

PFAS in Landfill Leachate

Factors contributing to PFAS concentration:

- Weather-precipitation, varying climates
- pH (decreased sorption with increasing solution pH due to protonation of the adsorbent surface, leading to fewer positive sites on the sorbent)
- How long the landfill has been in operation/not in operation
- Waste ages and composition
- Public/privately owned
- Leachate management system (leachate recirculation vs flow through)
- Electrical conductivity (a measure of ion concentration in solution)

United States: Lang et al (2017) National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate, *Environmental Science & Technology*, Vol 51 (4), 2197-2205, DOI: 10.1021/acs.est.6b05005

- The concentrations of 70 PFASs in 95 samples of leachate were measured in a survey of U.S. landfills (18 total) of varying climates and waste ages.
- The PFASs assigned to group 1 (>50% of samples exhibited quantifiable concentrations) belong to the PFCAs, FTCAs, PFSAs, fluorotelomer sulfonic acid (FTSAs), n-methyl fluoroalkyl sulfonamido acetic acids (MeFASAAs) and n-ethyl fluoroalkyl sulfonamido acetic acid (EtFASAAs) compound classes. The widespread presence of C4–C10 PFCAs and C4, C6, and C8 PFSAs in the sampled leachate is consistent with previous observations of these PFASs in leachate and as residuals on PFAS-treated products.

Australia: Gallen et al (2017) Australia-wide assessment of perfluoroalkyl substances (PFASs) in landfill leachates, *Journal of Hazardous Materials*, Vol 331, 132-141, <https://doi.org/10.1016/j.jhazmat.2017.02.006>

- 97 leachate samples were extracted and analyzed for nine PFASs; PFOA, PFOS, perfluorohexanoate (PFHxA), perfluoroheptanoate (PFHpA), perfluorononanoate (PFNA), perfluorodecanoate (PFDA), perfluoroundecanoate (PFUnDA) perfluorododecanoate (PFDoDA) and perfluorohexanesulfonate (PFHxS).
- PFASs were detected in all samples at all 27 landfill sites.
- Three PFCAs (PFHxA, PFHpA and PFOA) and two PFSAs (PFHxS and PFOS) were detected at all 27 landfills.
- On average, PFHxA was detected at the highest concentrations (mean 1700 ng/L; range 73–25000 ng/L), followed by PFHxS (mean 1200 ng/L; range 56–16000 ng/L), PFOA (mean 690 ng/L; range 17–7500 ng/L), PFHpA (mean 430 ng/L; range 18–4400 ng/L) and PFOS (mean 310 ng/L; range 13–2700 ng/L).

Spain: Fuertes, I., Gómez-Lavín, S., Elizalde, M. P., & Urtiaga, A. (2017). Perfluorinated alkyl substances (PFASs) in northern Spain municipal solid waste landfill leachates. *Chemosphere*, 168, 399–407. <https://doi.org/10.1016/j.chemosphere.2016.10.072>

- Samples were taken from 4 different municipal landfill sites and tested for 11 PFCAs and 5 PFSAs.

- 8 of the 16 PFASs were detected in the samples
- PFCAs accounted for the majority of the fluorochemicals quantified in the leachate samples.
- PFOA was the dominant compound in untreated leachate samples.
- PFOA and PFHxA were detected in every leachate sample.
- All leachate samples had the common characteristic that shorter chain PFASs were greater in abundance than their respective longer chain homologues.

Norway: Knutsen, H., Mæhlum, T., Haarstad, K., Slinde, G. A., & Arp, H. P. H. (2019). Leachate emissions of short- and long-chain per- and polyfluoroalkyl substances (PFASs) from various Norwegian landfills. *Environmental Science. Processes & Impacts*, 21(11), 1970–1979. <https://doi.org/10.1039/c9em00170k>

- 28 PFAS compounds were detected in all landfill leachate samples.
- In six out of ten landfills, there were higher concentrations of short-chain PFASs than long-chain PFASs.
- Overall, the short-chain PFBS contributed most to the total PFAS concentration.
- Short-chain PFASs are now major contributors in landfill leachate contamination.
- In sediment, long-chain PFASs such as perfluorooctanesulfonate (PFOS) and PFOS-precursors were dominant.

