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

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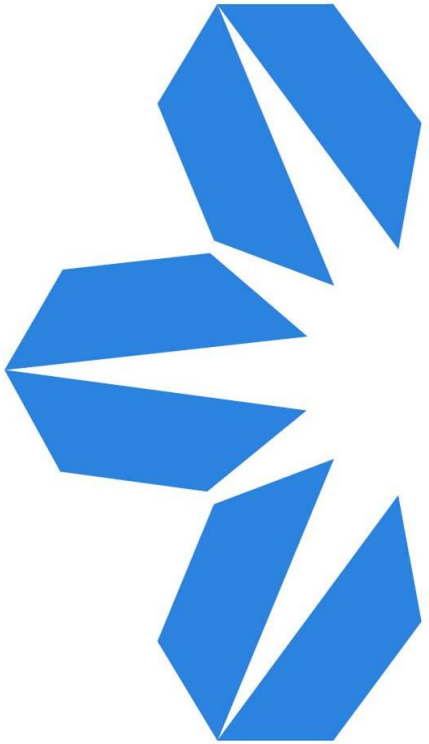
Content

What you can expect in this presentation

- Challenges in Biosolids Disposal and Treatment
- Gasification’s Role in PFAS Destruction
- PFAS Study Results



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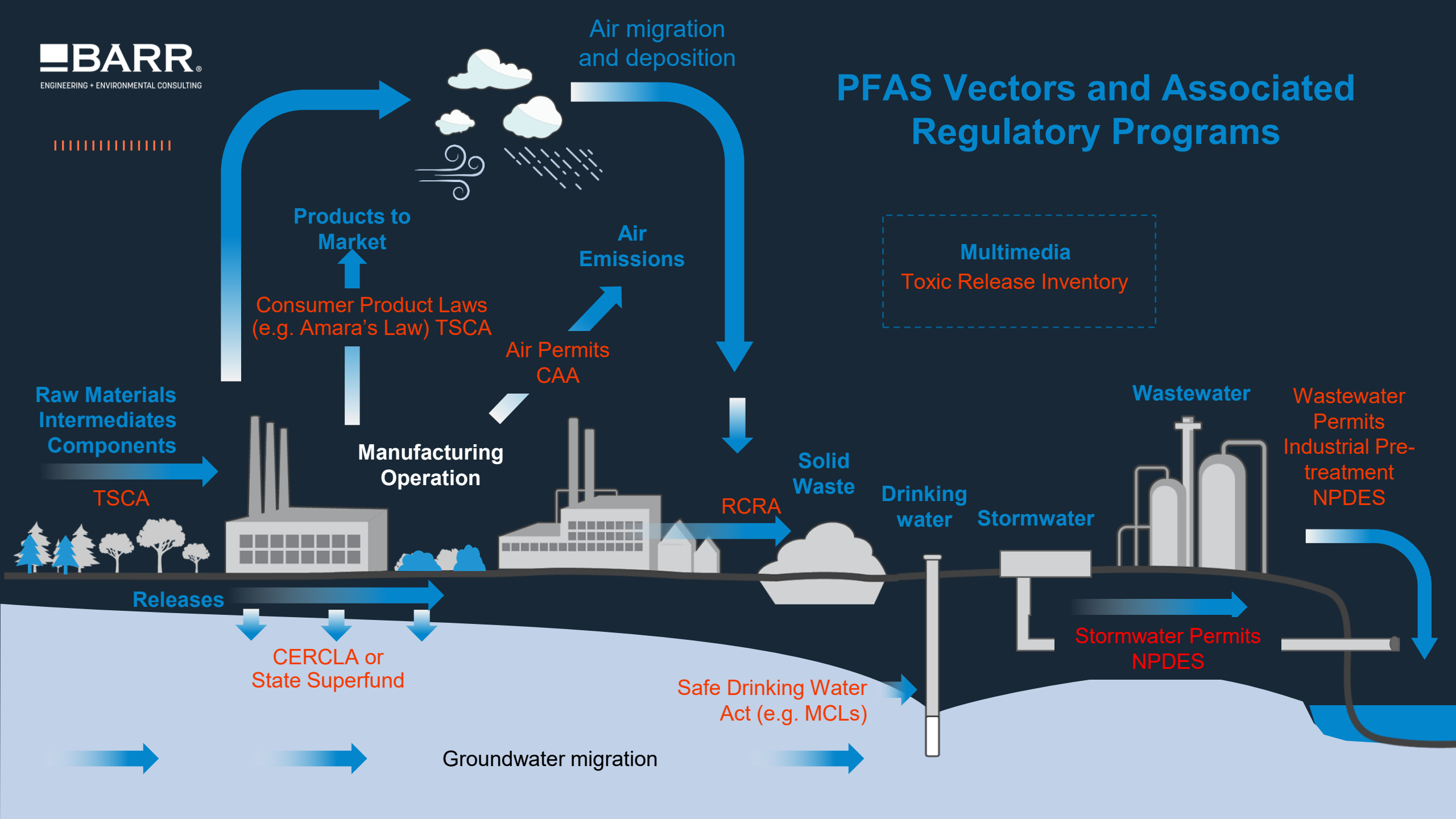
PFAS Vectors and Associated Regulatory Programs



