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



Nicole Robey, Ph.D.

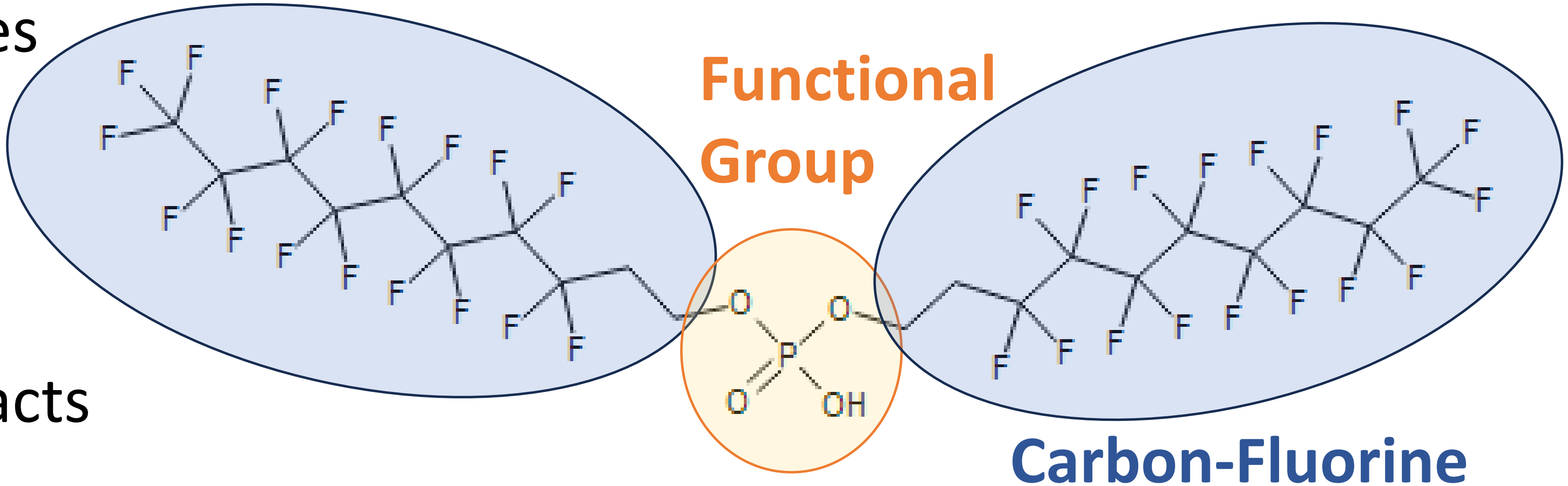
SWANA Florida Winter Conference 2024

February 2024

Innovative TECHNICAL SOLUTIONS

Introduction

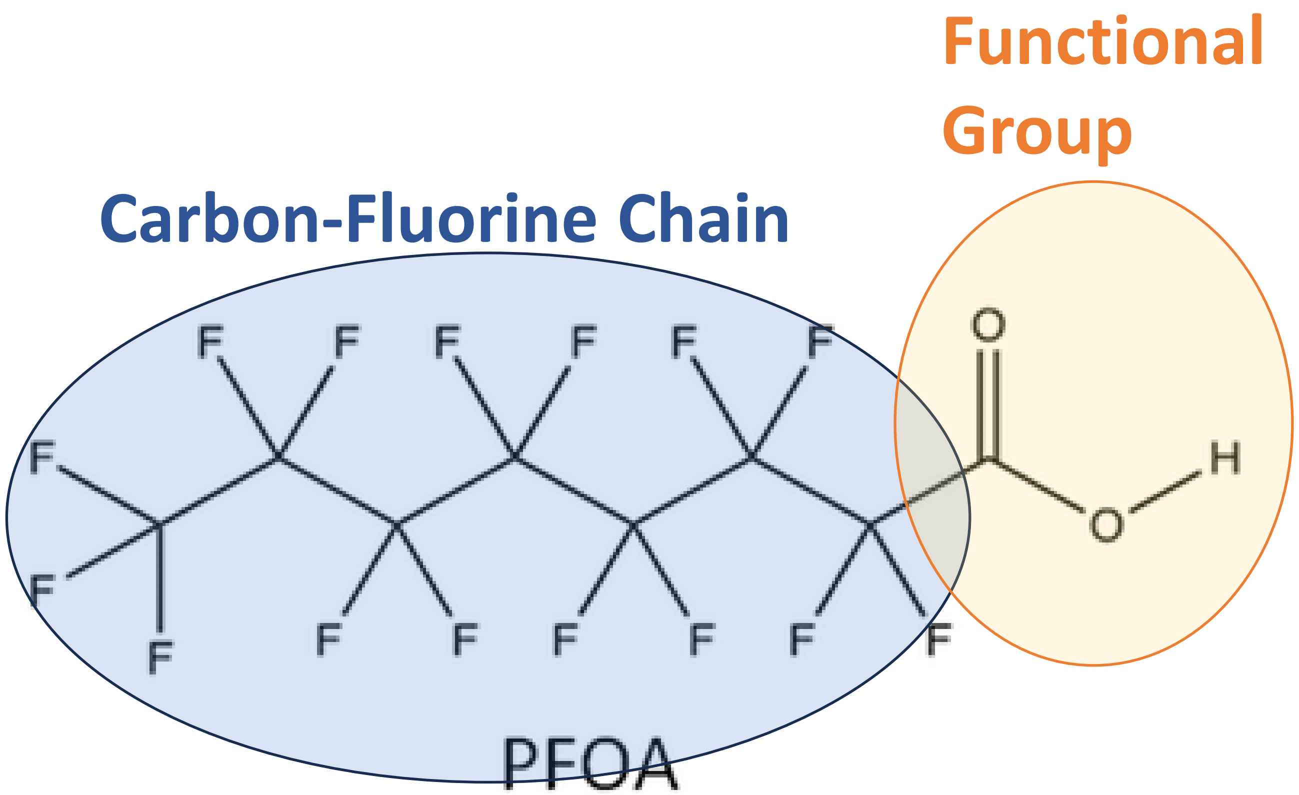
- This review discusses the state of waste-derived PFAS in landfills and the associated environmental impacts
- PFAS Basics
  - Terminal vs precursor
  - Class
  - Chain length



