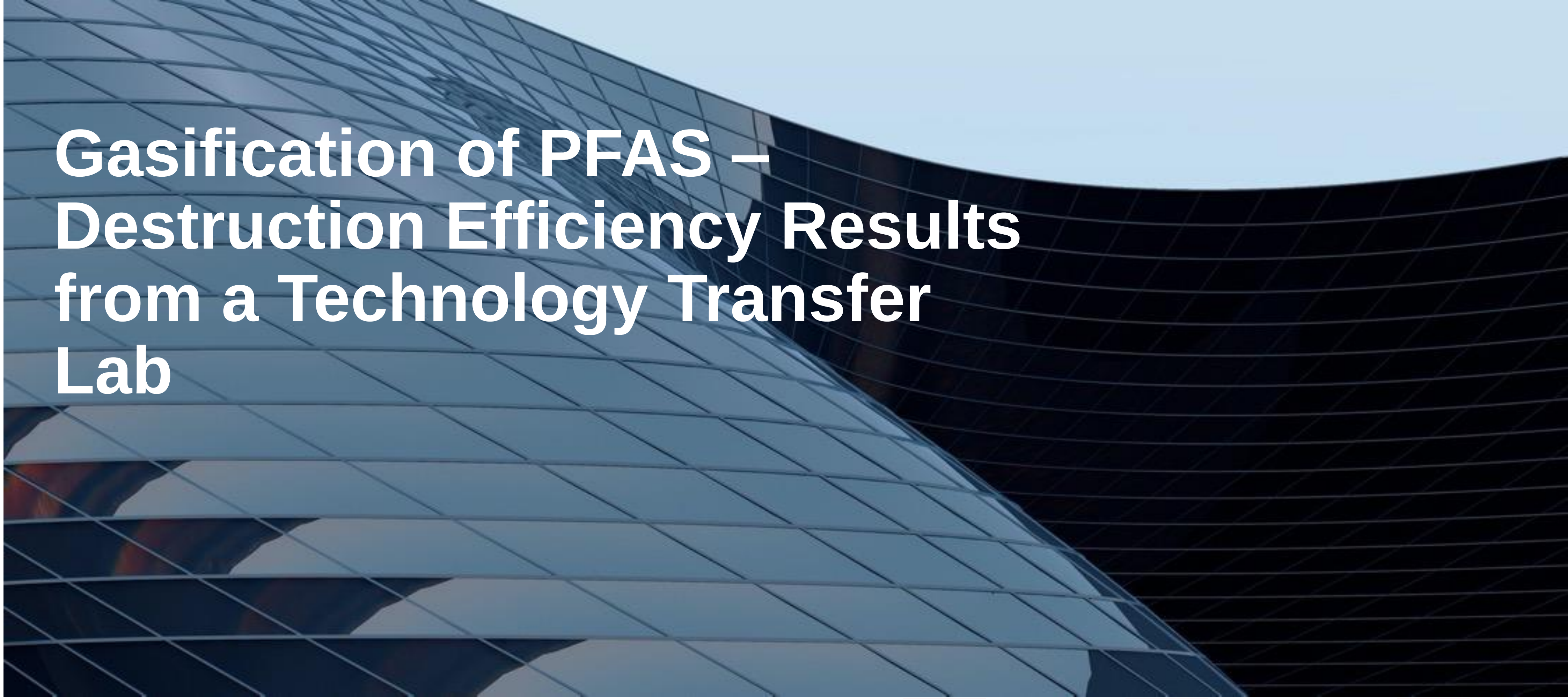


Gasification of PFAS – Destruction Efficiency Results from a Technology Transfer Lab

Bill Malyk, P.Eng.

Senior Principal Engineer
WSP Canada Inc.

October 17, 2024

wsp

Project Team

Organization	Lead Performer	Expected Contribution
WSP	Bill Malyk	Principal Investigator
	Justin Gal	Co-Performer
Matter Global Solutions, Inc.	Jay Zwierschke	Technical Advisor, Gasifier Design
University of Guelph	Professor Brandon Gilroyed	Technical Advisor, Gasifier Operation
NAVFAC-EXWC	John Kornuc	DoD Liaison, Technical Advisor, Sample Site Identification

Authors Bio

Bill Malyk
MEng, P.Eng.
Cambridge, ON, Canada

- Senior Principal Engineer and Global PFAS Water Treatment Lead
- 30 years of experience in industrial water treatment & 10 years with PFAS projects and applied R&D for PFAS.

Justin Gal, PE
VP Novi, MI
USA

- VP • Associate Engineer
- 20 years of experience in air, soil gas, groundwater and soil investigation and remediation. 12 years of experience with PFAS project, including several high-profile PFAS sites, (active landfills, former Air Force bases, and closed landfills)

Sean Gormley, VP
Portland, WA
USA

SVP • Principal Chemist

- +39 years of experience in contaminants related investigation and remediation & +17 years with PFAS investigation, fate and transport, and treatment/remediation techniques.

