EPA United States Environmental Protection Agency

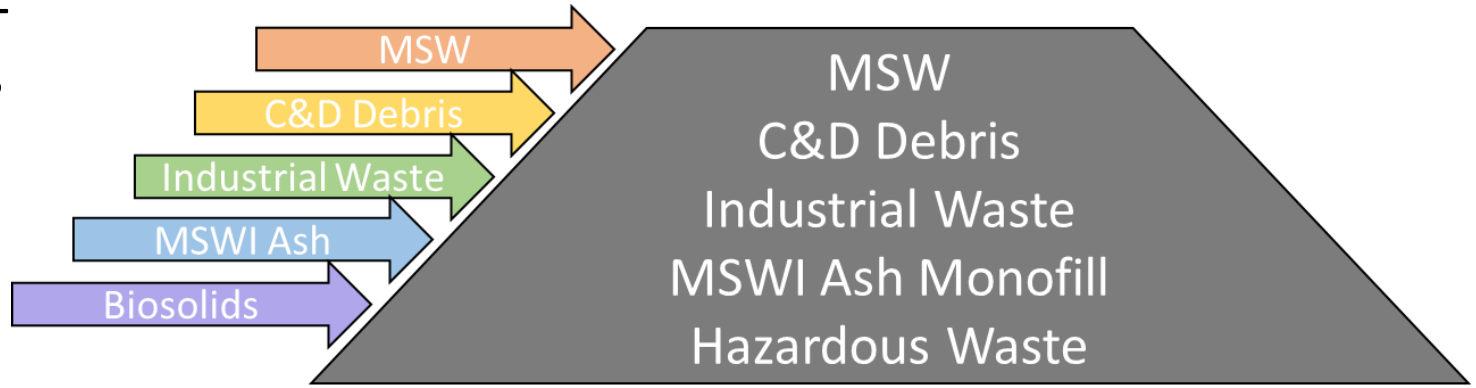
Landfill Disposal of Per- and Polyfluoroalkyl Substances :State of the Science

Thabet Tolaymat Ph.D., PE; Nicole Robey Ph.D., PE

8/25/2024

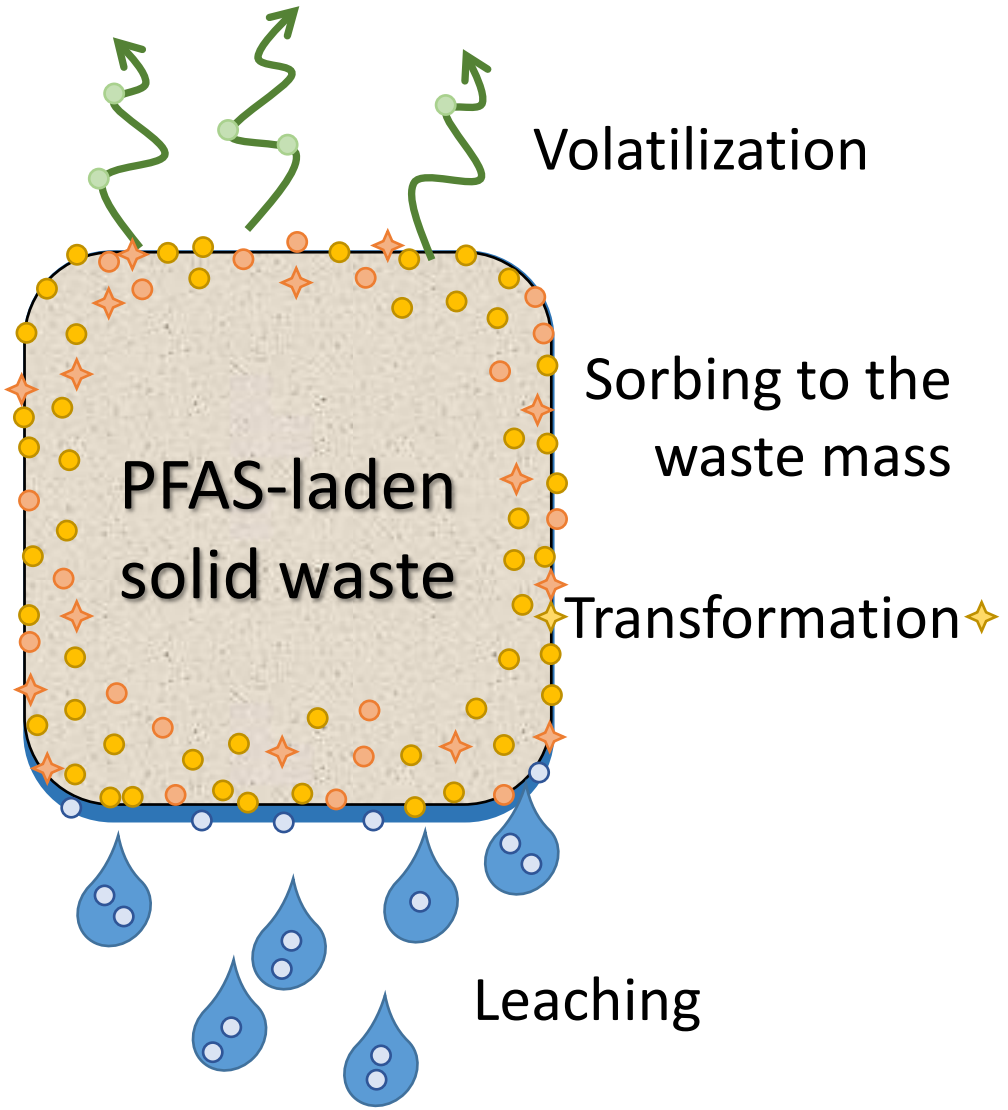
PFAS Inherent to Solid Waste

- Household waste
  - Biodegradable and non-biodegradable fractions
- Industrial Waste
  - Biosolids
  - MSWI ash
  - Manufacturing wastes
  - PFAS remediation residuals



