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MIDWEST BIOSOLIDS ASSOCIATION

Multiple Benefits of Thermal Oxidizers at Wastewater Treatment Plants

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Presentation Outline

- Regulatory requirements for air treatment at WWTPs and what drives the use of a thermal oxidizer?
- What is a thermal oxidizer (TO), and what is the difference between a TO, a recuperative TO and a regenerative TO?
- Why do regenerative TOs dominate in biosolids applications?
- Case study example of RTO at large municipal dryer installation
- Secondary benefits of RTOs in context of PFAS
- Emerging air regulations and regulatory uncertainty around PFAS in biosolids
- Summary and discussion

Use of air treatment systems at WWTPs are driven by regulations

Clean Water Act Requirements

Some WWTPs are mandated to address Hazardous Air Pollutants (HAPs), Volatile Organic Compounds (VOCs), and Sewage Sludge Incineration (SSI) controls

- **Section 112 - National Emission Standards for Hazardous Air Pollutants standards establish Maximum Achievable Control Technology (MACT) rules to curb toxic emissions like benzene, toluene, chloroform, and methylene chloride**
- **Title V Operating Permits are required for any facility with the potential to emit 10 tons per year (tpy) of a single HAP or 25 tpy of any combination of HAPs is designated a "major source"**
- **WWTPs in areas that fail to meet NAAQS—Nonattainment Areas—face pressure regarding VOCs, which are primary precursors to ground-level ozone**
- **Section 129 of the CAA regulates SSIs**
- **CAM (40 CFR Part 64) requires large emission control devices to assure ongoing compliance**

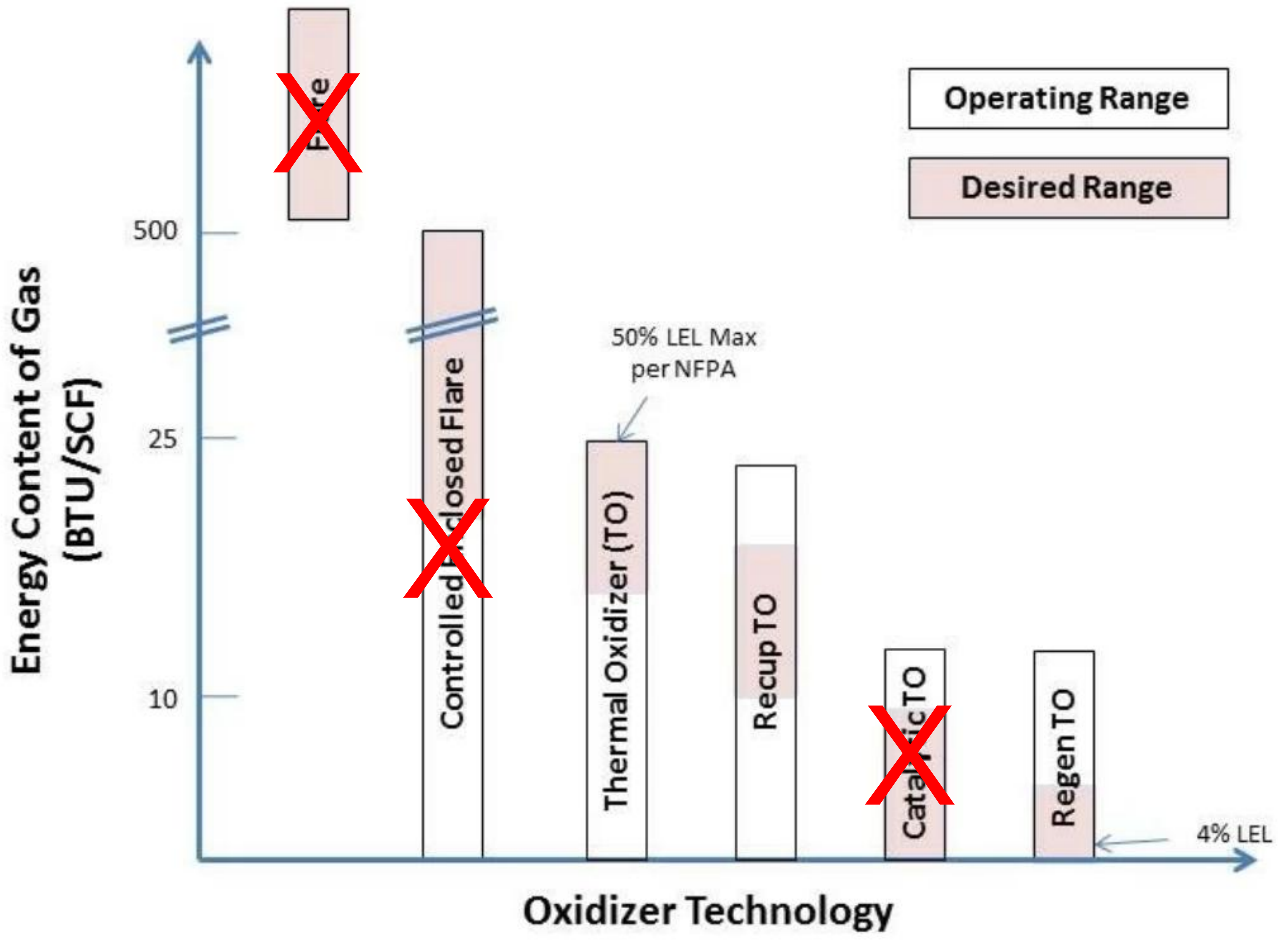
State Requirements

Nuisance odor rules may drive air treatment, but in general, a state will only drive the use of a thermal oxidizer when a wastewater facility crosses into these specific scenarios:

- **It adds a thermal sludge dryer (generating VOCs)**
- **It treats industrial/petrochemical wastewater (introducing highly regulated toxins like benzene or toluene)**
- **It is a severe ozone non-attainment county where the state has lowered the legal definition of a "Major Source"**

What is the difference among oxidizer technologies?

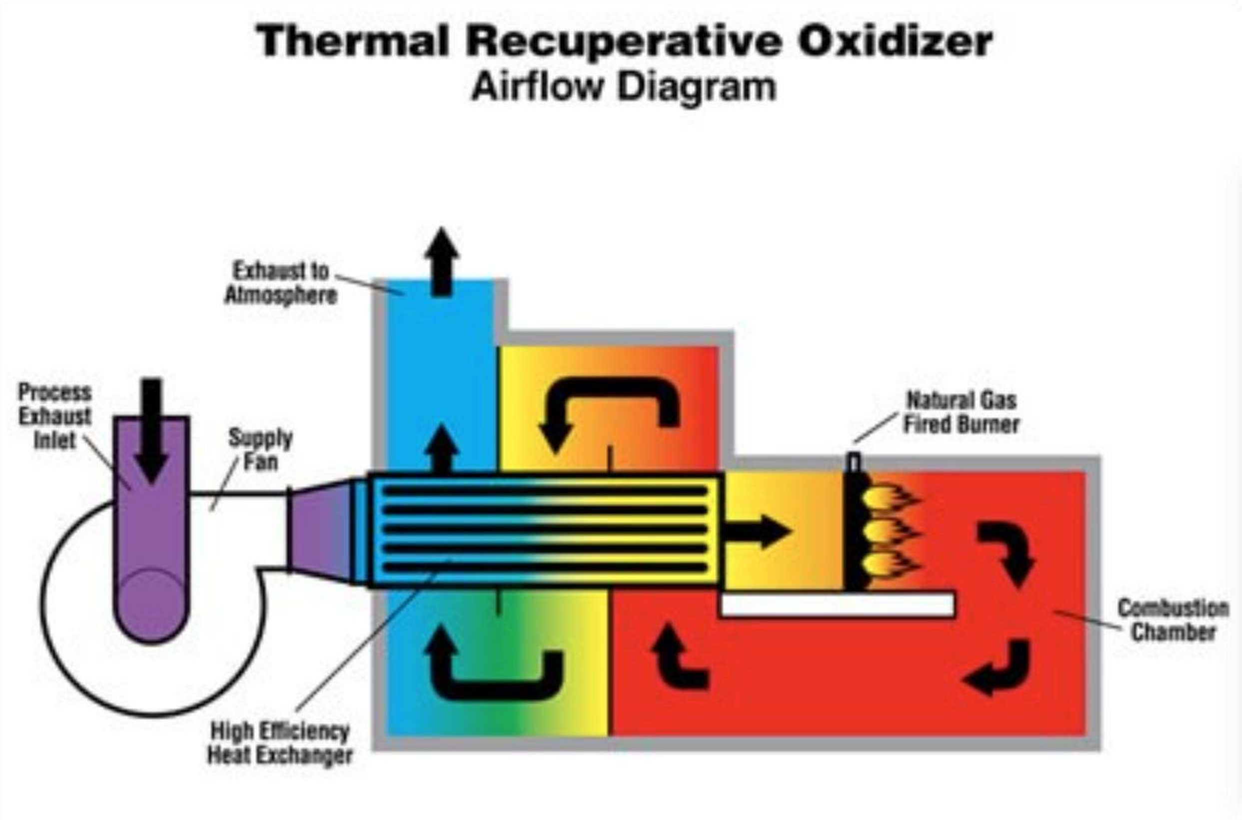
- In WWTPs, flares are used exclusively to manage methane-rich biogas; and while there is a preference to recycle gas (green electricity or heat), flares are a critical safety net and environmental control system when that recycling equipment is offline or overwhelmed:
  - Generation Equipment Maintenance or Outages
  - Excess Biogas Production (Surge Balancing)
  - Highly Contaminated Biogas
  - Plant Commissioning and Biological Startup
- Wastewater off-gases are frequently loaded with hydrogen sulfide and silicones (from defoamers and wastewater chemicals) which are severe catalyst poisons that rapidly coat or permanently mask the precious metals, destroying the catalyst bed and requiring incredibly expensive replacements