Dr. Brandon Gilroyed
Ridgetown, ON, Canada

- Anaerobic Digestion and Biofuel Research, Assistant Professor
- Interdisciplinary research using engineering principles and analytical chemistry,. The primary focus of his research group is the valorization of biomass and residues into bioenergy and bioproducts.

Destruction technologies

Field Implemented

- Incineration

Vendor Applications

- Electrochemical Oxidation (L)
- Supercritical water oxidation (L,S)
- Plasma (L)

Under Development

- Hydrothermal Alkaline (L, S)
- UV-Hydrated Electrons (L)
- Pyrolysis/gasification (L, S)
- Sonochemical (L)
- Mechanochemical (Ball-milling) (S)
- Biodegradation (L, S)
- Polar Aprotic Solvents (e.g., DMSO) (L, S)

L: liquid concentrate, such as AFFF, foam concentrate, regenerant waste stream, groundwater, landfill leachate
S: solid waste such as soil, spent media, biosolids. All have very limited case studies

Technical Background – Maturity

PITT - Technology Readiness Level and Research Needs:

PITT Introductory Paper on Four Innovative Technologies Studied

TRLs of Technology & PFAS Matrices

	Electrochemical Oxidation	SCWO	Mechanochemical degradation	Pyrolysis
Spent GAC / AEX	TRL 4[1] (GAC Only)	N/A[11]	TRL 2[9,11]	TRL 1[11]
Soils	TRL 1[2]	N/A[11]	TRL 5/6[9]	TRL 1[11]
Biosolids / Sludges	N/A[11]	TRL 6[5]	TRL 1[11]	TRL 7[10]
Spent and unused AFFF	TRL 4/6[1, 3]	TRL 7[5-8]	TRL 3/4[9]	N/A[11]
Landfill Leachate	TRL 4[4]	TRL 4[7]	N/A[11]	N/A[11]

Phase	TRL	Description
Research	1	Basic Principles observed
	2	Technology concept formulated
	3	Experimental proof of concept
Development	4	Technology validated in lab
	5	Technology validated in relevant environment
	6	Technology demonstrated in relevant environment
Deployment	7	System prototype demonstration in operational environment
	8	System complete and qualified
	9	Actual system proven in operational environment

https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels

EPA PITT BOSC Executive Committee Meeting – Findings on PFAS destruction Technologies (2021), Retrieved from PFAS THERMAL TREATMENT RESEARCH Technical Guidance for Destruction of PFAS Presented by the PFAS Innovative Treatment Team (PITT) (epa.gov)

Technical Background – Historical Gasification Uses and Applications

Typical inputs

Typical steam gasification reformation equations

Gasification with Steam

$$C + H_2O \longleftrightarrow CO + H_2$$

Water-Gas Shift

$$CO + H_2O \longleftrightarrow H_2 + CO_2$$

Methanation

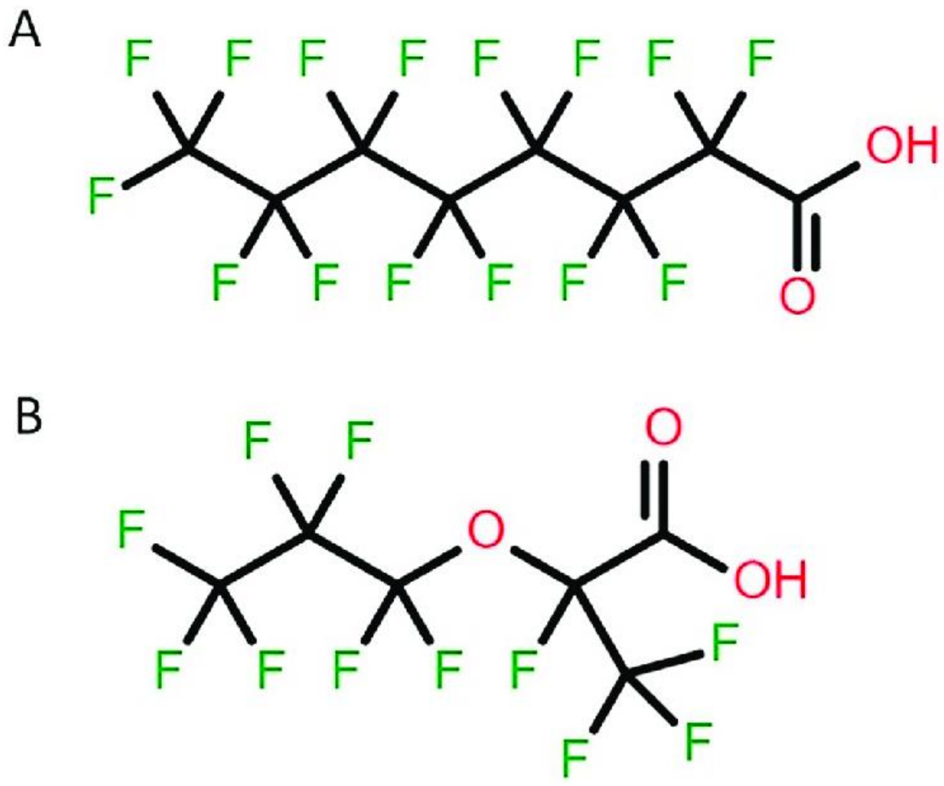
$$CO + 3H_2 \longleftrightarrow CH_4 + H_2O$$