Fate of PFAS in Landfills

- Two mechanisms – transformation and partitioning
- Behavior influenced by PFAS structure (class and carbon chain length)
  - Short chain, terminal PFAS are more mobile and more difficult to treat
- Ongoing transformation and changes in the landfill environment will affect PFAS profile of the effluent
  - Conversion to terminal PFAS over time

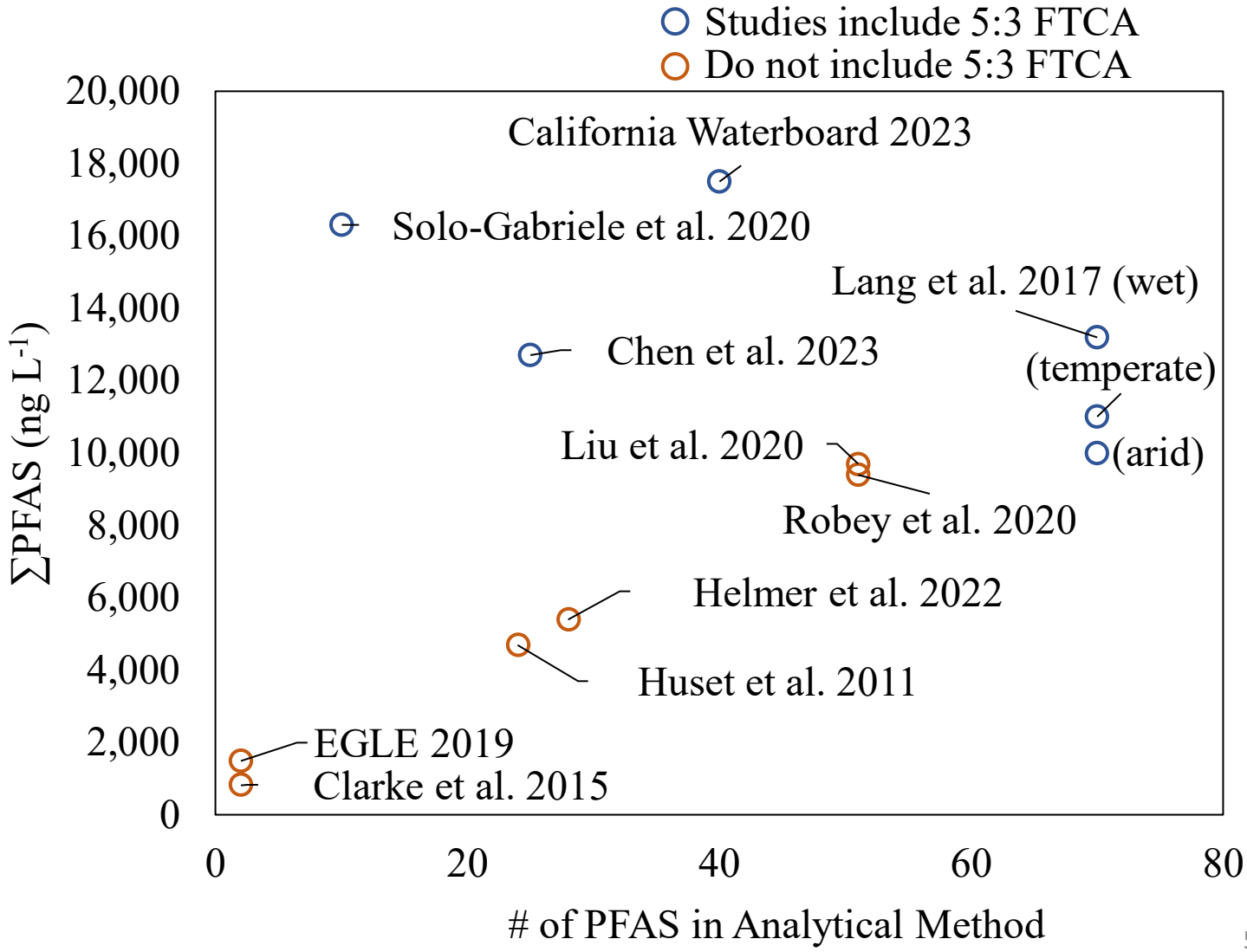


Literature Review: PFAS Partitioning to Landfill Leachate

	Studies	Samples
US MSW landfill leachate	12+	340+
US C&D landfill leachate (Florida)	2	15
MSWI ash monofill leachate (Florida)	2	33
Hazardous waste landfill leachate (California)	2	29
Number of PFAS included in leachate analysis	2 - 92	
PFAS quantified	2 - 50	All
Number of PFAS with RSLs reported in landfill leachate	5 (of 6)	

