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PFAS released by landfill waste: how effective are the treatments?

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SUMMARY

1. ATOLIX project
2. PFAS in raw leachates
3. Leachates treatment efficiency
4. PFAS in treated leachates
5. Conclusion



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ATOLIX project

ATOLIX project

Context

Widespread use + persistence in the environment → PFAS ubiquitously present in everyday consumer, commercial and industrial products

Landfills

disposal of solid waste from different sources:

- residential
- commercial
- industrial

178 active landfills in France

14 Mt of non-hazardous waste / year

PFAS detected in both closed and active landfills

average concentration $\sum PFAS_{leachate} \in [1 ; 100\,000] \text{ ng/L}$

ATOLIX project

Objectives

ATOLIX: Ecotoxicological Analyses and Advanced Oxidation Treatment of PFAS in Leachate from Municipal Landfills

Objectives

Overview of PFAS flux

Studying PFAS in landfill leachates

Study the treatment techniques already in place

Estimate the outflow from landfills

Developing a concentration + degradation treatment train

Pilot-scale study

Development of an ecotoxicological characterization method



ATOLIX project

Sampling points

Analysis

44 PFAS

EOF – Extractable Organic Fluorine

COD – chemical oxygen demand

Total nitrogen

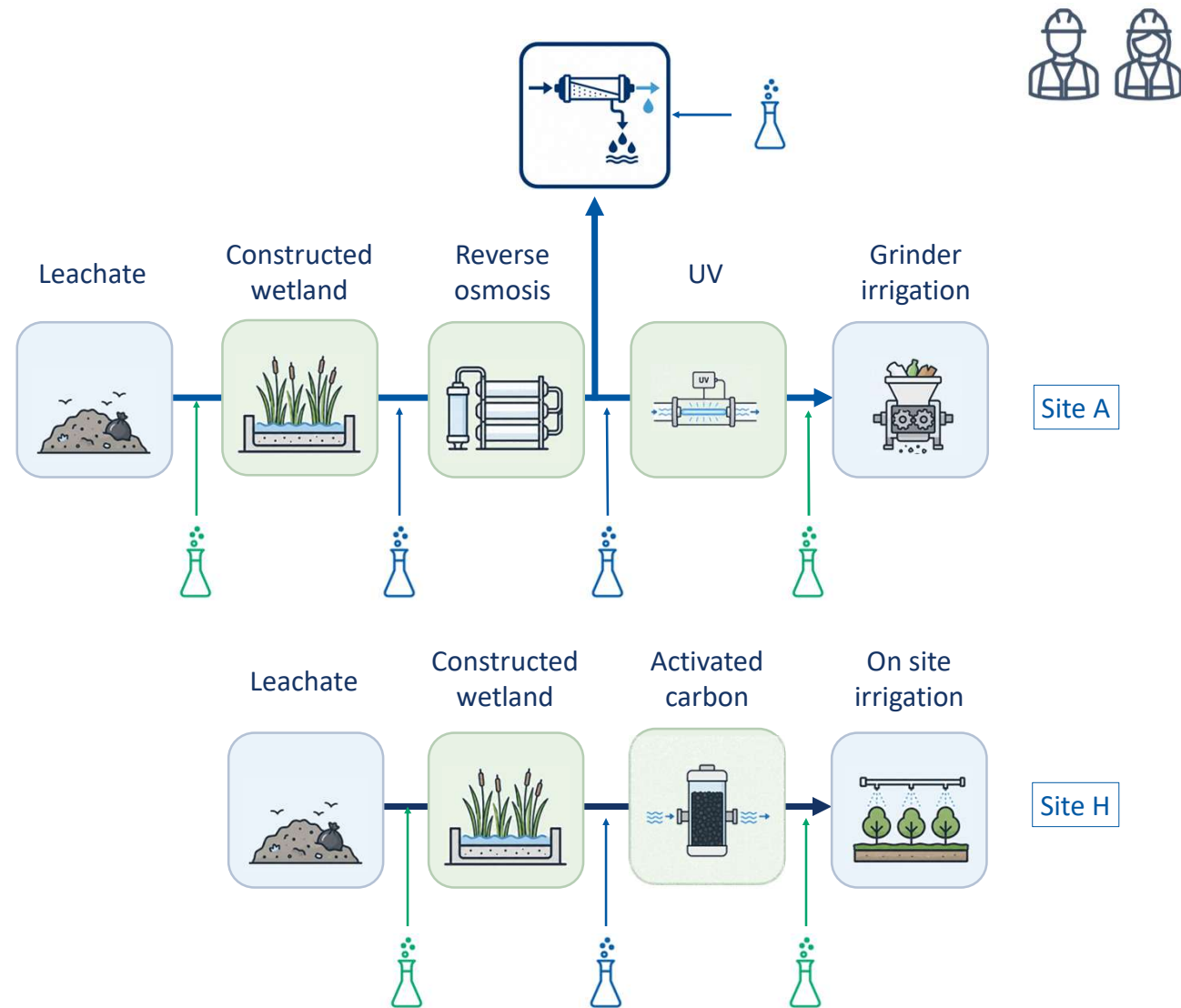
Fluorides

Chlorides



+ 5 Ultra Short Chains (USC)

+ TOP Assay



ATOLIX project

Raw leachates characteristics

Parameter	Ranges according to Kjeldsen et al. 2002	ATOLIX sites
	min - max	
pH	4,5 – 9,0	6,9 – 8,5
Conductivity (µs/cm)	2 500 – 35 000	2 775 – 15 200
Chemical oxygen Demand (mgO ₂ /L)	140 - 152 000	98 – 5 250
Organic nitrogen (mg/L)	14 – 2 500	25 – 1 200
Chloride (mg/L)	150 – 4 500	235 – 1940

Campaigns between February and April of 2026 → rainy conditions

Atolix leachates are within the common ranges for landfill leachates

PFAS in raw leachates



PFAS in raw leachates

PFAS containing wastes:

- Food packaging
- Textiles and carpets
- Paper

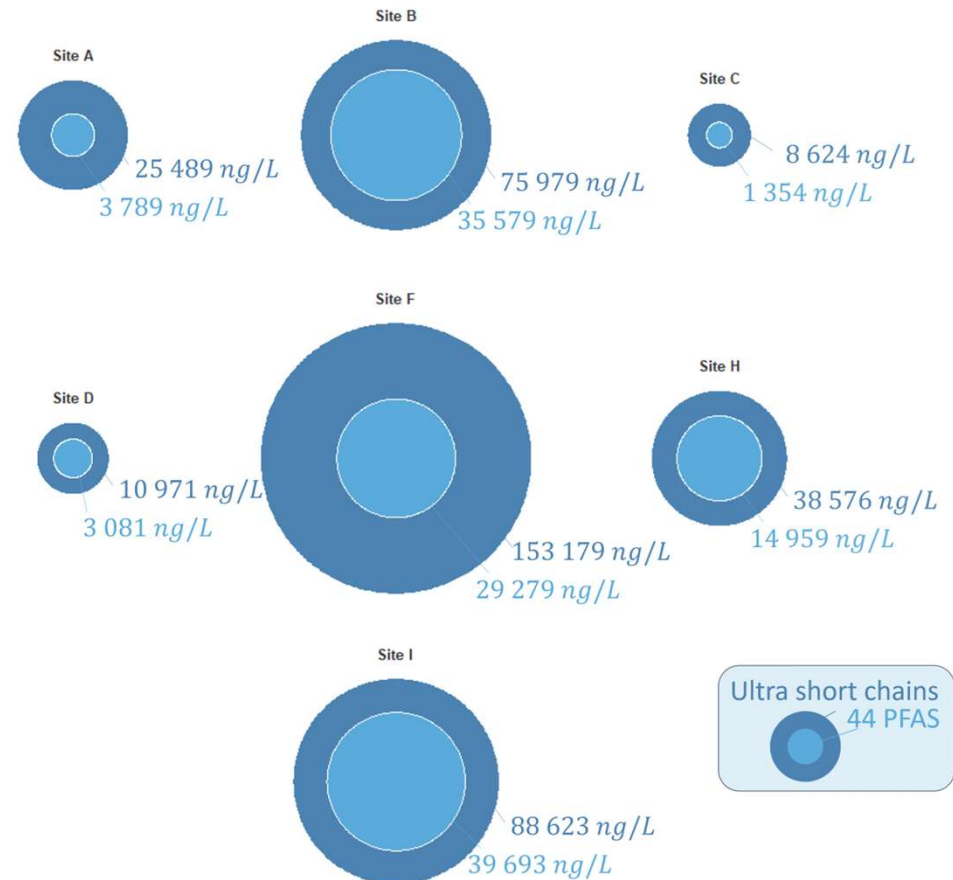
Another potential source: firefighting foams for landfill fires