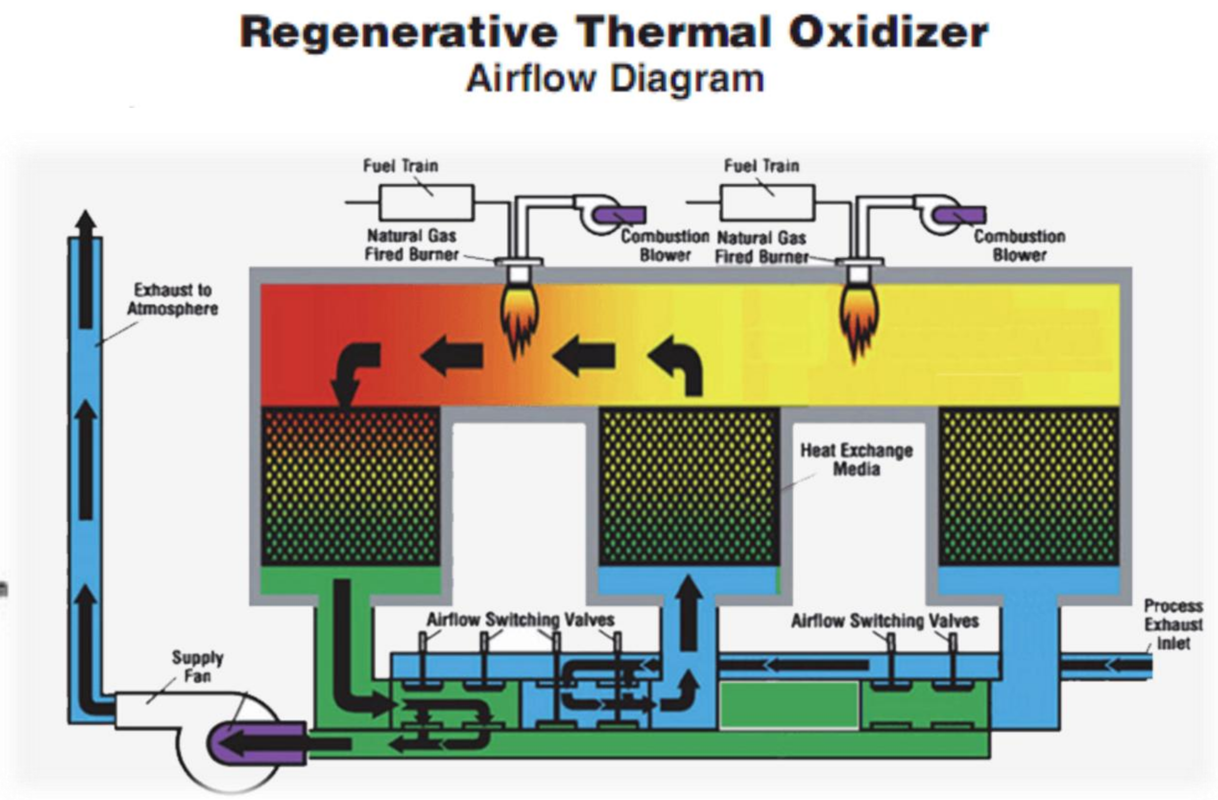


Feature	Direct-Fired Thermal Oxidizers (afterburners)	Recuperative Thermal Oxidizers	Regenerative Thermal Oxidizers (RTOs)
Destruction Removal Efficiency (DRE)	99 - 99.99%+	99 - 99.99%+	98 - 99.5%+
Primary Destruction Method	Direct thermal combustion without heat recovery	Thermal combustion with a metallic heat exchanger	Thermal combustion; ceramic media beds for heat storage
Operating Temperature	1200 - 1800F (650 - 1000C)	1400 -1500°F (760 - 815C)	1500 - 1600°F (815 - 870C)
Thermal Efficiency	0% - no internal heat recovery	50 - 80%	95 - 97%
VOC Concentration	Very high or variable	Moderate	Low to moderate
Fuel Consumption	$$$$$	$$$	$
Capital Cost	$	$$	$$$
O&M Costs	$$$$	$$$	$$
Footprint & Weight	Smallest and lightest	Medium size and weight	Largest and heaviest
Particulate Tolerance	High tolerance; minimal clogging risk	Low tolerance; high risk of heat exchanger fouling	Moderate tolerance; periodic bake-outs

Comparison of recuperative and regenerative TO processes

https://www.thecmmgroup.com/air-emissions-treatment/; http://www.yjeep.cn/en/index.php/core-products/5.html





Ceramic media types and maintenance considerations

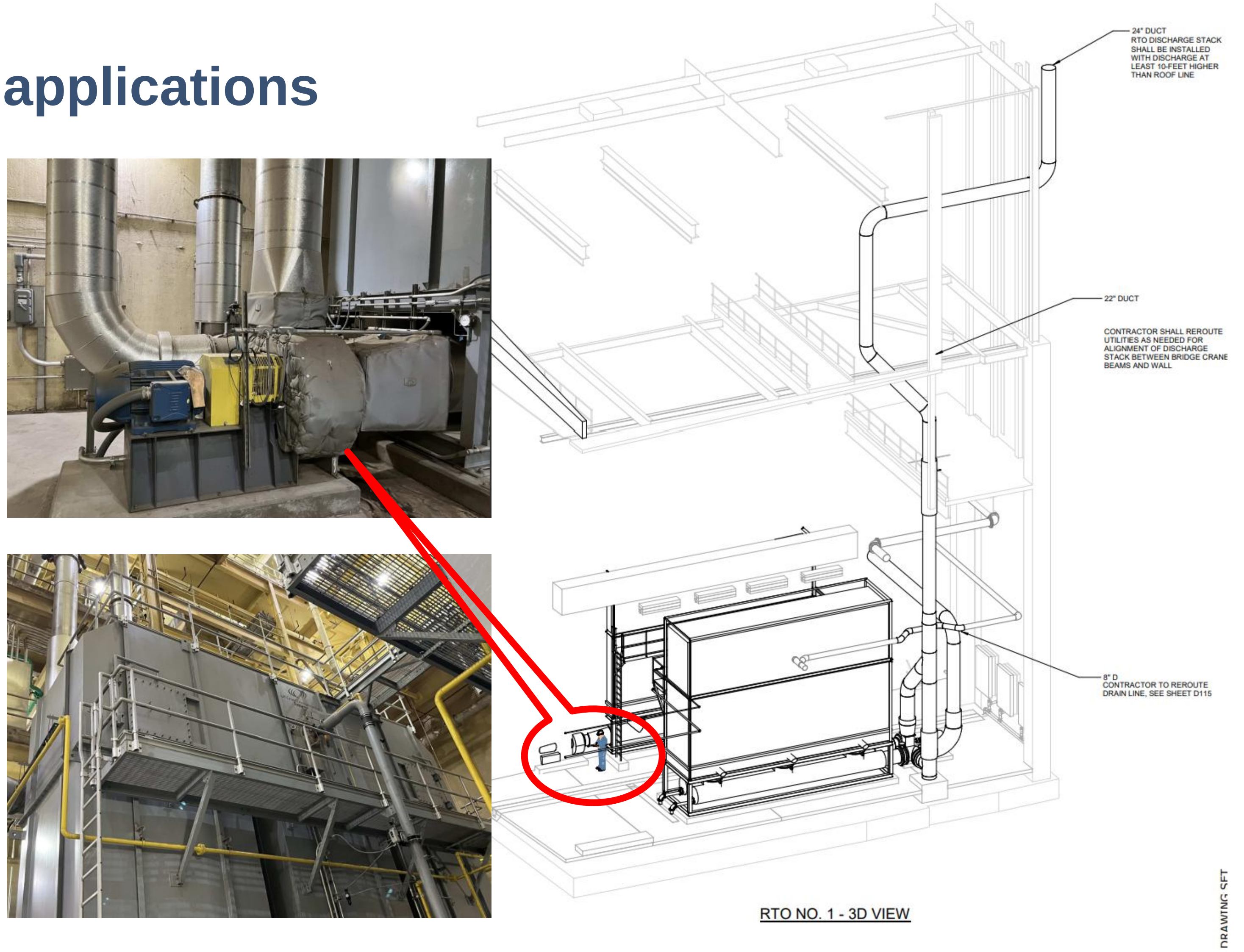
https://www.cpilink.com/blog/rto_media_and_maintenance

Summary of RTO manufacturers (not comprehensive)