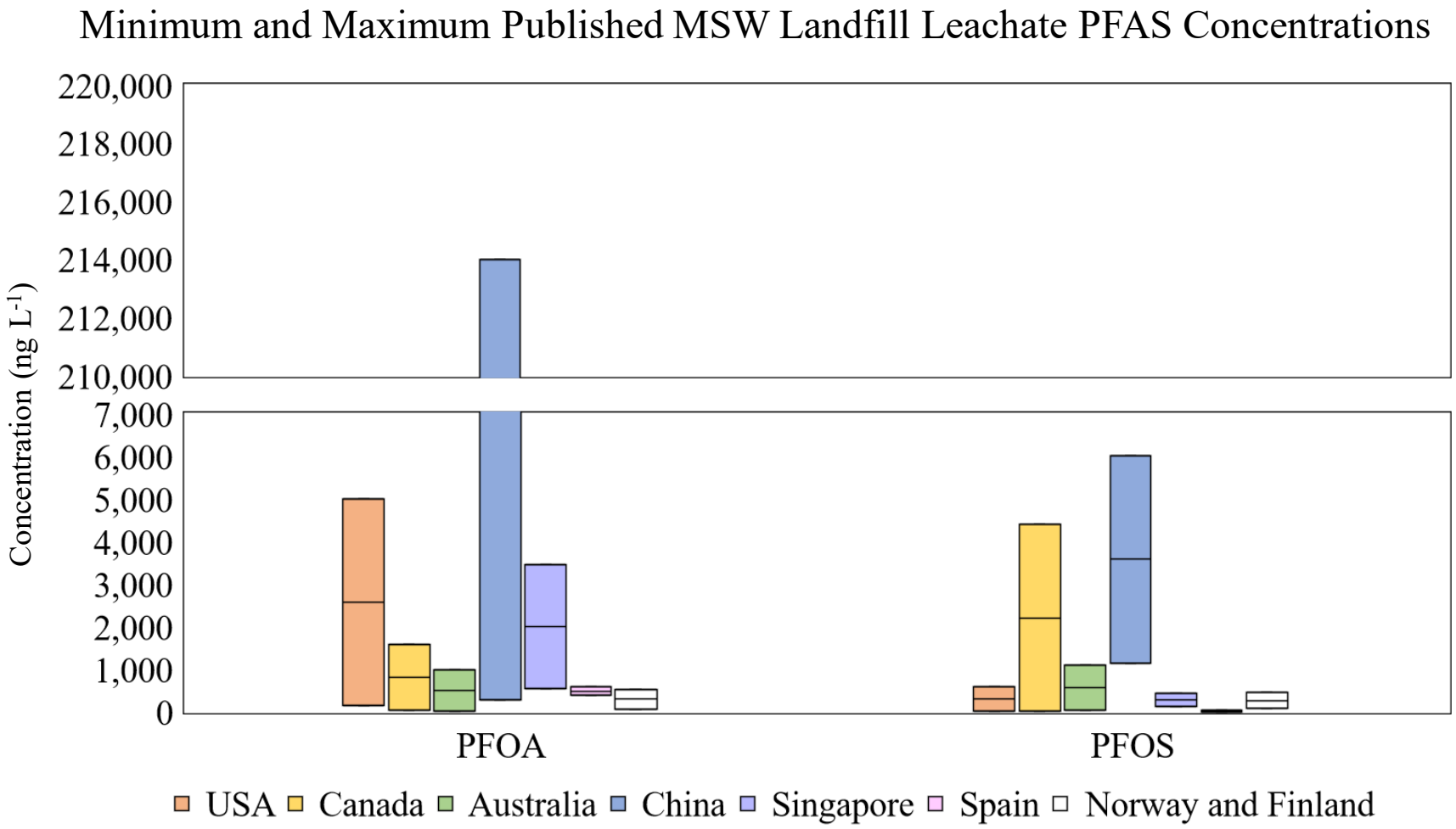
PFAS in MSW Landfill Leachate (US Studies)

- ∑PFAS content of MSW landfill leachate in nine published US studies ranges from BDL - 104,000 ng L^{-1}
  - Weighted average: 12,300 ng L^{-1}



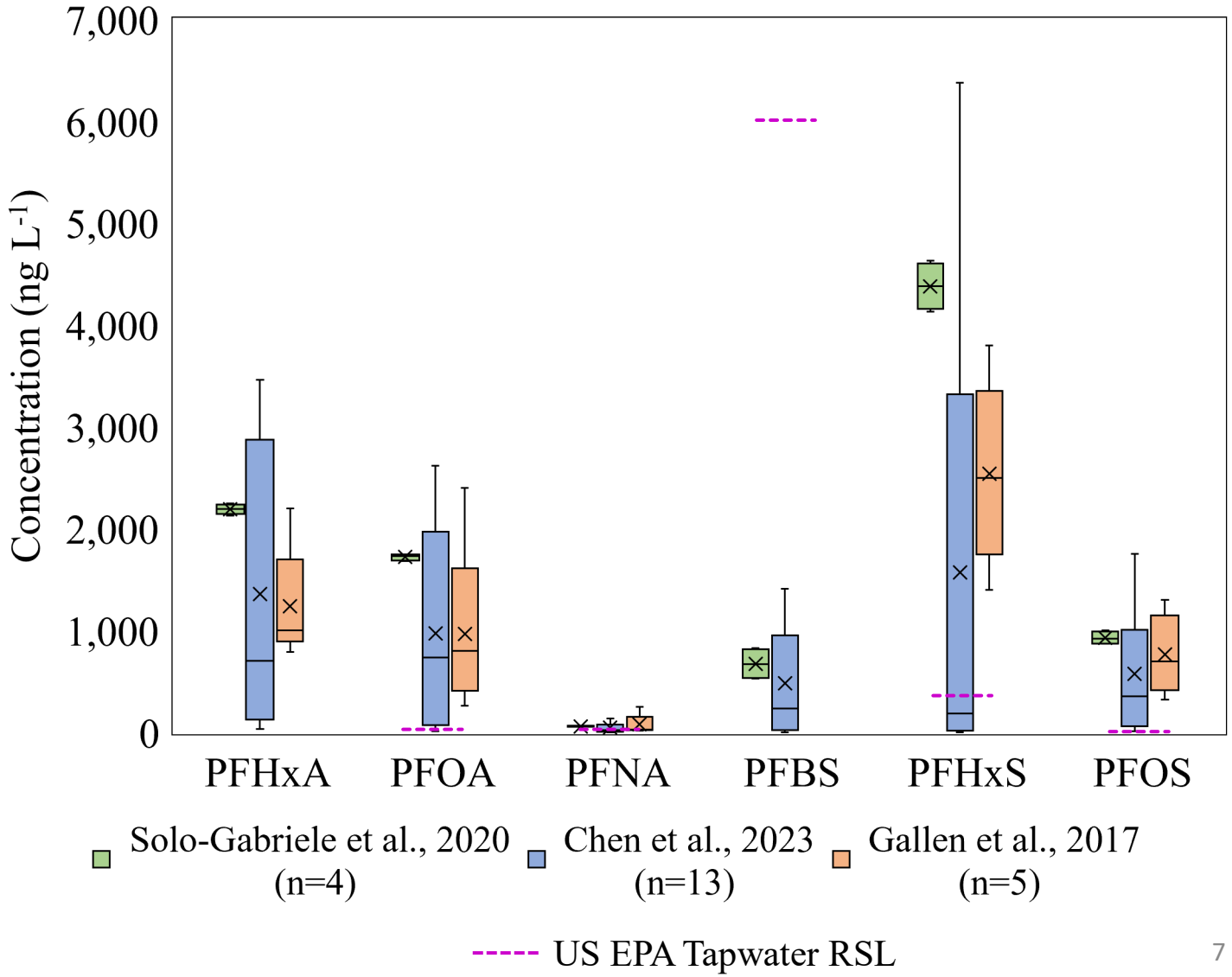
PFAS in MSW Landfill Leachate (International)

