Success Stories from PFAS stack testing

Mark Petersen
ESAA Calgary PFAS Symposium

December 4, 2025

BARR

Current Developments

Barr has performed stack emission tests to evaluate the PFAS destruction and removal of the following technologies:

- Thermal oxidation
- Scrubbing/filtration
- Gasification/pyrolysis
- Plasma Arc
- Carbon filtration
- Municipal waste combustion
- Biosolids combustion
- Landfill gas combustion
- Subsurface thermal treatment
- SCWO (supercritical water oxidation)

PFAS Destruction: The Role of Gasification in Addressing Forever Chemicals in Biosolids

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The Biosolids Problem

Biosolids restrictions are driving up tipping fees

- Biosolids are the solid material recovered from the wastewater treatment process
- Over 1 million dry tons[1] of biosolids are produced everyday worldwide regardless of economic, environmental, or societal conditions
- Biosolids must be disposed of in a timely manner, and current options are under intense regulatory pressure
- As disposal options diminish cost of disposal is increasing

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Aries Clean Technologies' Biosolids Gasification Process and Output Results

0.76 g/hr of PFAS
in wet biosolids

25,000 lbs/hr

Thermal Energy

Recovered heat provides heat for the drying of incoming sludge

6 HEAT RECOVERY

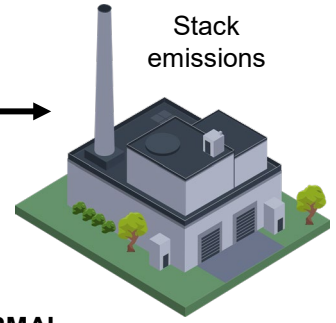
Emission control device

Exchanger 2

Exchanger 1

0.017g/hr of PFAS

Stack emissions



Flue Gas

Secondary step in PFAS destruction

5 THERMAL OXIDATION

1 DRYING

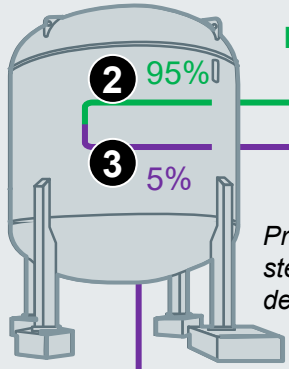
Sludge Storage bins

Dryer 1

Dryer 2

Dried **biosolids**

GASIFICATION



2 95%

3 5%

Producer Gas

Biochar

Primary step in PFAS destruction

Cyclone

Producer Gas

4

Condensate

0.0 g/hr of PFAS after further processing

0.0 g/hr of PFAS

4

PFAS destruction and removal efficiency (DRE) increases when condensate is treated or disposed of

Not treated	97.3%
Treated	**98.9%**

Calculations based on Run 3, which contained design efficiencies

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1 Wet biosolids are dried from ~18-22% solids to 90% solids in a 2-train drying system.

2 Biosolids are converted to molecules of methane, carbon monoxide, hydrogen, and other minor species to form a low energy producer gas.

3 Approximately 5% of the total volume after gasification remains as biochar, which consists of elemental carbon and ash and are separated through the top of the gasifier and captured in a cyclone.

5 Producer gas is combusted to create heating for the system.

6 Heat exchangers recover thermal energy from gasification process.

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Stack Emissions Highlights

Parameter Test Methods EPA 1-4, OTM 45 Test Date Compound	Gasifier Stack Run 1 Date Lb/hr	Flags	Run 2 Date	Flags	Run 3 Date Lb/hr	Flags	Average	Flags	Detection Limit
Perfluorobutanoic acid (PFBA)	**4.1E-06**	H	**3.6E-06**	H	< **1.8E-06**	J H	< **3.1E-06**	H J	DLL
Perfluoropentanoic acid (PFPeA)	**7.8E-06**	H	**5.6E-06**	H	**2.6E-06**	H	**5.3E-06**	H	ADL
Perfluorohexanoic acid (PFHxA)	**2.6E-05**	B H	**2.1E-05**	B H	**9.0E-06**	B H J	**1.9E-05**	B H J	ADL
Perfluoroheptanoic acid (PFHpA)	**3.3E-06**	B H	**2.2E-06**	B H	**1.1E-06**	J B H	**2.2E-06**	B H J	ADL
Perfluorooctanoic acid (PFOA)	**5.3E-06**	H J x	**5.0E-06**	H x	**1.9E-06**	H J x	**4.1E-06**	H J x	ADL
Perfluorononanoic acid (PFNA)	**1.6E-06**	H J x	**1.2E-06**	H J x	**5.1E-07**	J H x	**1.1E-06**	H J x	ADL
Perfluorodecanoic acid (PFDA)	**1.5E-06**	H J	**1.5E-06**	H J	**5.1E-07**	H	**1.2E-06**	H J	ADL
Perfluoroundecanoic acid (PFUnA)	< **3.3E-07**	J H	**3.4E-07**	H J	**1.1E-07**	J H	< **2.6E-07**	J H	DLL
Perfluorododecanoic acid (PFDoA)	< **1.7E-07**	H	**2.2E-07**	H J	**6.2E-08**	J H	< **1.5E-07**	H J	DLL
Perfluoro-3-methoxypropanoic acid (PFMPA)	< 6.3E-08	H	**2.1E-07**	J H	< **7.7E-08**	H J	< **1.2E-07**	H J	DLL