RTO Vendor	Global Installations (All Sectors)	Wastewater & Biosolids Market Focus	Application Profile
Anguil Environmental Systems	Thousands	High (NA leader in municipal projects)	Frequently specified for municipal sludge drying; provides deep reference lists for WW facilities
Colt Technologies	Hundreds	High (Specialized niche focus)	Low total system volume but high concentration of dedicated 3-chamber systems designed specifically to prevent sludge-media plugging
CECO Environmental (Adwest)	Thousands	High (Named in municipal specs)	Known for "flameless" natural gas injection (NGI) that vastly lowers NOx emissions
Andritz (Geoenergy)	Thousands	High (Tier-1 multinational OEM)	Pairs proprietary GeoTherm® RTOs with their turnkey sludge dewatering and drying processing trains
Ship & Shore Environmental	Hundreds	Moderate to High (Frequent alternative in specs)	Excels at customized, energy-efficient heat recovery integration
Durr Systems	Thousands	Moderate (Large industrial/EU projects)	Massive global conglomerate footprint; municipal wastewater systems are standard in Europe but less dominant in North American sludge systems
Zeeco Inc.	Thousands	Low to Moderate (Primarily heavy industrial WW)	Focuses heavily on refining chemical and petrochemical waste streams rather than standard municipal sludge dryers
The CMM Group	Hundreds	Low (Industrial manufacturing)	Core focus is on converting coating and printing industries; handles custom industrial wastewater projects on a turnkey basis

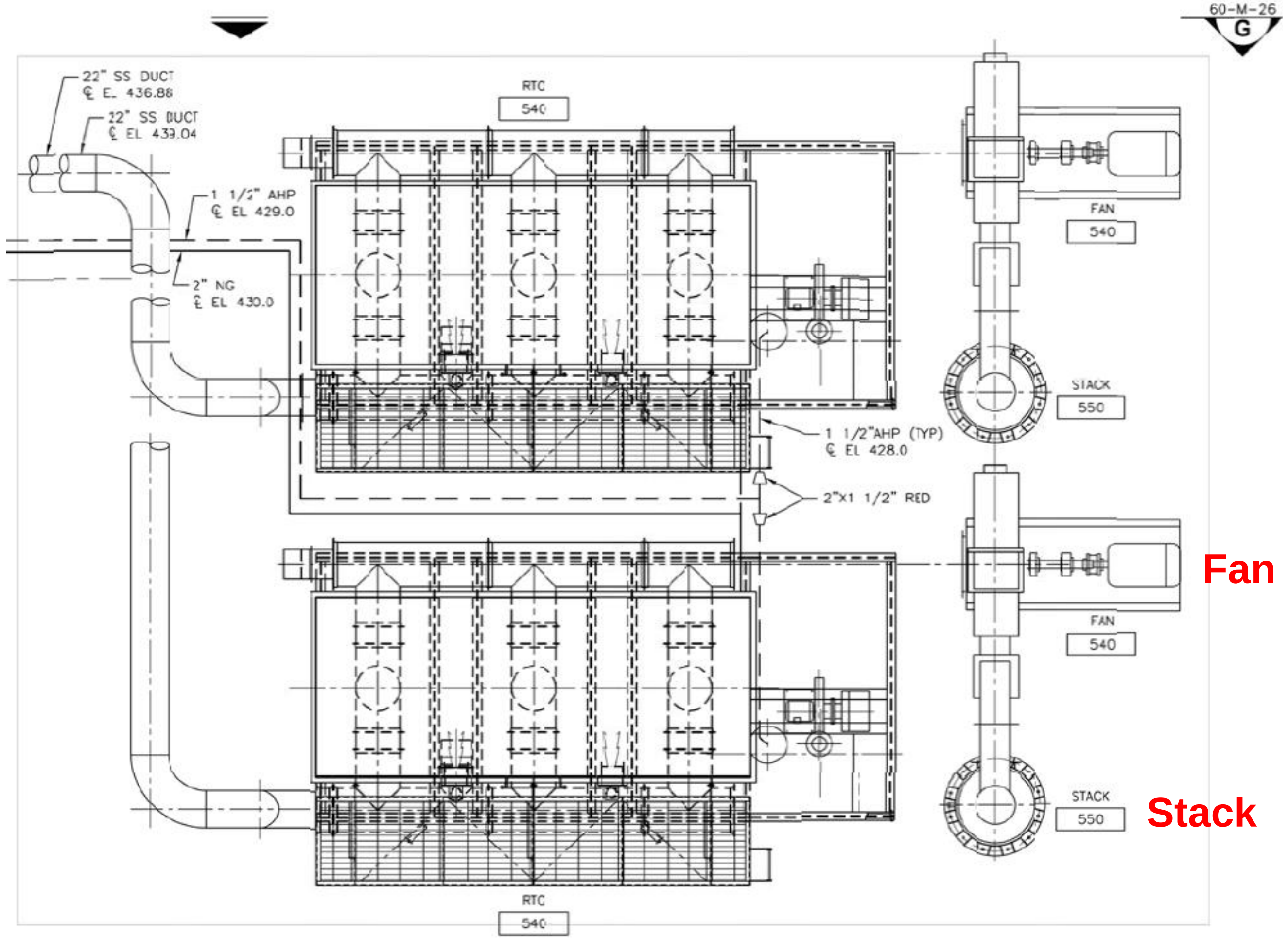
RTOs dominate biosolids dryer applications

- Biosolids dryers drive off massive volumes of water vapor blended with trace volatile organic compounds (VOCs), organic dust, and odors
- Because this air stream has virtually zero natural heating value, it requires an immense amount of external energy to keep the oxidizer at contaminant destruction temperatures
- The 90%+ thermal efficiency of an RTO captures the heat from the exhaust and uses it to preheat the incoming wet dryer air, preventing natural gas utility bills from becoming unsustainably expensive

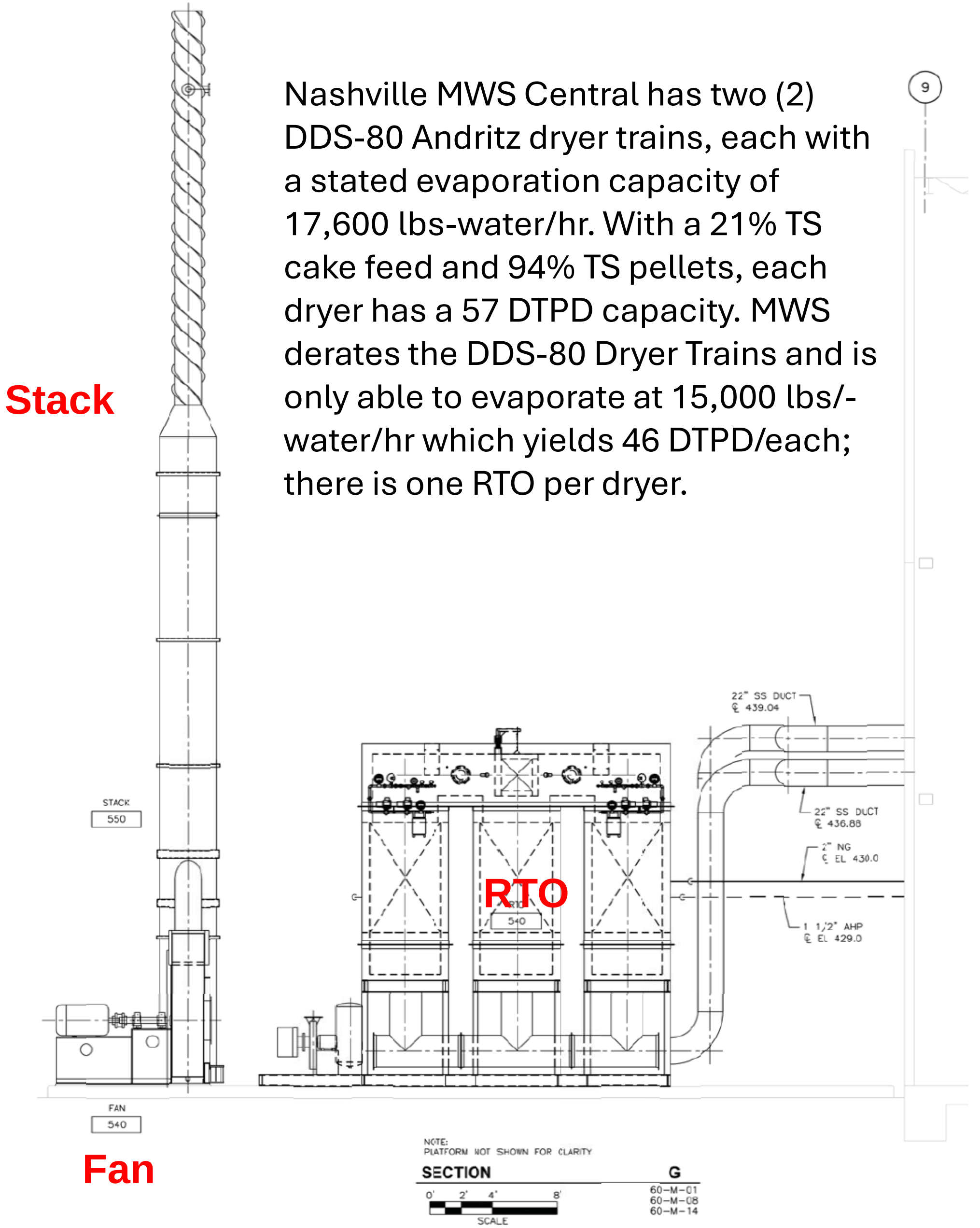


LMSD MFWQTC has two (2) DDS-90 Andritz dryer trains, each with a stated evaporation capacity of 19,000 lbs-water/hr. Operations targeted 25% TS cake feed and 94% TS pellets at 77.6 DTPD/each. There are two (2) RTOs – 1 for each dryer train and are noted to handle a max process air rate of 10,000 SCFM and VOC loading of 52,718 BTU/hr.