- PFAS in international studies are comparable
- Overall, leachate described in studies from China have more PFOS and PFOA than US landfills



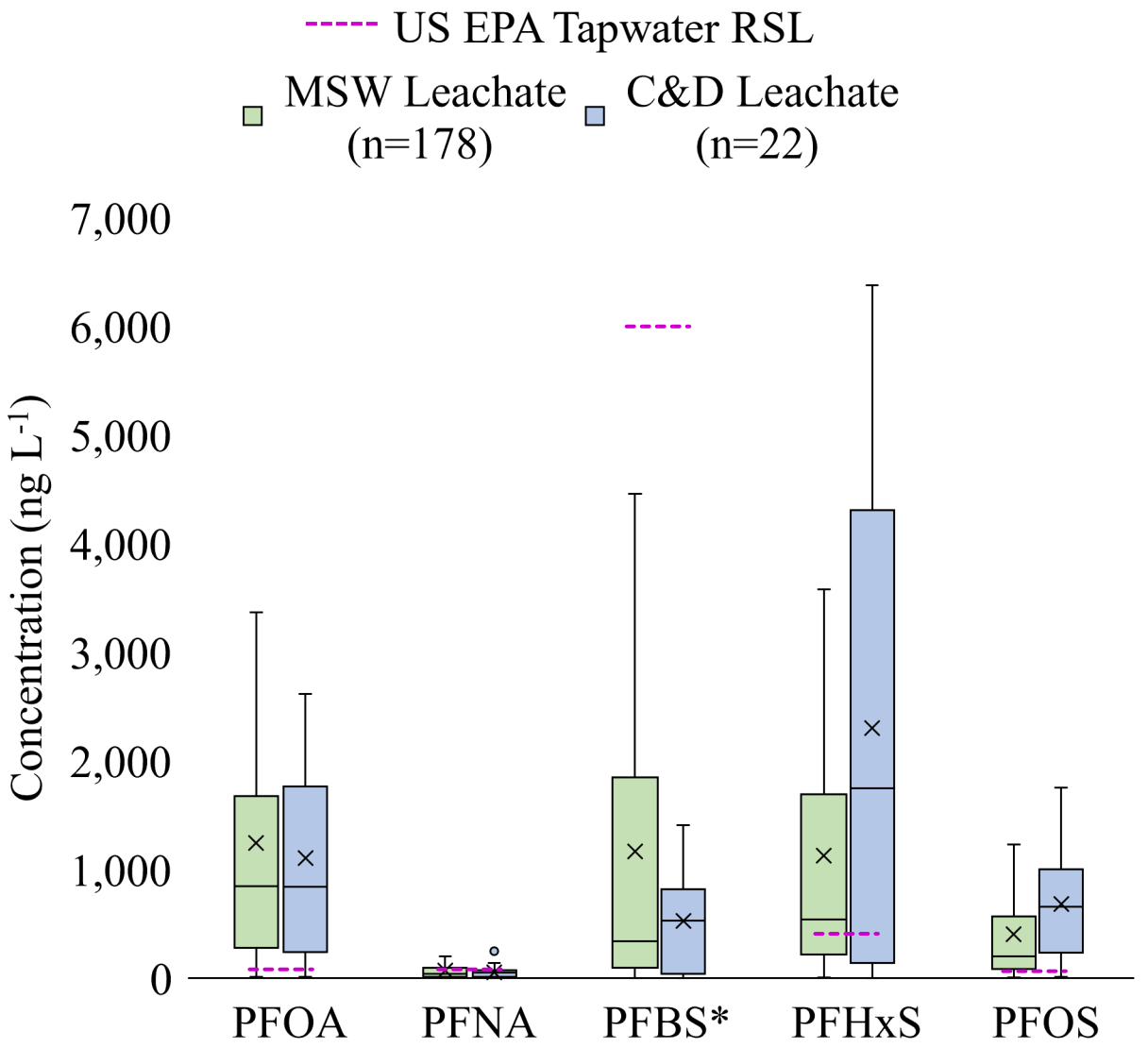
PFAS in C&D Landfill Leachate

- ∑PFAS content of C&D landfill leachate in two published US studies (both from Florida landfills) ranges from 270 - 30,500 ng L^{-1}
  - Weighted average of 10,300 ng L^{-1}
- Significantly, most C&D landfills are not required to use liners or collect leachate
- One study from Australia included five C&D landfill leachate samples