Historical uses and typical benefits

- Low-level radioactive waste destruction.
- Converts biomass and municipal solid waste into clean syngas.
- Converts waste plastics into clean syngas to enable the low-cost production of electricity, high-value chemicals, hydrogen, and transportation fuels.
- Identified by DOE as new option for synthesizing liquid fuels from coal and coal blends.

Planning an attack

- We know the C-F bond is highly electronegative and difficult to break
- Strength of C:F bond requires higher temperatures and residence times (1,100°C @ min 2 seconds)
- Products of incomplete combustion (PICs) require further study (along with mass balance on F)
- HF is a hazardous air pollutant and highly corrosive
- Co-contaminants play a significant role in developing a treatment approach.



A – PFOA, B - GenX

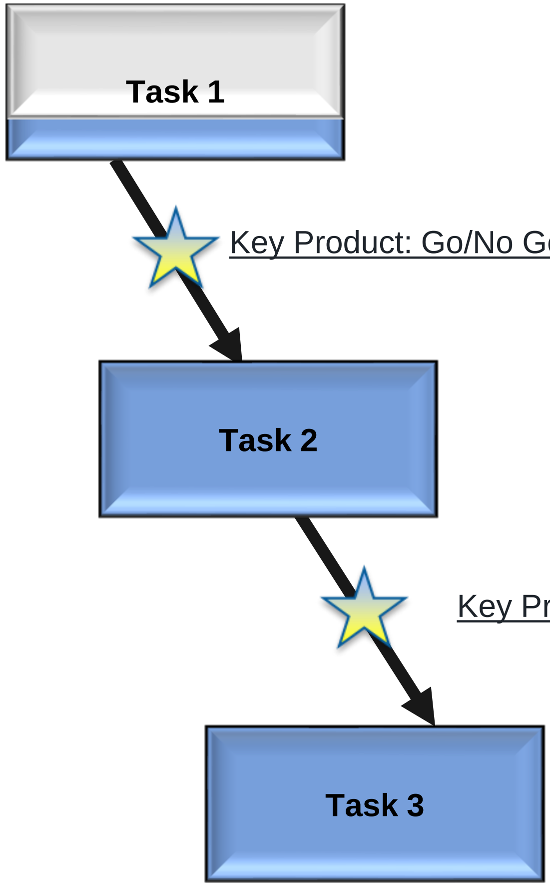
Project Technical Objective

- Evaluate the feasibility and effectiveness of gasification thermal treatment to achieve complete destruction of PFAS in spent treatment system media (GAC, organoclay, and/or AER) and/or AFFF concentrate

Bench Configuration and Go/No Go Testing

Technical Approach

☆ Go/no go decision point



- **Task 1:** Bench Configuration and Go/No Go Testing.
  - Select temperature, residence time, moisture content and any additives required
  - Demonstrate on spiked GAC for target PFAS

Key Product: Go/No Go Decision White Paper

- **Task2:** Collect Test Media and Bench Testing.
  - Spent media, source media, AFFF concentrate
  - Analyze for target and non-target PFAS, EOF, TOF, TICs, HF, Freons, CF_4