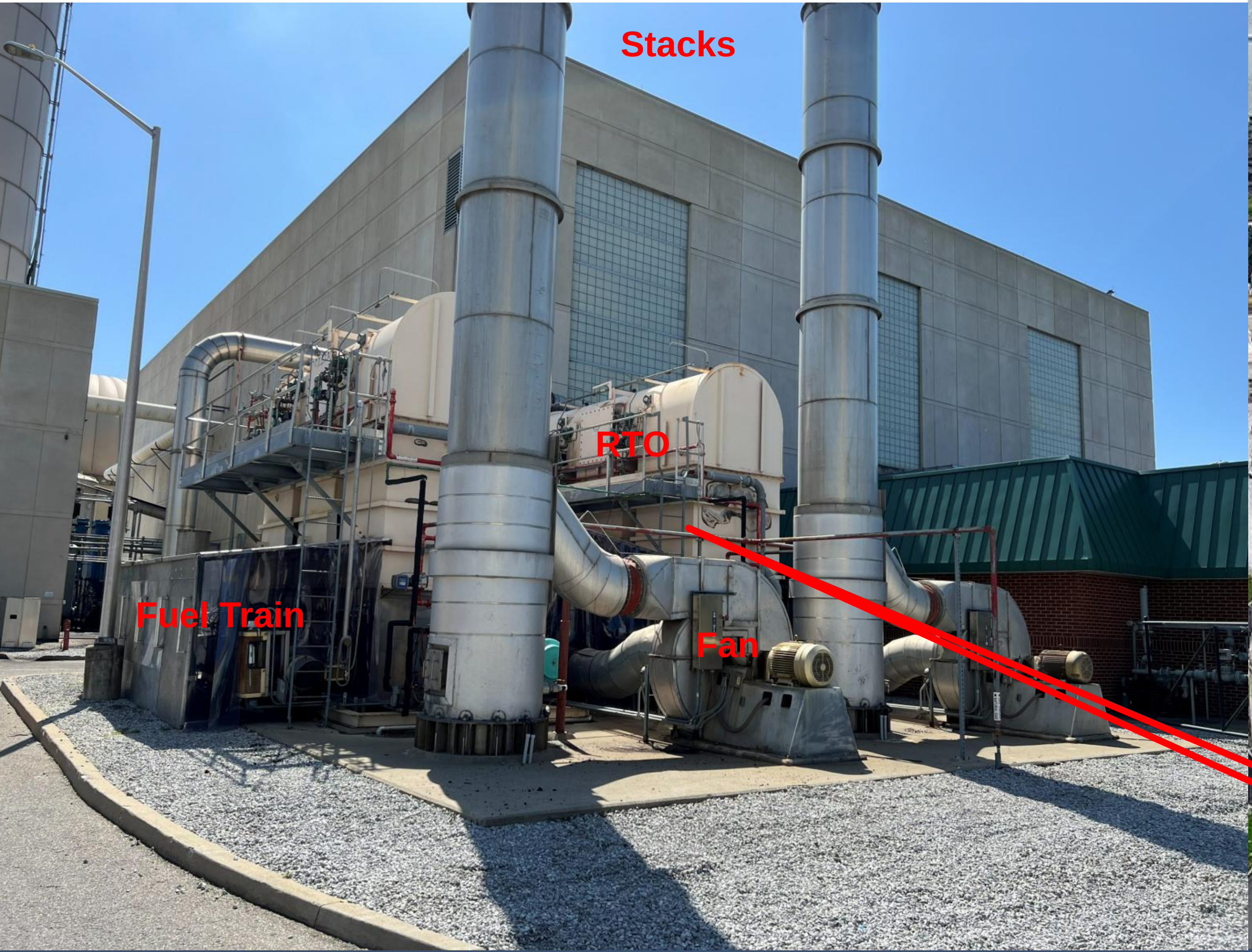
So, what do these things look like?



Nashville MWS Central has two (2) DDS-80 Andritz dryer trains, each with a stated evaporation capacity of 17,600 lbs-water/hr. With a 21% TS cake feed and 94% TS pellets, each dryer has a 57 DTPD capacity. MWS derates the DDS-80 Dryer Trains and is only able to evaporate at 15,000 lbs/-water/hr which yields 46 DTPD/each; there is one RTO per dryer.



RTOs for dryer exhaust



Biosolids drying has been suggested as a PFAS reduction method

“Reduction of PFAS concentrations in biosolids may be necessary in some regions to meet land application regulations. While the implementation of novel treatment technologies may be prohibitive in terms of scale and energy costs, biosolids drying is a conventional technology that can reduce the concentration of PFAS in biosolids.”

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PFAS reduction during biosolids drying correlates to initial moisture content and is accompanied by detection of PFAS in dryer condensate

Jessica Calteux,[a] Lynne Moss,[b] Rosely Ayala,[c] Aileen Baza,[c] Zhongzhe Liu,[c] Eric Redman,[d] Taryn McKnight,[d] Fabrizio Sabba,[be] Leon Downing[b] and Patrick McNamara *[ab]

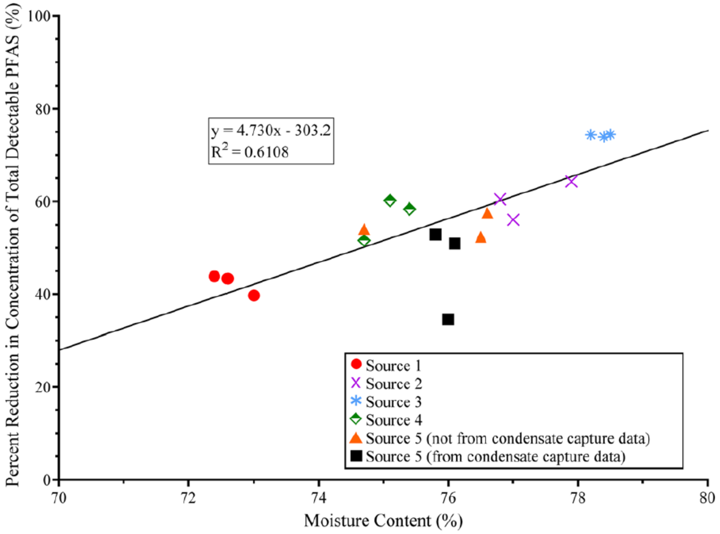


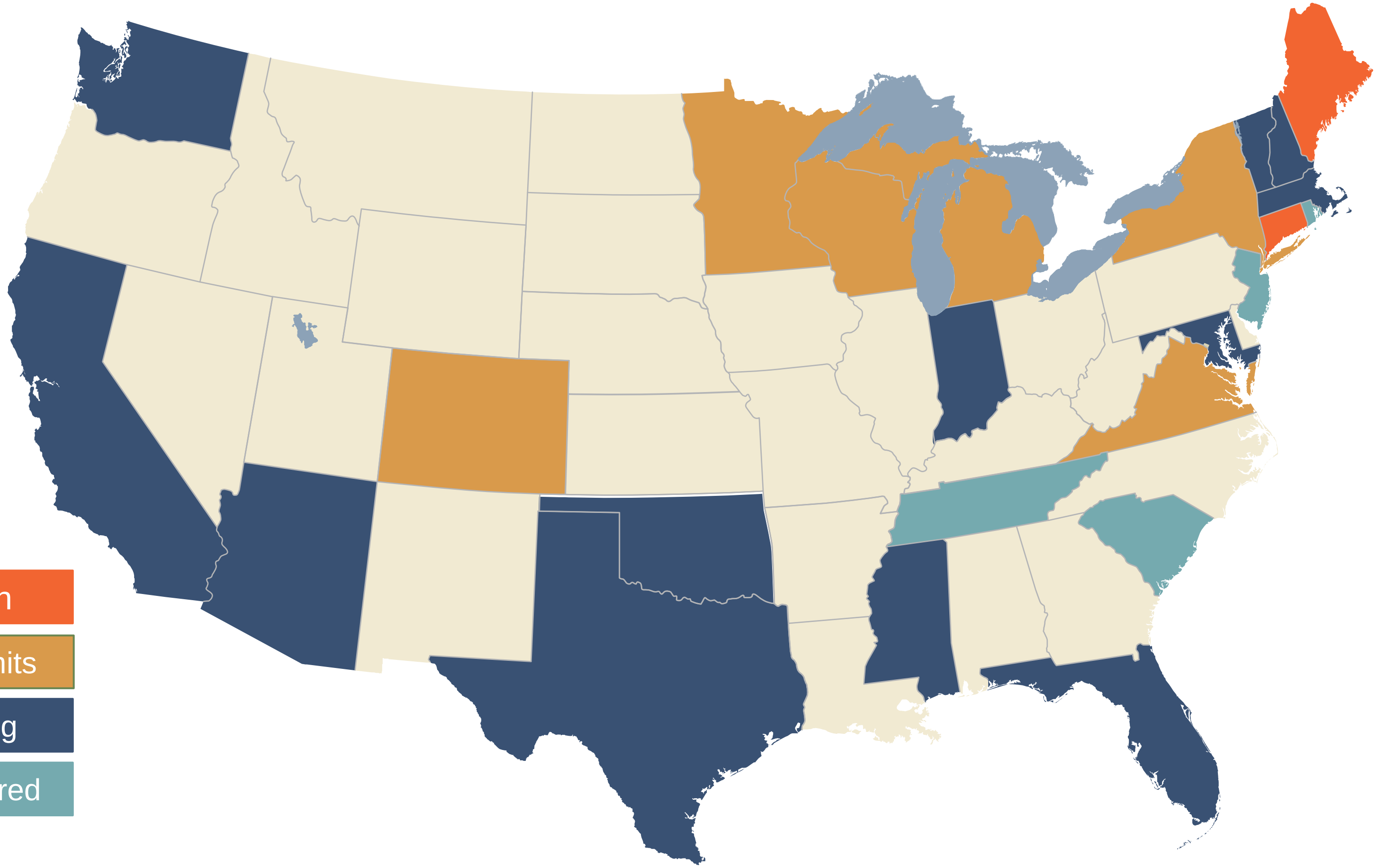
Fig. 2 Initial moisture content of biosolids is positively correlated to concentration reduction of total detectable PFAS (n = 18). Reporting limits were substituted in for non-detects. Reprinted with permission. © The Water Research Foundation.

