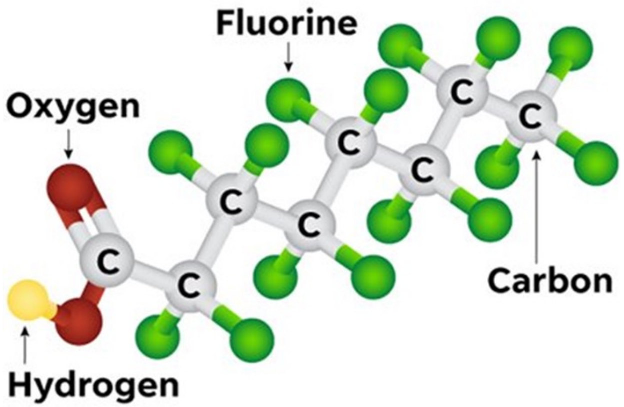
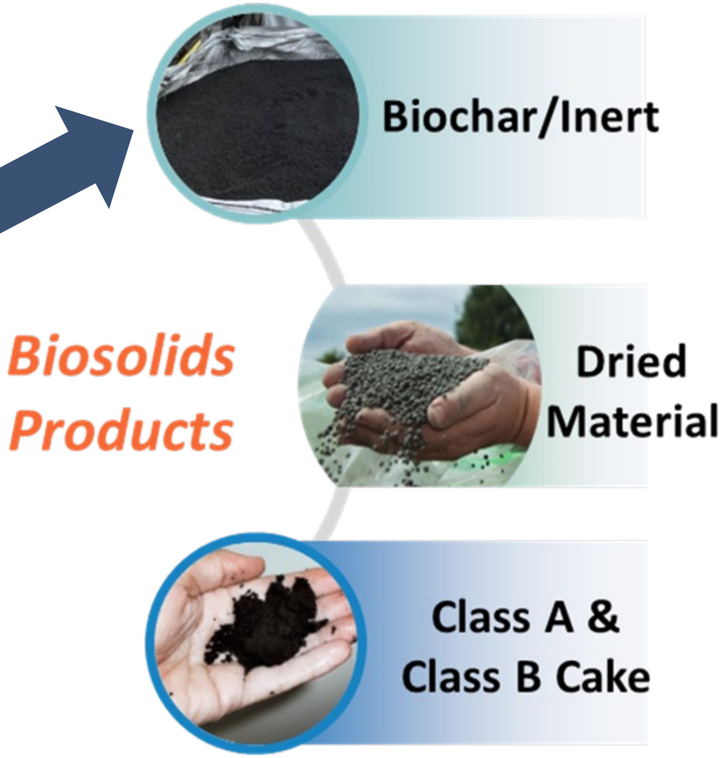
Hazen





NEWEA
WORKING FOR WATER QUALITY

Technology Demonstration and Cost Analysis for PFAS Destruction in Biosolids

January 22, 2024

Agenda

- PFAS (in) 101 (seconds)
- PFAS Regulations
- Destruction?
  - SCWO
  - Pyrolysis/ Gasification
- Demonstration AirSCWO-6 At Orange County Sanitation District, CA
- Understanding Pyrolysis for PFAS Removal (WRF #5107)
- Minnesota Pollution Control Agency (MPCA) Analysis of Alternatives for PFAS
- Conclusions

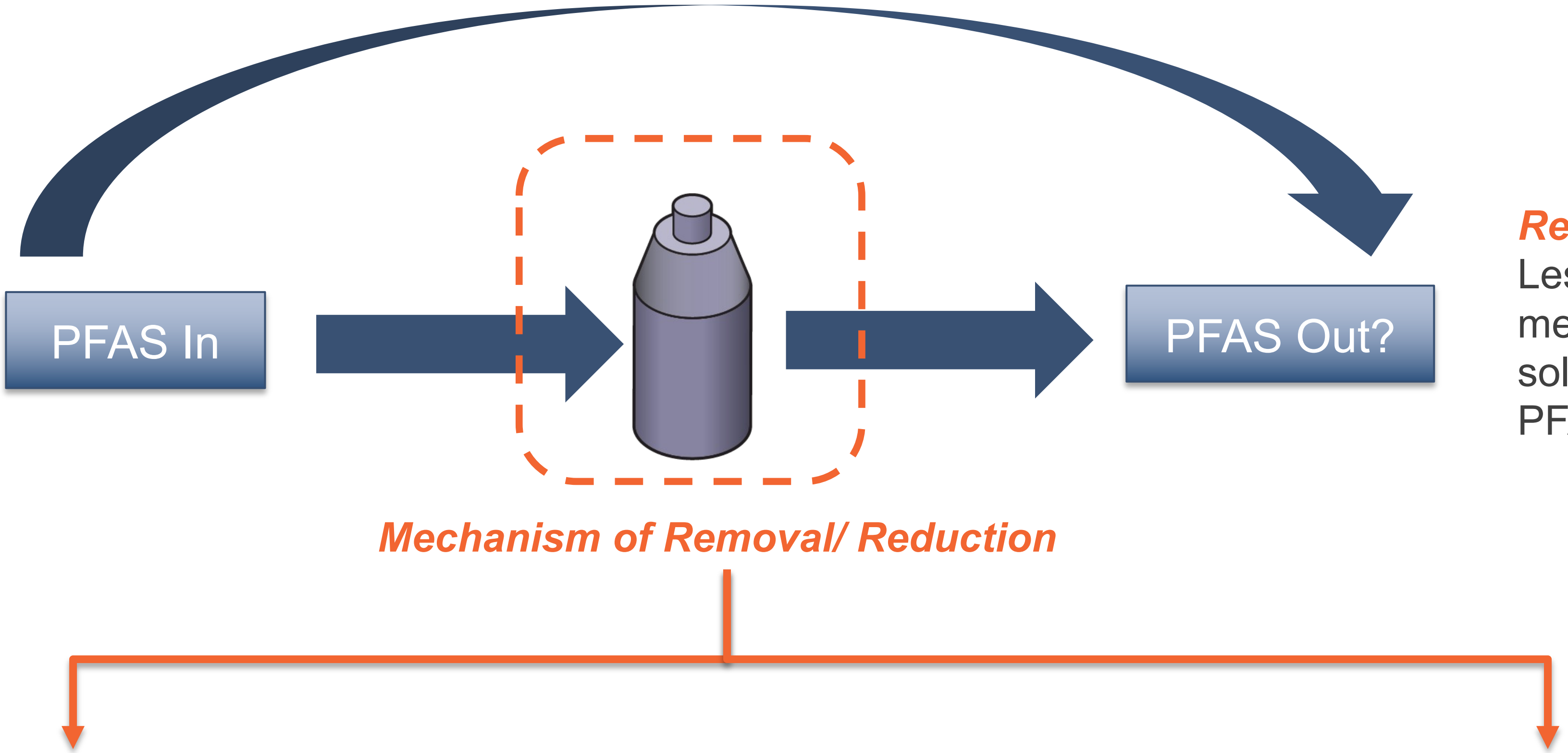
OC SAN ORANGE COUNTY SANITATION DISTRICT

THE Water Research FOUNDATION

MINNESOTA POLLUTION CONTROL AGENCY

PFAS Removal?

Removal vs Transformation vs Destruction



Removal/ Reduction: Less PFAS in original medium (ie aqueous solution containing PFAS through GAC)

Transformation: Fluorinated compound different than original compound (ie shorter chains)