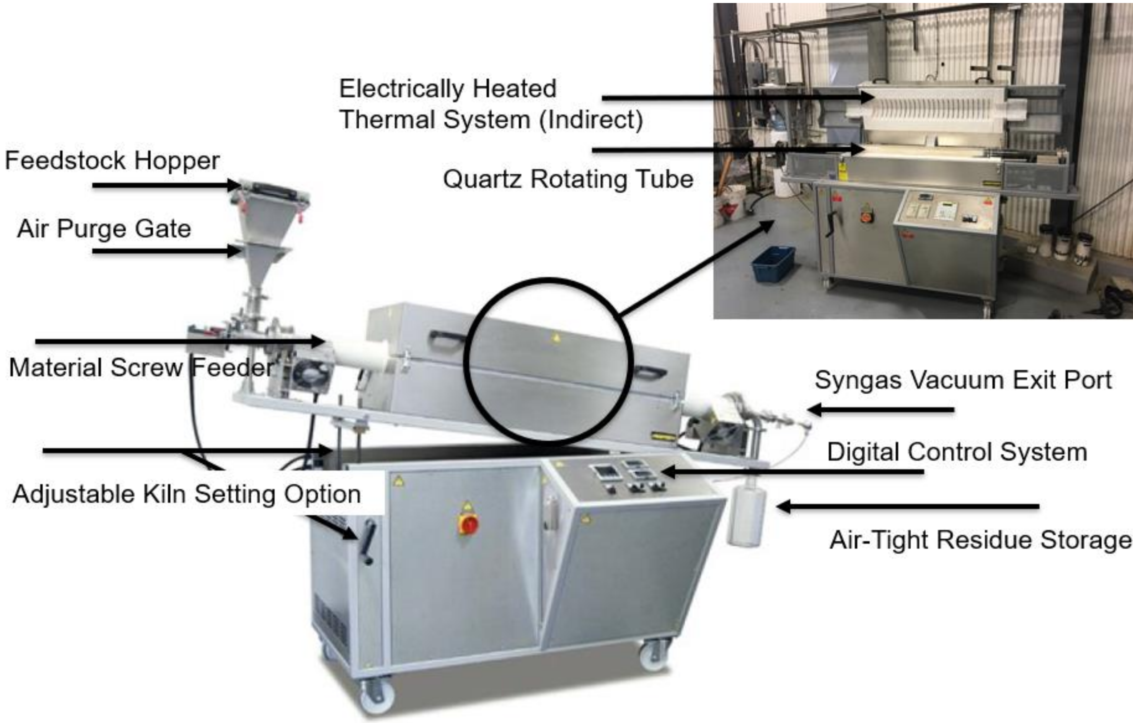
Key Product: Interim Technical Report

- **Task 3:** Syngas Testing and Data Analysis**.**

Key Product: Final Technical Report

Go/No Go Testing Plan

- Spiked GAC with known quantity of target PFAS
- Adjust gasification variables: temperature & residence time
- Modifications:
  - Pretest with unspiked media to calculate solids feed and discharge rates
  - Repaired the screw feed
  - Added hydrated lime to feed
  - Added nitrogen gas feed to hopper
  - Added H2S safety measures
  - Added procedures to maintain constant moisture and hydrated lime



Experimental Data Analysis Plan

- Utilize draft method 1633 for target PFAS analysis of solid phase samples
- Utilize OTM-45/LCMSMS for target PFAS analysis of syngas samples
- Modifications:
  - Replaced PFAS lab to comply with QSM 5.4 and improve OTM45 analysis
  - Added TOF analysis on solids feed and discharge
  - Added Ca and F- analysis on solids discharge
  - Added fixed gas analysis on syngas

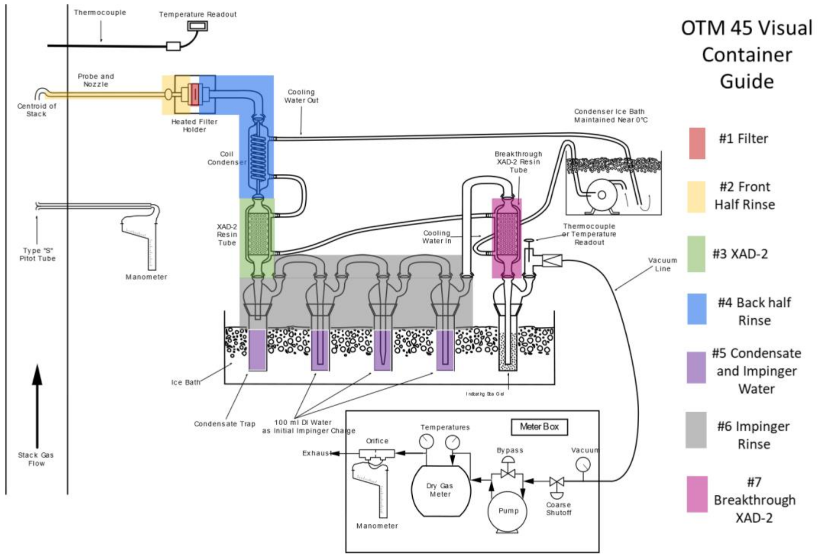


Figure OTM-45-1. Sampling Train

Results to Date – Summary

- Continuous flow bench system achieved a Destruction Efficiency (DE) > 99.99+% for spiked PFAS. Of that, only 0.0000% - 0.0567% measured in gas.
- Repeatability of DE% was observed for PFAS with higher spiked concentrations.
- Low total PFAS concentrations were observed at the gasifier outlet. PFAS gas discharged from the gasifier represents 0.0083% - 0.1565% of the total PFAS mass discharge from the system (gas + solids).
- May be a correlation between solids concentration of PFAS and gas retention time (rT). Several other parameters were monitored during testing, including temperature, oxygen and moisture content (MC).