States enacted biosolids PFAS rules in absence of federal regulations

The theme of state regulations advancing ahead of a federal (EPA) framework will be a repeated theme with respect to air emissions

Federal regulations could shift in one electoral cycle…

And, we see a clear increase in interest in projects on biosolids drying facility studies, design and installation



Ban on Land Application

Tiered Land Application Limits

Regulatory Efforts Ongoing

Monitoring/Reporting Required

Summary (not comprehensive) of major dryer types and manufacturers

Dryer Type	Major Manufacturers	Drying Temperature	Energy Consumption per ton evaporated H2O	Relative CAPEX	Typical Footprint	Key Operational Characteristics
Low-Temperature Belt	Veolia, HUBER	70 - 170C	550 - 750 kWh	$$$$$	Large to Very Large	Uses low-grade waste heat; safe; low fire risk; large physical footprint.
Indirect Thermal (Paddle/Film)	LCI Corp, Komline-Sanderson	150 - 300C	750 - 850 kWh	$$$	Compact to Medium	High thermal efficiency; minimal vapor flow; excellent heat recovery options.
Direct Thermal (Rotary)	Andritz, Baker-Rullman	150 - 600C	800 - 900 kWh	$$$$	Medium to Large	High capacity; rapid processing; intensive off-gas and odor control needed.

But, does drying temperature matter?

Maybe, yes?

- **Volatilization in context of chemical boiling points**

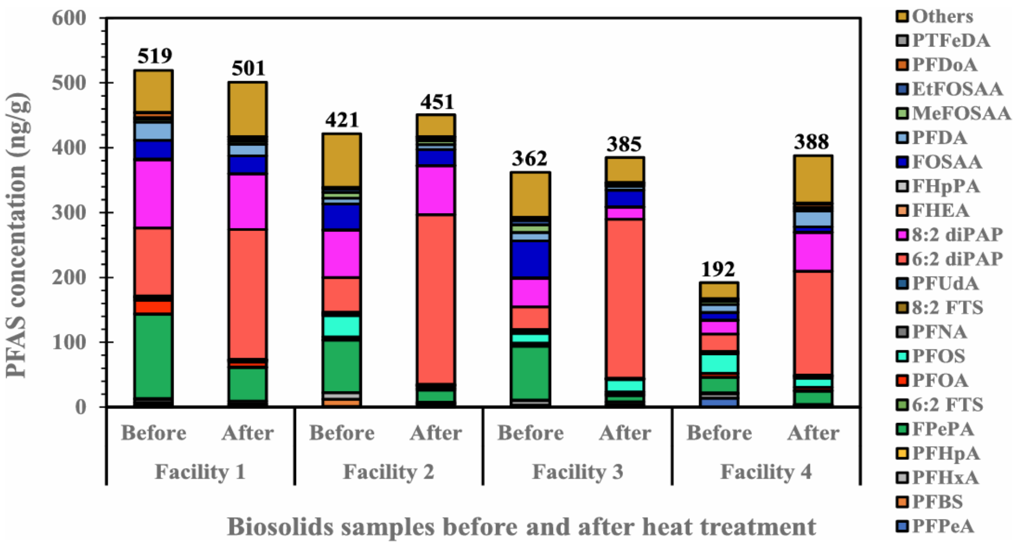
  Most regulatory-targeted, non-polymeric PFAS have high boiling points (PFOA ~188C and PFOS ~259C)

- **Low-temperature drying systems (70 – 110C)** results in mixed results with precursor transformation

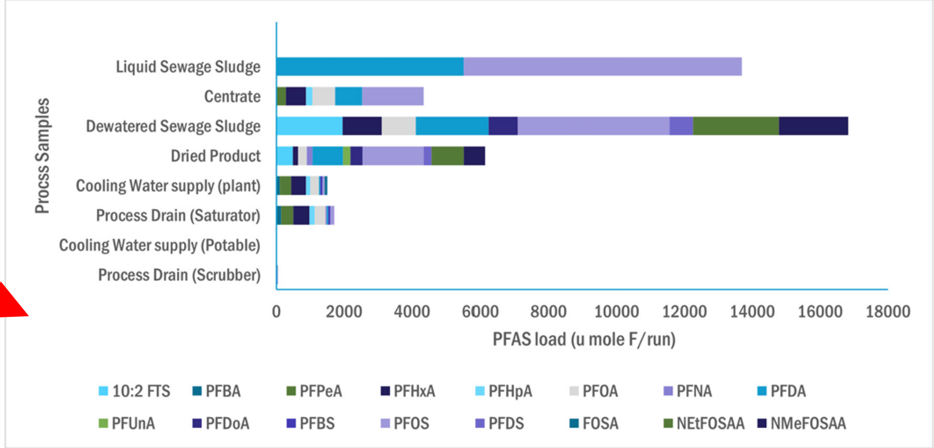
- **High-temperature systems (150C – 600C)**, including direct and indirect high-temperature dryers easily exceed the phase-change thresholds and > 60% of PFAS can volatilize and enter the dryer process off-gasses

THE Water Research FOUNDATION

WRF Project 5107 – Understanding Gasification for PFAS Removal (2025) also showed the same decreasing trend in PFAS through high temperature dryers



Hakeem, I. G., Halder, P., Patel, S., Selezneva, E., Rathnayake, N., Marzbali, M. H., Veluswamy, G., Sharma, A., Kundu, S., Surapaneni, A., Megharaj, M., Batstone, D. J., & Shah, K. (2024). Current understanding on the transformation and fate of per- and polyfluoroalkyl substances before, during, and after thermal treatment of biosolids. *Chemical Engineering Journal*, *493*, 152537. doi.org

