Brussels, 24/09/2023

Zero Waste Europe's response to the public consultation on the per- and polyfluoroalkyl substances (PFASs) restriction

Zero Waste Europe welcomes the opportunity to provide input on the restriction dossier on per- and polyfluoroalkyl substances (PFASs), and would like to thank to the authorities of Germany, Denmark, the Netherlands, Norway, and Sweden for their excellent work and submission of a proposal with such a comprehensive scope.

We recognise that evidence of cumulative high levels of many different PFAS in humans, as demonstrated by the joint European biomonitoring programme HBM4EU, is extremely worrying and highlights the urgency to take all possible measures to prevent further contamination of the European population. Therefore we hope that ECHA risk assessment committee (RAC) will minimise derogations for any non-essential uses of PFAS.

General Comments related to Food Contact Materials

It is recognised that, potentially, hundreds of hazardous chemicals may intentionally be present across a wide range of food contact materials (FCMs), with clear evidence for their migration into food. As the dossier submitters point out, PFAS are intentionally present across a wide range of FCMs, and in particular in disposable paper-based food packaging and tableware.

Paper and board are the fastest growing packaging material group in Europe. Reduced demand for paper from other sectors, such as graphic paper and sanitary paper, have been offset by a growth in packaging. This is mainly driven by the EU policies associated with a push towards reduction of single-use plastics - where disposable paper-based packaging is increasingly marketed as a 'sustainable' alternative, and by emerging trends including e-commerce and food delivery. In Europe alone, the online food delivery market is forecasted to grow with a 5.83% from 2020 to 2026.[1]

Additionally, the ban on certain single-use plastic FCM is resulting in a growing market for other alternative materials used in contact with food, which may also introduce chemical-related human health risks, as concluded by the recent Dutch report.[2] Examples of chemical(s) (groups) (thought to be) present in processed materials are, among others, PFAS.

All this creates extra burdens once the food packaging / disposable tableware reach their end of life phase, including when such articles are labelled as 'compostable'. Goossen et al. (2033) found that compost made

[1] https://inside-packaging.nridigital.com/packaging_may21/takeaway_packaging_throwaway_culture)
[2] Zwartsen A. et al. Alternative food contact materials on the Dutch market after implementation of the Single Use Plastic Directive and prioritisation of potential migrating chemical substances. RIVM report 2022-0102.

from manure and compostable service ware was contaminated with 20–45 times more PFAS chemicals than separated food waste composted with grass clippings and manure.[3]

The end-of-life phase and related emissions

The dossier submitters acknowledge the relevance of the End-of-life (EoL) but point out several data gaps. EoL is a very relevant emission and exposure pathway for PFASs, and more and more evidence confirms that those chemicals, once PFAS-containing articles reach their end of service phase, are often not fully destroyed and emissions take / can potentially take place during waste management. Therefore, we strongly believe that are in general underestimating the actual PFAS emissions.

We share here a number of studies that were not included in the dossier's references and which should be taken into account when assessing the fate and potential release of PFASs into the environment when PFAS-containing products become waste and are landfilled or incinerated:

Reinhart, D. R., Bolyard, S. C., & Chen, J. (**2023**). Fate of Per- and Polyfluoroalkyl Substances in Postconsumer Products during Waste Management. Journal of Environmental Engineering, 149(4). https://doi.org/10.1061/JOEEDU.EEENG-7060

This paper summarises the current knowledge associated with the fate and release of PFAS from postconsumer products from commonly used waste management processes (including landfilling, recycling, composting, and incineration). The results of comprehensive review indicate that:

- The waste sorting process can create a direct pathway for PFAS emissions and exposure to workers. The PFAS in electronic products creates significant potential for PFAS exposure for people handling and recycling e-waste, and the major pathways are inhalation, ingestion, and dermal exposure.
- Landfills are major sinks of PFAS because most PFAS-containing consumer products are landfilled, and PFAS was extensively reported in landfill leachate.
- Recycling and composting also present potential exposure pathways. The reprocessing of carpet and paper packaging was reported to cause direct exposure to onsite workers through PFAS volatilization and dust emissions. Recycling can cause the circularity of PFAS in the new product and subsequent release throughout its lifespan.
- Composted food packaging was found to contain PFAS and could cause contamination during the land application of compost.
- Some low-temperature regions within the incineration furnace may still result in products of incomplete combustion, such as short-chain perfluoroalkyl acids and other stable fluorinated compounds, which may be released in incinerator ash.
- At the lower temperatures employed during pyrolysis, C–C bonds in longer-chain PFAS tend to break prior to the C–F bonds, leading to the formation of highly unstable and electrophilic

[3] Goossen, C. P. et al. (2023). Evidence of compost contamination with per and polyfluoroalkyl substances (PFAS) from "compostable" food serviceware. Biointerphases, 18(3). https://doi.org/10.1116/6.0002746

fluoroalkyl radicals, which produce short-chain volatile fluorinated products such as perfluoroalkanes and alkenes. Six major classes of fluorinated products from pyrolysis that were largely absent at higher temperatures (890°C) were found, suggesting mineralization of PFAS and products occurs at high temperatures but not at lower temperatures. Effective decomposition of PFAS (pure substances) during pyrolysis at temperatures as low as 200°C was promoted by a radical chain mechanism involving chain cleavage at the bond between the perfluoroalkyl chain and the nonfluorinated moiety.

- Gasification is commonly done in the presence of low levels of oxygen and at temperatures below 600°C which are still too low to destroy some PFAS. Like pyrolysis, the low oxygen level may lead to incomplete PFAS destruction, production of short-chain PFAS, and volatilization.

Zhang, Man, et al. (**2023**) "Poly-and perfluoroalkyl substances (PFAS) in landfills: occurrence, transformation and treatment." *Waste Management* 155, 162-178. https://doi.org/10.1016/j.wasman.2022.10.028

- Based on the data published from 10 countries (250+ landfills), C4-C7 perfluoroalkyl carboxylic acids were found predominant in the untreated landfill leachate and neutral PFAS, primarily fluorotelomer alcohols, in landfill air. The effectiveness and limitations of the conventional leachate treatment technologies and emerging technologies were evaluated to address PFAS released into the leachate.

Capozzi, Staci L., et al. (**2023**) "PFAS in municipal landfill leachate: Occurrence, transformation, and sources." Chemosphere 334, 138924. https://doi.org/10.1016/j.chemosphere.2023.13892

- 32 PFAS were measured in landfill leachate from 17 landfills across Washington State
- As in other studies, 5:3 FTCA was the dominant PFAS in the leachate, suggesting that carpets, textiles, and food packaging were the main sources of PFAS.

Chen, Yutao, et al. (**2023**) "Evaluation of per-and polyfluoroalkyl substances (PFAS) in leachate, gas condensate, stormwater and groundwater at landfills." *Chemosphere* 318, 137903. https://doi.org/10.1016/j.chemosphere.2023.137903

- The study aimed to evaluate a wide cross-section of solid waste disposal facilities to identify PFAS levels in leachates (from municipal solid waste (MSW), construction and demolition debris (CDD), municipal solid waste incineration (MSWI) ash), gas condensates (from MSW and CDD gas wells, flare stations, and mixed sources), stormwater (including inlets and outlets from retention areas) and groundwater (from landfills with different leachate containment systems). In total, 281 aqueous landfill samples were collected from 39 landfills in 29 counties in Florida, US.
- Twenty-six PFAS including 11 perfluoroalkyl carboxylic acids (PFCAs), 7 perfluoroalkyl sulfonates (PFSAs), and 8 perfluoroalkyl acid precursors (PFAA-precursors) were measured in municipal solid waste (MSW) leachate, construction and demolition debris (CDD) leachate, municipal solid waste incineration (MSWI) ash leachate, gas condensate, stormwater, and groundwater from landfills. Based on the median, results show that PFAS levels in MSW leachate were the highest (10,000 ng/L), CDD leachate were intermediate (6200 ng/L), and MSWI ash leachate were the lowest (1300 ng/L) among the leachates evaluated. PFAS levels in gas condensate (7000 ng/L)