Results to Date – Sample Summary

Trial Identification	Temperature (°C)	Feedstock Feed Rate (kg/hr)	Solids rT (minutes)	Gas rT (seconds)
TRIAL-1	1,100	High - 1.93	12	8.26
TRIAL-2	1,100	Medium - 0.96	12	11.19
TRIAL-3	1,100	Low - 0.46	12	17.18
TRIAL-4	1,000	High - 1.93	12	10.64
TRIAL-5	1,000	High - 1.93	12	11.0
TRIAL-6	1,000	High - 1.93	12	9.44
TRIAL-7	1,000	Medium - 0.96	12	17.05
TRIAL-8	1,000	Low - 0.46	12	27.20
TRIAL-9	900	High - 1.93	12	14.70
TRIAL-10	900	Medium - 0.96	12	26.00
TRIAL-11	900	Low - 0.46	12	28.30

Notes:

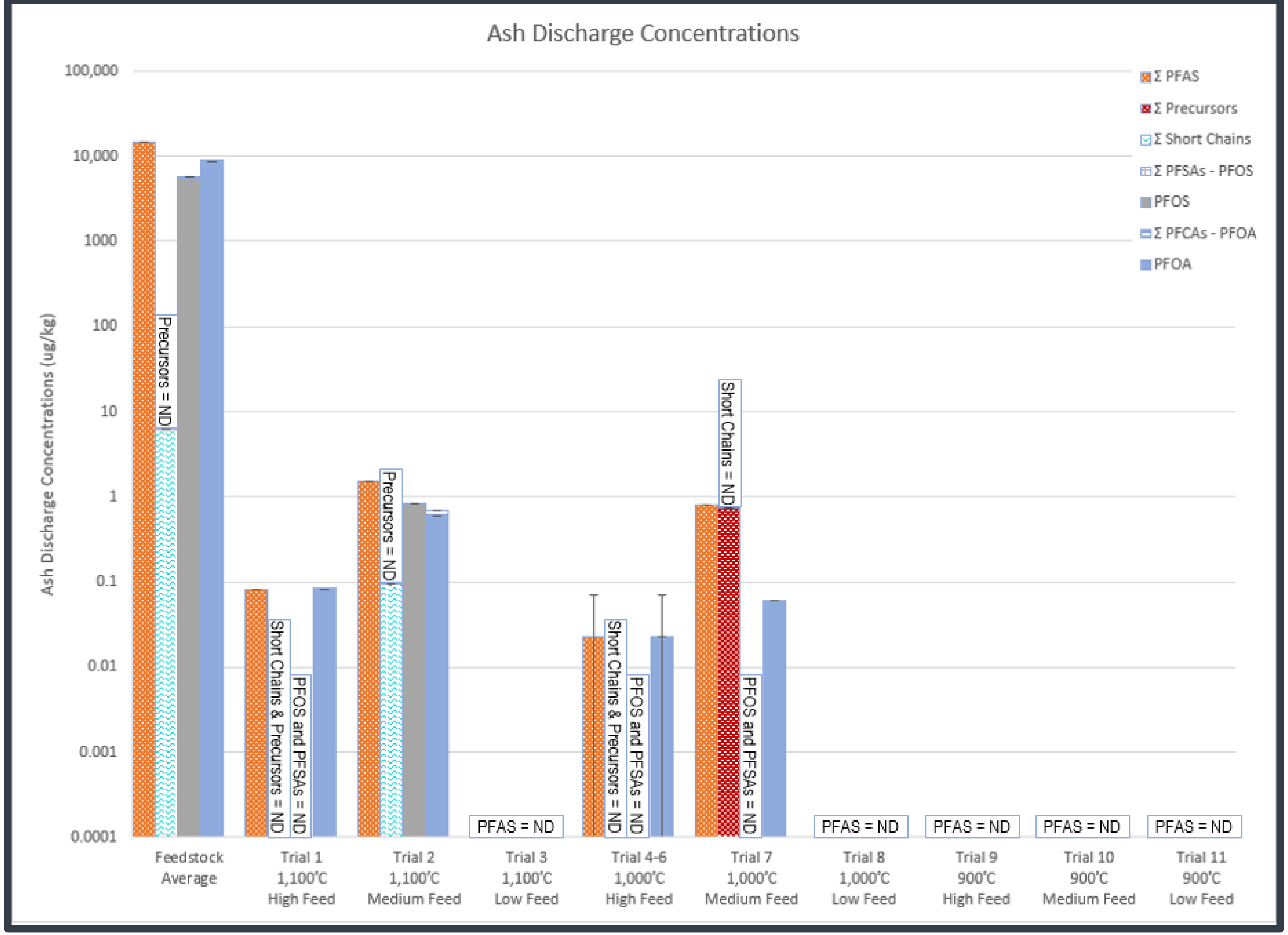
1. TRIAL-4, -5, and -6 were run as triplicate trials.
2. Three feed rates were selected to span available bench system settings.
3. Solid retention times were based on the heating tube tilt and rotation speed, which remained at constant settings.
4. Gas retention times varied based on feed and gas generation rates.