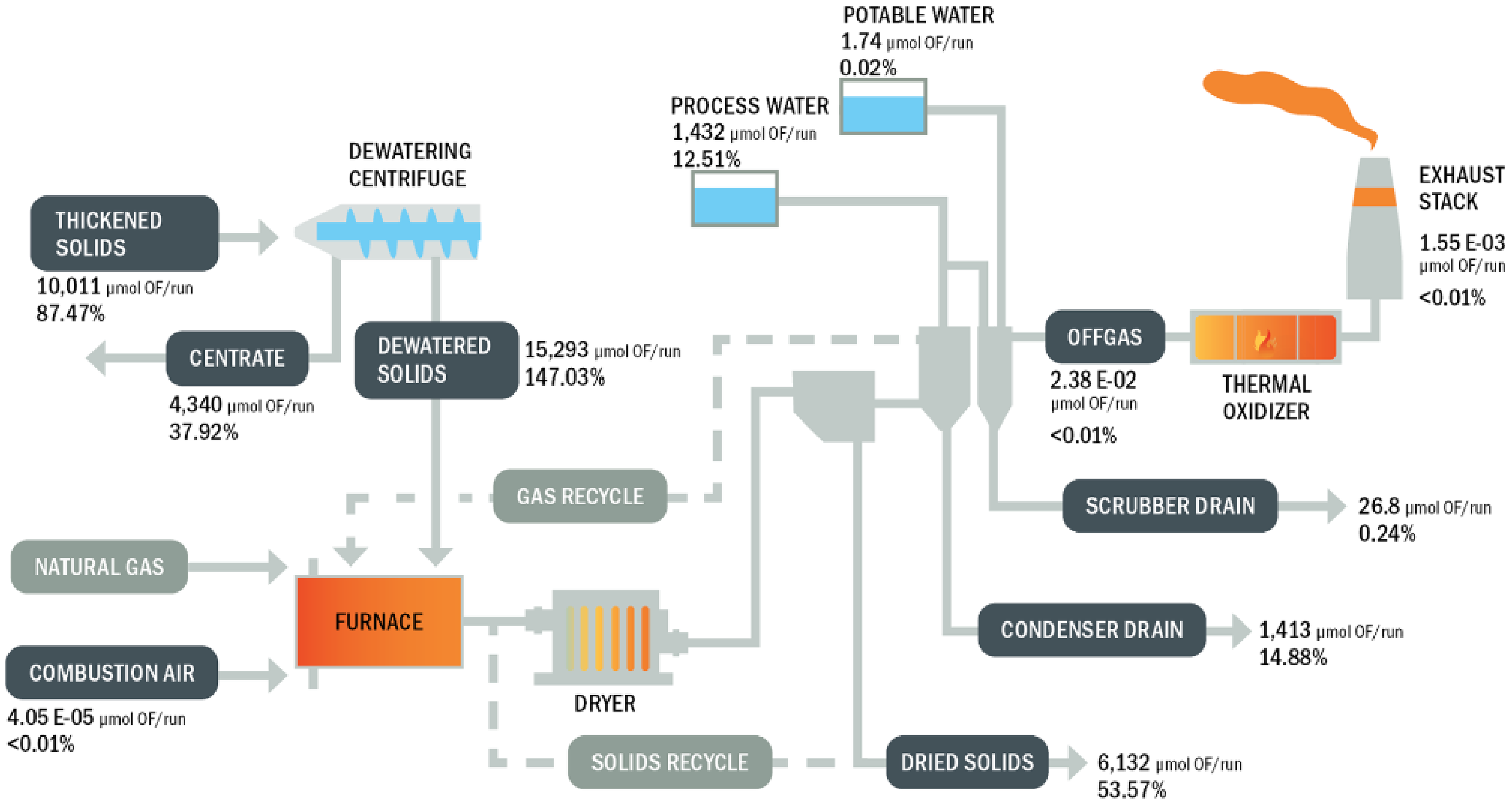


Comparison of PFAS mass reported within process samples.

Ross, J.J., Seidel, A., Kakar, F., Wells., M.J.M., Winchell, L., Bell, K., Song, D. (2025). Fate of PFAS Through a Biosolids Drum Dryer with Regenerative Thermal Oxidizer Emissions Control. *Water Environment Research*, 97:e70149.

RTOs have secondary benefits to VOC and odor control

- Recognizing that one proposed mechanism of reduction during drying is volatilization, capture and destruction of PFAS is critical, ***regardless of drying temperature***
- Recent full-scale studies show RTOs achieve >> 90% DRE for targeted PFAS released during the drying process



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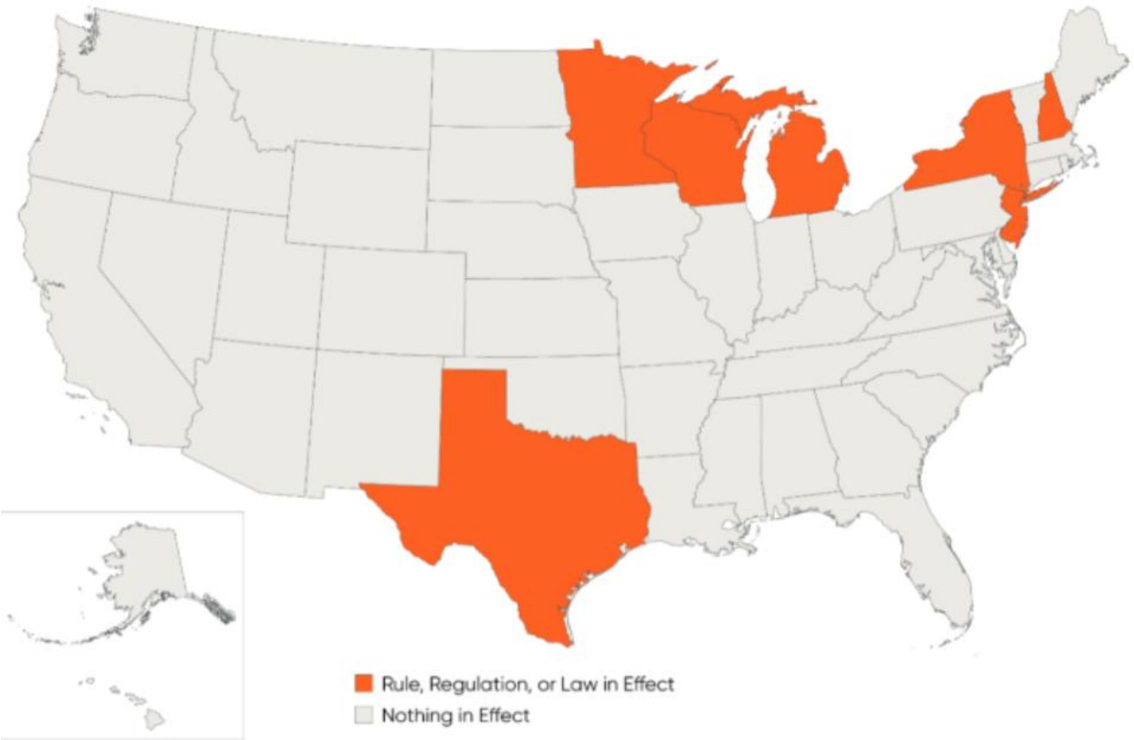
Emerging regulations for air emissions

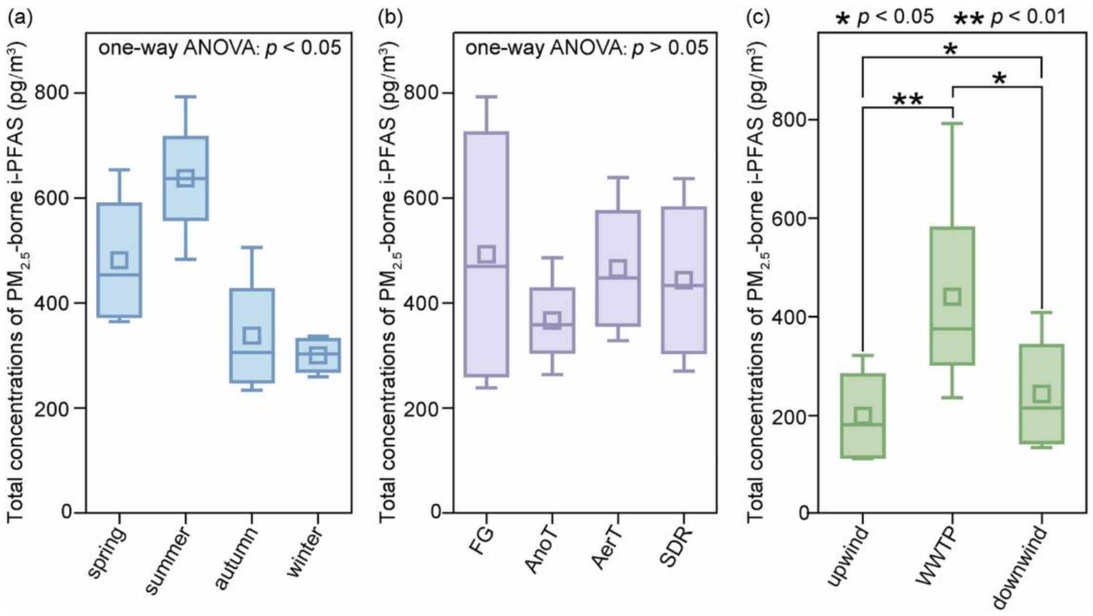
- The EPA is tackling PFAS (per- and polyfluoroalkyl substances) air emissions in two ways:
  - **Standardizing test methods to quantify stack pollution through Emissions Measurement; OTM-45 establishes a framework for sampling and measuring 50 PFAS compounds from stationary industrial sources. OTM-50 focuses on evaluating the efficiency of combustion systems to determine if they truly destroy PFAS or simply break them down into smaller byproducts.**
  - **Researching the effectiveness of thermal destruction technologies**
- This lays the groundwork for future enforceable Clean Air Act regulations…
- The EPA has faced petitions from environmental groups and state coalitions to formally add major PFAS chemicals (such as PFOA and PFOS) as HAPs which would mandate technology-based emissions limits, such as MACTs

Emerging state regulations and research on PFAS air emissions

https://www.lexology.com/library/detail.aspx?g=59524f19-fe86-4a29-aafd-378c531ed7de

States have already turned attention to legal analyses on consideration of regulating PFAS in air emissions, and they are rapidly moving ahead of federal rules (not unlike drinking water and biosolids regulations).