Linden Biosolids Processing Facility

Aries Flagship Project

Overview

- ✓ Located < 20 miles from mid-town Manhattan
- ✓ ~30 skilled, full-time employees
- ✓ Thermal energy produced accounts for 100% of thermal needs offsetting natural gas use
- ✓ No combustion due to controlled oxygen
- ✓ Gasifier and dryer have achieved integrated operations
- ✓ Thousands of tons of cake processed

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CHALLENGES IN BIOSOLIDS DISPOSAL AND TREATMENT

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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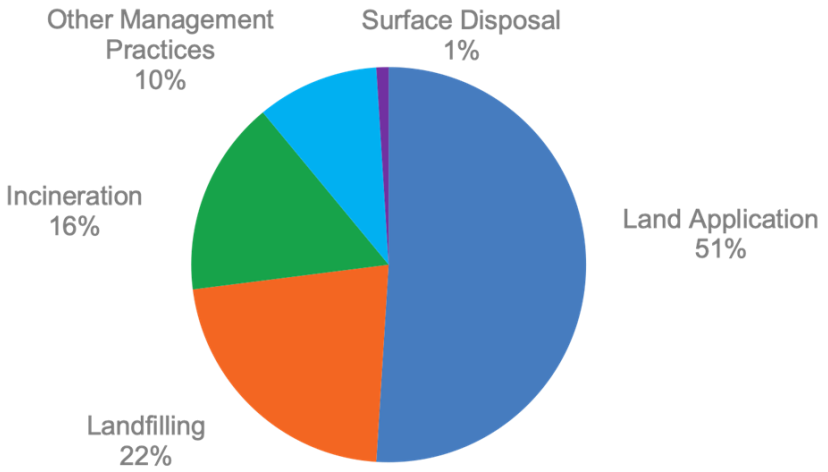
Current Biosolids Disposal Methods

Biosolids restrictions mean disposal options are rapidly diminishing

- Ocean dumping was banned in 1988, leading to landfilling, incineration, and land application as disposal options
- Landfills disposal of biosolids is decreasing due to capacity restrictions, land availability, and public opposition
- Incineration is becoming less prevalent due to stricter environmental regulations
- Land application is being restricted and increasingly regulated as due to contamination from PFAS and other chemicals of concern



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Biosolids and PFAS

PFAS concerns are gaining mainstream attention

npr

Sewage often becomes fertilizer, but the issue is it's tainted with PFAS

POLITICO

Farmers sue EPA over 'forever chemicals' in fertilizer

CNN

'They told us that this material would be safe.' Toxic PFAS discovered on US farms

Bloomberg Law

PFAS in Sewage Sludge, Industrial Wastewater Targeted for Rules

The New York Times

Sludge Contaminated 10,000 Acres of Farmland. What Should Be Done?

For years a textile mill gave farmers its sewage sludge as free fertilizer. Today the land is full of "forever chemicals."

The Guardian

Legal action could end use of toxic sewage sludge on US crops as fertilizer

THE TEXAS TRIBUNE

Texas farmers say sewage-based fertilizer tainted with "forever chemicals" poisoned their land and killed their livestock

THE WALL STREET JOURNAL.

New York City's Sewage Shipment Runs Afoul in Rural South

Alabamans want human-waste deliveries to local landfill to stop; 'We didn't produce it. We don't want it here.'