Range in raw leachates for 7 landfills:

8 624 – 153 179 ng/L

Significant variability across sites
USC are predominant in raw leachate

Closed sites (C,D) present lower PFAS concentrations



PFAS in raw leachates

Ultra Short Chains

TFA → 40 – 75 %

Ubiquitous presence

One order of magnitude higher than others

average[TFA]_{raw leachate} = **30 080 ng/L**

PFMeS → 2 – 10 %

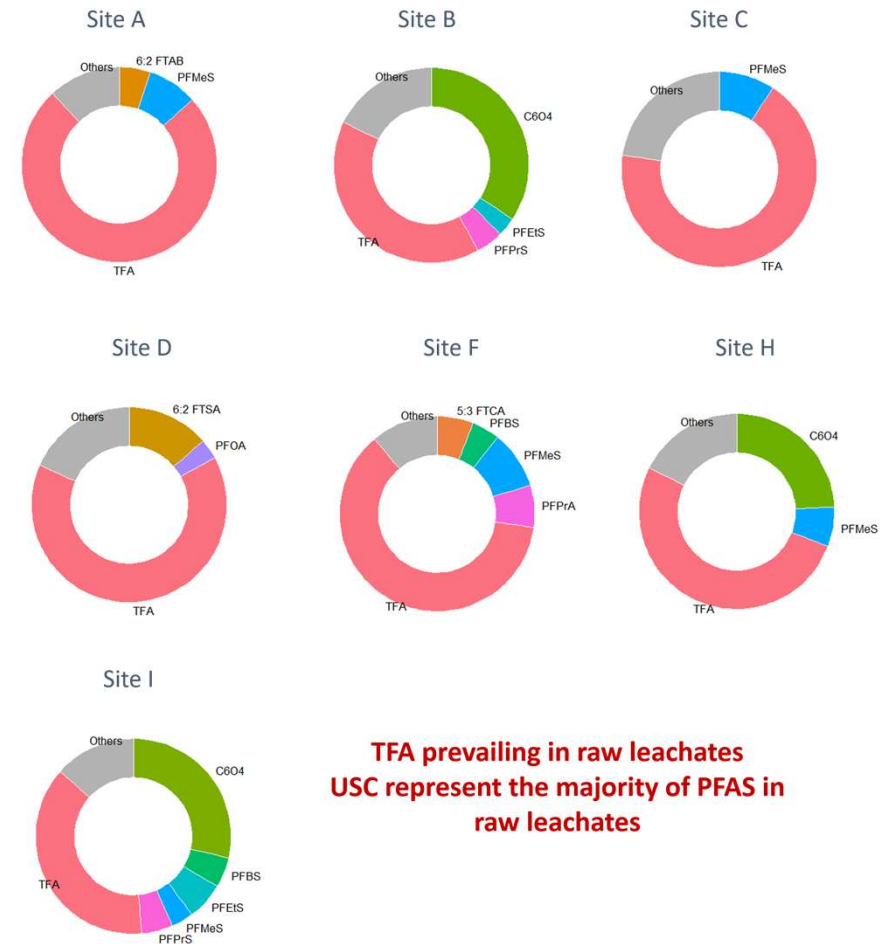
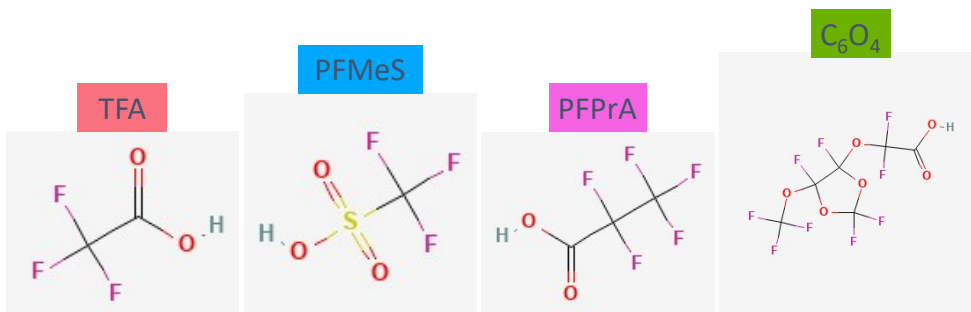
PFPrA → 1 – 7 %