8:2 diPAP

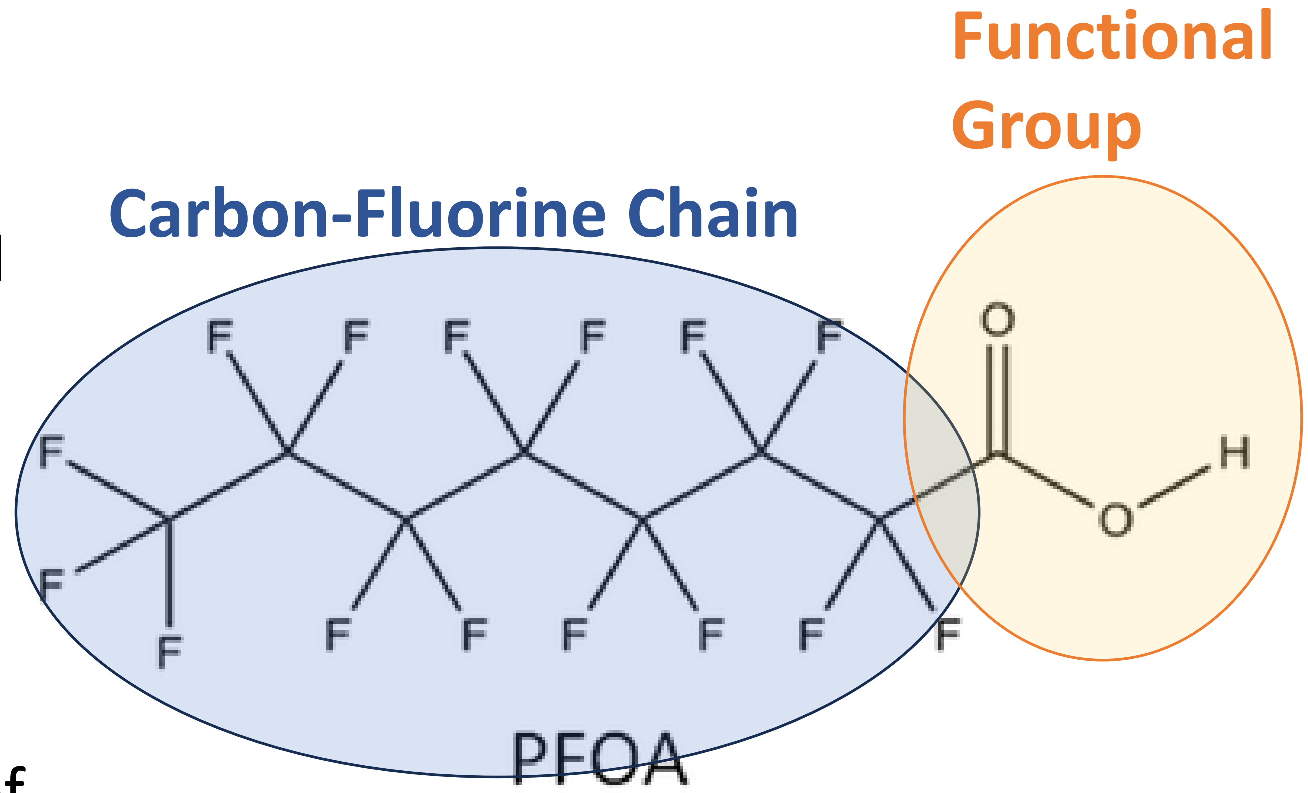
Introduction

- This review discusses the state of waste-derived PFAS in landfills and the associated environmental impacts
- PFAS Basics
  - Terminal vs precursor
  - Class
  - Chain length



Introduction

- This review discusses the state of waste-derived PFAS in landfills and the associated environmental impacts
- PFAS Basics
  - Terminal vs precursor
  - Class
  - Chain length
- Reported concentrations of "total PFAS" vary based on the number of PFAS included and inherent leachate variability
  - Analytical capabilities are rapidly expanding: water, soil, and air matrices



Innovative TECHNICAL SOLUTIONS

US EPA PFAS Initiatives

2009 — 2016 — 2021 — 2022 — 2023

2009: Provisional Health Advisory

Developed to assess potential risk from exposure to these chemicals through drinking water

Matrix: Drinking Water

2016: Drinking Water Guidance

Non-enforceable guidance adopted by several states

Matrix: Drinking Water

PFOA: 70 ng/L

PFOS: 70 ng/L

2021: PFAS Strategic Roadmap

Agency-wide plan to address PFAS concerns through 2024

2022: Interim Health Advisory Levels

Identify levels to protect humans from adverse health effects resulting from PFAS exposure

Matrix: Drinking Water

PFOA: 0.004 ng/L

PFOS: 0.02 ng/L

PFBS: 2,000 ng/L

Gen-X: 10 ng/L

2022: Regional Screening Levels

PFAS concentrations developed for Superfund site remediation

Matrices: Tapwater, Residential and Industrial Soil

PFprA, PFBA, PFHxA, PFOA, PFNA, PFUnDA, PFDoDA, PFTetDA, PFODA, PFBS, PFHxS, PFOS, Gen-X

2023: Proposed Maximum Contaminant Level

Enforceable National Primary Drinking Water Regulation. Proposed goal of zero.

Matrix: Drinking Water

PFOA: 4 ng/L

PFOS: 4 ng/L

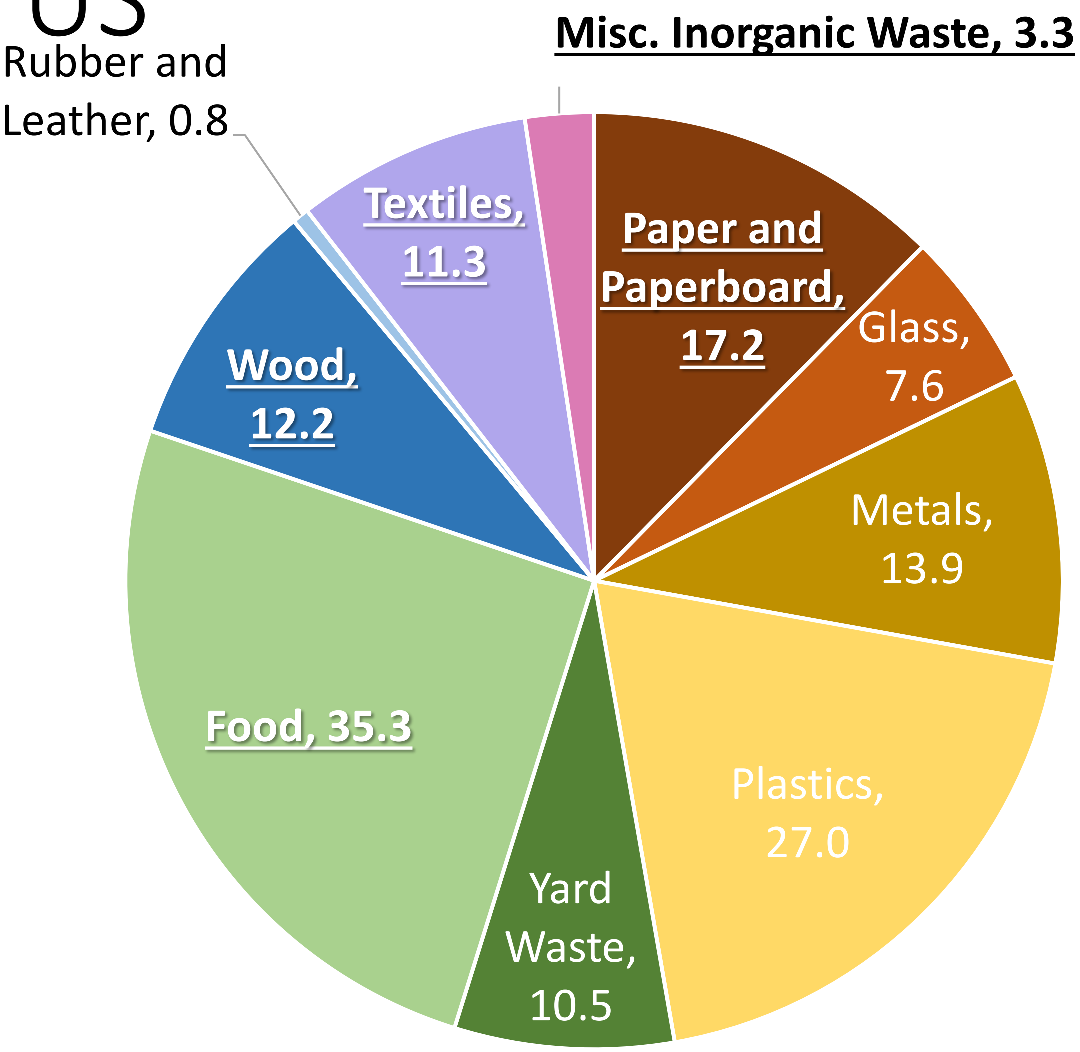
PFNA, PFBS, PFHxS, Gen-X: Combined Limit, Hazard Index=1.0