U.S. News & World Report

Sewer Sludge Is Dangerous to Health, EPA Says of Biosolids and PFAS

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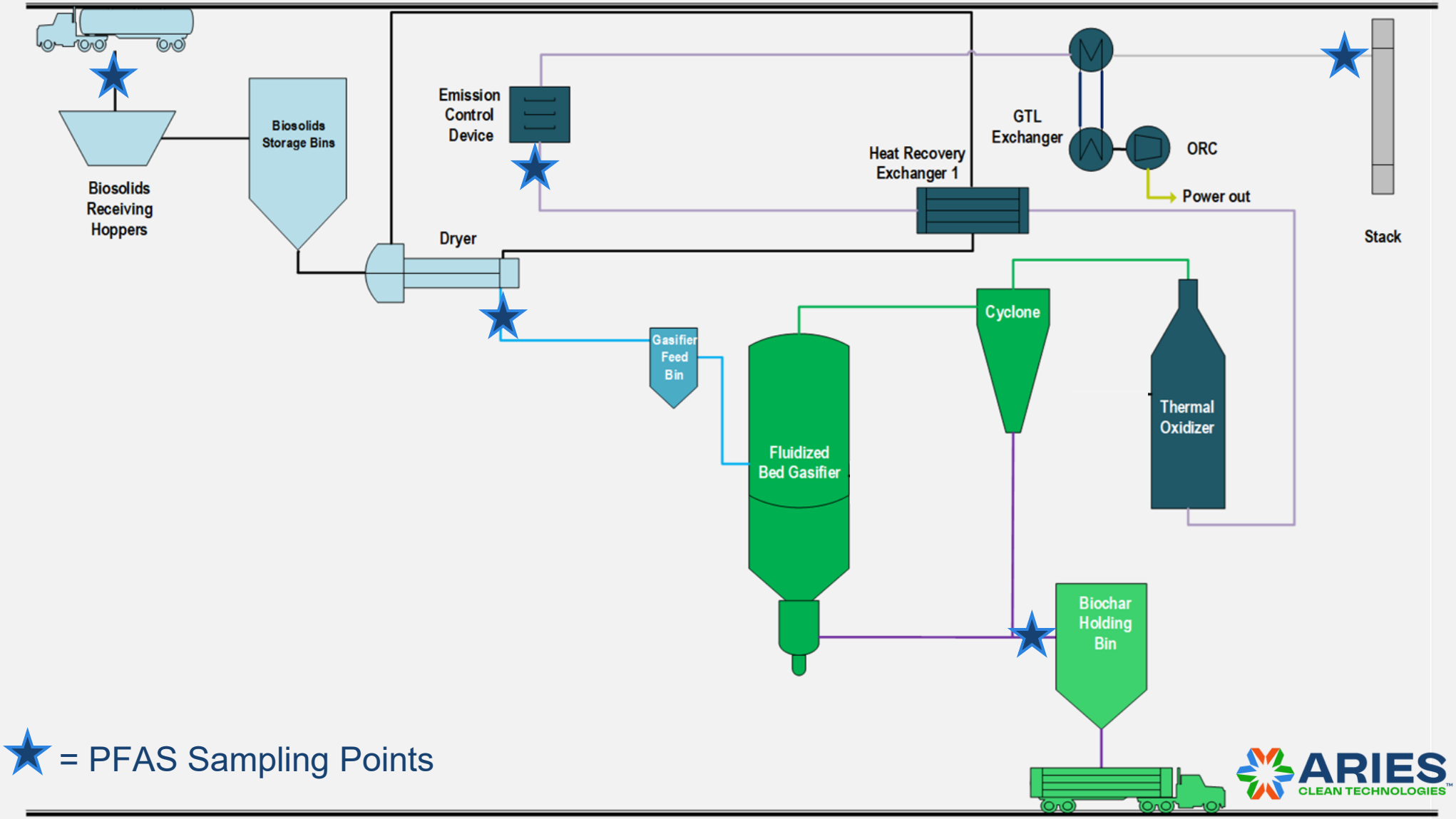
GASIFICATION'S ROLE IN PFAS DESTRUCTION