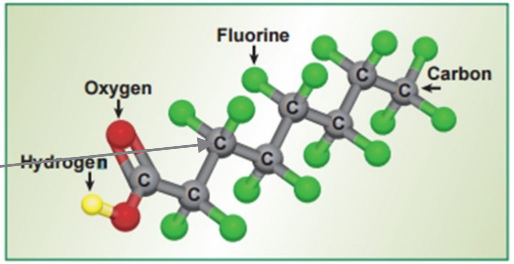
Destruction: All C-F bonds are broken

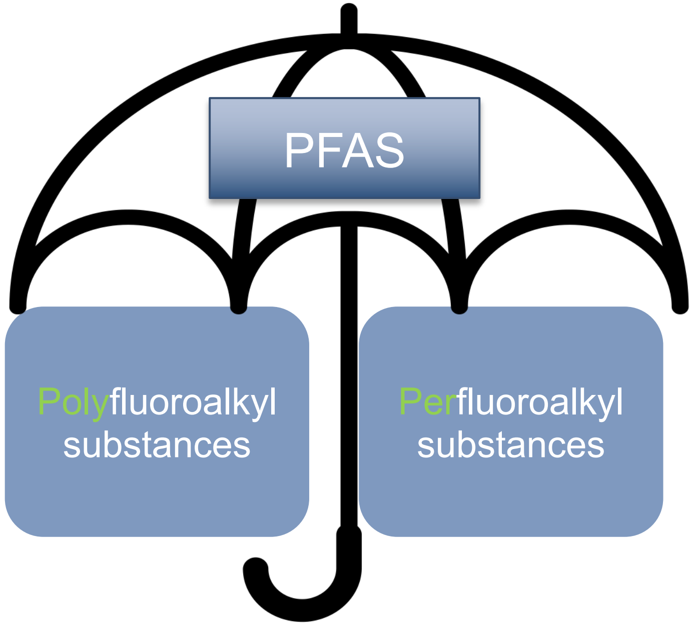
PFAS 101

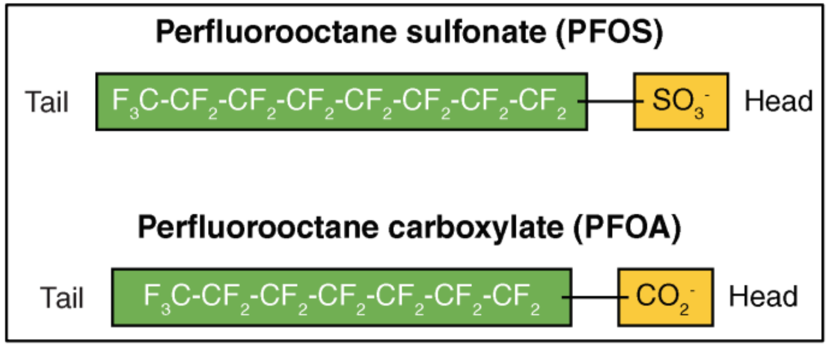
The (expanding) world of PFAS compounds

Over 8,000+ compounds (ECHA, 2020)

PFAS: At least one Fluorine – Carbon bond

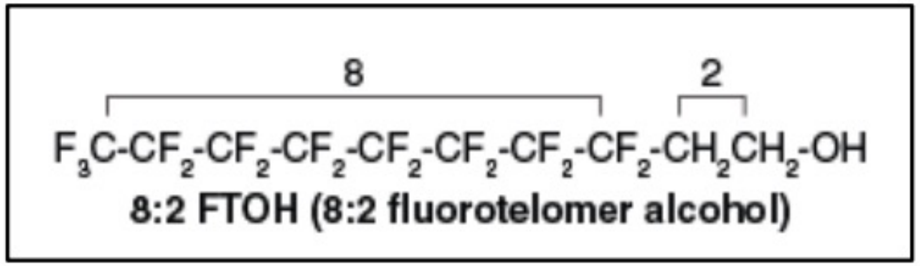






Per – Fully fluorinated carbon chain

- PFOS
- PFOA



Poly – Partially fluorinated carbon chain

- FTOH

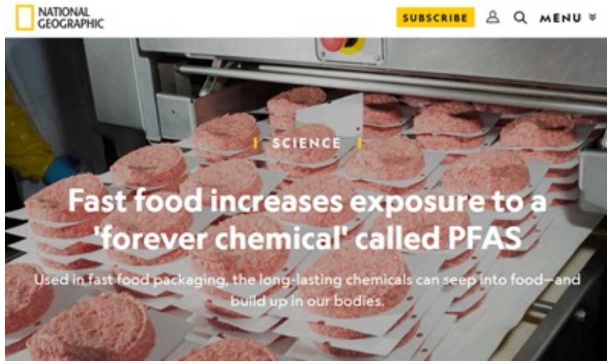
C-F bond is one of the strongest known covalent bonds, and the multiple C-F bonds in PFASs provide their chemical and thermal stability

Source: [Naming Conventions of Per- and Polyfluoroalkyl Substances (PFAS) (itrcweb.org)]

PFAS Is Everywhere

Commercial and Consumer Products Containing PFAS:

- paper and packaging
- clothing and carpets
- outdoor textiles and sporting equipment
- ski and snowboard waxes
- non-stick cookware
- cleaning agents and fabric softeners
- polishes and waxes, and latex paints
- pesticides and herbicides
- hydraulic fluids
- windshield wipers
- paints, varnishes, dyes, and inks
- adhesives
- medical products
- personal care products (for example, shampoo, hair conditioners, sunscreen, cosmetics, toothpaste, dental floss)



PFAS Regulations

Roadmap of Actions Regarding PFAS

1998
EPA First alerted to risks

2000
ES&T[1] article on global PFAS distribution, Dupont WV crisis

2006
Manufacturers phase out chemicals via participation in EPA's Stewardship Program

2015
Third Unregulated Contaminant Monitoring Rule (UCMR3) nationwide occurrence study

2016
EPA revised Health Advisories for PFOA and PFOS (70 ppt)

2019
EPA PFAS Action Plan

State level regulatory action and monitoring

CA, NH, VT…

2020
Preliminary regulatory determination for PFOA/PFOS;

State regulatory action and monitoring

MI, NJ, MA…

2021+
"PFAS 2021 +"

National Occurrence Testing UCMR5 (2023 – 2025)

New PFAS HALs (2022)

Proposed CERCLA Hazardous Designation (2022)

EPA PFAS Roadmap for Biosolids

Winter 2024:
Completion of the risk assessment for PFOA and PFOS.

2025 – 2026:
Anticipated that EPA would issue a Final Rule

2026 – 2031:
Assuming a 5-year compliance schedule

The risk assessment will serve as the basis for determining whether regulation of PFOA and PFOS in biosolids is appropriate.

EPA
United States
Environmental Protection
Agency

PFAS Strategic Roadmap:
EPA's Commitments to Action
2021–2024

NY State Interim Strategy for the Control of PFAS Compounds (DMM7)

- Policy was approved Sept 20th, 2023
- Policy took effect on Oct 20th, 2023

Main takeaway:

Goal is to limit industrial PFAS contributors to WRRFs

17

Policy Details

Within 180 days of policy issuance, all permitted 361-2 and 361-3 facilities accepting biosolids must:

- Develop & submit sampling plan to DEC
- Sample each source (WRRF) and submit data to DEC (DEC *may* fund)
- Draft EPA Method 1633 required (must analyze all PFAS compounds provided by that method)

PFOA or PFOS in biosolids, dry weight (ug/kg or ppb)*	Action Required for Biosolids that are Recycled
20 or less	No action required.
20 – 50	Additional sampling required. DEC will take appropriate steps to restrict recycling after 1 year if PFOS or PFOA levels are not reduced to below 20 ppb or less.
50 or greater	DEC will take action to prohibit recycling until PFOS or PFOA concentration is below 20 ppb.

*DEC may require additional analyses using the SPLP (synthetic precipitation leaching procedure) and use those results in the determination.

Massachusetts

- A Joint Committee on State Administration and Regulatory Oversight gave a favorable report to S.2053
- Proposed act establishing a moratorium on the procurement of structures (ie incineration, pyrolysis, dryers(?)) or activities generating PFAS emissions.
- Not clear of impacts of upgrades/ rehabilitation projects

SENATE DOCKET, NO. 1716 FILED ON: 1/19/2023

SENATE . . . . No. 2053

The Commonwealth of Massachusetts

PRESENTED BY:

Marc R. Pacheco

To the Honorable Senate and House of Representatives of the Commonwealth of Massachusetts in General Court assembled:

The undersigned legislators and/or citizens respectfully petition for the adoption of the accompanying bill:

An Act establishing a moratorium on the procurement of structures or activities generating PFAS emissions.

"Perfluoroalkyl and polyfluoroalkyl substances" or "PFAS" - a class of fluorinated organic chemicals containing at least 1 fully fluorinated carbon atom

Destruction?

Promising Technologies

EPA's PFAS Innovative Treatment Team (PITT)

- Assess current and emerging **destruction methods** being explored by EPA, universities, other research organizations, and industry.
- Explore the efficacy of methods, including consideration of potentially hazardous byproducts .
- Evaluate methods' feasibility, performance, and costs to better understand potential solutions