were similar to MSW leachate. PFAS in stormwater and groundwater were low (medians were less than 500 ng/L). Dominant subgroups included PFCAs and PFAA-precursors in all leachates. PFSAs were also found in CDD leachate, PFAA-precursors in gas condensate, and PFCAs in stormwater and groundwater. Landfill characteristics significantly correlated with ∑26PFAS included waste proportions (percentage of MSWI ash in landfill, |rs| = 0.22), operational status (active or not, |rs| = 0.27) and rainfall (30-d cumulative rainfall, |rs| = 0.39).

Liu, Y. et al. (**2022**). Municipal solid waste incineration (MSWI) ash co-disposal: Influence on per- and polyfluoroalkyl substances (PFAS) concentration in landfill leachate. *Waste Manage.*, *144*, 49– 56, DOI: https://doi.org/10.1016/j.wasman.2022.03.009

- Authors hypothesise that leachate generated in co-disposal scenarios (incineration ash with unburned waste) preferentially flows through PFAS-rich unburned materials and that biotransformation of precursors enhanced by unburned waste degradation further contributes to higher concentrations of terminal PFAS in ash co-disposal sites. Landfill operators should expect PFAS in leachates to be higher when PFAS-rich unburned wastes are disposed of alongside MSWI ash, even if the unburned fraction is small.

Li, J., et al. (**2022**). "A critical review of the occurrence, fate and treatment of per-and polyfluoroalkyl substances (PFASs) in landfills". Environmental Research, 114980. https://doi.org/10.1016/j.envres.2022.114980

- A review of 119 articles showed that short-chain PFASs (<8 carbons) are more common than long-chain PFASs (≧8 carbons) in landfill leachate. PFASs in landfill leachate are eventually transported to the surrounding groundwater, surface water and soil. Some PFASs evaporate from landfills to the ambient air.

Björklund, Sofie, et al. (**2021**) "Occurrence of per-and polyfluoroalkyl substances and unidentified organofluorine in leachate from waste-to-energy stockpile - A case study." *Chemosphere* 278: 130380. https://doi.org/10.1016/j.chemosphere.2021.130380

- A case study investigated releases of PFASs from temporarily stored waste by determining quantities of 34 PFASs in leachate from a Waste-to-Energy stockpile (45 000 ± 2000 tonnes) during five months in 2019. Extractable organofluorine (EOF) was also measured, to account for PFASs not included in the target list.
- The mean total concentration of the 34 PFAS (Σ_{34}PFAS) was 211 ± 31 ng/L, and short-chain (C4–C7) perfluorocarboxylic acids (PFCAs) accounted for 56–60% of the total. Moreover, Σ_{34}PFAS only accounted for 12% ± 4% of EOF detected in the leachate.
- The results demonstrate that waste stockpiles are unexplored sources of PFASs in the environment, and the dominance of short-chain PFCAs is consistent with observed profiles of contaminants in landfill leachates.

Björklund, Sofie, et al. (**2023**) "Emission of Per-and Polyfluoroalkyl Substances from a Waste-to-Energy Plant— Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas." *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.2c08960

- This study forms part of a comprehensive investigation of the occurrence and distribution of PFASs in Waste to Energy residues. Samples were collected at a full-scale WtE plant in northern Sweden.
- PFASs were identified in all examined residues, with short-chain (C4–C7) perfluorocarboxylic acids being the most abundant.
- Results demonstrate that some PFASs are not fully degraded by the high temperatures during Waste to Energy conversion and can be emitted from the plant via ash, gypsum, treated process water, and flue gas.
- By establishing the PFAS concentrations of all fractions leaving the WtE facility, an estimate of the total annual release of PFASs could be conducted.