Presence in firefighting foams

C₆O₄

Syensquo fluorosurfactant

PFOA substitution



TFA prevailing in raw leachates
USC represent the majority of PFAS in raw leachates



Leachates treatment efficiency

Treatment efficiency

Treatment Wetlands (TW)

Treatment wetlands with vertical and horizontal flows.

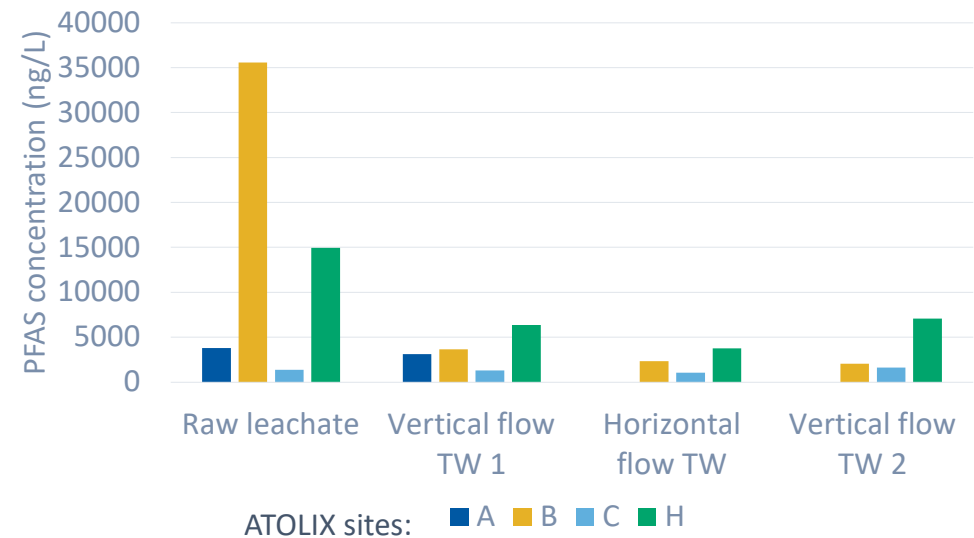
Overall efficiency **between 0 and 94 %**.

Great removal of C_6O_4

USC not analyzed

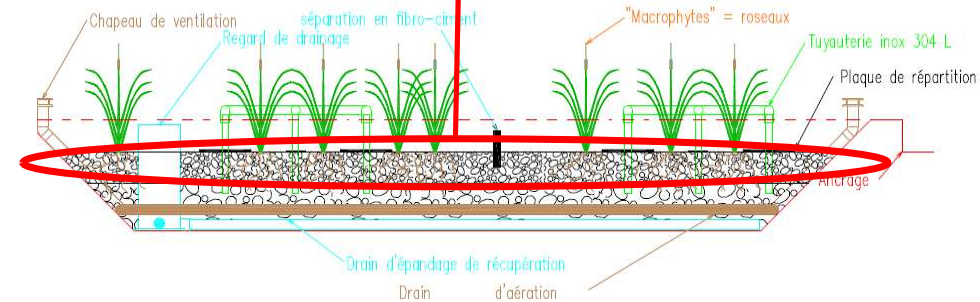
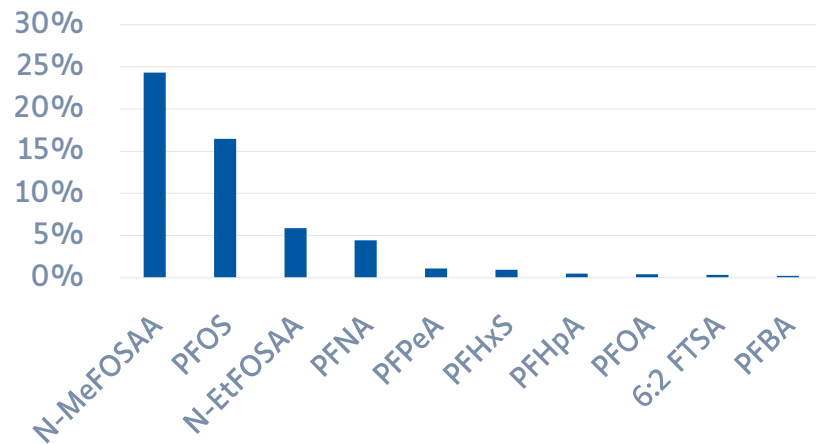
Polyfluoroalkyl substances degraded. Ex: C_6O_4 , 5:3 FTCA and N-MeFOSAA