Pyrolysis/Gasification

Supercritical Water Oxidation

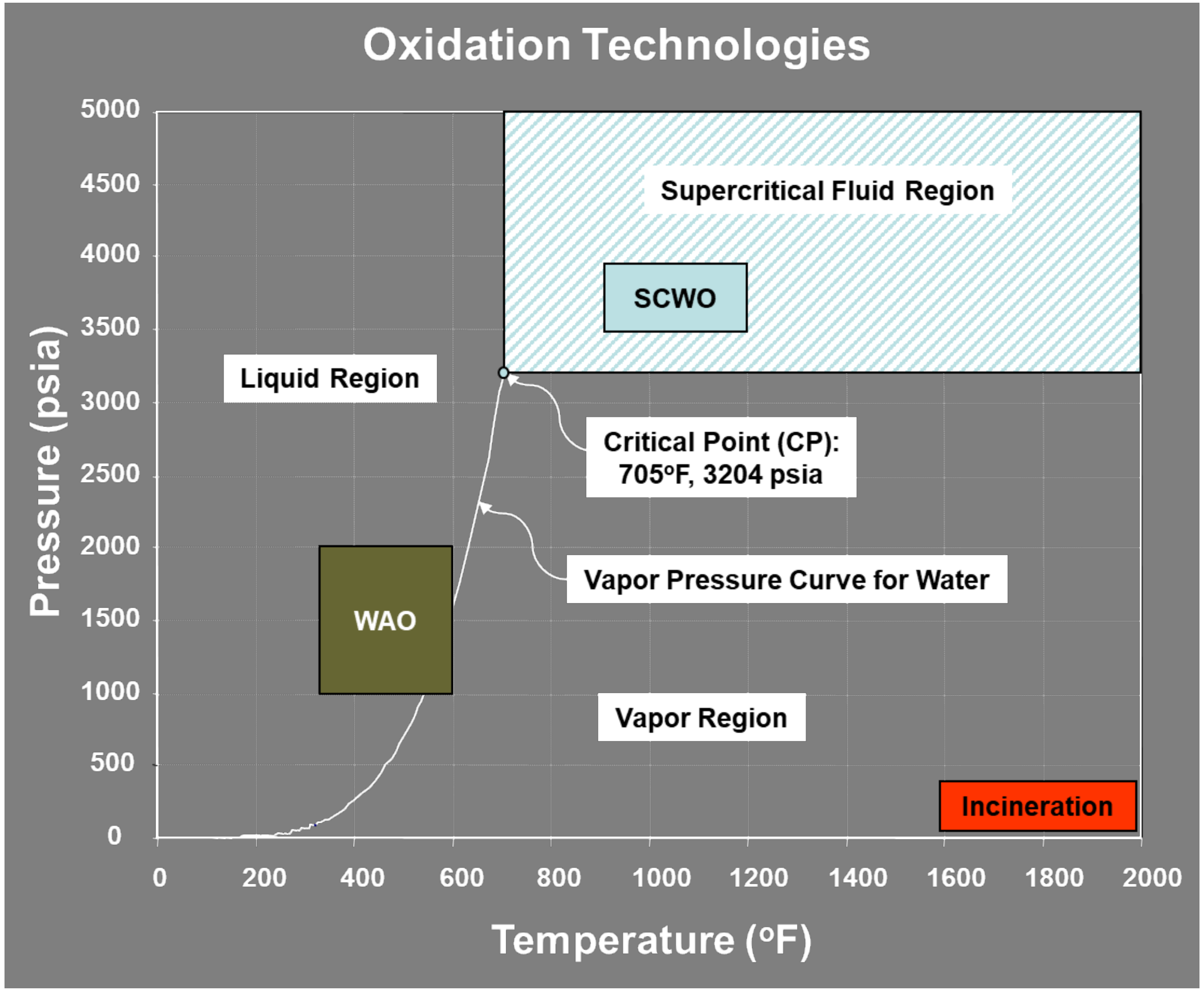
Electrochemical Oxidation

Mechanochemical Degradation

https://www.epa.gov/chemical-research/pfas-innovative-treatment-team-pitt

SCWO Introduction

Supercritical Water Oxidation



- A special phase of water with both liquid-like and gas-like properties
- As pressure increase, water temp increases beyond the boiling point
- Beyond critical point, organic matter rapidly dissolve and becomes simple molecules, oxygen is fully miscible, and salts are insoluble
- With air/O_2, organics are fully oxidized
- Peak temp in SCWO is not hot enough to produce NOx
- It is not a combustion technology by EPA!!!

Technology Background

It is not new

Company (currently active ones in bold)	**Year of Establishment or First Involvement**	**Licensees or Partners**
MODAR, Inc.	1980	Organo Corp.
MODEC (Modell Environmental Corp.)	1986	Organo Corp., Hitachi Plant Engineering & Construction, Ltd., NGK Insulators, Ltd., NORAM Engineering and Constructors, Ltd.
Oxidyne Corp.	1986	-
EcoWaste Technologies, Inc.	1990	Chematur Engineering AB, Shinko Pantec (Kobelco)
Abitibi-Price, Inc.	1991	General Atomics
General Atomics (GA)	1991	Komatsu Ltd., Kurita Water Industries, Ltd.
Turbosystems Engineering	1992	-
Foster Wheeler Development Corp.	1993	Aerojet Gencorp Corp., Sandia National Laboratory
SRI International	1993	Mitsubishi Heavy Industries, Ltd.
KemShredder, Ltd	1993	-
Hanwha Chemical	1994	-
Chematur Engineering AB	1995	Johnson Matthey, WS Atkins, Stora-Enso, Feralco AB
HydroProcessing, L.L.C.	1996	-
Hydrothermale Oxydation Option (HOO)	2000	-
SuperWater Solutions	2006	-
SuperCritical Fluids International (SCFI)	2007	-
Innoveox	2008	-

- Rapid destruction of a wide variety of organic material
- Most hydrocarbons and oxygenated hydrocarbons are converted to CO_2 and H_2O

Marrone, 2013

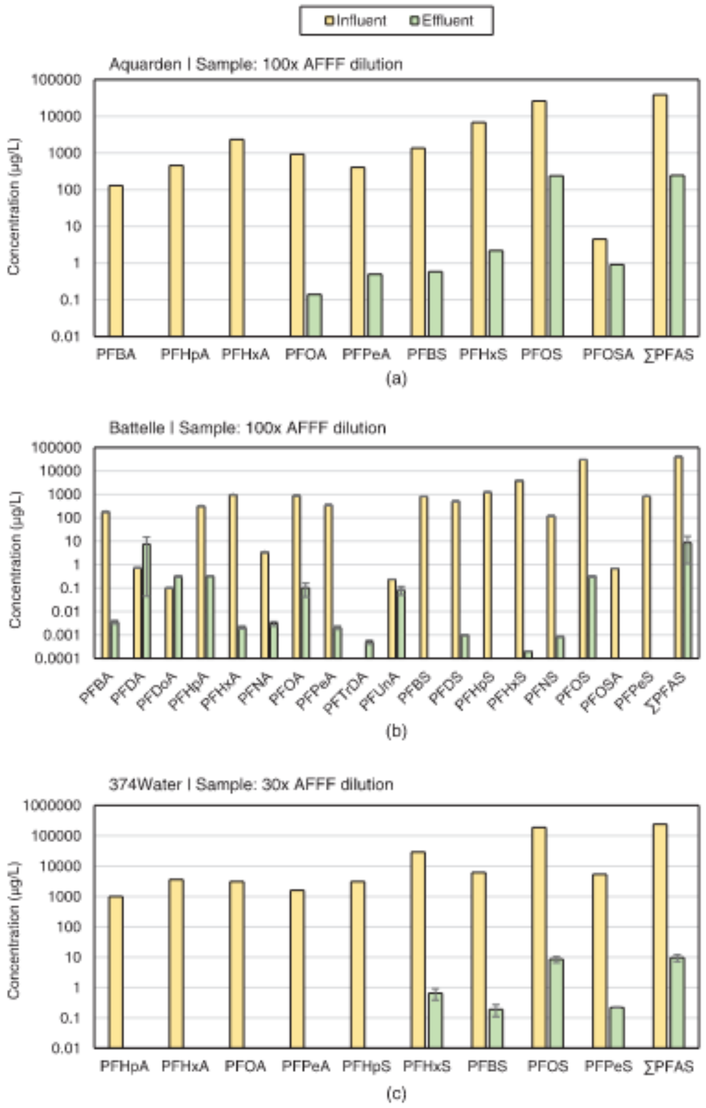
https://doi.org/10.1016/j.supflu.2012.12.020

SCWO and PFAS Removal

Recent Studies showed promising results

- Achieved greater than 99% destruction efficiency of ΣPFAS (also PFOS and PFOA) in the liquid phase
- The targeted analyses of the liquid-phase, showed positive results
- More rigorous examinations of the influent and effluent composition, including gas-phase products, are needed

SUBSTANCE	RESIDUAL ng/L (ppt)	REMOVAL %
PFBA	10.20	99.86%
PFPeA	5.10	ND in feed <5600 ng/L
PFHxA	5.15	99.89%
PFHpA	2.35	ND in feed <2100 ng/L
PFOA	3.15	ND in feed <6200 ng/L
PFNA	1.07	99.90%
PFDA	0.80	99.97%
PFUnA	ND <1.10 ng/L	>99.89%
PFTeA	0.30	ND in feed <3900 ng/L
PFBS	ND <0.19 ng/L	>99.98%
PFPeS	ND <0.29 ng/L	>99.98%
PFHxS	0.28	99.994%
PFOS	0.65	99.998%
Total PFAS	**29.1 ppt**	**99.95%**



Kraus et al,
J. Environ. Eng., 2022, 148(2)