Blotevogel, J et al. (**2023**). Incinerability of PFOA and HFPO-DA: Mechanisms, kinetics, and thermal stability ranking. Chemical Engineering Journal, 457, 141235. https://doi.org/10.1016/j.cej.2022.141235

- To address critical knowledge gaps around the incinerability of PFAS, highest-level coupled cluster theory was applied to elucidate the primary thermal destruction pathways, mechanisms, and kinetics for perfluorooctanoic acid (PFOA) and hexafluoropropylene oxide dimer acid (HFPO-DA, sometimes referred to as "GenX").
- Initial decomposition of both carboxylic acids proceeds through HF elimination at the α-carbon, but for PFOA surprisingly shifts towards C-COOH bond dissociation in the presence of ammonia due to ammonium stabilisation of the variational transition state. Branching substantially reduces the required incineration temperatures, while chain length has no impact on perfluoroalkyl carboxylic acid (PFCA) decomposition rates. Bimolecular reactions with secondary species such as counterions and radicals have lower activation barriers than unimolecular decomposition, but their second-order kinetics depend on concentration and thus waste stream composition, which varies in practice.
- Simulating radical concentrations under typical incineration conditions, the determined free energies of activation suggest an incinerability ranking for linear PFOA in Class 3, for branched PFOA in Class 4, and for HFPO-DA as well as both PFOA and HFPO-DA ammonium salts in Class 5. Collectively, the temperatures needed to destroy 99.99% of PFOA, HFPO-DA, and other PFCAs in 2 seconds gas residence time are well below those of other commonly incinerated organic compounds such as chlorobenzene (Class 1). Ultimately, sufficient supply of radical donors is critical to ensure safe, efficient, and complete destruction of PFAS during thermal treatment.

- Zhang, Hekai et al. (**2023**). "Comparison of the Pfas and Physical-Chemical Parameter Fluctuations between an Ash Landfill and a Msw Landfill." Available at SSRN: https://ssrn.com/abstract=4530925 or http://dx.doi.org/10.2139/ssrn.4530925
- In this study, aqueous landfill samples (leachate, treated leachate, gas condensate, groundwater) were collected once a month for six months from the same two landfills (an MSW - municipal solid waste, and an MSWA - MSW incinerator ash landfill) geographically located within proximity, which provides the unique opportunity to compare fluctuations between landfill types.
- Results showed that the CV of total detected PFAS concentrations in leachate was higher for the MSW landfill (CV=43%) compared to the MSWA landfill (CV=16%). As expected, the total detected PFAS concentration in MSW leachate samples (mean: 8639 ng/L) was higher than the total detected PFAS concentration in MSWA leachate samples (mean: 2511 ng/L) ($p < 0.05$). Within a landfill, PFAS concentrations were correlated ($rs>0.6$, $p<0.05$) with alkalinity, TOC, and ammonia.
- Overall, results showed that differences between landfill types and fluctuations in PFAS within landfills should be considered when designing landfill leachate systems to remove PFAS.

Shanshan Liu et al. (**2021**) "Perfluoroalkyl substances (PFASs) in leachate, fly ash, and bottom ash from waste incineration plants: Implications for the environmental release of PFAS." *Science of the Total Environment* 795: 148468. https://doi.org/10.1016/j.scitotenv.2021.148468

- Relatively lower levels of PFASs in fly ash and bottom ash indicated that high-temperature incineration destroyed most of the PFASs.
- In general, short chain PFASs, including perfluorobutyric acid (PFBA) and perfluorobutane sulfonate (PFBS), were the primary PFASs in leachate samples. In addition, PFOS was the predominant PFASs in fly ash samples.
- The results showed that leachate, fly ash, and bottom ash from municipal solid waste incineration plants are important vectors of PFASs.

Liu, Xuemei, et al. (**2023**): "Occurrence and removal of per-and polyfluoroalkyl substances (PFAS) in leachates from incineration plants: A full-scale study." Chemosphere 313, 137456. https://doi.org/10.1016/j.chemosphere.2022.137456

- The overall objectives of this study were to characterise leachate PFAS concentrations in MSW incineration plants operated with full-scale treatment processes, and to use the concentration data of the influent and effluent samples to estimate the removal of PFAS from each treatment unit.
- Seventeen PFAS species were found to be present in the raw leachates and finished effluents, with higher occurrence of short-chain PFAS. The considerable variability in PFAS concentrations before and after treatment indicated the effectiveness of the combined treatment processes for PFAS reduction.