PFCA removal rate > PFSA removal rate



Treatment efficiency

Gravel in Treatment Wetlands



The adsorption of PFAS onto the surface gravel of wetlands is low – approximately 5%
Higher molecular weight PFAS' adsorption is greater

Treatment efficiency

Activated sludge treatment

Aerobic and anaerobic biochemical processes

Removal for only:

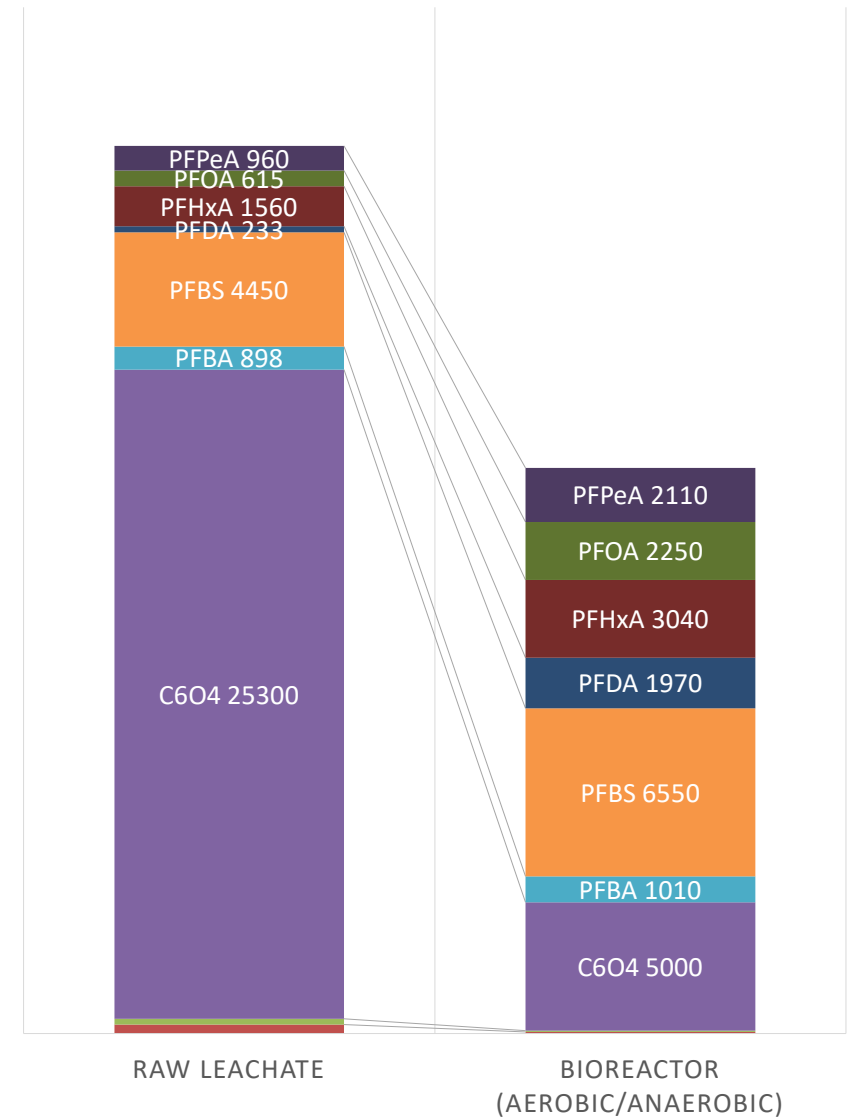
- 6:2 FTOH (83 ±11 %)
- 8:2 FTOH (77 ±14 %)
- C₆O₄ (80 ±13 %)