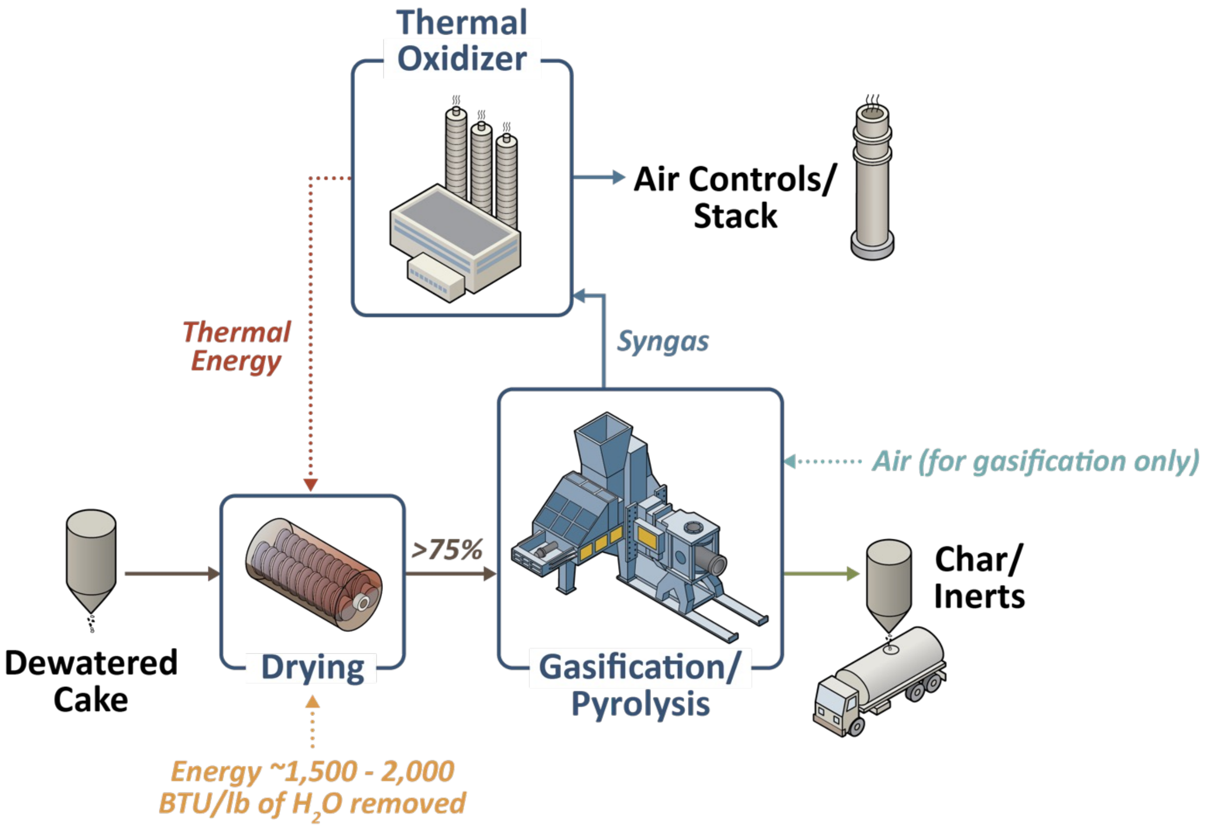
Gasification/ Pyrolysis Introduction

Pyrolysis/Gasification

Parameter	Combustion (Incineration)	Gasification	Pyrolysis
Temperature (°F) as reported by Literature (Vendor specific)	1,650-2,000	1,100-1,800	390-1,100
O_2 Supplied	> Stoichiometric (Excess Air)	> Stoichiometric (Limited Air)	None
By-Products	Flue Gas (CO_2, H_2O) and Ash	Syngas (CO, H_2) and Ash	Pyrolysis Gas, Oils, Tars and Char

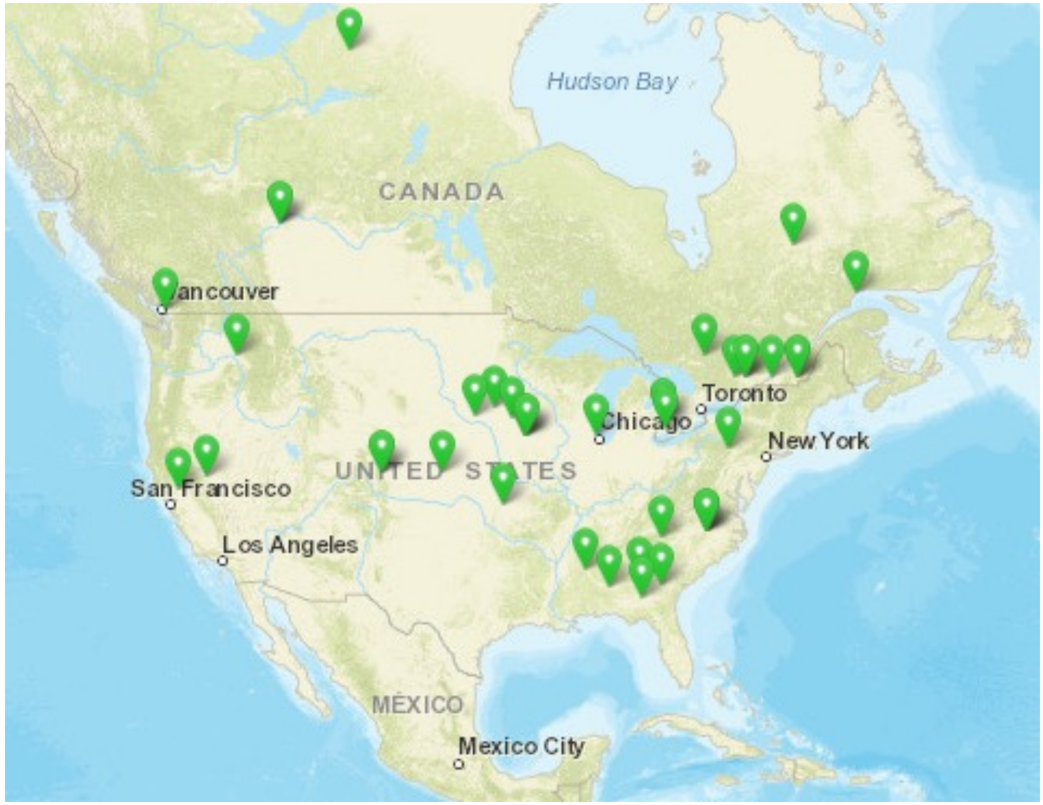
Incineration: complete combustion of organic matter

Gasification/ Pyrolysis: no combustion due to limited or no oxygen



Installations | Bioenergy (ieabioenergy.com)

Non-Wastewater Gasification/ Pyrolysis in US/ Globally



Waste material includes:

- Agriculture wastes
- Biomass
- Forest residues
- Lignocellulosic
- Oils
- Organic residues
- Sugar and starch

Historical Perspective – Biosolids Pyrolysis/ Gasification

1970

1975
- Central Contra Costa Sanitary District
- Gasification
- Switched to incineration mode due to complexity and cost

1983
- Virginia Advanced Water Treatment Facility (Arlington, VA)
- Two 36-dtpd trains (gasification or incineration mode)
- Switched to incineration mode due to complexity and cost

1996-2004
- Prime Energy
- Pilot at Philadelphia Water
- On and off operation
- ~4,000 tons of cake processed
- Thermal dryer implemented

2008
- Tulsa, OK
- Pilot
- Pasteurization implemented

2008-2009
- Stamford, CT
- Piloting of multiple vendors
- Cost too high

2009-2014
- Kore Pilot
- LACSD JWPCP
- Received EPA 2012 Green Chemistry Award
- Used to develop full-scale facility (LA Startup 2021)
- Test facility to convert biosolids into diesel fuel
- Hydrogen sulfide corrosion from pyrolysis off-gas

2009-2013
- Sanford, FL
- Full-scale Issues with Dryer/ Gasifier – both replaced
- Bankruptcy

2015
- Anaergia Pilot Encina, CA
- Different technology selected

2016
- Aries (purchased Maxwest IP)
- Facilities in TN, designed to take wood waste, tires, sludge
- Never took sludge

PFAS destruction

- Several data points showing no PFAS in biochar

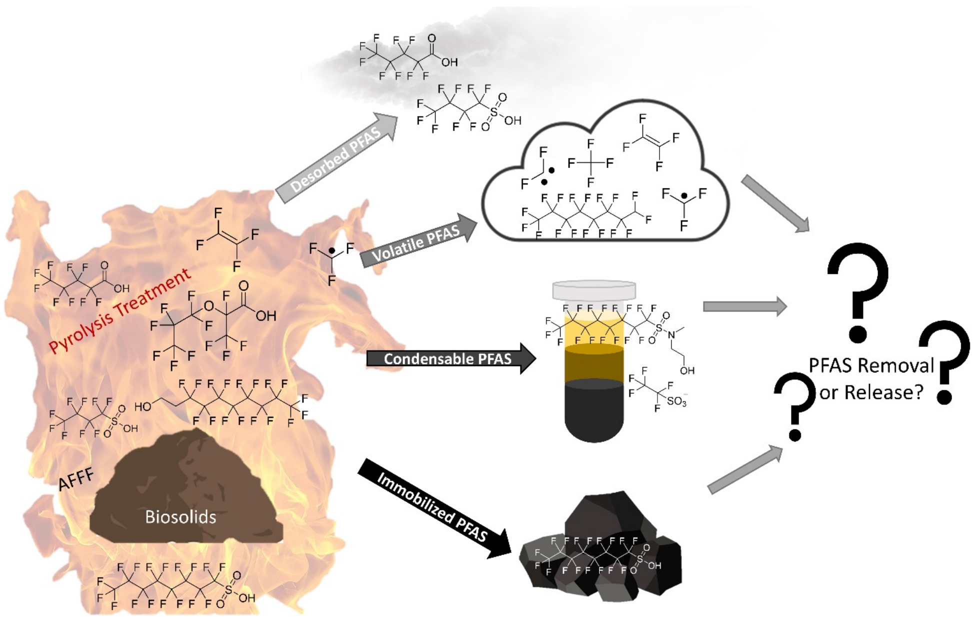
Bioforcetech , Ecoremedy, LLC, Chartech

Operating data:
Input Material: Anaerobically digested Biosolids at 91% solid content
Location : Silicon Valley Clean Water, Redwood City, California
Pyrolysis Conditions: Temperature 600°C +/- 20°C (1,112°F +/- 68°F), Residence time ~20 Minutes
Lab Info: Vista Analytical Laboratory, 1104 Windfield Way , El Dorado Hills, CA