Motivation

- Landfills represent an important component of the human-environment PFAS cycle
- Landfills are often identified as "significant" emitters of PFAS
  - Which incoming waste and landfill effluent streams are most significant?
  - How can the solid waste community use this information?

MSW Management in the US

- 300 million tons MSW generated
  - 150 million tons (50%) goes to landfills
- PFAS content of significant waste streams has been the subject of multiple studies
  - Paper, textiles, engineered wood, food, e-waste
- Industrial waste streams that are disposed of in landfills:
  - Biosolids, MSWI ash, PFAS remediation residuals, manufacturing waste

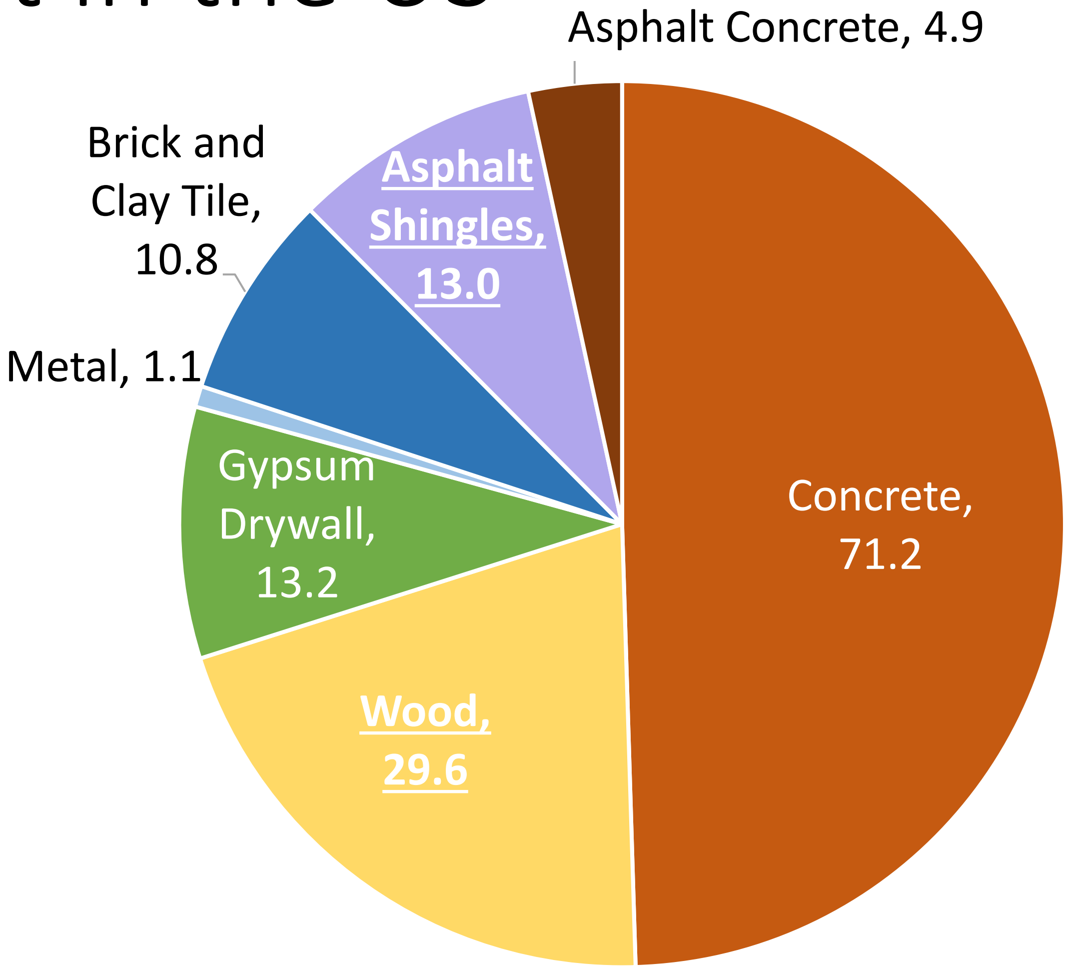


Composition of Landfill-disposed MSW

Innovative TECHNICAL SOLUTIONS

C&D Debris Management in the US

- 600 million tons C&D debris generated
  - 24% of C&D debris disposed of in landfills (144 million tons)
- PFAS-significant waste streams represent a small fraction of landfilled C&D
  - Carpets, weatherproofing, insulation, engineered wood
- Landfill conditions will impact PFAS leaching