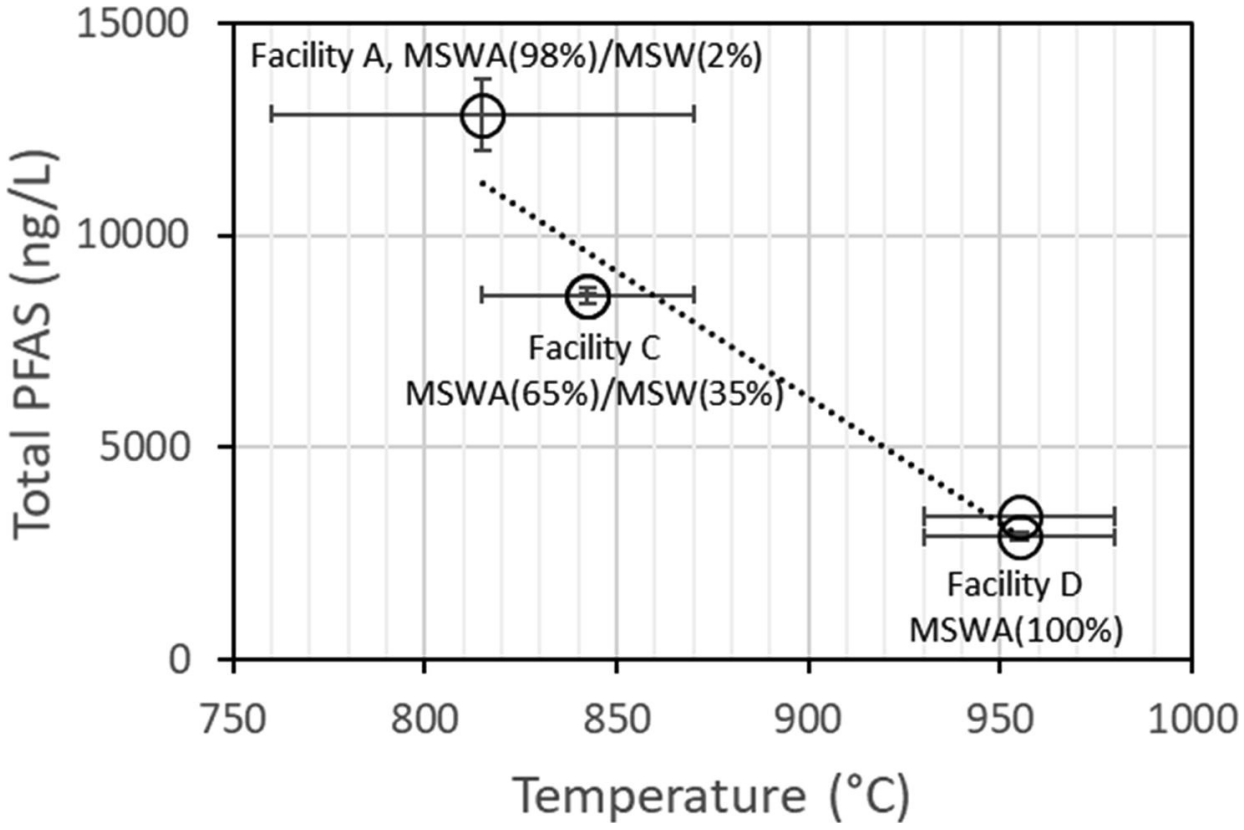
MSW vs. C&D Landfill Leachate

- Three studies (two US, one Australian) measure PFAS in MSW and C&D landfill leachates
- ∑PFAS in MSW and C&D landfill leachates are similar, individual PFAS may be higher or lower, on average
- C&D landfill leachates contain proportionally more terminal PFAS
- Potential explanations
  - density, decomposition, surface area



