustion
- Total installations (pilot + full scale): 200+
- Operating period:
  - Multiple hearth since 1930s
  - Fluidized bed since 1965
- Manufacturers:
  - Suez
  - Hankin

Thermal Oxidation (BioCon™ ERS, Veolia)



Cross section of a multiple hearth furnace

Buffalo Wastewater Treatment Plant, MN

Pyrolysis

- Operating temperature: 350-900°C
- No oxygen required
- Total installations:
  - SVCW, CA (pilot + full scale)
  - Encina, CA (pilot)
  - Rialto Bioenergy, CA (full scale)
- Operating period: 2015 – Present
- Manufacturers:
  - Anaergia, Inc.
  - Bioforcetech Corporation
  - CHAR Technologies

Rialto Bioenergy Facility, CA (pyrolysis installation ongoing)

Silicon Valley Clean Water, CA

Gasification

- Operating temperature: 680-980°C
- Controlled levels of O_2
- Total installations:
  - Sanford, FL (pilot)
  - Lebanon, TN (full-scale)
  - Morrisville, PA (pilot)
- Operating period: 2009-Present
- Manufacturers:
  - Aries Clean Technologies
  - Ecoremedy, LLC
  - Earthcare, LLC
  - Thermal Process System

Morrisville Municipal Authority, PA

Linden Biosolids Facility, NJ, (installation ongoing)

Super Critical Water Oxidation

- Operating temperature: 374°C
- Operating pressure: 221 bar
- Compressed air or oxygen needed
- Harlingen, TX (full-scale)
- Pilot-scale testing
- Operating period: Emerging technology
- Manufacturers:
  - 374Water
  - Aquarden Technologies
  - Battelle

374Water Pilot-scale systems

Hydrothermal Liquefaction

- Operating temperature: 300-350°C
- Operating pressure: 205 bar
- Total installations:
  - Annacis Island, MV (pilot)
  - Altamonte Springs, FL (pilot)
  - Clean Water Services, OR (pilot)
- Operating period: 2017-present
- Manufacturers:
  - GeniFuel Corporation

Clean Water Services, Durham, OR
James Oyler, President
Genifuel Corporation

Hydrothermal Carbonization

- Operating Temperature: 190-250°C
- Operating pressure: $1.5x10^6$ Pa
- Borough of Phoenixville, PA - Full-scale to be commissioned
- Operating Period: Pilot testing in 2018
- Manufacturers:
  - C-Green
  - SoMax

Borough of Phoenixville WWTP

Jeremy Taylor, Chief Sustainability Officer
SoMax Circular Solutions

Other Treatment Technologies

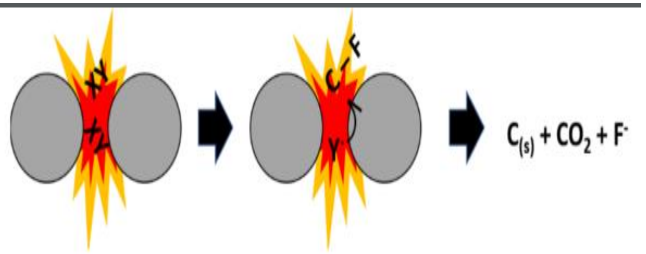
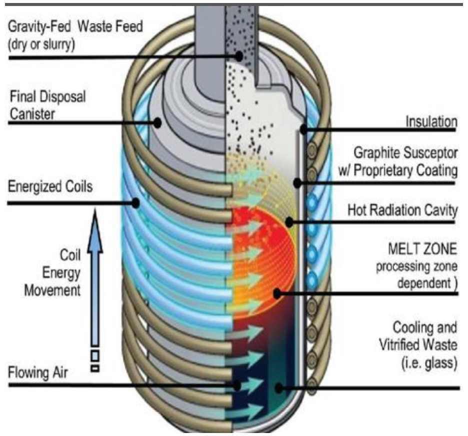