	Dry Biosolids (ng/g)	Biochar (ng/g)
PFBA	7.03	ND
3:3 FTCA	ND	ND
PFPeA	5.94	ND
PFBS	2.3	ND
4:2 FTS	ND	ND
PFHxA	33.7	ND
PFPeS	ND	ND
HFPO-DA	ND	ND
5:3 FTCA	64.5	ND
PFHpA	7.45	ND
ADONA	ND	ND
PFHxS	ND	ND
6:2 FTS	ND	ND
PFOA	89.1	ND
PFHpS	ND	ND
7:3 FTCA	40	ND
PFNA	5.3	ND
PFOSA	ND	ND
PFOS	26.3	ND
9Cl-PF3ONS	ND	ND
PFDA	11.3	ND
8:2 FTS	5.68	ND
PFNS	ND	ND
MeFOSAA	23.5	ND
EtFOSAA	19.6	ND
PFUnA	3.39	ND
PFDS	ND	ND
11Cl-PF3OUdS	ND	ND
10:2 FTS	ND	ND
PFDoA	5.85	ND
MeFOSA	ND	ND
PFTrDA	ND	ND
PFTeDA	2.44	ND
EtFOSA	ND	ND
PFHxDA	ND	ND
PFODA	ND	ND
MeFOSE	17.1	ND
EtFOSE	ND	ND

Is PFAS destroyed or going to the vapor phase?

- Chemours report
- Thoma et al, EPA 2022
- More research

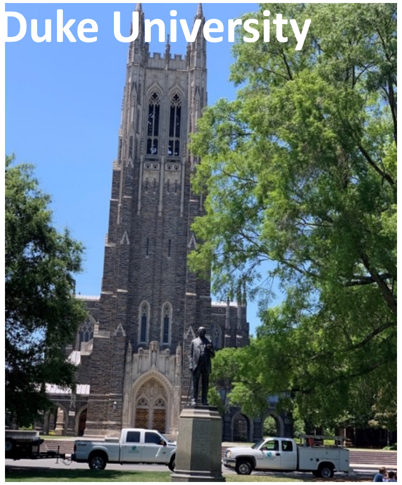


Supercritical Water Oxidation Demonstration
Orange County Sanitation District

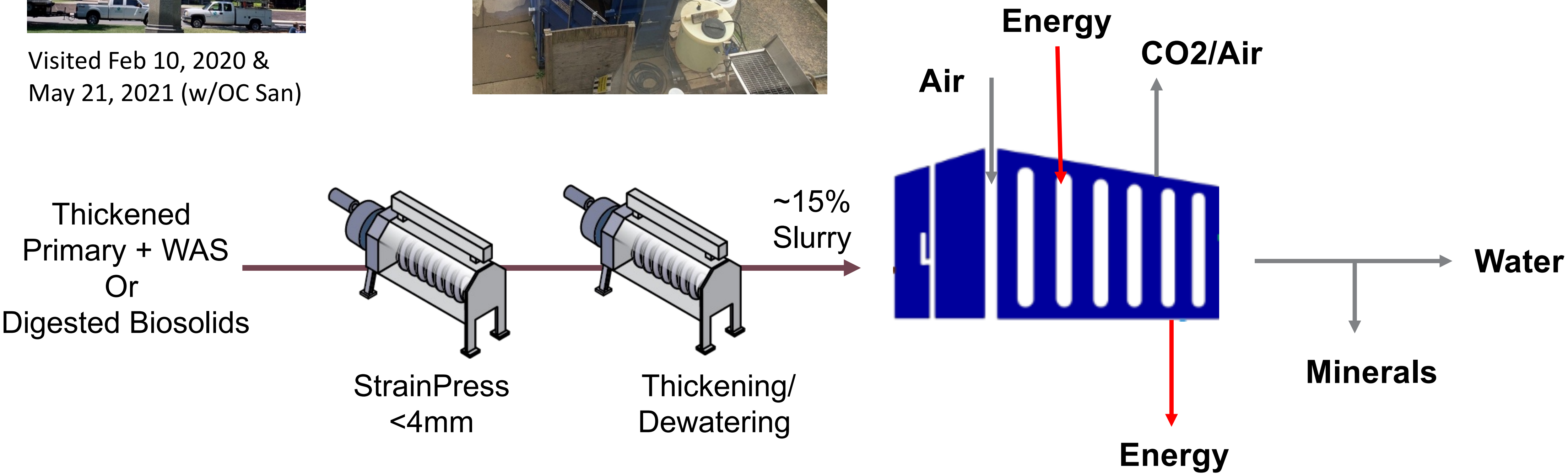
OCSAN
ORANGE COUNTY SANITATION DISTRICT

Super Critical Water Oxidation (SCWO, 374Water)

Since 2013, Funding form Bill & Melinda Gate Foundation



Visited Feb 10, 2020 &
May 21, 2021 (w/OC San)



374Water AirSCWO PFD – continuous process

- No biosolids product at the end → Increase in biosolids beneficial use cost and scarcity of end use
- End products are resources
- Insignificant/low emission
- One of three technologies identified by EPA for destroys PFAS from biosolids

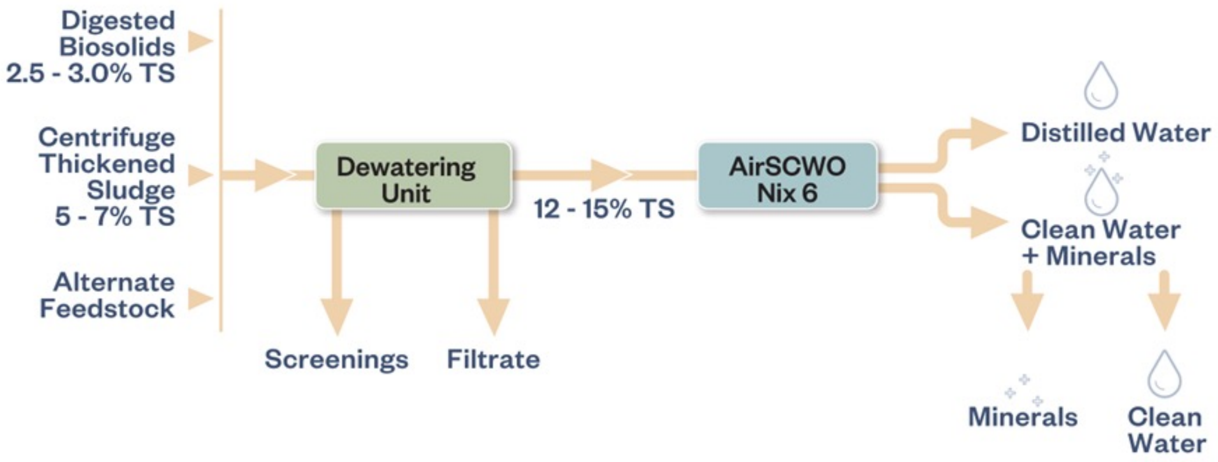
374Water AirSCWO-6 Demonstration at Orange County Sanitation District

OC San

- Plan for PFAS issues in the residuals
- Plan for future land application restrictions