Hamid et al (2018) Review of the fate and transformation of per and polyfluoroalkyl substances (PFASs) in landfills, *Environmental Pollution*, Vol 235, 74-84, <https://doi.org/10.1016/j.envpol.2017.12.030>

Despite the high variabilities in PFAAs profiles and concentrations in landfill leachate reported in North America, Europe, China and Australia (Yan et al., 2015; Clarke et al., 2015; Allred et al., 2014; Bossi et al., 2008; Kallenborn et al., 2004), a few general trends emerge.

- PFCAs are generally found to be the dominant PFASs (Fuertes et al., 2017; Allred et al., 2014; Li et al., 2012; Huset et al., 2011).
- C4-C7 chain length PFAAs are more abundant than their longer-chain (>C8) homologues (Fuertes et al., 2017; Li et al., 2012; Busch et al., 2010; Bossi et al., 2008; Kallenborn et al., 2004).
- Short-chain PFAAs are prone to preferential release and leaching from municipal solid waste (MSW), consistent with their higher aqueous solubilities and lower organic carbon-water partition coefficients relative to longer-chain PFAAs (Yan et al., 2015)."
- Shift in production of C4-C7 PFAAs since the early 2000s could be related to the increase in shorter chains found in landfills.
- Biodegradation is arguably one of the most important factors determining the fate of PFASs in landfills. Allred et al. (2015) and Lang et al. (2016) studied the evolution of PFASs into leachate using anaerobic landfill reactors (fed with MSW, carpets and clothing). While PFASs were released through a combination of biological (e.g., biodegradation) and abiotic (e.g., desorption) processes, the leachates from live bioreactors (producing methane) had on average 5 to 10 times higher PFAS than the average for biologically inactive reactors (Lang et al., 2016; Allred et al., 2015).

The FTCAs and FTUCAs are known degradation products of FTOHs (Buck et al., 2011), a major raw material of fluorotelomer polymers (FTPs), commonly used in textiles, upholstery, paper and carpets as surface protection agent (Rao and Baker, 1994). In addition to FTOH monomer released through biological (Washington et al., 2015; Rankin et al., 2014) and abiotic hydrolysis (Washington and Jenkins, 2015), residual FTOH present in FTPs (Dinglasan-Panlilio and Mabury, 2006) can biodegrade to FTCAs

and FTUCAs, and subsequently to PFCAs in soil and activated sludge from WWTPs under both aerobic and anaerobic conditions (Liu and Avendano, 2013).

While many of the PFAA-precursors and their degradation products (e.g., FTOHs, fluorotelomer iodides (FTIs), FOSEs) are semivolatile in nature, the role of landfills as sources of PFAS gaseous emissions to the atmosphere has received little attention. Two studies (Ahrens et al., 2011; Weinberg et al., 2011) reported higher (2-30 times) PFAS concentrations in landfill ambient air compared to control sites that were presumably not contaminated with landfill emissions.

Recent studies show that FTPs can undergo abiotic (Washington and Jenkins, 2015) and biological hydrolysis releasing FTOHs, which then biodegrade to PFCAs with an estimated half-life range of 8-100 years (Washington et al., 2015; Rankin et al., 2014).

Studies need to include landfill gas to understand degradation pathways and the overall fate of PFAS. This would also enable more realistic assessments of the release of PFASs to the environment with landfill gas.

Leaching cell tests with sand/bentonite mixture barriers showed partial retention of PFASs (10 PFCAs, 4 PFASs, 1 FOSA and 3 FTUCAs), decreasing over time, indicating limited effectiveness of sodium bentonite liners in landfills in containing PFASs (Li et al., 2015).