PFAS in MSWI Ash Monofill Leachate

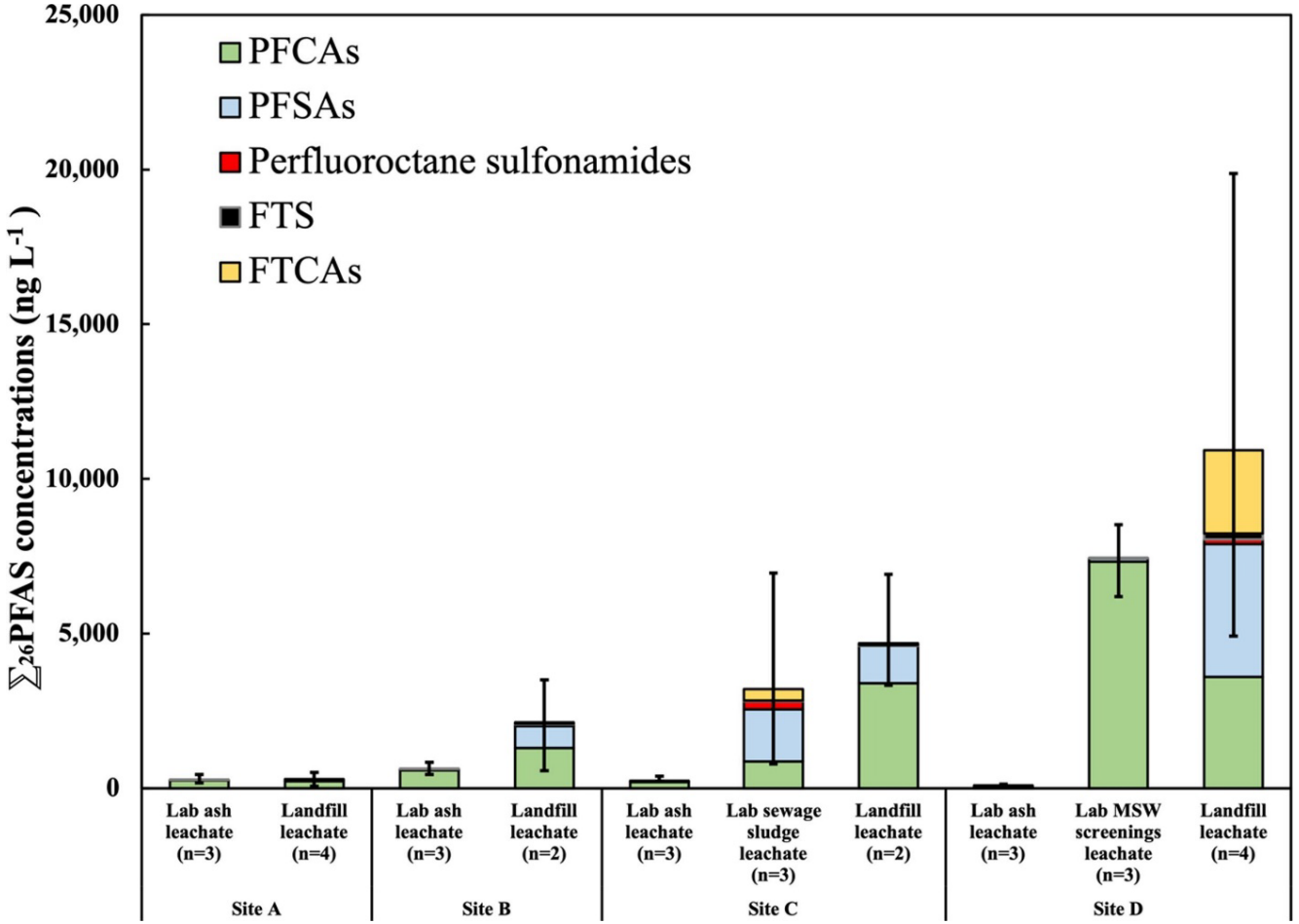
- Ash monofill leachates contain lower PFAS concentrations than MSW and C&D landfill leachates.
  - 39 – 54,500 ng L^{-1}
- Negative correlation between ∑PFAS and incineration temperature



Solo-Gabriele, H.M., Jones, A.S., Lindstrom, A.B., Lang, J.R., 2020. Waste type, incineration, and aeration are associated with per-and polyfluoroalkyl levels in landfill leachates. Waste Management 107, 191–200.