Seay, Brannon A., et al. (**2023**) "Per-and polyfluoroalkyl substances fate and transport at a wastewater treatment plant with a collocated sewage sludge incinerator." *Science of The Total Environment* 874 162357. https://doi.org/10.1016/j.scitotenv.2023.162357

- Study measured PFAS and inorganic fluoride (IF) at all influents/effluents of a wastewater treatment plant (WWTP) operating a sewage sludge incinerator (SSI).
- Most PFAS mass discharged in aqueous effluent; small contributions to air/landfill.
- The total PFAS destruction and removal efficiency of 51 % indicated the SSI may inadequately remove PFAS.

Strandberg, Johan, et al. (**2021**) "PFAS in waste residuals from Swedish incineration plants." https://www.ivl.se/download/18.556fc7e17c75c849331b76d/1636533451380/B2422%20PFAS%20from%20Swedish%20Waste%20Incineration%20Plants.pdf

- The collected samples of bottom ash, fly ash and condensate from incineration plants in Sweden (in total 31 furnaces) were analysed for 27 different PFAS. The chemicals have been divided into PFSA, PFSA precursors, PFCA, and PFCA precursors.
- Analysis showed detectable levels of PFAS-27 in the pooled bottom ash samples from 9 out of 31 furnaces, in concentrations between 0.22 to 12.76 µg/kg. PFCA precursors, especially 6:2 diPAP was the dominant type found in 6 of the 9 furnaces. For fly ash, there were detectable levels of PFAS-27 in 15 out of 31 furnaces, at concentrations between 0.18 to 37.71 µg/kg. In 12 of those 15 samples, the total PFAS-27 concentration was below 2 µg/kg. Three samples stand out from the others, with concentrations above 21.3 µg/kg. For condensate water, there were detectable levels of PFAS-27 in 13 out of 31 furnaces, at concentrations between 0.28 to 182.95 ng/L. The most dominant PFAS were total PFCA with a large representation of short-chain PFCA's.
- Conclusion: High incineration temperatures or a high proportion of a particular type of waste is not a guarantor of low concentrations of PFAS.

Orr, J. (**2023**). Lab-scale Evaluation of PFAS Decomposition and Flue Gas Qualities from Biosolids Incineration Process. In *Residuals and Biosolids 2023*. Water Environment Federation. https://www.accesswater.org/publications/proceedings/-10091958/lab-scale-evaluation-of-pfas-decomposition-and-flue-gas-qualities-from-biosolids-incineration-process

- In order to better understand the fate and transport of PFAS compounds in wastewater sludge undergoing thermal combustion, a bench-scale system, that mimics a full-scale biosolids incineration, was constructed. Two batch studies were conducted with the system in 2020 and 2021 to investigate: 1) the decomposition and removal efficiency (DRE) of the PFAS in biosolids; 2) the residual PFAS concentrations in the ash, 3) the PFAS concentrations in the flue gas, and 4) the effect of operating parameters on the performance. The operating parameters evaluated were combustion temperature and gas residence time.

- The PFAS decomposition efficiency based on total PFAS (sum of the 36 analysts) was at a level of 99.9999% (6 logs) for the 2021 study and 99.67% (close to 3 logs) for the 2020 study, on average. The major difference in operating conditions between the two studies was the gas residence times - 2 seconds for the 2020 study and 4 seconds for the 2021 study. The two tests were run at the same combustion temperature of 1,150°C. Therefore, it was believed that doubling the gas residence time from 2 s to 4 s improved the PFAS decomposition efficiency.
- The average flue gas PFOA and PFOS levels for the 2020 study were about 132.3 ng/m3 and 152.7 ng/m3, respectively. However, the average levels of PFOA and PFOS for the 2021 study were about 60.8 ng/m3 and 59.4 ng/m3, respectively. The results from the 2021 study suggest that the air combustion operated at 1150°C and 4 seconds GRT can lower the emissions.
- Conclusions: this bench scale study demonstrates that thermal combustion can be effectively and efficiently utilized to achieve near complete PFAS decomposition in the biosolids. The gas residence time of 4 seconds at a combustion temperature of 1150°C improved the total PFAS decomposition and lowered the air emission for PFOA and PFOS, compared to the 2 seconds GRT.