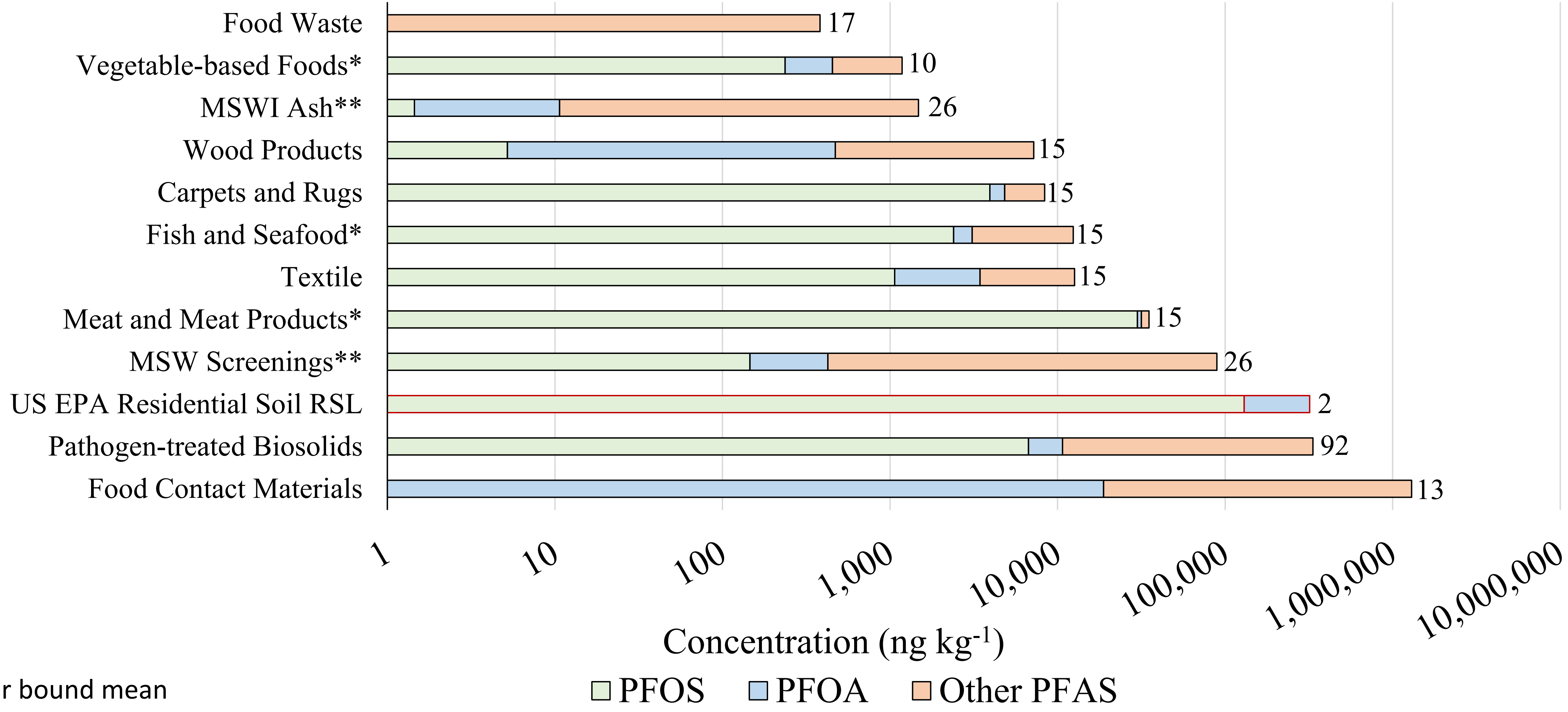


Composition of Landfill-disposed C&D Debris

Innovative TECHNICAL SOLUTIONS

Sources of PFAS in Solid Waste

Averages from the Literature

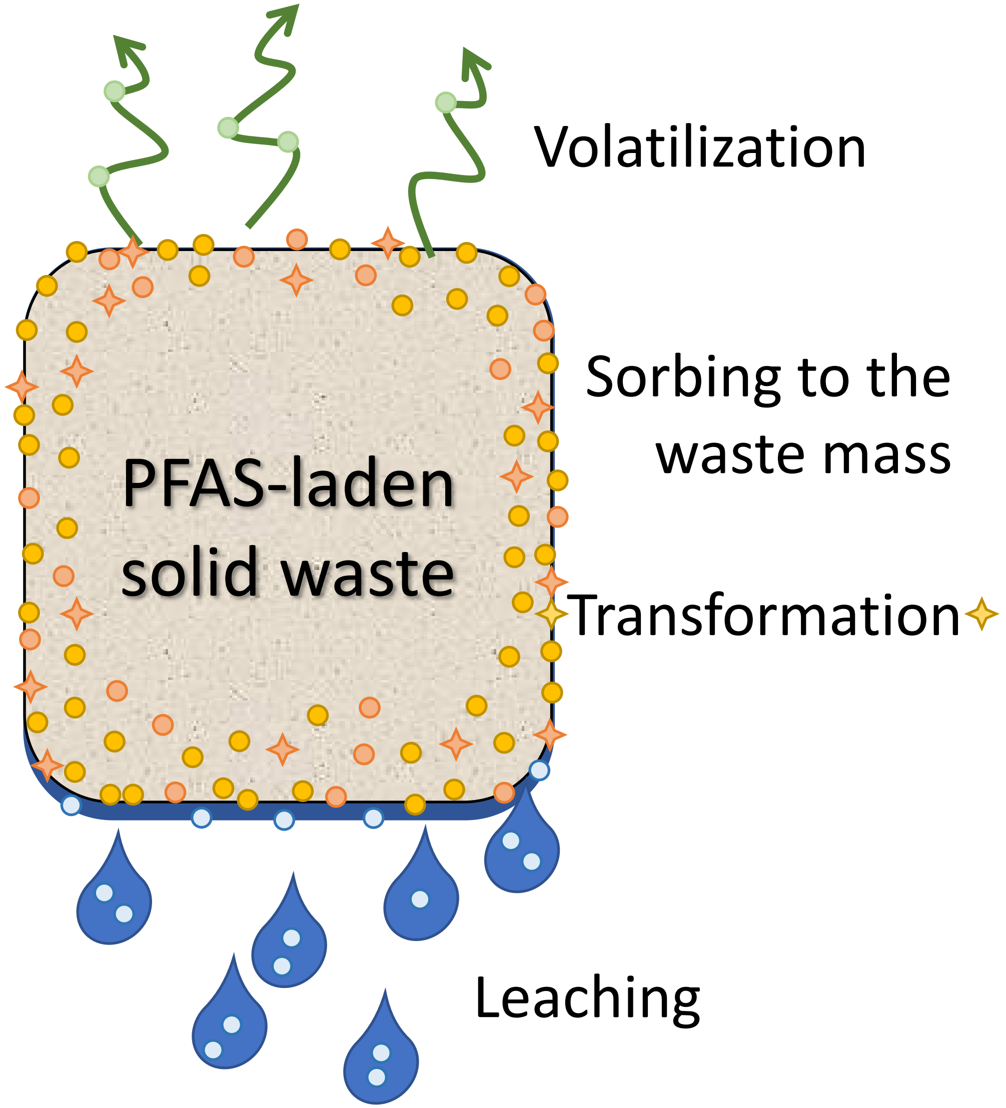


* upper bound mean

** minimum total PFAS based on leachable fraction

Fate of PFAS in Landfills

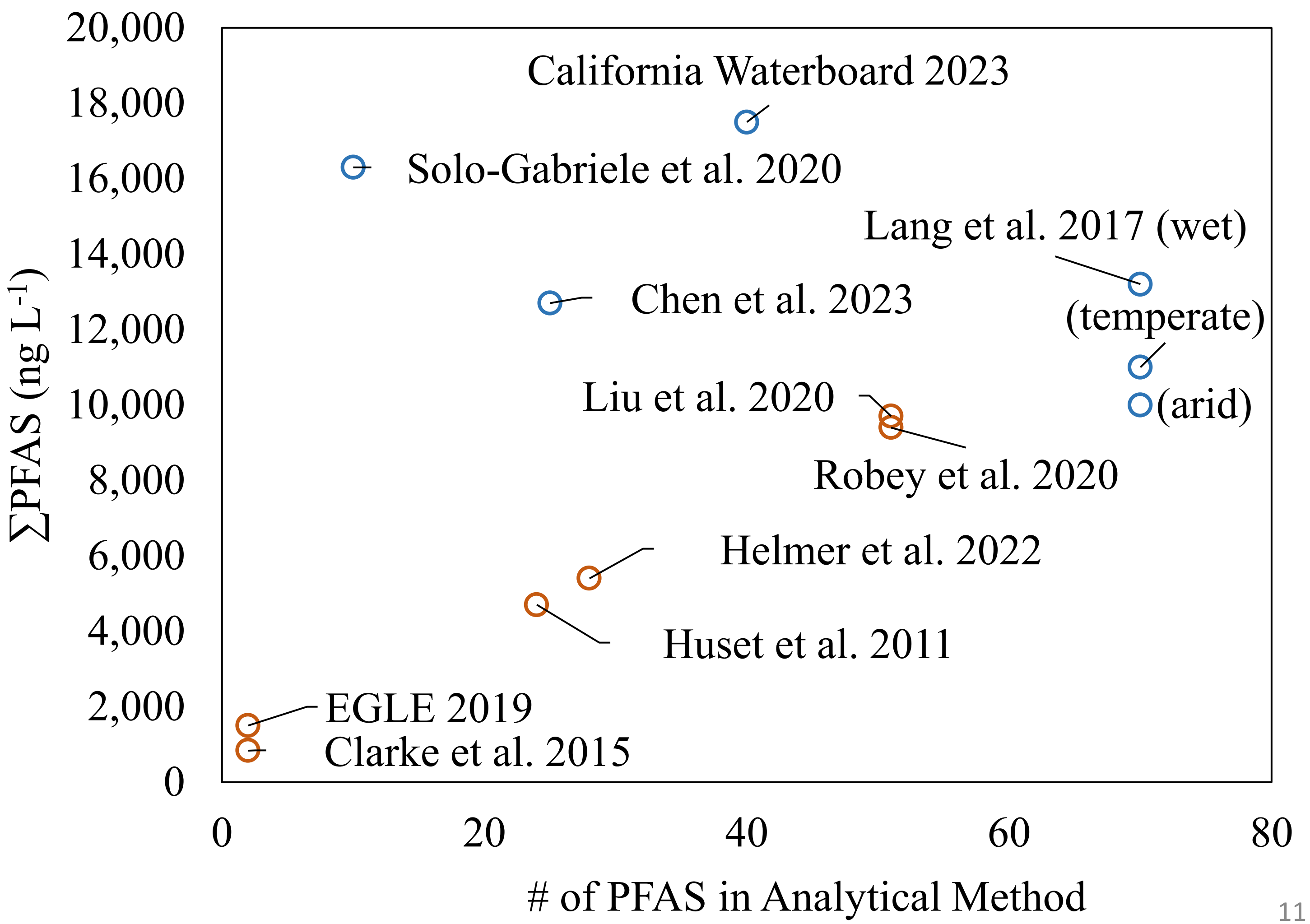
- Two mechanisms – transformation and partitioning