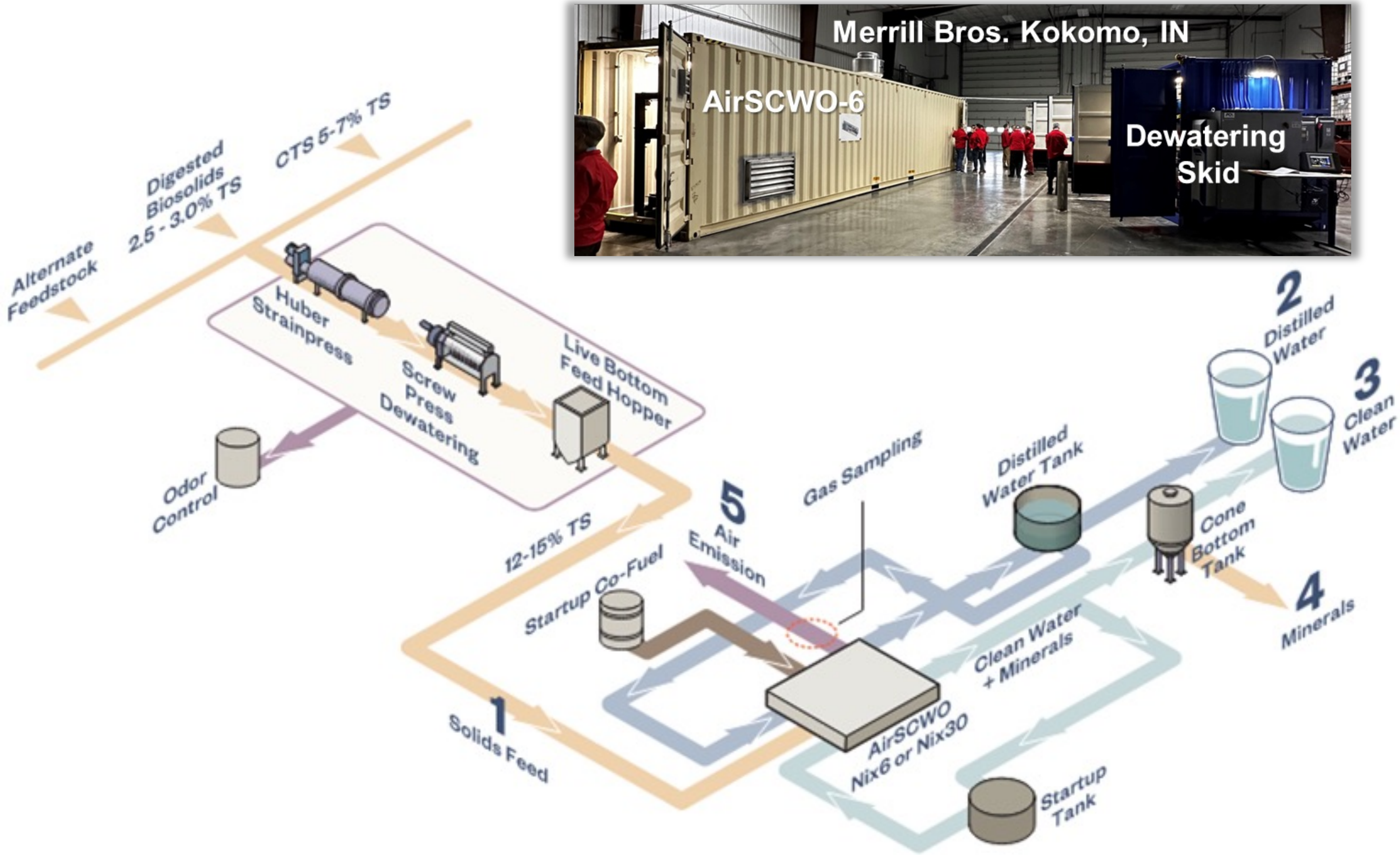
Goals:

- Design/construct first AirSCWO-6 (6 wtpd system)
- Demonstrate continuously and cost competitively processing biosolids
- Recover resources in the form of energy, mineral nutrients, heat and reusable water
- Eliminate pharmaceuticals, PFAS, microplastics and antibiotic resistant bacteria
- Move to AirSCWO-30 (30 wet tons per day), if successful



AirSCWO-6 Demonstration Project Status

- Started January 2022
- Design complete for balance of demonstration units
- Contractor is selected and work in progress
- AQMD research permit submitted:
  - Air testing and sampling conducted at Duke in August 2022
- On-site in March of 2024



Advanced Thermal Processes: Pyrolysis/Gasification

THE Water Research FOUNDATION

WRF #5107 – Understanding pyrolysis for PFAS removal

- WRF Project Partners (WRF matches cash)
- Goals
  - Fate of PFAS in the pyrolysis process
  - Mass balances on metals and organics
  - Energy balance
  - Syngas quantity and quality
  - Life cycle cost comparison to other established processes

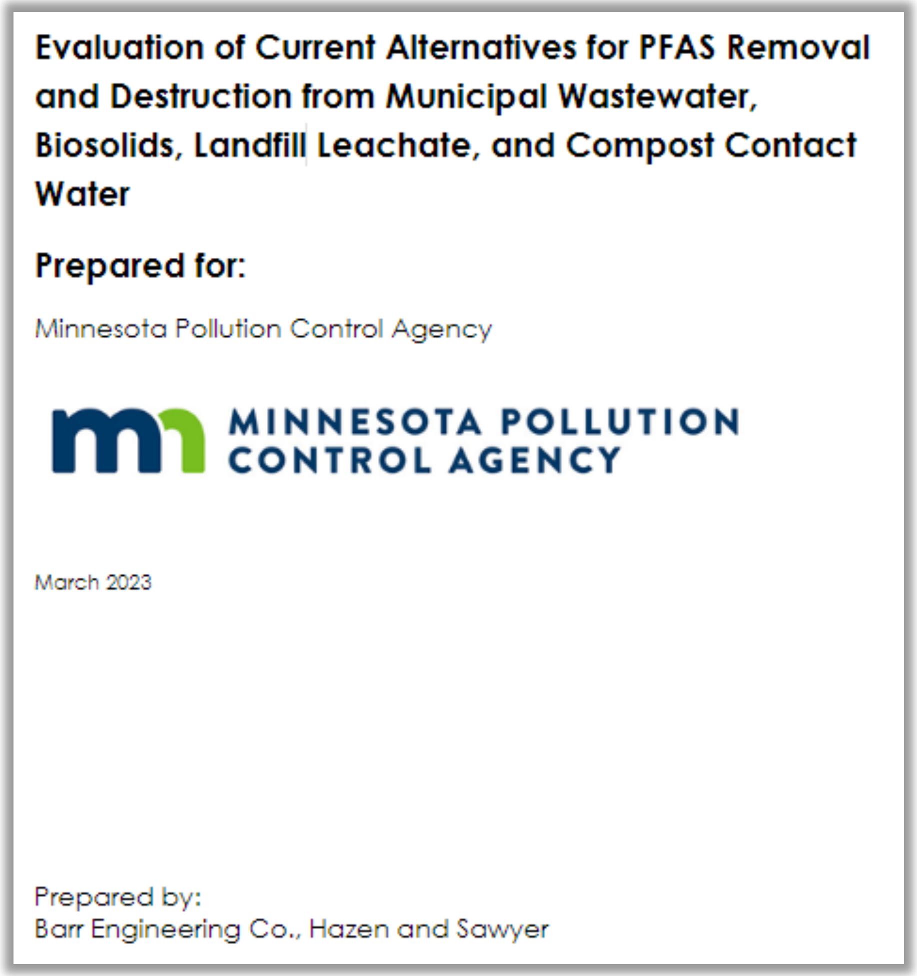
Commercial Status

Company	Location	ATP	Scale	Status	Biosolids Capacity (WT/d)
Ecoremedy	Derry Township, PA	Gasification	Full-Scale	Construction expected April 2024 with commissioning Q4 2024	70
	Edmonds, WA	Gasification	Full-Scale	Operating since August 2023	50
Northeastern Biochar Solutions	Moreau, NY	Pyrolysis	Full-Scale	Open to Comment by DEC, no construction to date.	
BioForceTech	Redwood City, CA	Pyrolysis	Full-Scale	Operational Since 2017. Back online March 2024.	8.3
	Ephrata, PA	Pyrolysis	Full-Scale	Almost Finalized (1/17/2024 update). Commission and start-up expected to begin March 2024.	11
	Redding, CA	Pyrolysis	Full-Scale	Almost Finalized (1/17/2024 update). Commission and start-up expected to begin March 2024.	8.3
	Yelm, WA	Pyrolysis	Full-Scale	Equiment almost ready to be shipped to Client's location (1/17/2024 update).	2.7
	Scappoose, OR	Pyrolysis	Full-Scale	Equiment almost ready to be shipped to Client's location (1/17/2024 update).	2.7
	Brentwood, CA	Pyrolysis	Full-Scale	Start-up and commissioning expected in 2025.	20-22
Earthcare	Bethel, PA	Gasification	Full-Scale	Near Complete. Early February 2024 Expected.	190
Anaergia	Rialto, CA	Pyrolysis	Full-Scale	Expected to start commissioning January 2024. Operations currently delayed while Rialto focuses on brining up Anaerobic Digestion.	300
CHAR Technologies	Synagro	Pyrolysis	Full-Scale	Expected to be operational by end of 2025.	35 (8 DTPD)
	Thorold, ON	Pyrolysis	Demonstration	Pilot is operational.	27 (6 DTPD)
Heartland Water Technology	Murfreesboro, TN	Plasma Gasification	Demonstration	Operational	4 – 6 DTPD

MN Pollution Control Agency Analyzing Alternatives for PFAS Removal

MINNESOTA POLLUTION CONTROL AGENCY

Project overview



Evaluation of Current Alternatives for PFAS Removal and Destruction from Municipal Wastewater, Biosolids, Landfill Leachate, and Compost Contact Water