Abbreviations:

°C = degrees Celsius
kg/hr = kilograms per hour
rT = retention time

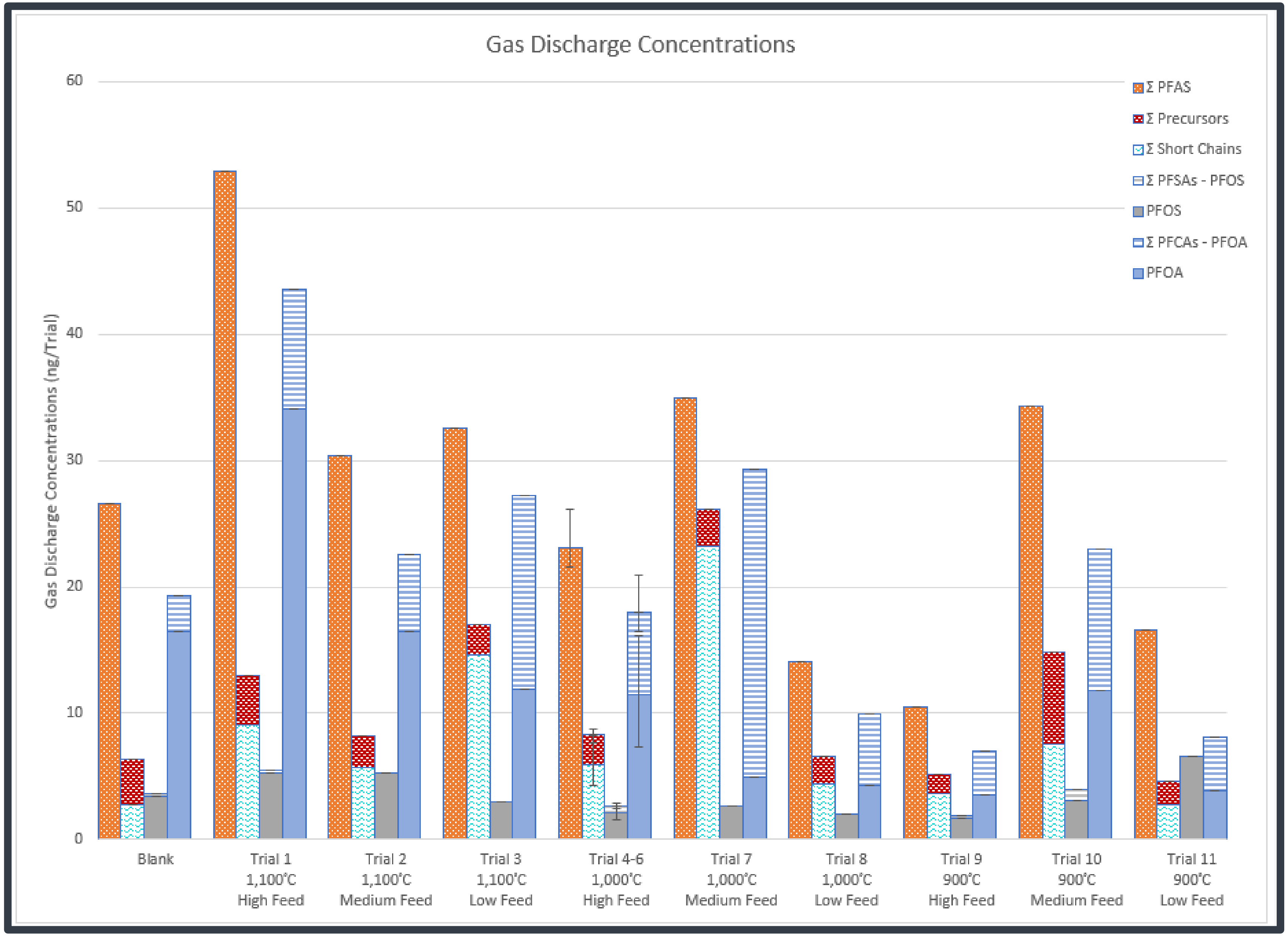
- Solid retention time less variable than gas retention time
- Measurable CH_4 generation, expect higher for higher organic content feed
- O_2 controlled