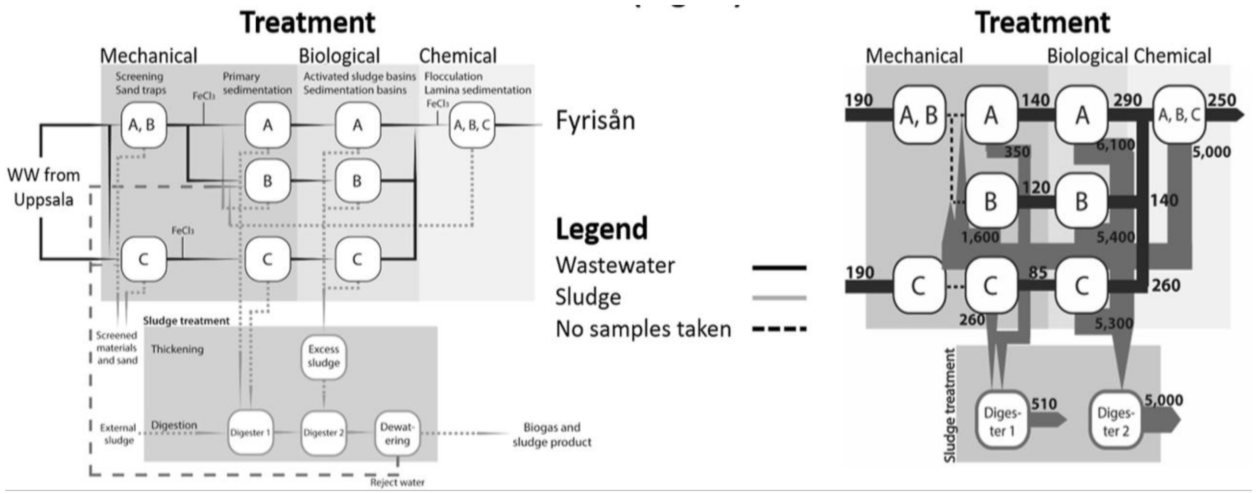


Wang, X., Zhang, Z., Zhang, Y., Han, Y., Pei, S., Li, X., Bi, X., Huang, S., & Yang, T. (2026). Ionic per- and polyfluoroalkyl substances in inhalable aerosols from wastewater treatment processes: Spatiotemporal variations, dispersion characteristics, influencing factors, and risks. *Journal of Hazardous Materials*, *507*, Article 141684. doi.org [1]

Emerging research points to other processes at WWTPs as significant contributors to air emissions of PFAS through aerosolization.

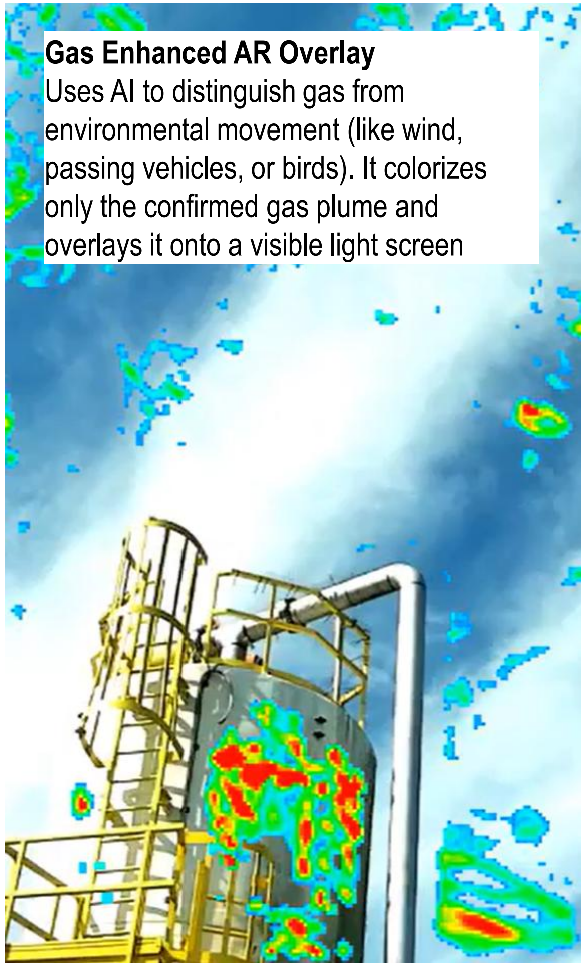
What wastewater utilities should consider and do now?

- Consider whether a particular facility has a higher PFAS air-emission risk, which results from
  - **Receiving wastewater from PFAS-using industries (plating, semiconductor, textile, chemical manufacturing)**
  - **Producing biogas/RNG from AD (e.g., fugitive methane emissions, may indicate PFAS emissions)**
  - **Operating thermal processes (dryers, pyrolysis/gasification)**
  - **Using dryers which can volatilize PFAS**
- Strengthen source control program
- Understand PFAS occurrence of PFAS, acknowledging FOIA considerations
- Did I say strengthen source control program?
- **Consider PFAS in facility plans and build a trigger-based roadmap**
- Did I say strengthen source control program?



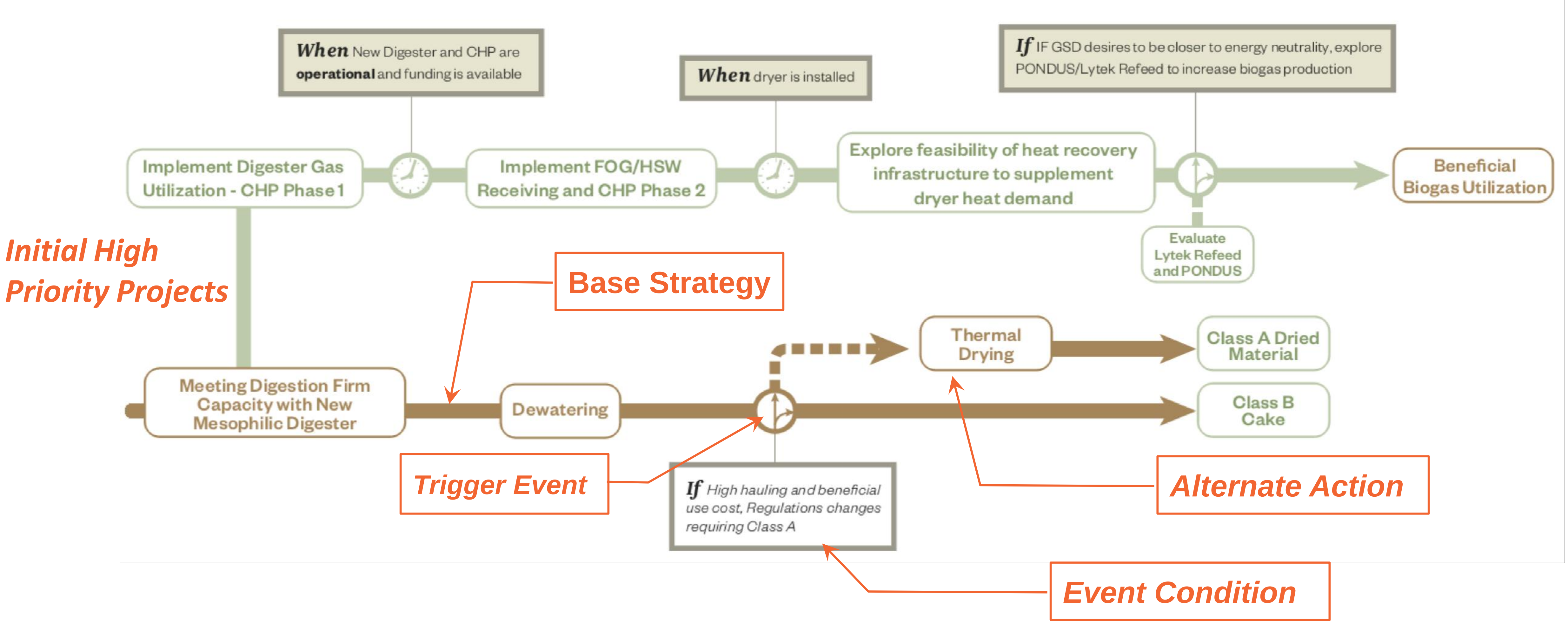
Gobelius, L., Wiberg, K., & Nguyen, M. A. (2023). Mass flow of per- and polyfluoroalkyl substances (PFAS) in a Swedish municipal wastewater network and wastewater treatment plant. *Chemosphere*, *336*, 139182. doi.org