×2 increase for (PFBA, PFBS, PFDA, PFHxA, PFOA and PFPeA)

Aerobic + anaerobic bioreactor generates short and long chains perfluoroalkyls

Degradation of volatile and biodegradable compounds

* 6:2 FTAB has been removed from the data



Treatment efficiency

Coagulation - Flocculation

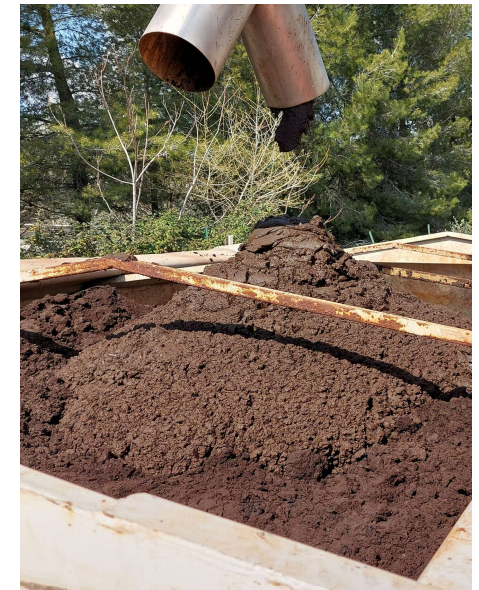
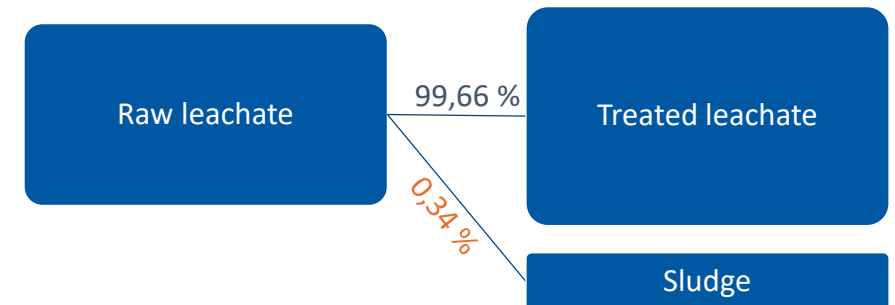
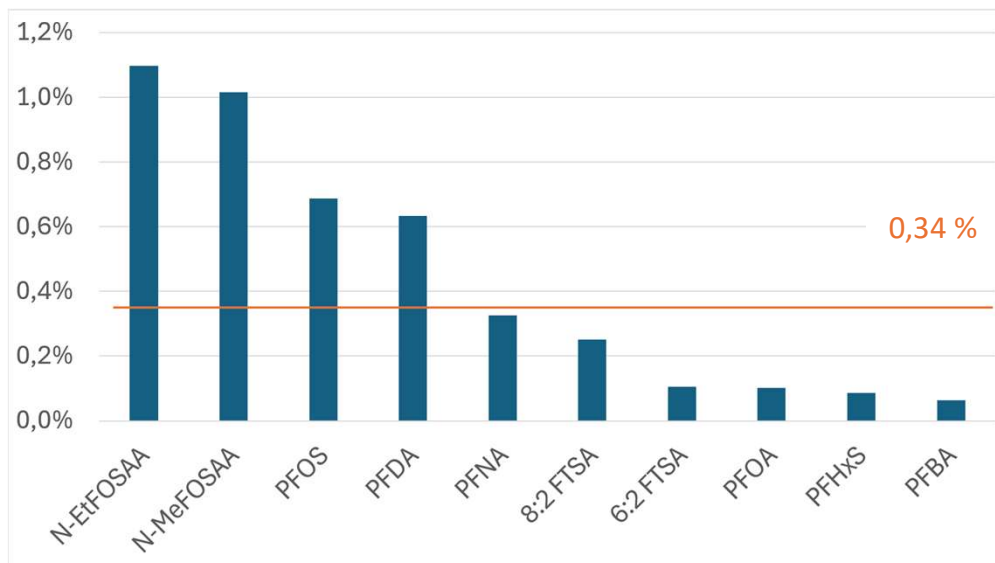
$\text{FeCl}_3 + \text{Ca(OH)}_2 + \text{Anionic flocculant}$
No effect of PFAS removal **with USC**