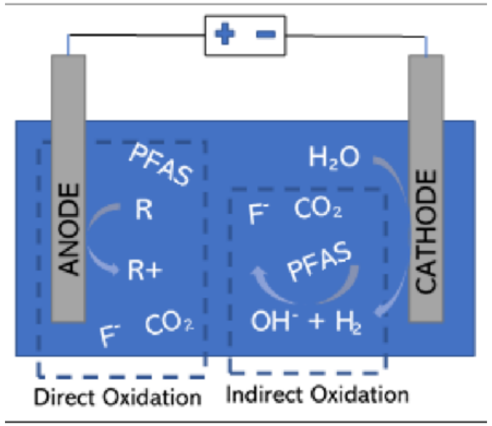
Figure 1. Ball impacts create radicals from co-milling materials and localized high temperatures that mineralize PFAS.

Mechanochemical Degradation

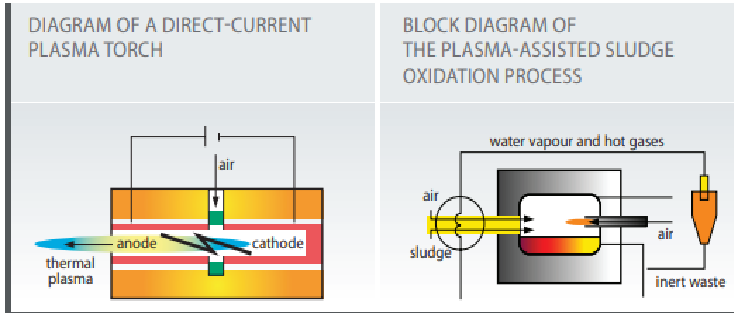


Vitrification

EPA PITT Program - PFAS Innovative Treatment Team



Electrochemical Oxidation



Plasma-Assisted Sludge Oxidation

https://www.epa.gov/sites/default/files/2021-01/documents/pitt_research_brief

04

Current PFAS Status

What do we know about PFAS destruction so far?

Incineration	Pyrolysis	Gasification
• Limited full-scale studies • Temperature-dependent • Significant PFAS destruction • PFAS still detected in ash and flue gas	• Pilot studies • >99% removal • No gas phase testing	• Pilot studies • >99% removal • No gas phase testing

Preliminary PFAS testing shows removal from ash and biochar. Need to test gas emissions

What do we know about PFAS destruction so far?

Supercritical Water Oxidation

- Pilot studies
- >99% removal
- <0.2% in the effluent gas

Hydrothermal Carbonization

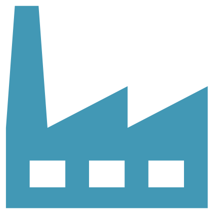
- Lab-scale studies
- 69% reduction in total PFAS

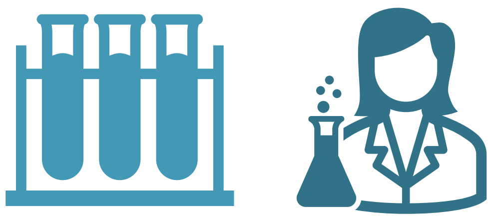
Hydrothermal Liquefaction

- Lab-scale studies
- 96-99% transformation of some PFAS compounds

SCWO shows PFAS removal in gas emissions.
HTL and HTC only bench testing data available. Need further studies to show PFAS removal