Prepared for:

Minnesota Pollution Control Agency

MINNESOTA POLLUTION CONTROL AGENCY

March 2023

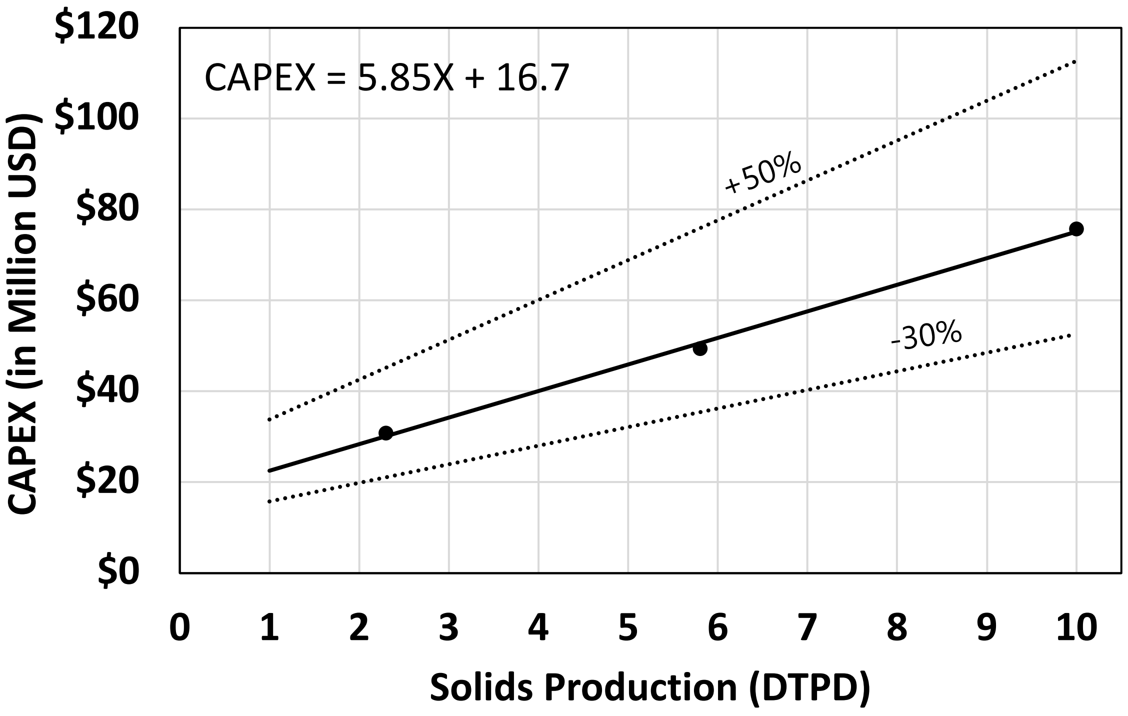
Prepared by:
Barr Engineering Co., Hazen and Sawyer

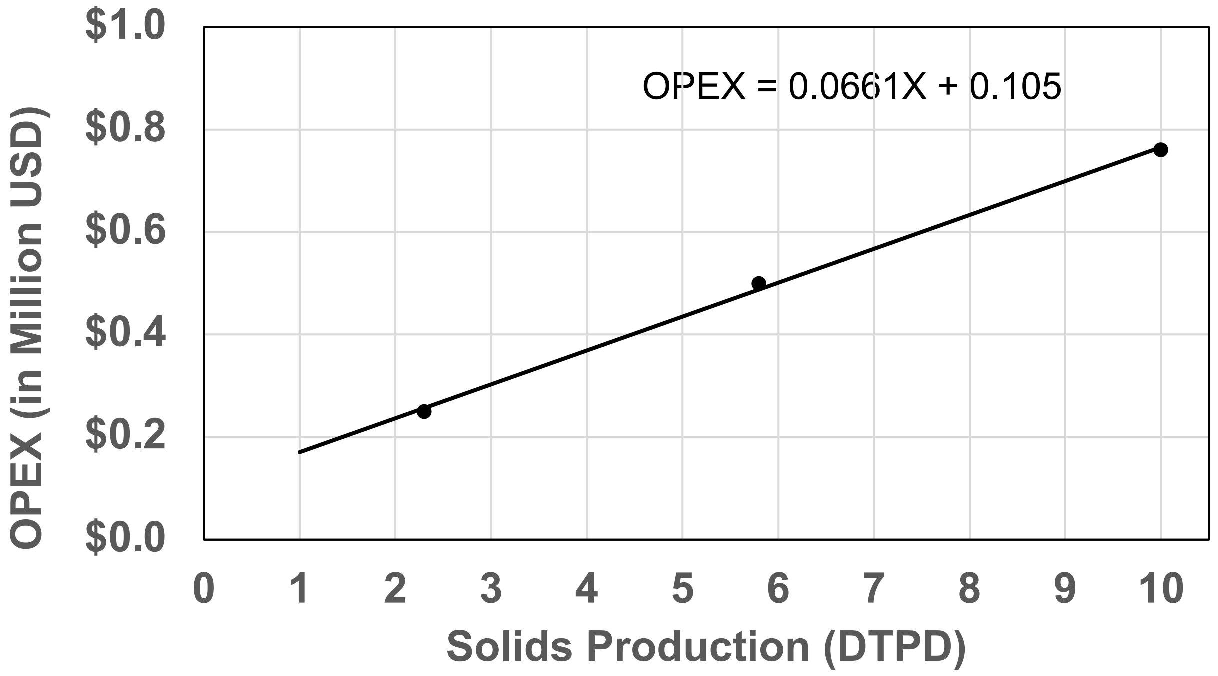
Technology Screening

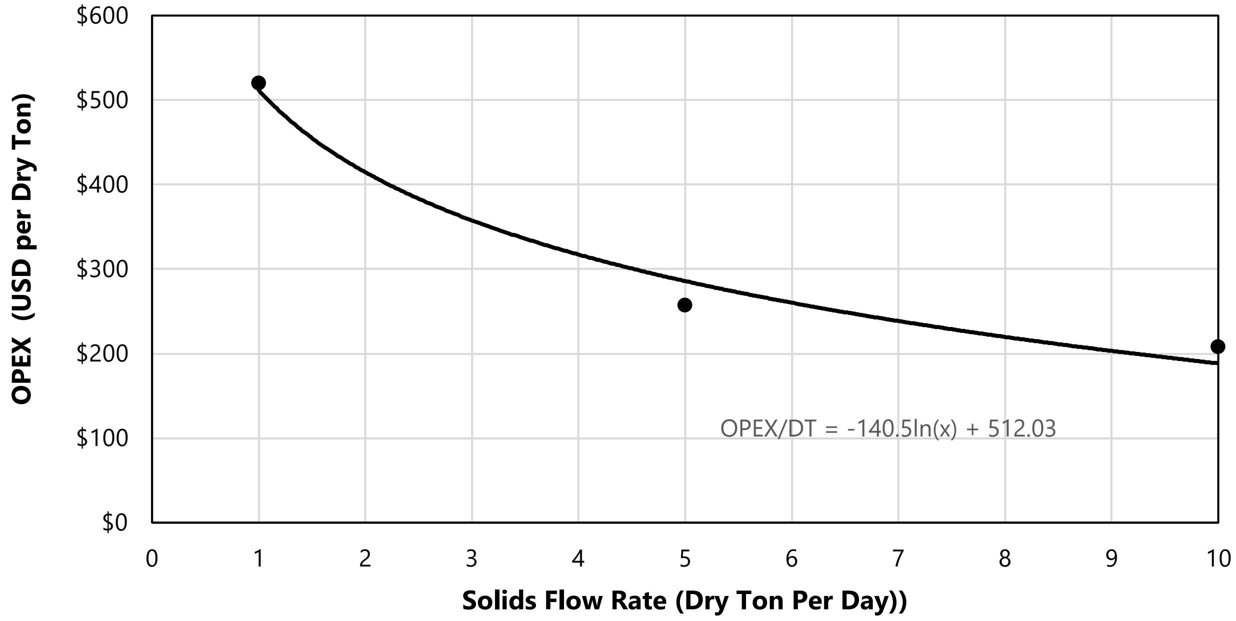
Technology	Degree of Commercialization	Demon-strated for PFAS	>90% PFAS Destruction Efficiency
Super Critical Water Oxidation (SCWO)	PFAS removal/destruction – developing Example vendors: Battelle PFAS Annihilator, Aquarden Technologies, 374Water.	Yes	Yes (Greater than 99% reduction of the total PFAS identified in a targeted compound analysis, including PFOS and PFOA.[1])
Pyrolysis with Thermal Oxidation (biosolids)	Full-scale. Example vendors: Anaergia, Bioforcetech, Biowaste.	Yes	Yes (Complete removal from biochar. Thermal oxidizer destroys PFAS at an efficiency greater than 99.99%.[2,3])
Gasification with Thermal Oxidation (biosolids)	Full-scale. Example vendors: Aries, Ecoremedy.	Yes	Yes (99.5% total PFAS removal between feed and char when coupled with thermal oxidation.[4])
Biosolids Incineration	Mature technology. Full-scale.	Yes	No (Sewage sludge incinerators (SSIs) operate at 700-1,000°C. Complete destruction of PFAS requires temperatures over 1,000°C.[5,6])
Thermal Drying	Mature technology. Full-scale.	No	No