- Behavior influenced by PFAS structure (class and carbon chain length)
  - Short chain, terminal PFAS are more mobile and more difficult to treat
- Ongoing transformation and changes in the landfill environment will affect PFAS profile of the effluent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



Innovative TECHNICAL SOLUTIONS

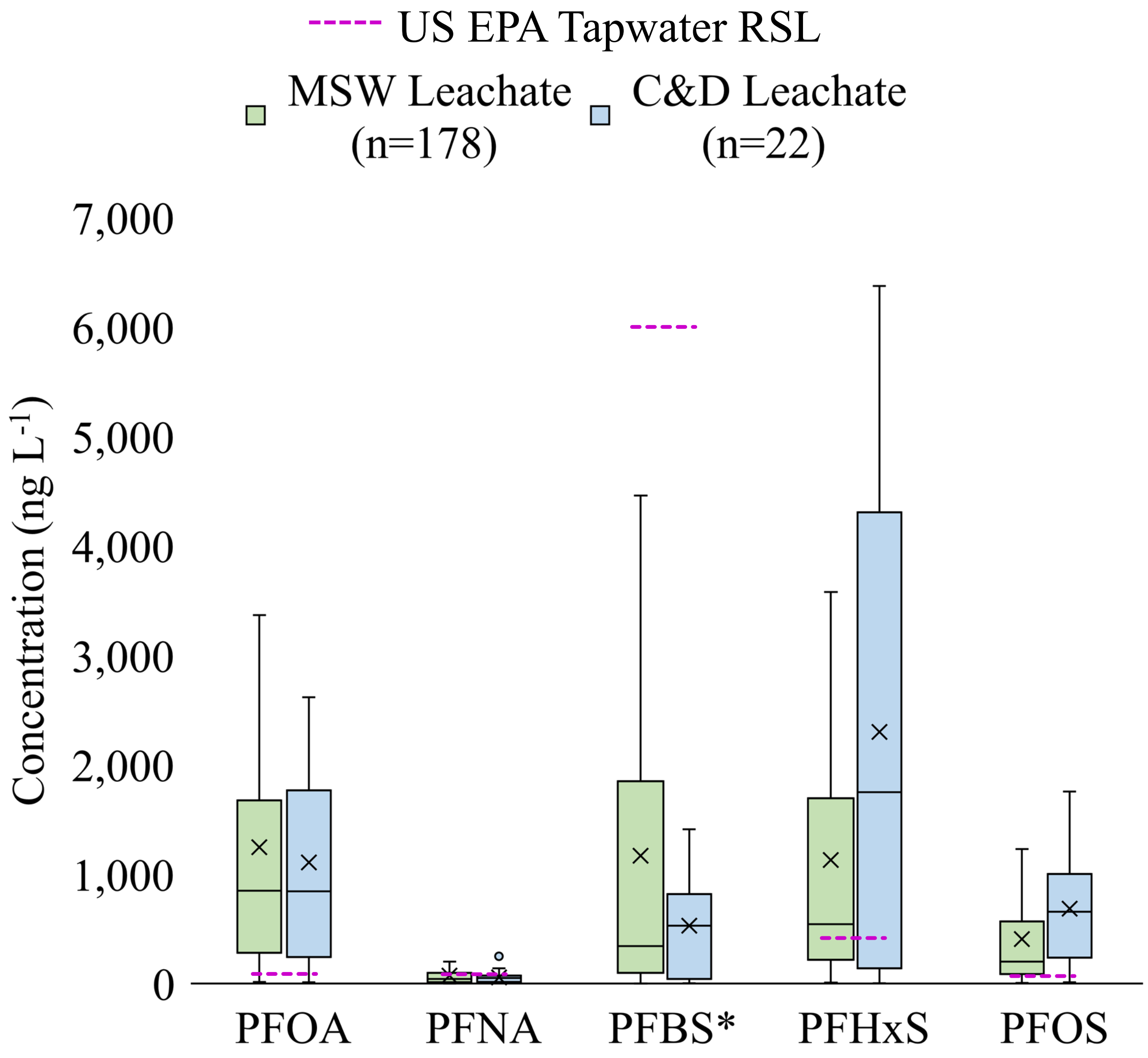
PFAS in MSW Landfill Leachate (US Studies)