Criteria to evaluate Technology Readiness Level

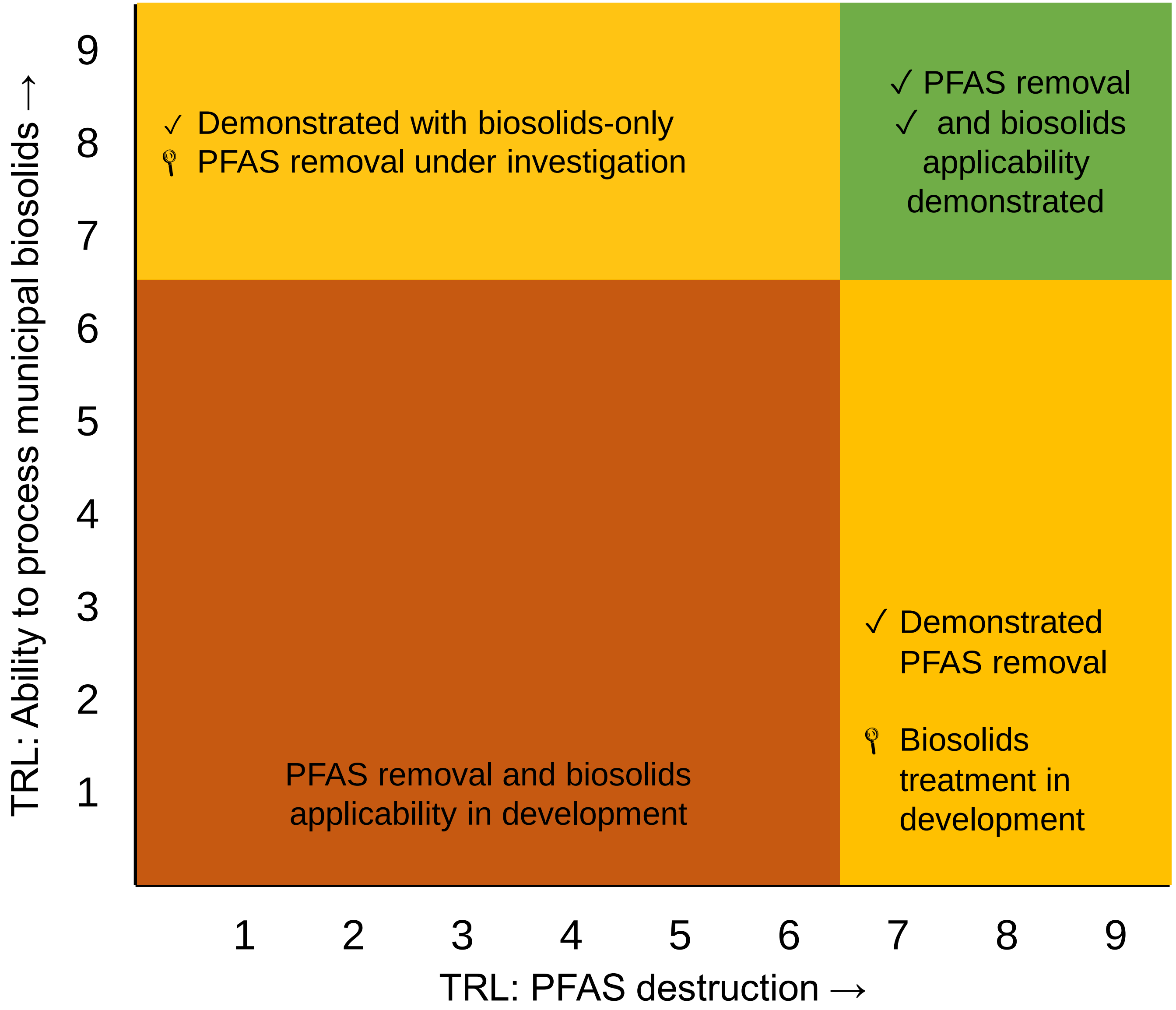




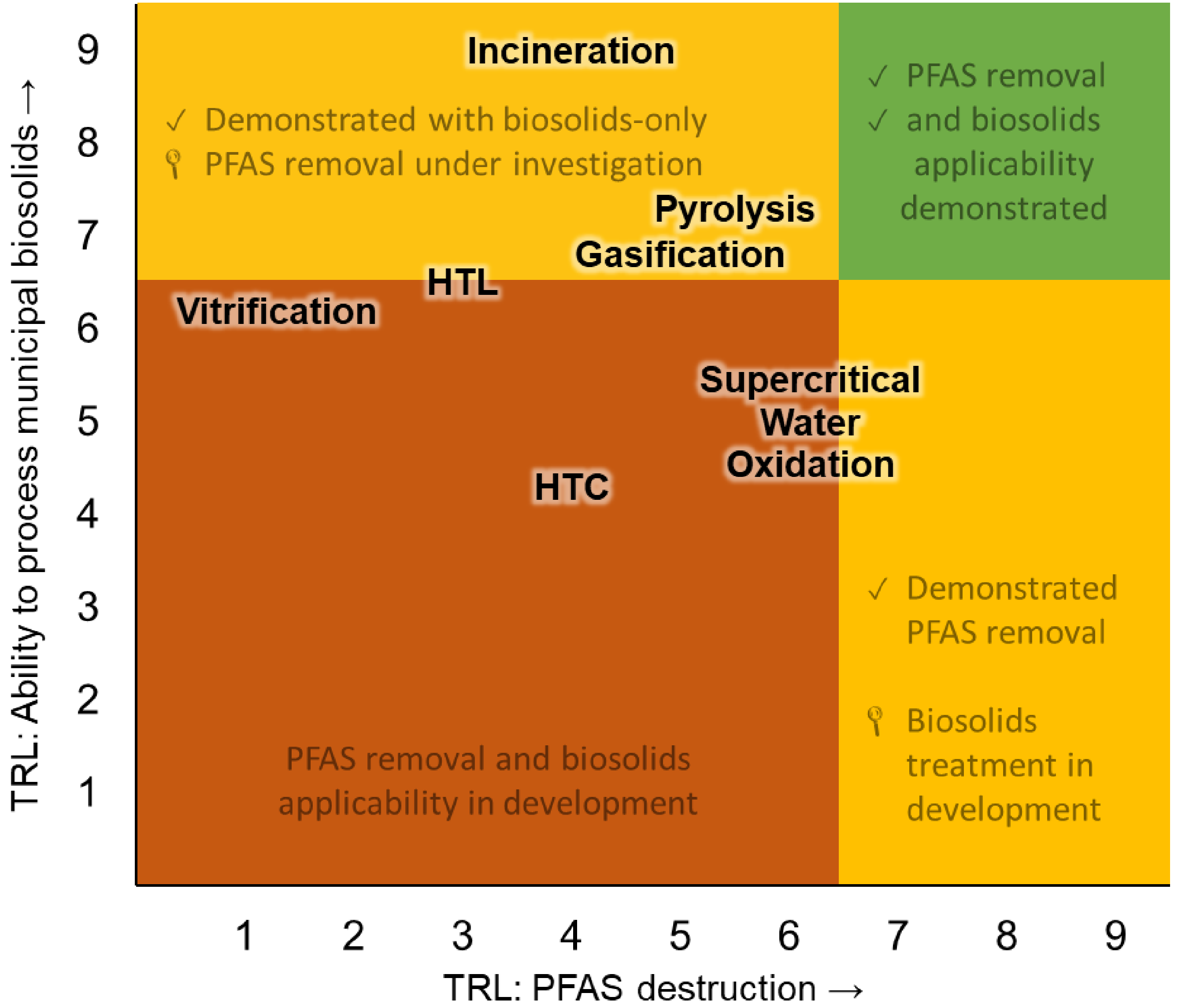
	TRL	Description	Examples
Deployment	9	Actual system proven in operational environment	Multiple full-scale systems in operation for several years
	8	System complete and qualified	A currently active full-scale permanent installation operating continuously for at least one year
	7	System prototype demonstration in operational environment	A one-year pilot installation operating continuously under a wide range of operating conditions
Development	6	Technology demonstrated in relevant environment	Prototype system operating with feedstocks under typical conditions (not necessarily continuously)
	5	Technology validated in relevant environment	Lab-scale system with actual feedstocks
	4	Technology validated in lab	Lab-scale system with representative feedstocks
Research	3	Experimental proof of concept	Limited laboratory measurements to validate analytical predictions
	2	Technology concept formulated	Limited analytical studies, often speculative
	1	Basic principles observed	Scientific observations