Pyrolysis/Gasification Systems Cost Curves

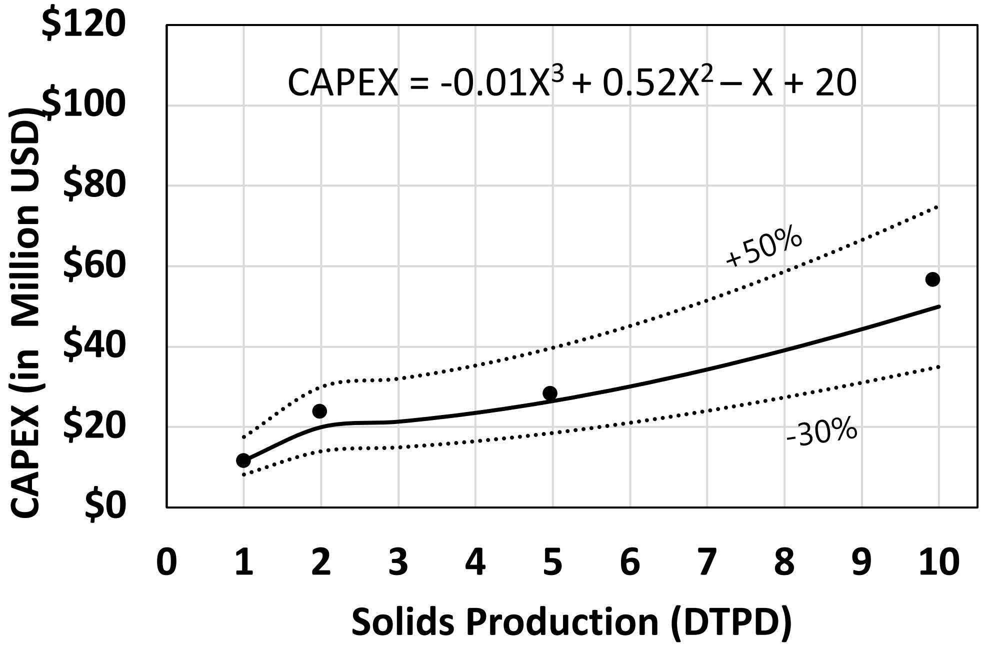
MINNESOTA POLLUTION CONTROL AGENCY





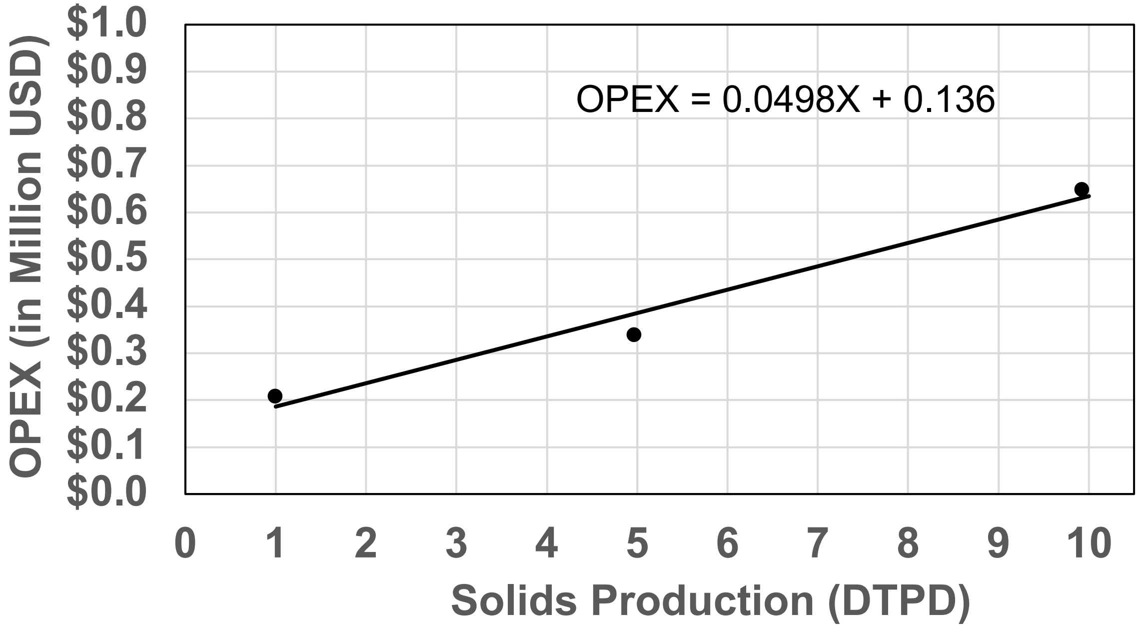


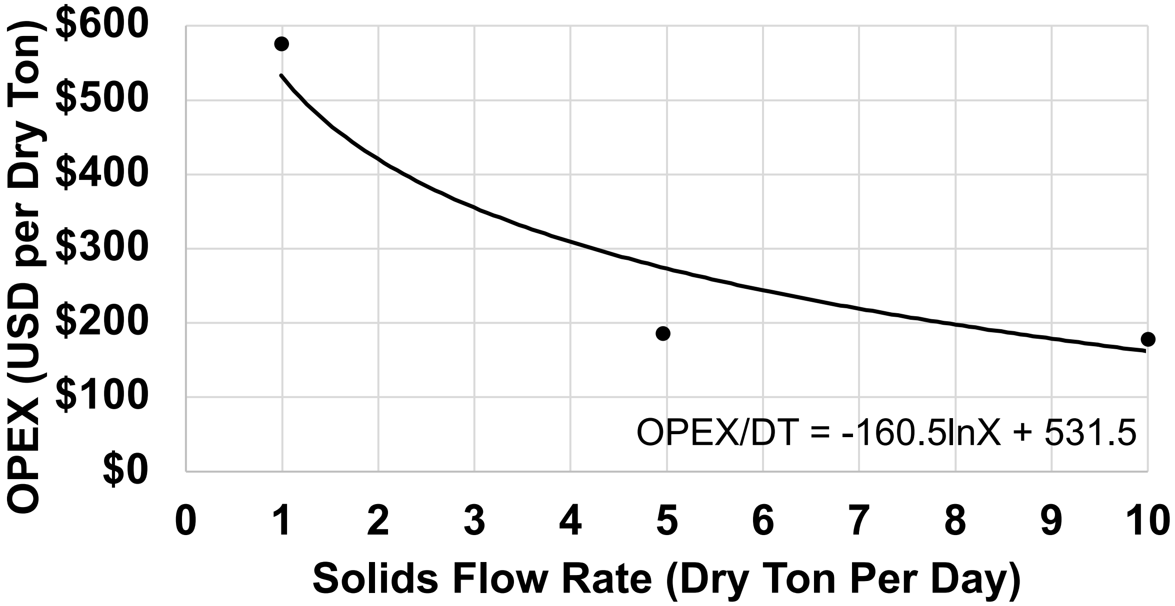
SCWO System Cost Curve



Construction cost includes:
- Installation
- Building
- Supporting elect, I&C, mech.

Does not include:
- Sludge screening, dewatering





MINNESOTA POLLUTION CONTROL AGENCY

Available Online

Findings indicate PFAS destroying technologies for biosolids competitive with other processes

Evaluation of Current Alternatives and Estimated Cost Curves for PFAS Removal and Destruction from Municipal Wastewater, Biosolids, Landfill Leachate, and Compost Contact Water

Prepared for
Minnesota Pollution Control Agency

MINNESOTA POLLUTION CONTROL AGENCY

May 2023

Prepared by:
Barr Engineering Co., Hazen and Sawyer

"…..In contrast, emerging biosolids technologies capable of destroying PFAS can be cost-competitive with current practices."

Groundbreaking study shows unaffordable costs of PFAS cleanup from wastewater | Minnesota Pollution Control Agency (state.mn.us)

Conclusions

Conclusions

- Pyrolysis and SCWO are identified as potential technologies for PFAS destruction in biosolids.
- Despite their promise, critical knowledge gaps remain concerning the identity and fate of resulting transformation products in potential pyrolysis configurations and treatment conditions.
- While targeted, non-targeted, and total PFAS analyses will remain indispensable, it is critical to develop methods for volatile PFAS characterization.
- Both technologies still have limited full scale implementation.
- These technologies also lack information on long term operational information
- These technologies convert organics into other products and eliminate/minimize the disposal

Thank you!

Micah Blate, PE – Speaker

mblate@hazenandsawyer.com

Co-authors:

Mo Abu-Orf, PhD

Derya Dursun, PhD, PE

Hazen