- ∑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}



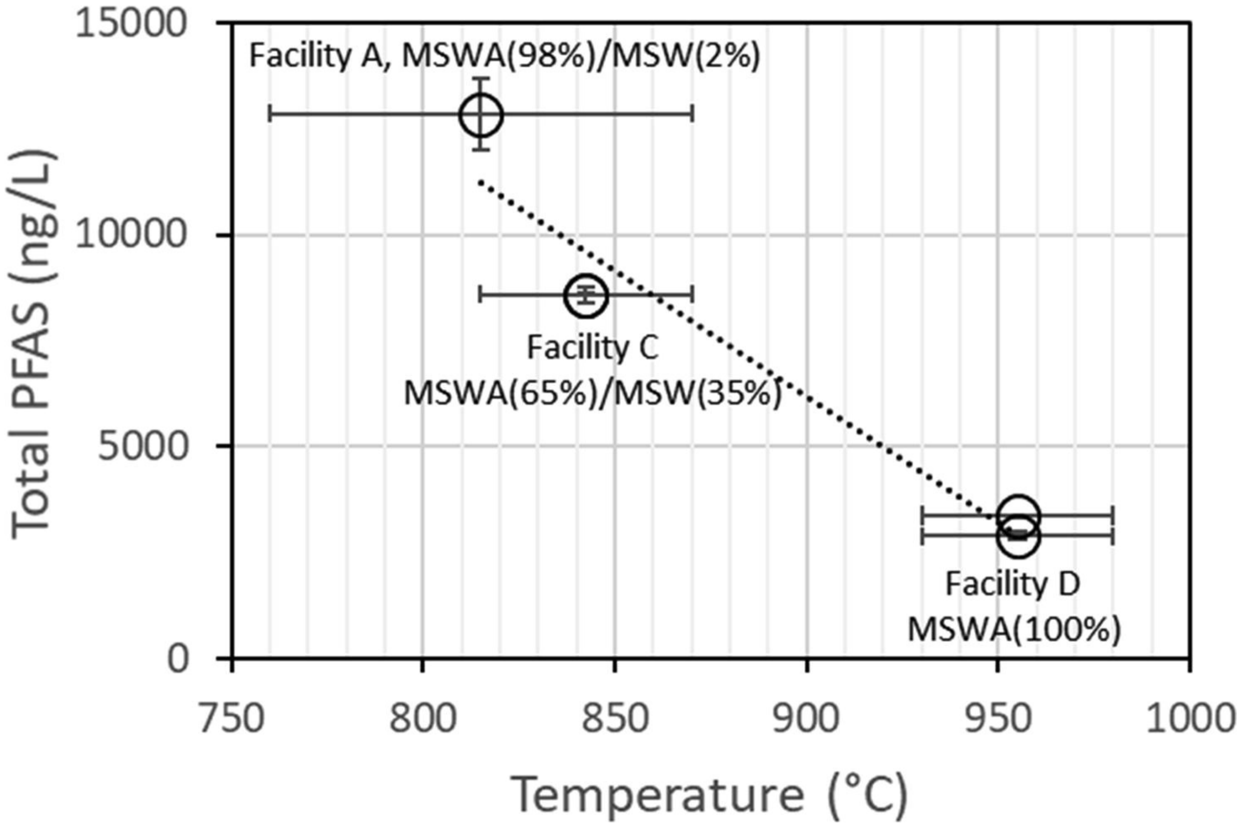
MSW vs. C&D Landfill Leachate

- ∑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}
- Many C&D landfills are not required to use liners or collect leachate



MSW Incineration Ash Monofill Leachate

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



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.

Innovative TECHNICAL SOLUTIONS

US MSW, C&D, MSWI Ash Landfill Leachate vs. EPA Regional Screening Levels

PFAS	MSW Landfill	C&D Landfill	MSWI Ash Landfill	EPA RSL
PFOA	1,400	1,100	800	60
PFOS	260	660	400	40
PFNA	67	50	59	59
PFBS	800	530	1,400	18,000
PFHxS	550	2,200	510	390
PFHxA	2,800	1,600	1,300	9,900
5:3 FTCA	3,500	1,400	700	n/a

Other Factors Affecting PFAS in Leachate

Waste age

pH

Large precipitation events

Rainfall

Fate of PFAS in Traditional Landfill Gas Management Systems

- One peer-reviewed study of *in situ* MSW LFG PFAS
  - FTOHs highest
  - ∑Neutral PFAS average 10,200 ng m^{-3}
- 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 (~1,000 °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

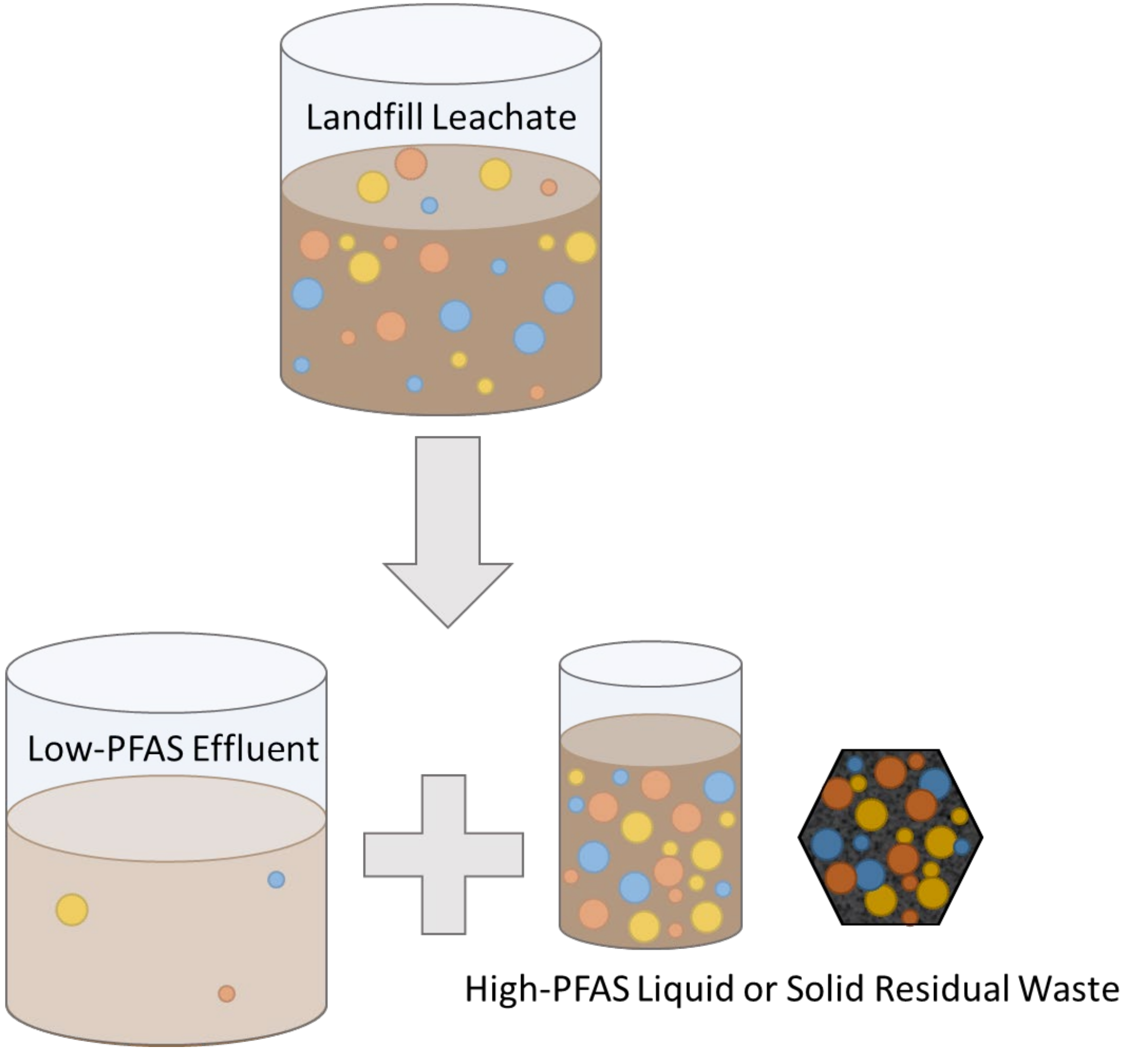
Fate of PFAS in Traditional Landfill Leachate Management Systems