Note: " < " indicates one or more fractions contributing to the total results are below analytical minimum detection level (MDL)

Bold indicates result or sum of results includes fraction with mass above the analytical reporting limit (RL)

Detection Limit Flags

ADL = Above detection limit, where each fraction has detected amounts of a target compound (9.5.1 OTM-45)

BDL = Below detection limit, where all fractions were at or below the detection limit for a target compound (9.5.2 OTM-45)

DLL = Detection limit limited, where at least one of the fractions is below detection limit and at least one fraction is above the detection limit (9.5.3 OTM-45)

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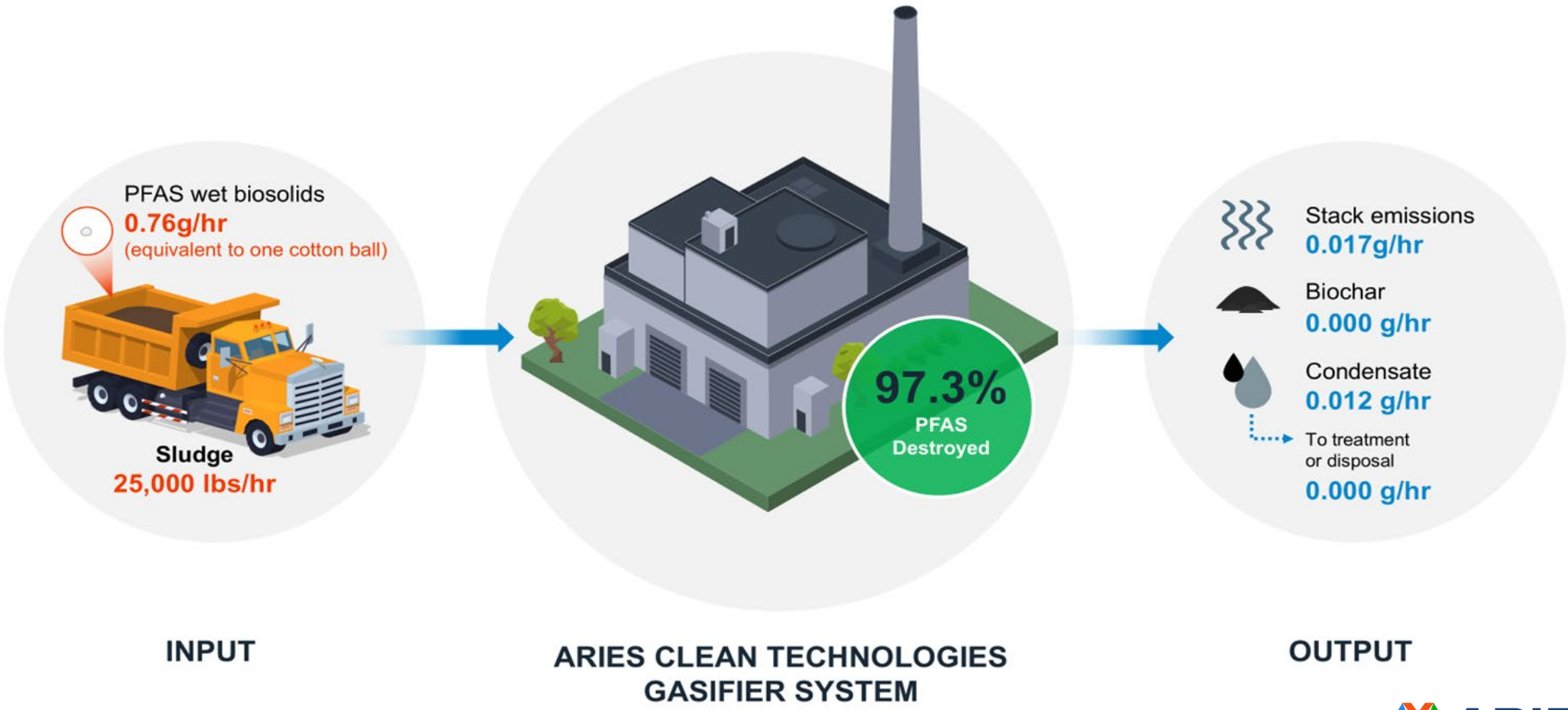
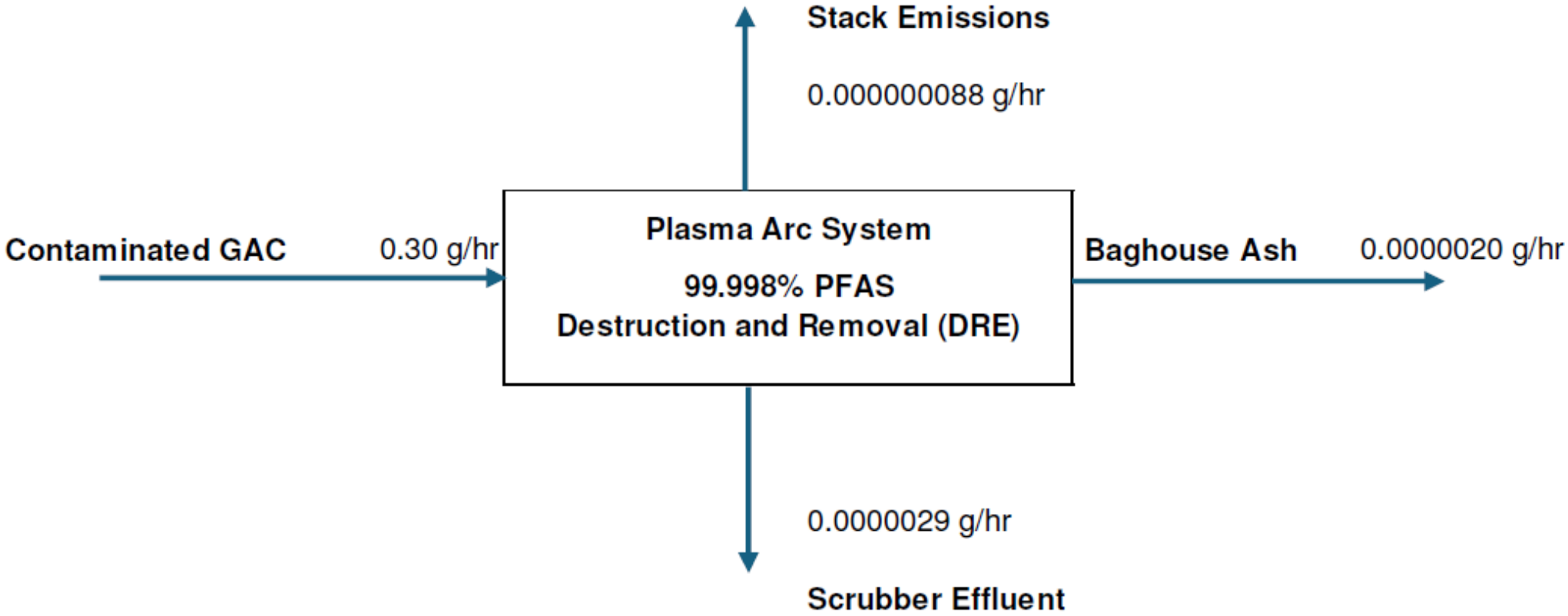
Mass Balance Results



Plasma Arc Furnace

Image Courtesy of InEnTec, Inc

PFAS Mass Balance and DRE – Plasma Arc Furnace



Total detected mass of analyzed PFAS compounds incorporated into this mass balance for each input and output stream

Detected PFAS compounds in stack emissions – Plasma Arc Furnace

Parameter Test Methods EPA 1-4, OTM 45	Run 1		Run 2		Run 3		Average		Flags	Detection Limit
Compound	Lb/hr	Flags	Lb/hr	Flags	Lb/hr	Flags				
Perfluorooctanoic acid (PFOA)	< 4.54409E-11	J x y	< 4.72381E-11	J x y	< 7.9152E-11	J x y	< 5.7E-11		J x y	DLL
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOS/	< 1.41947E-11	J	< 1.22646E-11		< 2.12372E-11		< 1.6E-11		J	DLL
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA)	< 2.19408E-10	x	< 2.1945E-10	x	< 3.98222E-10	J x	< 2.8E-10		x J	DLL