Arkenbout, Abel. (**2018**) "Long-term sampling emission of PFOS and PFOA of a Waste-to-Energy incinerator." NGO ToxicoWatch Foundation, Harlingen, The Netherlands. https://www.researchgate.net/profile/Abel-Arkenbout/publication/327701467_Long-term_sampling_emission_of_PFOS_and_PFOA_of_a_Waste-to-Energy_incinerator/links/5b9fc34c45851574f7d24cbd/Long-term-sampling-emission-of-PFOS-and-PFOA-of-a-Waste-to-Energy-incinerator.pdf

- Flue gas of the REC incinerator in Harlingen (Netherlands) was analysed in a long-term sampling program.
- The results showed PFOS only detectable (above LOQ) at one shutdown event with 8,23 pg/Nm3. PFOA was detectable in all (n=6) long-term sampling periods (433 – 794 hours). Minimum-maximum is 0,0134 – 0,004 ng/Nm3, average emissions are 0,002 ng/Nm3, which results in a yearly load estimate of 40,1 mg PFOA and 4,9 mg PFOS.
- Finding PFOA in the stack can be an indicator of incomplete combustion, i.e. not complying with a minimum 2 seconds residence time at 850 °C.

Importantly, there is a good number of biomonitoring studies dedicated to study the influence of incineration on accumulation of hazardous chemicals, including PFAS, in the vicinity of installation(s). Those studies prove that PFAS are emitted from incinerators.

The analysis of the available records of the continuous measurements of atmospheric emissions at the Zubieta waste plant (Spain) in the years 2020 and 2021, together with other available information, points to serious non-compliance with IPPC regulations on integrated pollution prevention and control. The full report is available in PDF format through this link.

Martin, K. V. et al. (**2023**). PFAS soil concentrations surrounding a hazardous waste incinerator in East Liverpool, Ohio, an environmental justice community. Environmental Science and Pollution Research, 1-12. https://doi.org/10.1007/s11356-023-27880-8

- A pilot study to examine the distribution and concentration of PFAS in soil samples surrounding the incinerator situated in eastern Ohio, East Liverpool (US).
- All 35 soil samples had measurable amounts of PFAS including perfluorobutanesulfonic acid (PFBS), perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), and hexafluoropropylene oxide dimer acid (HFPO-DA)/GenX. PFOS was measured in the majority of soil samples (97%) with a range of 50–8,300 ng/kg. PFOA was measured in 94% of soil samples with a range of 51 ng/kg to 1300 ng/kg. HFPO-DA/GenX was measurable in 12 soil samples with concentrations ranging from 150 ng/kg to 1500 ng/kg.

Building on the 2021 results, **Zero Waste Europe coordinated a more recent biomonitoring research on incinerator emissions across Europe**, together with ToxicoWatch, Hnuti Duha, Ziedine Ekonomika, and Ecologists en Accion Spain. The results (published in Q1 2023) again found high levels of persistent organic pollutants (POPs) in the vicinity of incinerators. High quantities of PFAS (the limited chemical analysis identified PFOS and GenX) were found in moss, pine needles and backyard chicken eggs around the waste incinerators,in all three (3) areas, i.e. Spain, Lithuania and the Czech Republic.[4]

Very recent study from Italy (published in September 2023) confirmed that PFAS were found in eggs sampled through a biomonitoring campaign sampling around an incinerator (and power station) in Venice.