Aries Process Flow Diagram



★ = PFAS Sampling Points

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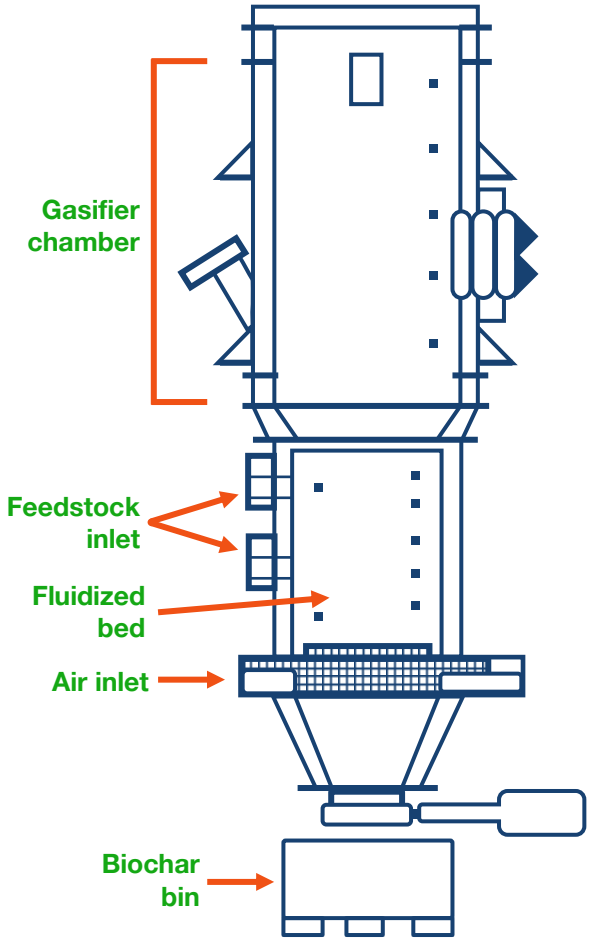
Patented fluidized bed gasification technology

Fluidized bed gasifier



Gasifier benefits

Patented technology

System can cleanly reduce biosolids by as much as 95% through **a proprietary patented** thermo-chemical process

Beneficial byproducts

Clean energy syngas, a synthetic fuel gas for industrial use and **Bio-Fly-Ash,** which has industrial and manufactured product applications

Financial benefits

Energy production is used to **offset current costs**, as well as adding additional monetary value of using renewable power

Sustainability benefits

Reducing carbon footprints through achieving zero landfill and/or land application goals for industry and municipalities

Key patent information

Aries gasifier is protected by US patents governing both the downdraft and fluidized bed gasification technologies

Patents were filed under the Patent Cooperation Treaty and have global reach

Most patents expire in 2033 but can be extended adding claims under methods

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PFAS Destruction via Gasification

Aries patented process operates at temperatures high enough to break down PFAS

Drying Unit (200°F)

- Removes excess moisture from biosolids and prepares the biosolids for gasification
- Product leaves dryers at around 10% moisture content

Gasifier (1250°F)

- Liberates and decomposes PFAS compounds with stronger chemical bonds from biosolids at 1,250F
- By-products are syngas and biochar

Thermal Oxidizer (1800°F)

- Decomposes PFAS remaining in syngas thermally at 1800°F
- Residence time at temperature is approximately 2 seconds

Emissions Control System (700°F)

- Emissions control system used as a final polishing step for flue gas
- Reduces criteria pollutants below minor source thresholds

PFAS Destruction

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Aries Greenhouse Gas Reductions

Lifecycle Analysis shows GHG reduction of up to 88% vs other disposal methods

13 CLIMATE ACTION

Substantial GHG reduction

Aries's disposal option minimizes truck traffic and associated emissions by up to 88% compared to sending biosolids to a landfill, land application, or incineration