Fugitive methane emissions could be indicators of PFAS emissions



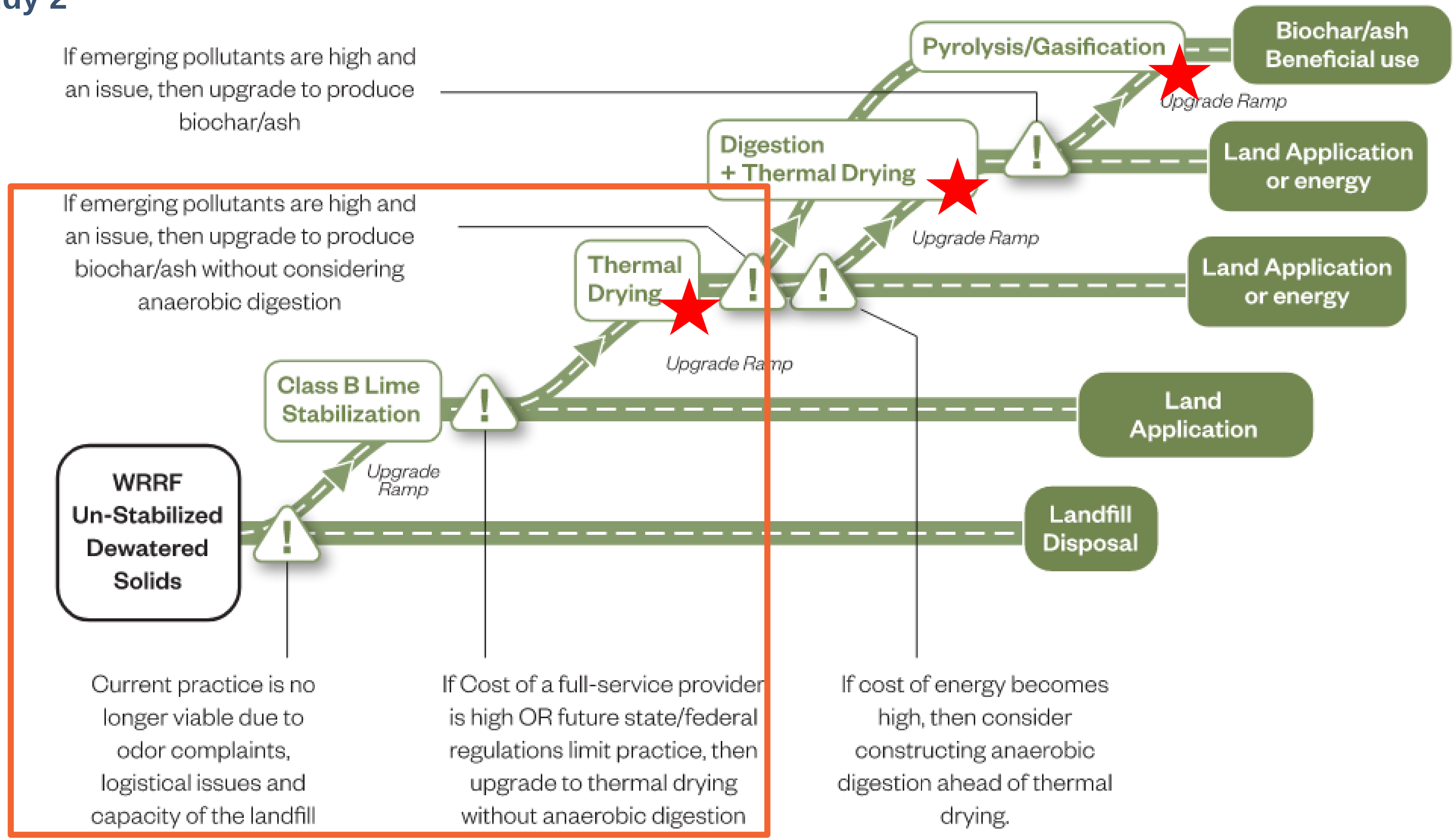
Build a flexible PFAS plan with a trigger-based implementation “Road Map”

Case Study 1



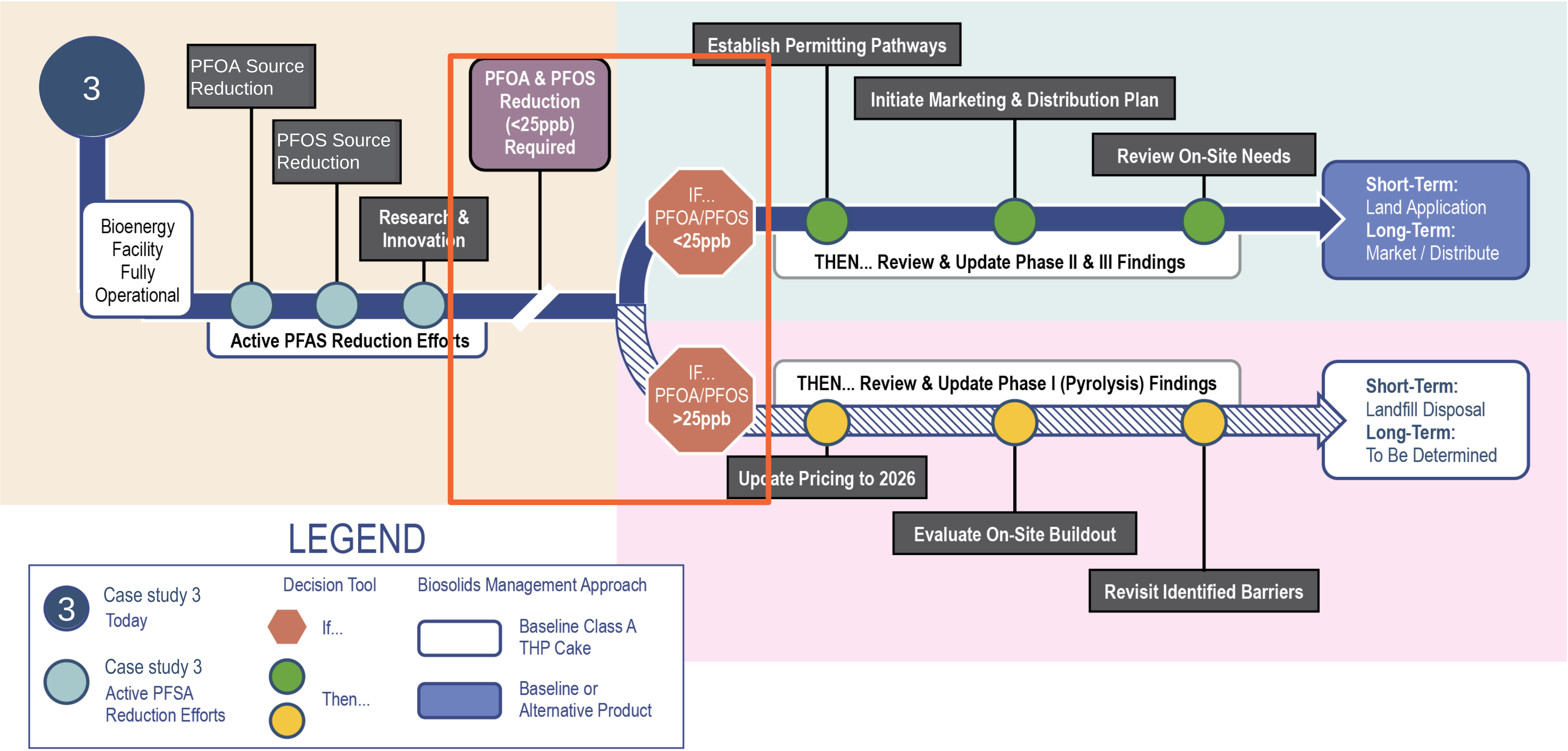
Build a flexible PFAS plan with a trigger-based implementation "Road Map"

Case study 2



Build a flexible PFAS plan with a trigger-based implementation "Road Map"

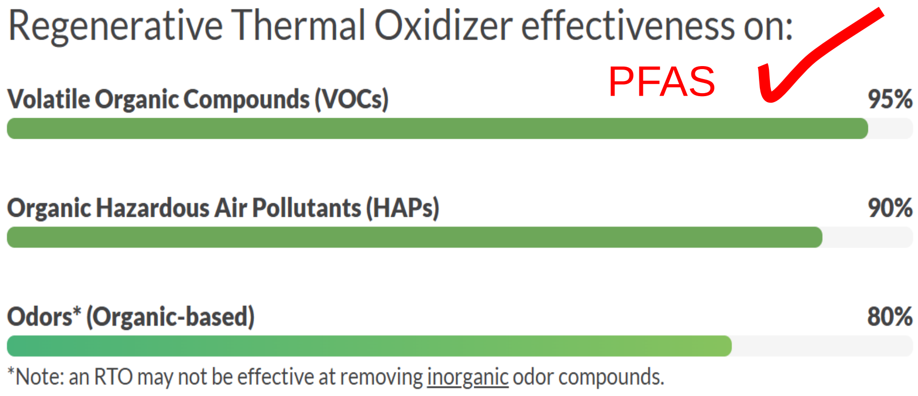
Case study 3…in progress



Summary and Discussion

RTOs are expensive and can be a maintenance challenge, but with changing regulations, they may be justified

- Given recent attention to emerging PFAS regulations and documented releases from aeration basins and biosolids handling processes (e.g., dryers and pyrolysis/gasification), TOs, and specifically RTOs, can have a dual benefit of addressing odor, hazardous air pollutants and PFAS.
- There are currently no requirements in the CAA for PFAS, EPA is developing a regulatory foundation, with through the PFAS Strategic Roadmap (2021–2026) with PFAS air regulation as a major priority; and, in absence of federal regulations, states are developing rules
- A forward-looking approach to PFAS includes attention to WWTP air emissions as an environmental release route of PFAS, to prepare for future compliance.
  - Wastewater utilities should have a trigger-based roadmap to avoid reactive expenditures when future regulations are promulgated
  - When utilities do facility planning, it is important to use evidence-based analysis of PFAS air-emission risks, including already published data on PFAS release rates and robust monitoring strategies
  - And, when considering PFAS air emissions, along with other objectives, use of TOs (RTOs) may be justified



https://www.ipeadvisor.com/regenerative-thermal-oxidizer

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