- Limited studies suggest minimal diffusion of PFAS through HDPE liners
  - Liner integrity imperative for preventing PFAS transmission to the environment
- Liner leachate collection efficiency: 98.1%
- Compacted clay liners ineffective (based on bentonite clay studies)
- Traditional leachate treatment is not effective PFAS treatment
  - Many rely on chemical or biological oxidation
    - Likely to facilitate transformation to terminal (potentially regulated) PFAS
    - Actual total PFAS may not change but terminal PFAS and *apparent* total PFAS may increase
  - PFAS should be removed prior to treatment targeting other constituents (e.g., ammonia, COD)

Innovative TECHNICAL SOLUTIONS

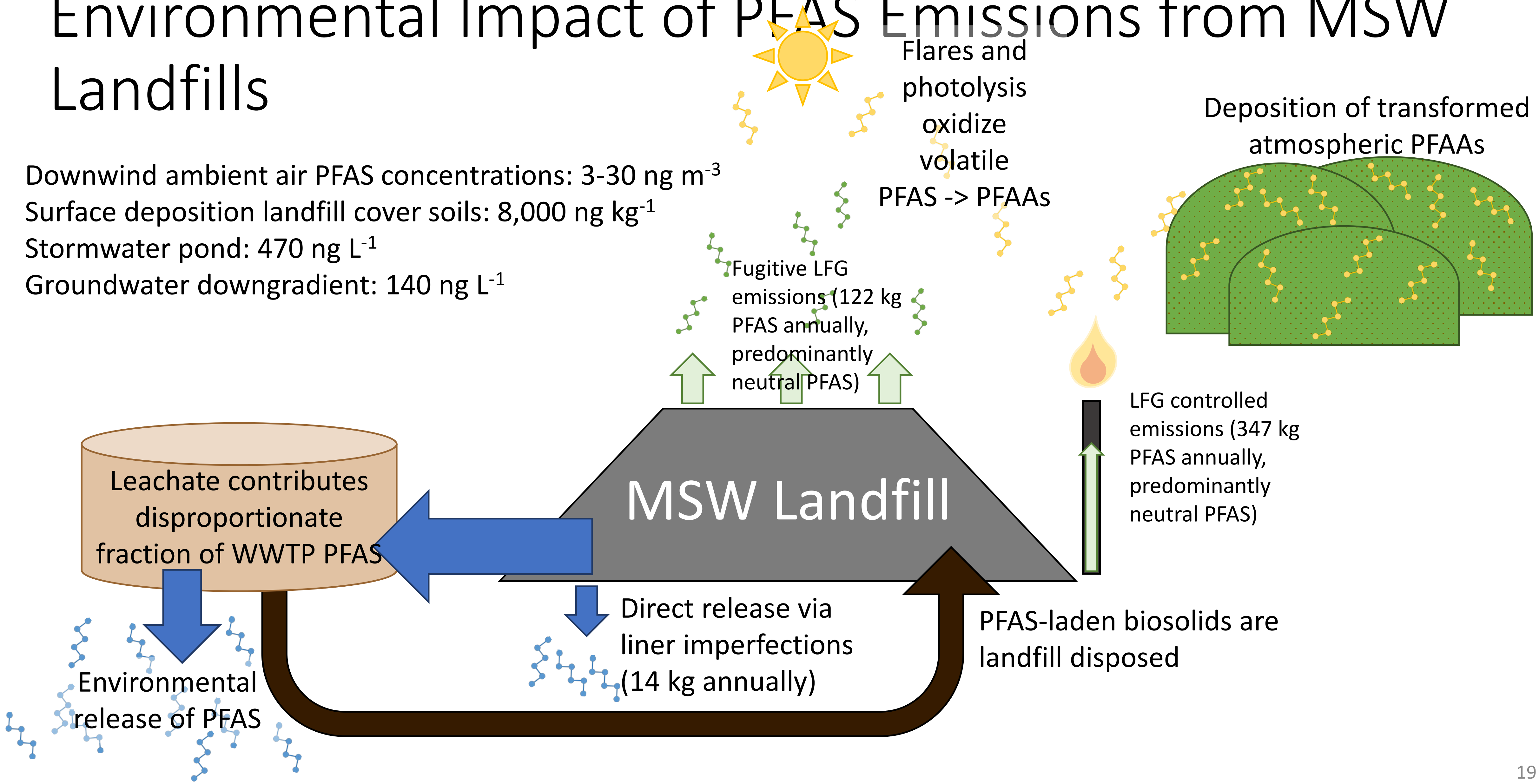
Targeted Removal of PFAS from Landfill Leachate

- PFAS-specific effluent limits for landfill leachate will necessitate treatment prior to leachate disposal
- PFAS-targeted treatment falls into two categories: separation and destruction
- Destructive treatment requires high energy chemical reactions, localized high temperatures
  - Limited studies focused on PFAS in landfill leachate
- Separation treatment results in solid or liquid residuals which require management
  - Reverse osmosis and other membrane separation
  - Foam fractionation
  - Evaporation
  - Activated carbon and other sorbtive media
  - Consider other by-products, such as air emissions