Adapted from: [What are Technology Readiness Levels (TRL)? - (twi-global.com)]

Where do all the technologies stand?
(a snapshot in time)

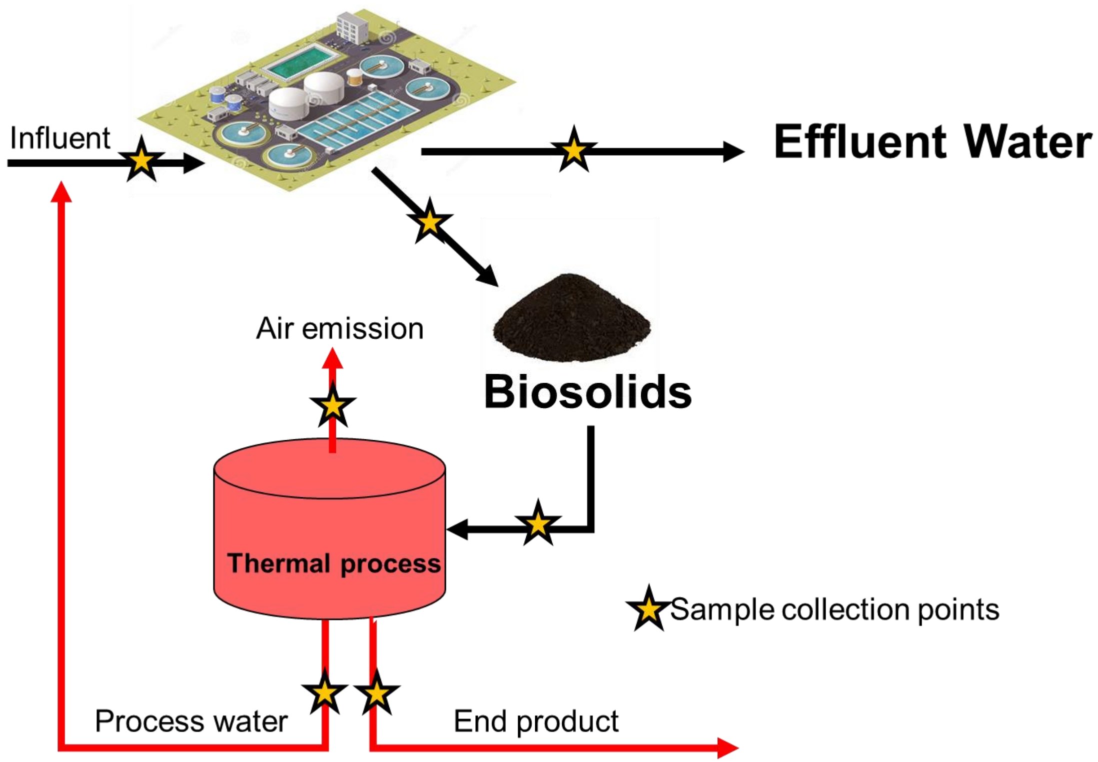


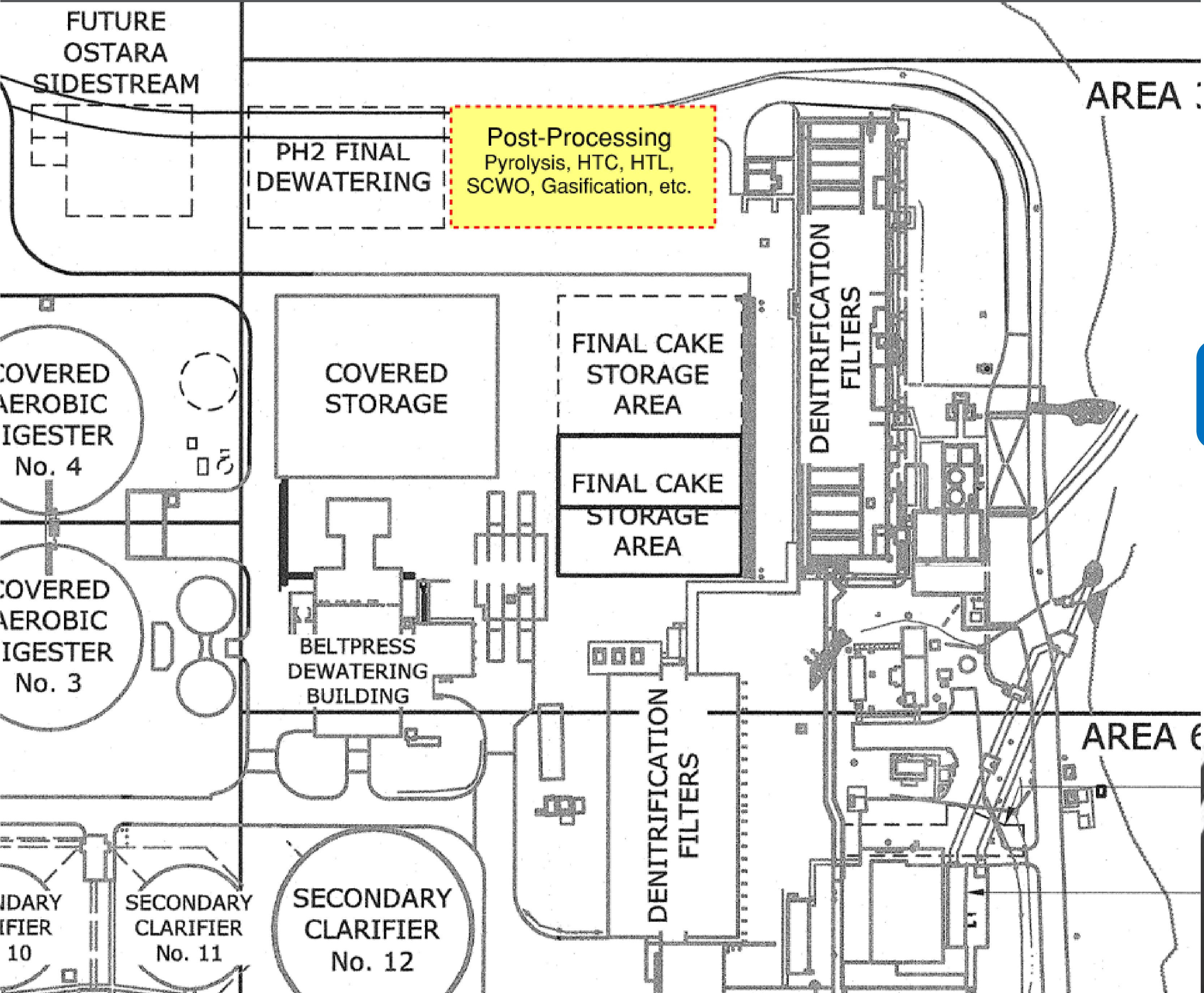
Where do all the technologies stand?
(a snapshot in time)