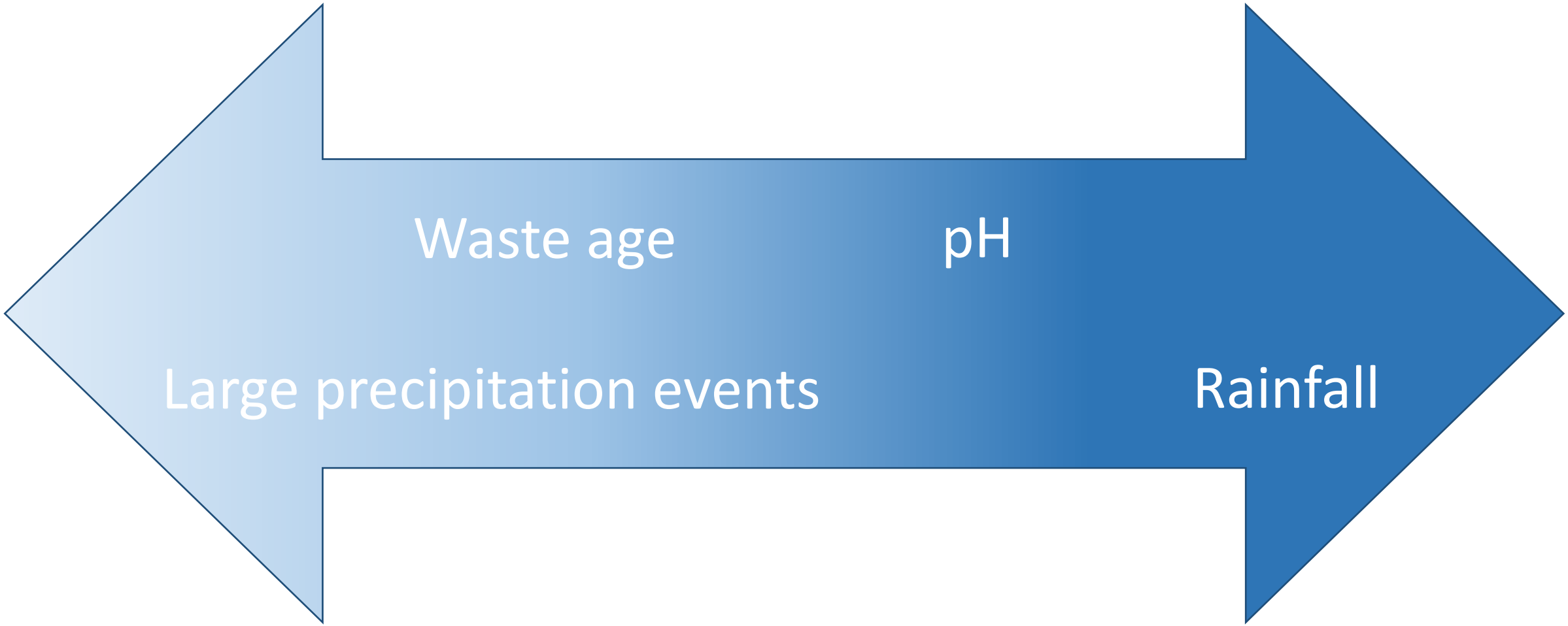
Co-disposal of PFAS-laden Wastes

- Co-disposal of unburned waste (e.g., biosolids, MSW screenings) results in disproportionately high ∑PFAS in leachate
  - Suggests short-circuiting of leachate
  - Care should be taken to dispose of MSW and MSWI ash separately



Liu, Y., Mendoza-Perilla, P., Clavier, K.A., Tolaymat, T.M., Bowden, J.A., Solo-Gabriele, H.M., Townsend, T.G., 2022. Municipal solid waste incineration (MSWI) ash co-disposal: Influence on per- and polyfluoroalkyl substances (PFAS) concentration in landfill leachate. Waste Management 144, 49–56. https://doi.org/10.1016/j.wasman.2022.03.009

Other Factors Affecting PFAS in Leachate

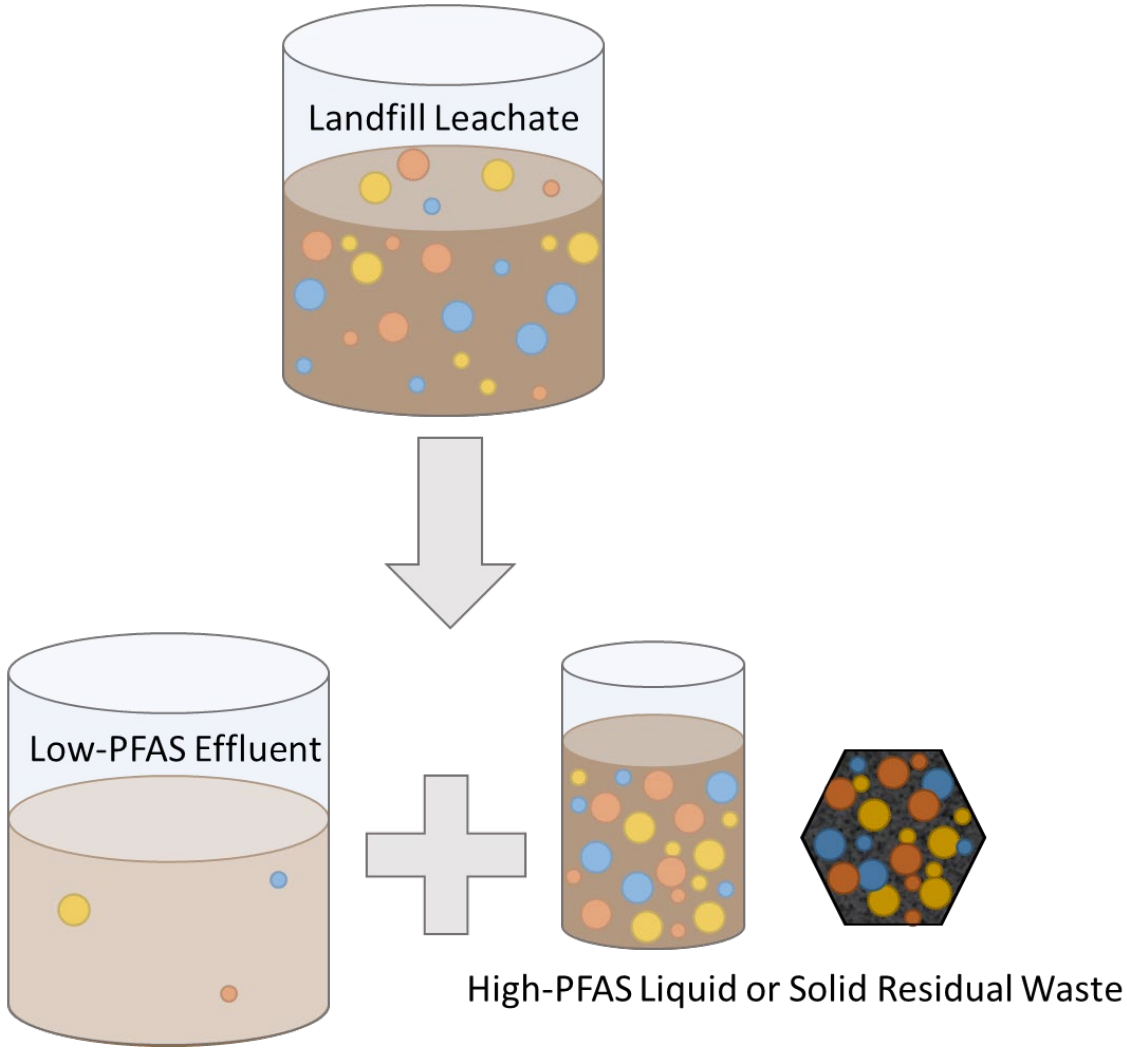


Literature Review: PFAS in MSW Landfill Gas

- Neutral PFAS well-documented to volatilize
  - AFFF headspace study (PFAAs, FTS, neutral PFAS)
  - 15,000 µg m^{-3} PFOA
- Two peer-reviewed studies of *in situ* MSW LFG PFAS
  - FTOHs highest
  - Titaley et al. (2023): ∑Neutral PFAS average 10,200 ng m^{-3}
  - Lin et al. (2024): ∑Neutral PFAS ranged from 210,000-940,000 ng m^{-3}
- Minnesota LFG study
  - PFAAs and FASA 4.1 to 18.7 ng m^{-3}