Finally, even if not proven technologies yet, the market share for pyrolysis and gasification is expected to grow due to a current push towards chemical recycling (and notably for plastics to be used in food contact applications). The high temperatures and residence times achieved by pyrolysis or gasification followed directly by combustion of the hydrogen-rich syngas stream in a thermal oxidizer (or afterburner) could potentially destroy PFAS by breaking apart the chemicals into inert or less recalcitrant constituents. However, this mechanism, as well as evaluation of potential products of incomplete destruction, remain a subject for further investigation and research.

Ross, J. (**2023**). PFAS Study Updates: Sewage Sludge Incineration (WRF# 5111) and Biosolids Pyrolysis with Thermal Oxidation (WEF). In *Residuals and Biosolids 2023*. Water Environment Federation. https://www.accesswater.org/publications/proceedings/-10091982/pfas-study-updates-sewage-sludge-incineration-wrf-5111-and-biosolids-pyrolysis-with-thermal-oxidation-wef-

[4] https://zerowasteeurope.eu/wp-content/uploads/2023/01/2023-Biomonitoring-report-FULL-REPORT-FINAL.pdf

- PFAS testing at two full-scale sewage sludge incinerators was recently completed under Water Research Foundation Project #5111 and results are expected for publication at the end of 2023.
- Preliminary PFAS sampling was conducted at the Silicon Valley Clean Water biosolids pyrolysis system and a lab-scale unit commissioned to mimic its operating parameters under a Water Environment Federation collaborative research project.
- Formal PFAS sampling is expected to occur this summer for the lab-scale unit and early 2024 for the full-scale pyrolysis system. This presentation presents several insights into test plan development and the status of analytical tools available to characterise the fate of PFAS through these systems.

Sørmo, E., Castro et al. (**2023**). The decomposition and emission factors of a wide range of PFAS in diverse, contaminated organic waste fractions undergoing dry pyrolysis. *Journal of Hazardous Materials*, *454*, 131447. https://doi.org/10.1016/j.jhazmat.2023.131447

- Dry pyrolysis is an emerging alternative to these practices, but there is uncertainty related to the fate of PFAS during this process.
- A mass balance was established for 56 different PFAS during full-scale pyrolysis (2–10 kg biochar/hr^{-}, 500–800 °C) of sewage sludges, food waste reject, garden waste and waste timber. PFAS were found in all wastes (56–3651 ng/g), but pyrolysis resulted in a ≥ 96.9% removal. Residual PFAS (0.1–3.4 ng/g) were detected in biochars obtained at temperatures up to 750 °C and were dominated by long-chain PFAS.
- Emitted PFAS loads ranged from 0.01 to 3.1 mg/tonne of biochar produced and were dominated by short chain PFAS. Emissions made up < 3% of total PFAS-mass in the wastes. Remaining uncertainties are mainly related to the presence of thermal degradation products in flue gas and condensation oils.

Wallace, J.S et al. (**2023**). Burning questions: Current practices and critical gaps in evaluating removal of per-and polyfluoroalkyl substances (PFAS) during pyrolysis treatments of biosolids. *Journal of Hazardous Materials Letters*, *4*, p.100079. https://doi.org/10.1016/j.hazl.2023.100079

- Biosolids generated during municipal wastewater treatment are a major environmental source of PFAS due to prevailing disposal practices as fertilisers.
- Pyrolysis is emerging as a viable, scalable technology for PFAS removal from biosolids while retaining nutrients and generating renewable, raw materials for energy generation. Despite early successes of pyrolysis in PFAS removal, significant unknowns remain about PFAS and transformation product fates in pyrolysis products and emissions.
- Applicable PFAS sampling methods, analytical workflows, and removal assessments are currently limited to a subset of high-interest analytes and matrices. Further, analysis of exhaust gases, particulate matter, fly ashes, and other pyrolysis end-products remain largely unreported or limited due to cost and sampling limitations. This paper identifies critical knowledge gaps on the pyrolysis of biosolids that must be addressed to assess the effectiveness of PFAS removal during pyrolysis treatment.