Next steps to fill the knowledge gaps

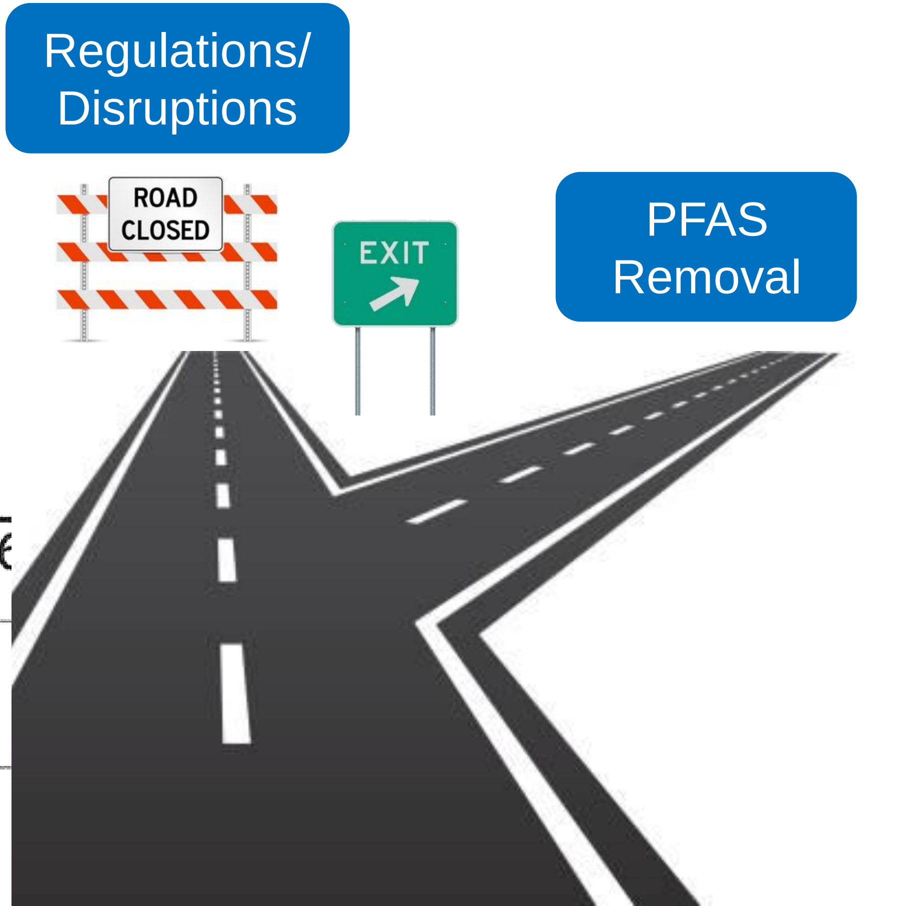
- PFAS fate study in full-scale installations
- Multiple sample points along the WRRF and thermal treatment process to develop PFAS mass balance
- Continuous testing with varying source waters
- Analysis should look at both target and non-target compounds to confirm complete mineralization.





Biosolids Master Planning

Plan ahead: setting aside space on site for future PFAS removal process



Conclusion

- Treatment technologies for PFAS destruction in biosolids are continuously evolving
- Some technologies have shown potential
  - Need further work to verify complete PFAS destruction
  - Additional work necessary to confirm reliable implementation with municipal biosolids
- Multiple studies underway (WRF 5111, EPA PITT program)
- Regulatory developments may continue to outpace study efforts

EPA recently revised "Lifetime Health Advisory" limits are well below detection limits.

PFOA- 0.004 ppt (detection limit- 0.82 ppt)

PFOS- 0.02 ppt (detection limit- 2.4 ppt)

Acknowledgements

Technology Manufacturers

Anaergia, Inc.
Bioforcetech Corporation
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Ecoremedy, LLC
Earthcare, LLC
Aries Clean Technologies
Thermal Process System
374 Water
Aquarden Technologies
Veolia
SoMax
Genifuel Corporation

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Further Reading…
PFAS in Biosolids Research

WRF #5031
Occurrence of PFAS Compounds in US Wastewater Treatment Plants

WRF #5111
Studying the Fate of PFAS through Sewage Sludge Incinerators

WRF #5082
Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater

WRF #5107
Understanding Pyrolysis for PFAS Removal

WRF #5042
Assessing Per- and Polyfluoroalkyl Substance Release from Finished Biosolids

Questions

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