Targeted Removal of PFAS from Landfill Leachate

- PFAS-targeted treatment falls into two categories: separation and destruction
- Separation treatment results in solid or liquid residuals which require management
- Destructive treatment requires high energy chemical reactions, localized high temperatures
  - Limited studies focused on PFAS in landfill leachate
- PFAS-specific effluent limits for landfill leachate will necessitate treatment prior to leachate disposal

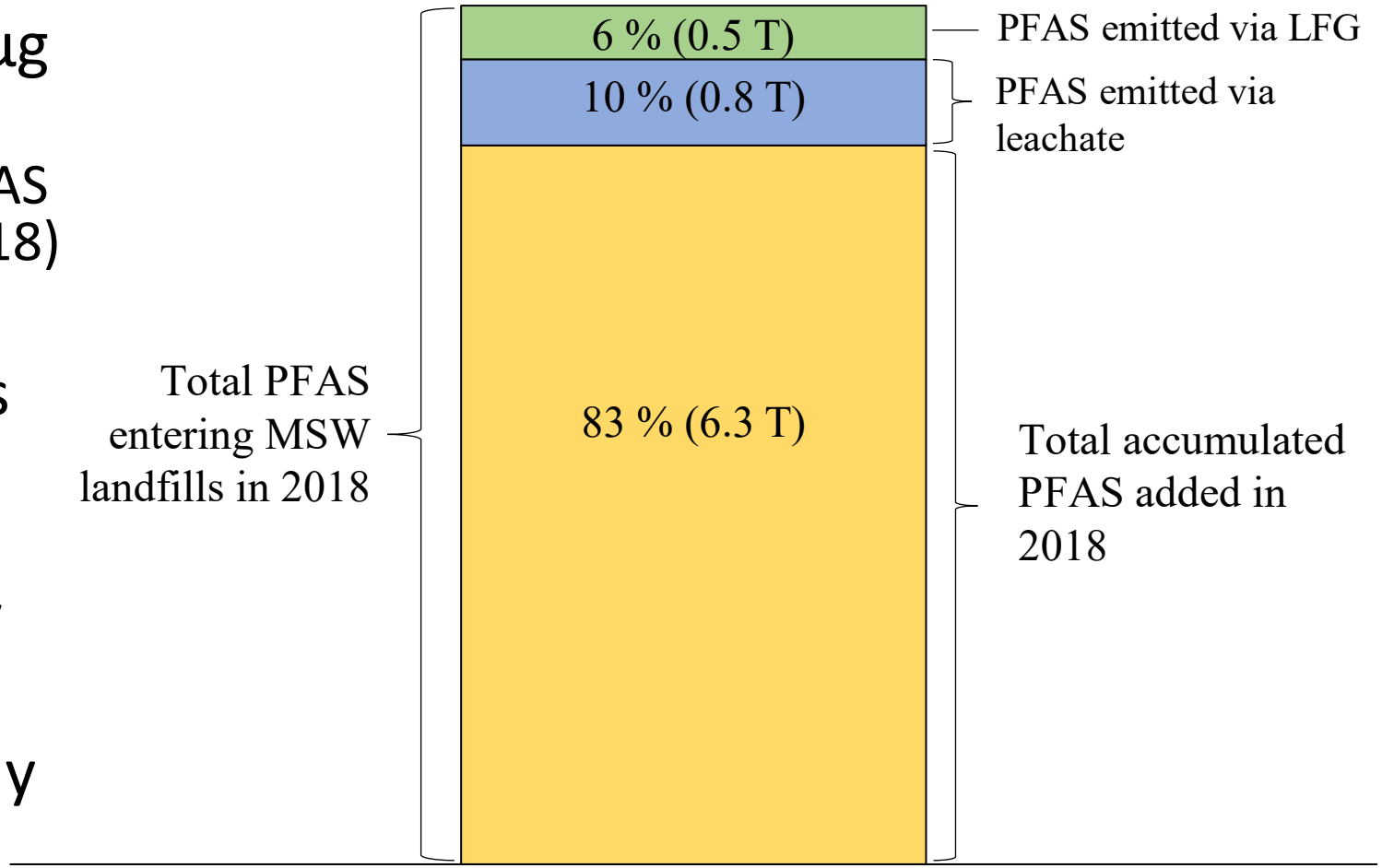


Fate of PFAS in Traditional Landfill Gas Management Systems

- Flare, LFG combustion systems have not been demonstrated to be effective for PFAS treatment
- Flare temperatures (650 °C – 850 °C) may be too low to destroy PFAS (~1,100 °C)
  - Residence times also may be too short
- Likely contribute to transformation of volatile PFAS to PICs and other PFAS
- LFG pretreatment or PFAS-optimized flare operation may mitigate emissions

Estimate of US MSW Landfill PFAS Mass Balance

- Conservative estimate of 50 µg PFAS per kg of MSW
  - Corresponds to **6,600 kg** of PFAS entering landfills annually (2018)
- Additional **850** kg of PFAS entering landfills via biosolids (2018)
- **750 kg** emitted from MSW landfills via leachate annually
- **460 kg** PFAS emitted from MSW landfills via LFG annually



Questions?

Thabet Tolaymat
tolaymat.thabet@epa.gov