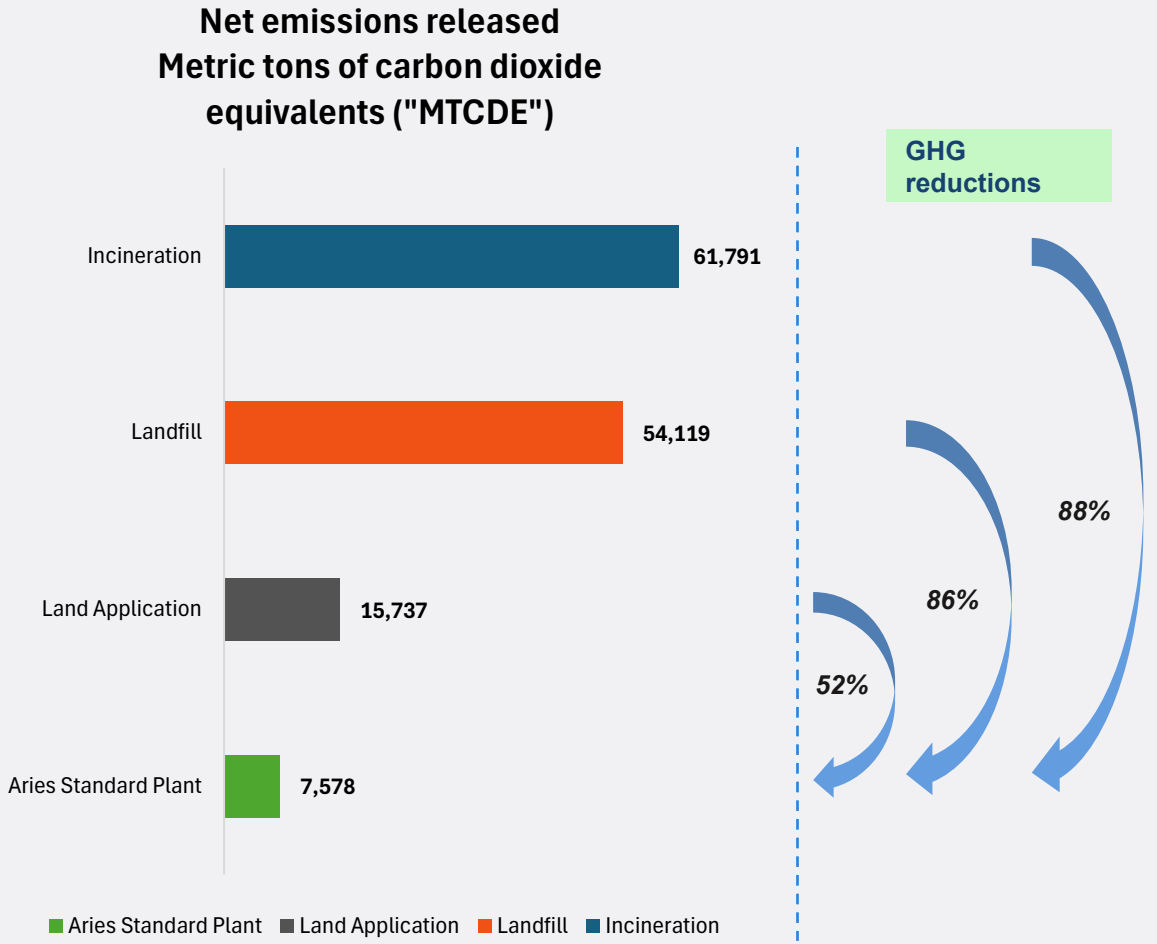
Stantec, a carbon accounting firm was engaged by Aries to quantify annual greenhouse gas emissions from an Aries facility

GHG inventories were produced in an excel-based calculator specifically focused on wastewater & solids management emissions

This analysis illustrates that Aries produces significantly less emissions than if biosolids were disposed by any other method

Analysis showed that Aries standard plant design has a GHG footprint:

- **88% less** than a biosolids incineration plant of the same size
- **86% less** than transportation and disposal of the same amount of biosolids in a landfill
- **52% less** than drying the same amount of biosolids and land applying them as fertilizer



PFAS STUDY RESULTS

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Third-party study lead

- Aries hired Barr as a third-party independent resource
- Study design included sampling of incoming biosolids, dryer condensate, biochar, APCD sorbent and stack emissions
- Barr followed EPA stack test method OTM-45 and Barr PFAS sampling protocols and SOPs
- Barr arranged to have the input and output process samples analyzed by Eurofins in Lancaster, PA and to have the stack samples analyzed by Eurofins in Knoxville, TN
- Barr conducted a thorough QA/QC review and data validation
- Barr conducted mass balance calculations
- Barr authored the study report