Reportable Qualifiers
Detection Limit Flags
DLL = Detection limit limited, where at least one of the fractions is below detection limit and at least one fraction is above the detection limit (9.5.3 OTM-45)
Project Analytical Flags
X = compound was above MDL in FMSB
Y = Proof Blank results is > 10% of total run compound mass
Lab Qualifiers
J = Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Municipal Waste Combustion

Minnesota Pollution Control Agency (MPCA)
- PFAS Blueprint
- PFAS Monitoring Plan

Three of five representative facilities were tested in fourth quarter 2024

Testing included PFAS analysis of residual ash

PFAS content of incoming waste developed from published values

MRRA represents passive receivers of PFAS including MSW combustors, municipal landfills, wastewater treatment plants and resource recovery facilities in Minnesota

MINNESOTA RESOURCE RECOVERY ASSOCIATION

PFAS Testing Results – Air Emissions

- Emission Rates: estimated emissions per year using measured PFAS emissions
- Emission Factor: used to estimate future annual emissions
- **Comparison: 64 grams/year of dioxin furans at one facility, less than 0.4% of permit limit**
- 15 of 49 PFAS compounds were detected with 8 PFAS compounds detected at all three

Facility	Emission Rate	Emission Factor
Facility 1	1.82 grams per year	145 micrograms per ton of MSW
Facility 2	4.37 grams per year	141 micrograms per ton of MSW
Facility 3	26.8 grams per year	147 micrograms per ton of MSW
Average	N/A	144 micrograms per ton of MSW

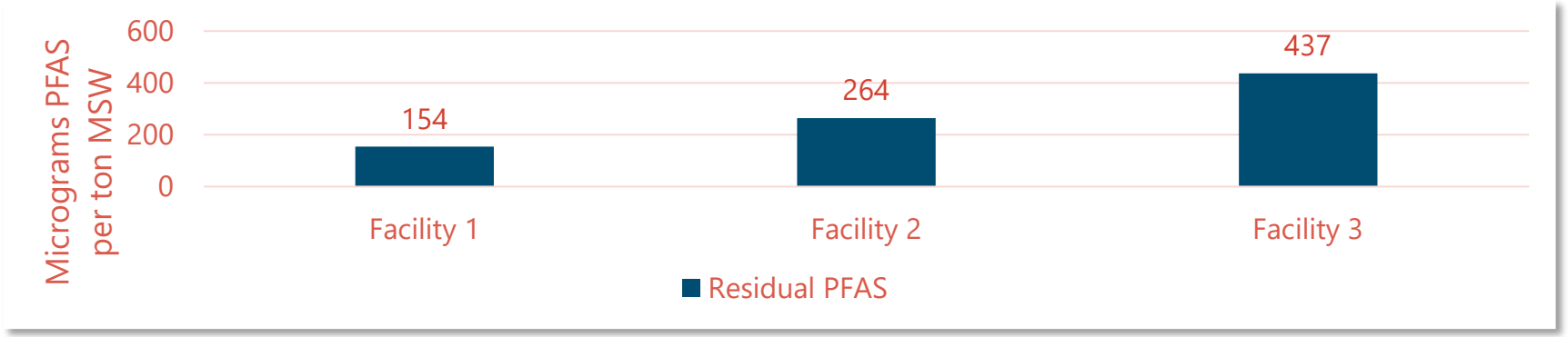
Source: Study of the Fate of PFAS through Resource Recovery Facilities, MRRA, 2025

PFAS Testing Results – Ash Samples

- Few PFAS compounds detected in ash samples
  - Maximum of 3 compounds at any one site

Mass Loading	Facility 1	Facility 2	Facility 3
Bottom Ash	0 grams per year	3.80 grams per year	51.7 grams per year
Fly Ash	0.1 grams per year	0 grams per year	1.3 grams per year