Results to Date – Solid Analysis



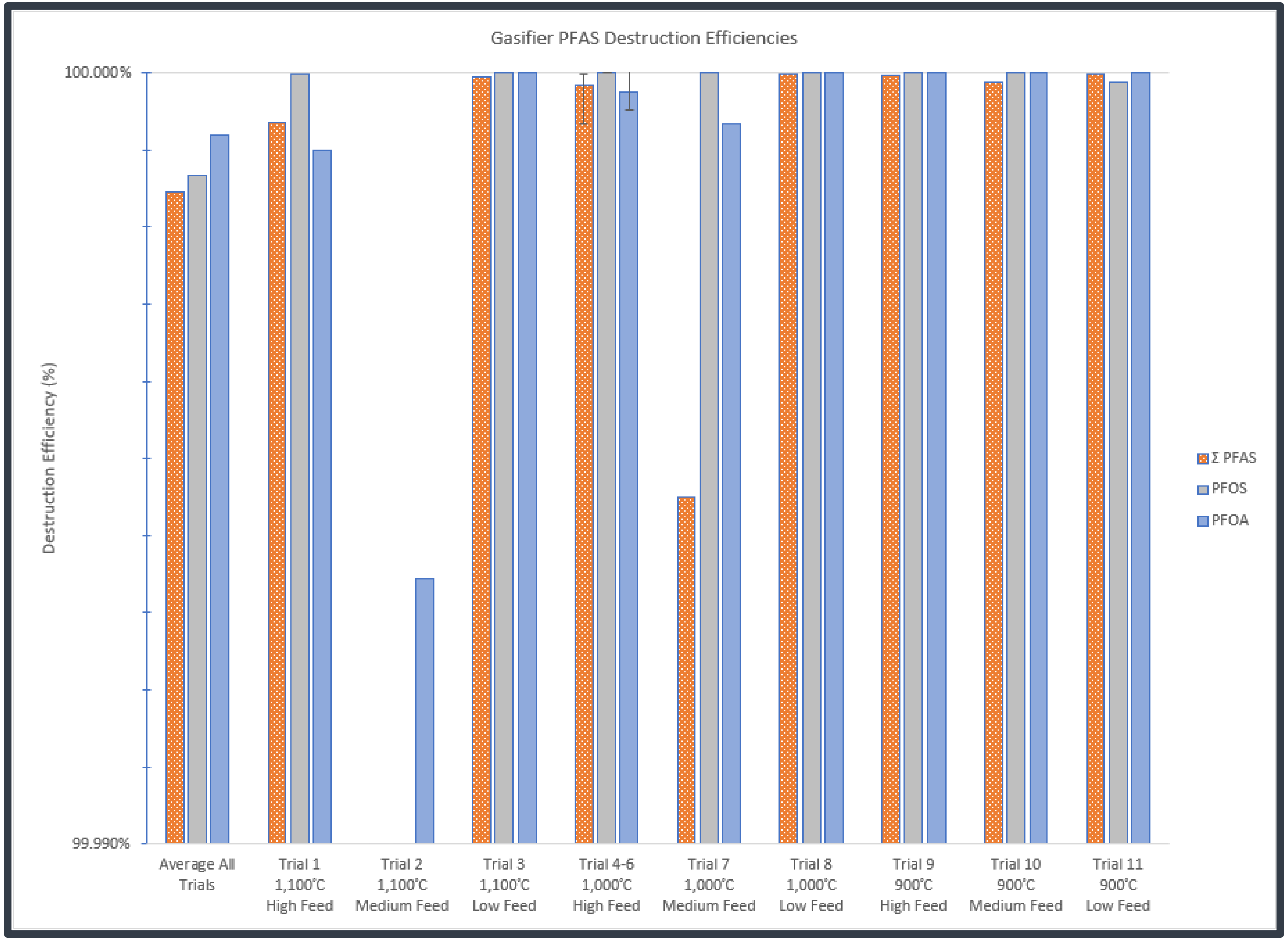
- Mass reduction of short chains relatively unchanged due to low input value
- Low concentrations exiting the gasifier (PFBS/A reported as DL)
- May be a correlation between solids concentration of PFAS and gas rT