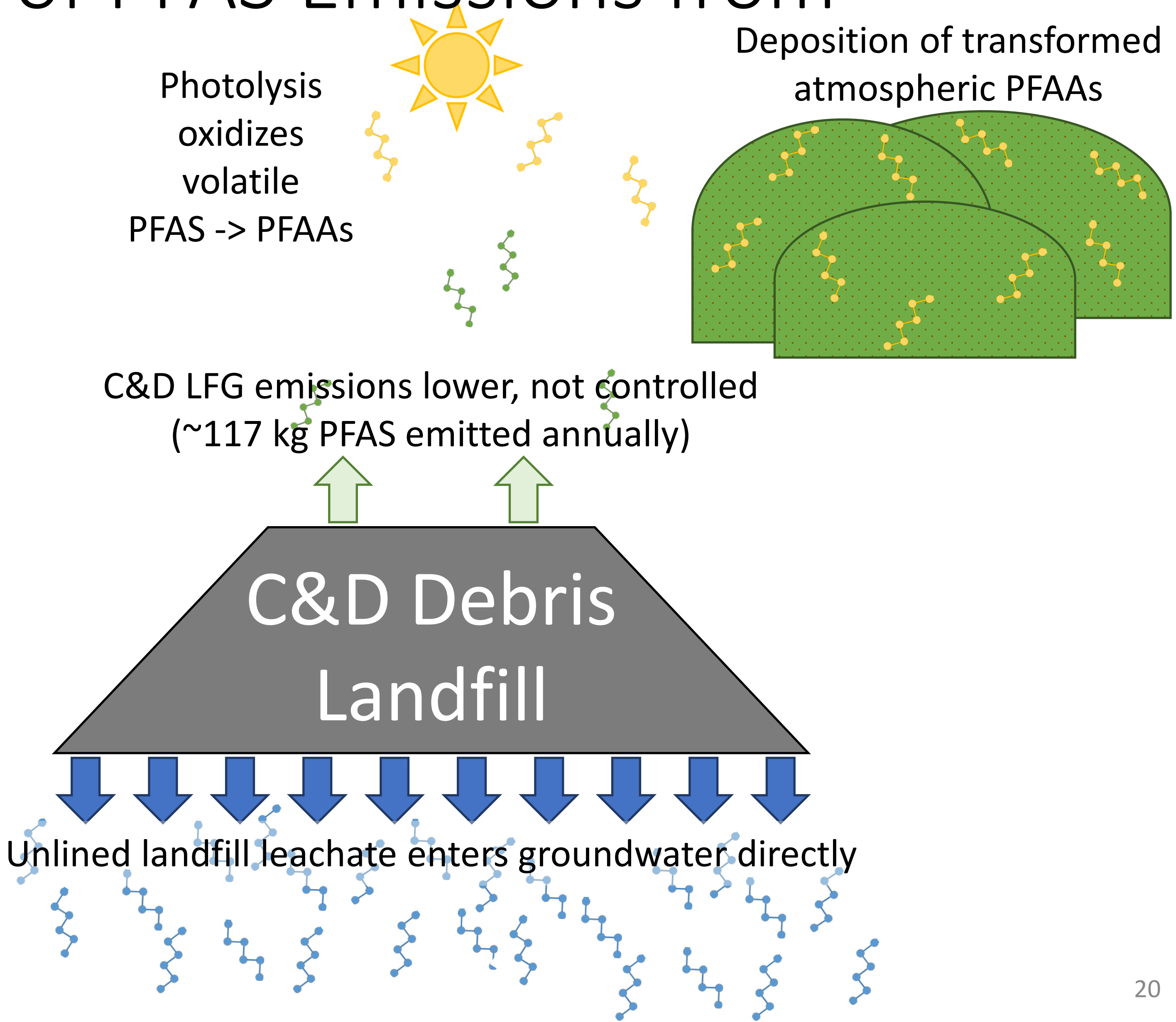
Environmental Impact of PFAS Emissions from MSW Landfills

- Downwind ambient air PFAS concentrations: 3-30 ng m^{-3}
- Surface deposition landfill cover soils: 8,000 ng kg^{-1}
- Stormwater pond: 470 ng L^{-1}
- Groundwater downgradient: 140 ng L^{-1}



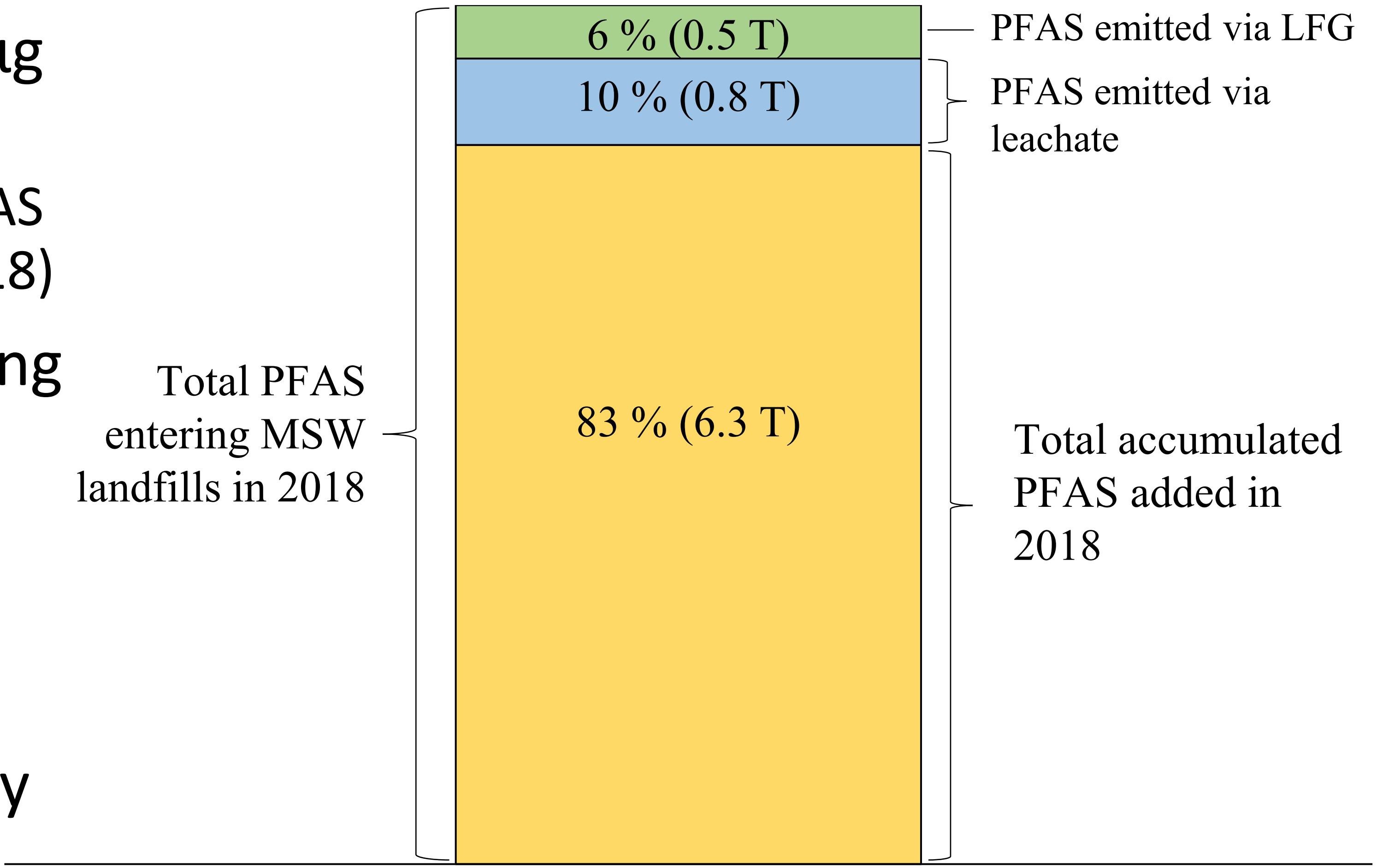
Environmental Impact of PFAS Emissions from C&D Debris Landfills

- C&D leachates are more likely to enter groundwater directly at unlined landfills
- Estimated 26 g PFAS per hectare annually at C&D landfills
    - At least 1,500 active C&D landfills in the US
    - No published estimate of C&D landfill leachate generation



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** 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



Innovative TECHNICAL SOLUTIONS

Major Findings

- Solid waste management strategies impact PFAS emissions
- Biological activity and the presence of biodegradable waste increases PFAS transformation, leaching
- In both C&D and MSW landfill leachates, PFOA has the highest ratio to its respective RSL
- MSWI ash contains less PFAS, but co-disposal with unburned waste results in disproportionately high leachate PFAS
- C&D landfills present a significant source of PFAS to the environment since PFAS concentrations are similar to MSW and many C&D landfills are not lined
- The majority of PFAS in landfills remains within the waste mass, indicating landfills will remain a source of PFAS for the long term


Questions?