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Barr Engineering Company

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 Lb/hr	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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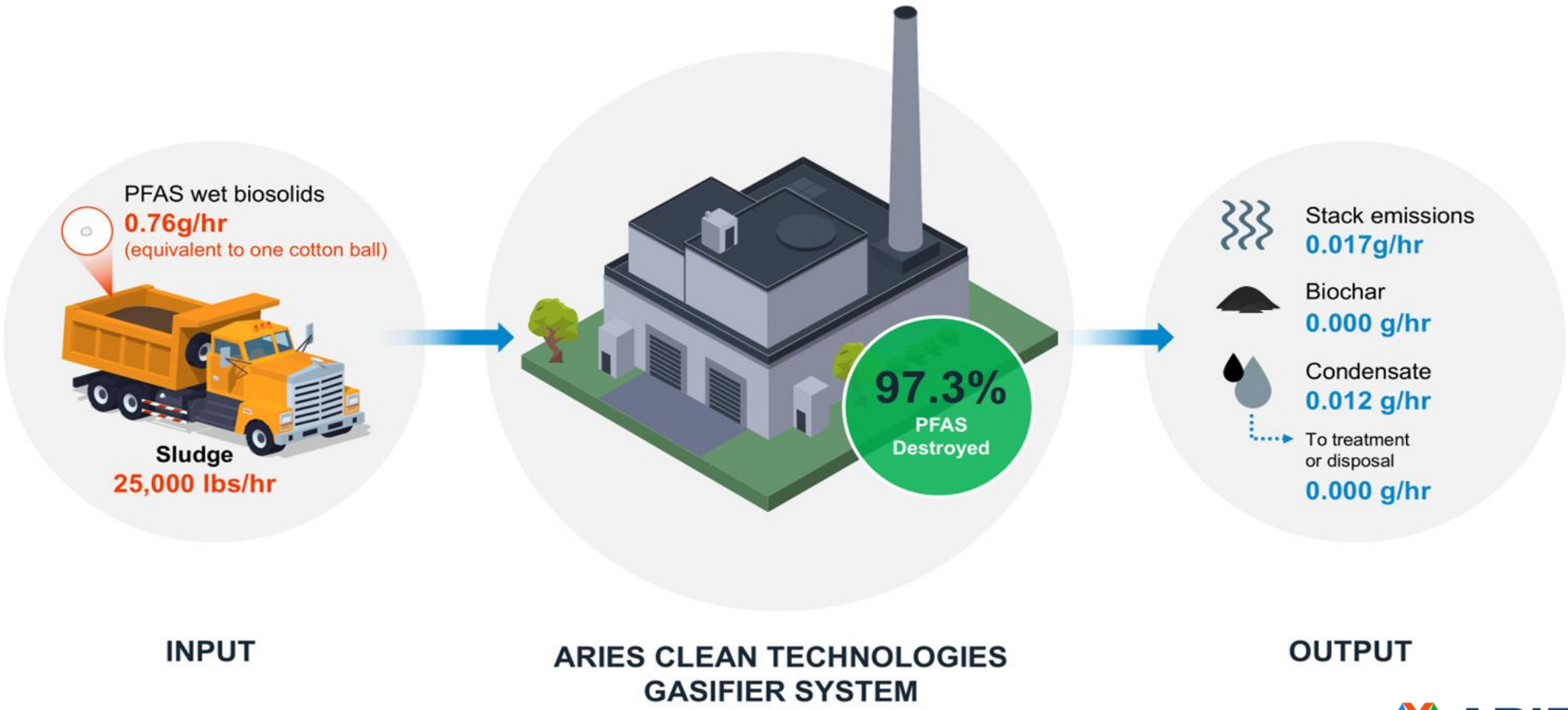
Mass Balance Results



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

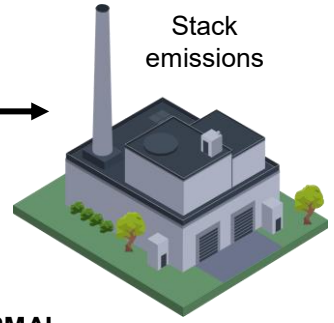
Emission control device

Exchanger 2

Exchanger 1

0.017g/hr of PFAS

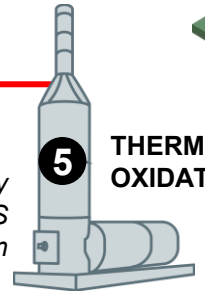
Stack emissions



Flue Gas

5 THERMAL OXIDATION

Secondary step in PFAS destruction



1 DRYING

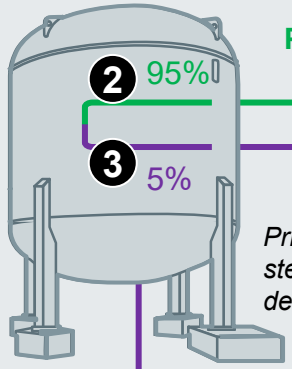
Sludge Storage bins

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.

Current Developments

Focus on evaluation of technologies to destroy or remove PFAS from air streams treating a variety of environmental media (gases, liquids and solids)

Barr has performed stack emission tests to evaluate 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)

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