Results to Date – PFAS Syngas



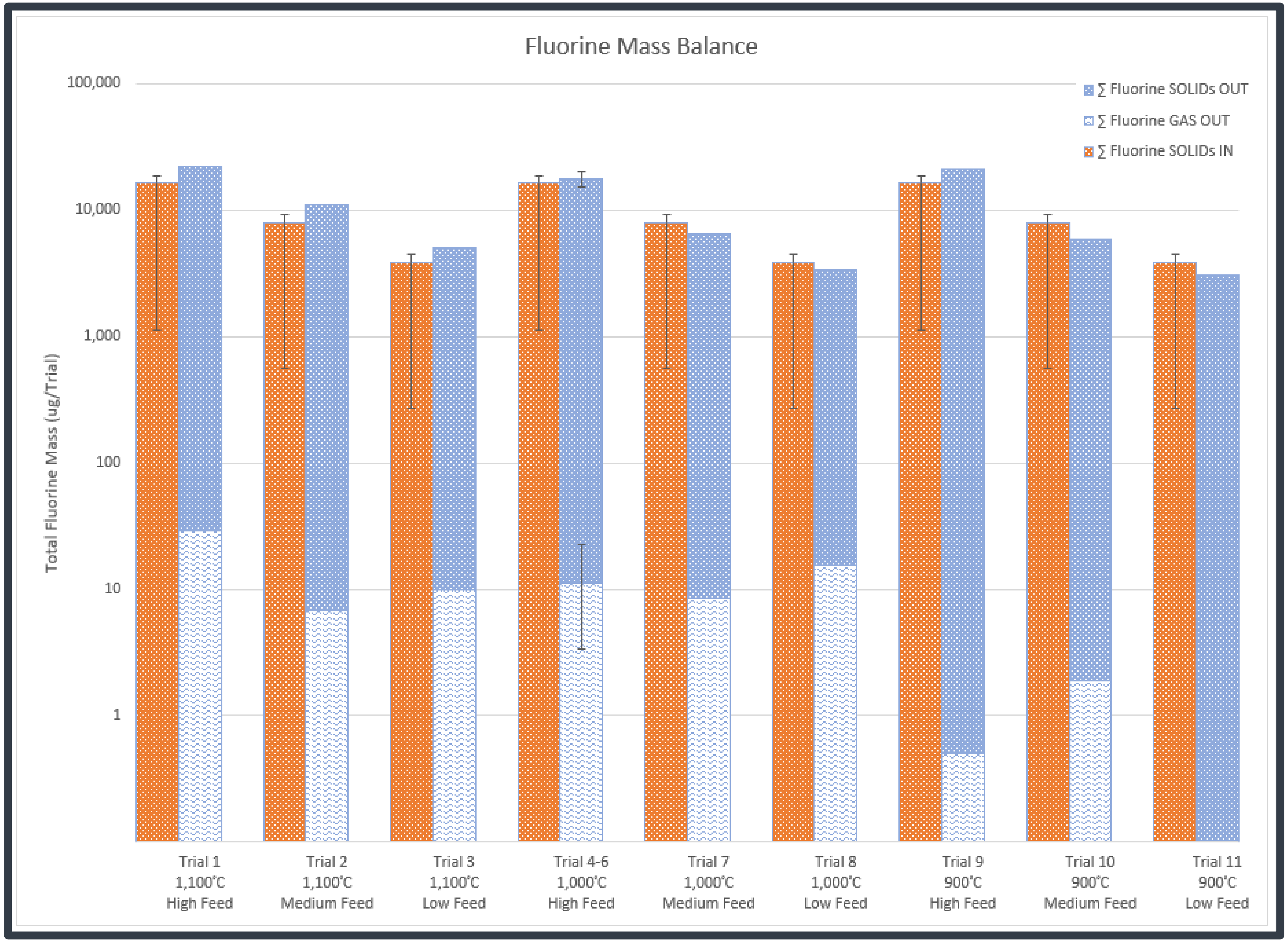
- Uncorrected results = gas sampling results (includes blank conc.)
- Corrected results = gas sampling results (subtracted max blank conc.)

Results to Date – Destruction Efficiency



- DE > 99.99+% for spiked PFAS
- Repeatability for PFAS with higher spiked concentration
- PFBS/A at Non-Detect concentrations at outlet (DE% based on MDL).

Results to Date – Fluorine Mass Balance



Key Points

- Continuous flow bench system was used as is intended for full scale application and for scaling for design – not designed for PFAS but technology is transferable for PFAS applications
- Compared to other PFAS destruction technologies, gasification appears effective and can process solids without pretreatment.
- For shorter chains, gas rT may be important as well as solid rT and/or temperature.
- For longer chains, lower temperatures meet DE% objectives
- Gas emissions of PFAS are low using this bench testing gasifier
- Water content and hydrated lime important add mixtures

Next Steps

- Collect and Test field impacted media
  - PFAS loaded GAC media
  - PFAS loaded ion exchange media
  - PFAS loaded organoclay media

  - Scheduled for Fall 2024

Wrap Up / Questions?

University of Guelph, Ridgetown Campus - Technology transfer and commercialization center for waste recovery, clean energy and technology development.

Steam Gasification Unit (picture provided by Matter Global Solutions)

Thank you

wsp.com