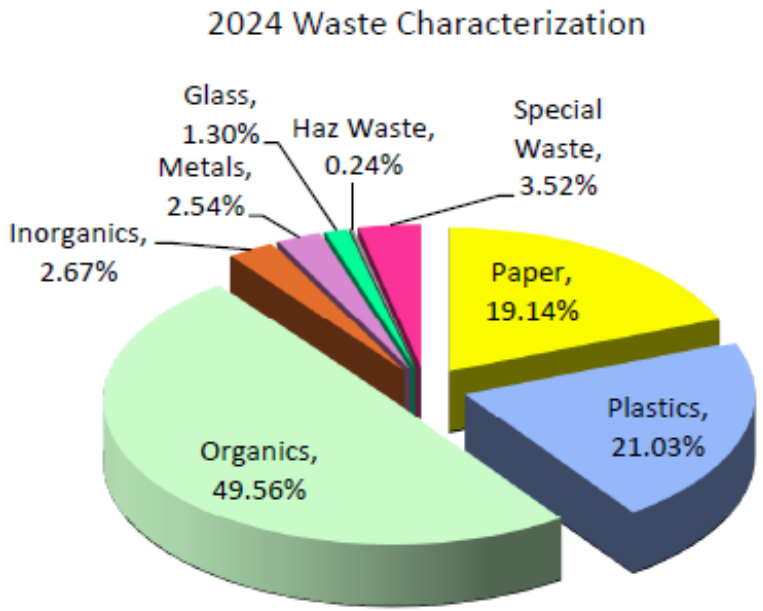
- Total Residual PFAS, expressed as micrograms (ug) per ton of MSW



Source: Study of the Fate of PFAS through Resource Recovery Facilities, MRRA, 2025

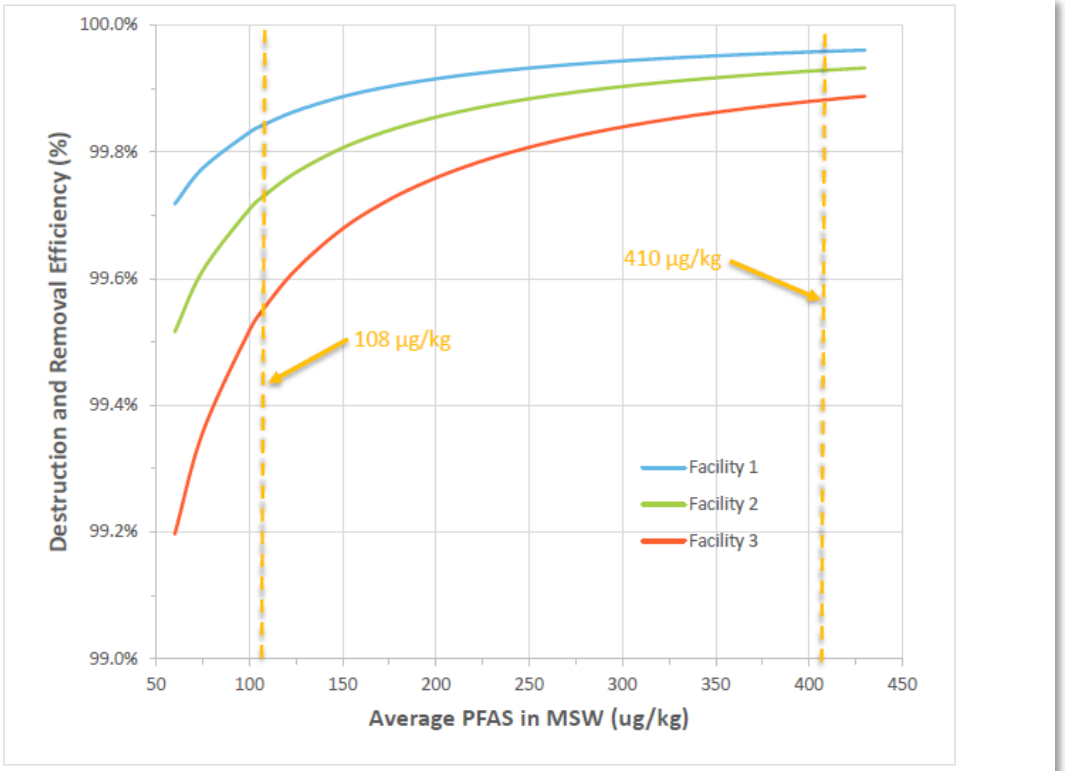
Additional Context – PFAS in MSW

- Literature Review – multiple academic sources
  - Varied waste composition
  - Estimated PFAS concentrations
- Combine these:
  - 50 – 300 micrograms PFAS/kilogram MSW
  - 108 – 410 micrograms PFAS/kilogram MSW



Destruction and Removal Efficiency (DRE)

- Overall, between **99.6% to 99.97% reduction** from fuel to residual



The estimated range of PFAS concentrations in MSW is 108 to 410 µg PFAS/ kg MSW.

Figure 2 **Calculated PFAS destruction efficiency as a function of the average PFAS concentration in the incoming MSW for the three sampled resource recovery facilities**

Source: Study of the Fate of PFAS through Resource Recovery Facilities, MRRA, 2025

Questions?

www.Barr.Com\PFAS

Mpetersen@Barr.com

or

Trussell@Barr.com