Coagulation – flocculation has no effect on the removal of PFAS in those conditions



Treatment efficiency

Sludge of Coagulation - Flocculation



No significant PFAS mass in the sludge

PFAS with significant molecular weight are partially adsorbed onto the sludge

Treatment efficiency

Activated carbon

Activated carbon removal efficiency

Between 0 and 51% for **44 PFAS**

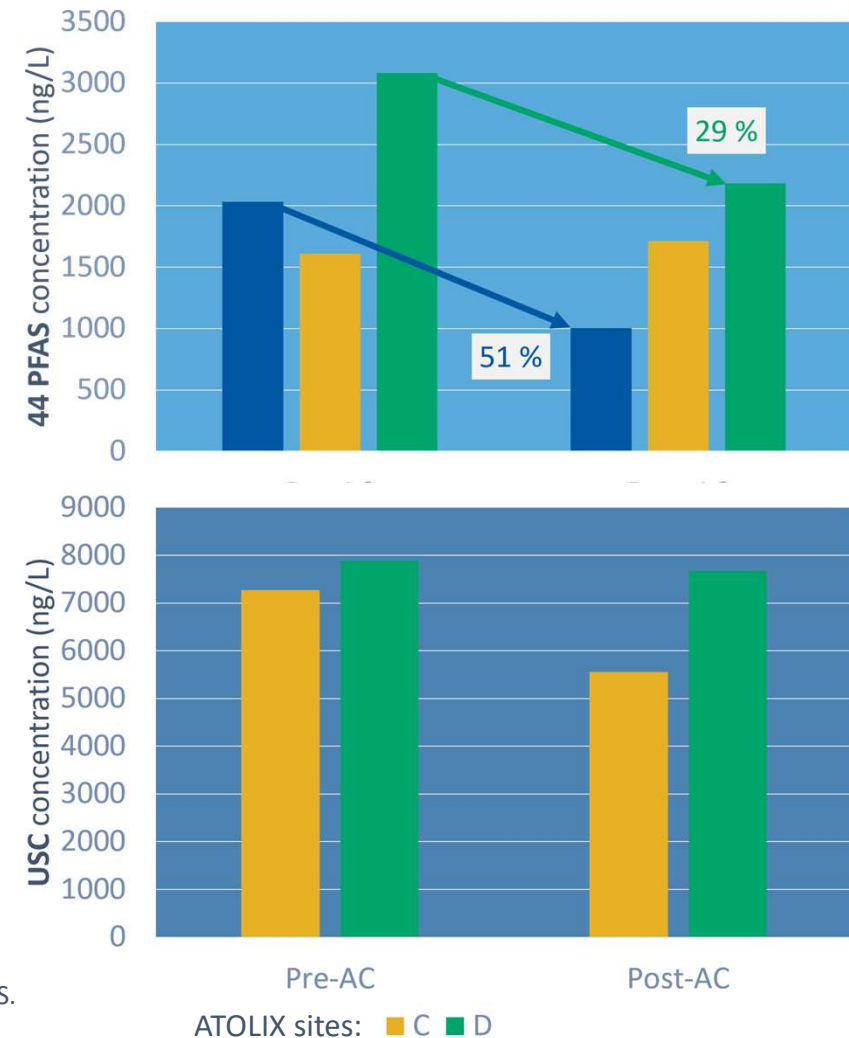
No significant impact for **USC**

Duration of exploitation	Average inlet COD (mgO ₂ /L)	44 PFAS removal
2 months	206	51%
5 months	98	29%
11 months	110	Not significant

Removal in spite of high COD

Removal efficiency of AC depends on its saturation

Existing on-site activated carbon treatment systems were not designed for the removal of PFAS.



Treatment efficiency

Reverse osmosis, ultra & nanofiltration

Ultrafiltration

UF removal rate linked to PFAS adsorbed on organic matter or membrane

Nanofiltration

78% removal rate for 44 PFAS

33% removal rate for USC

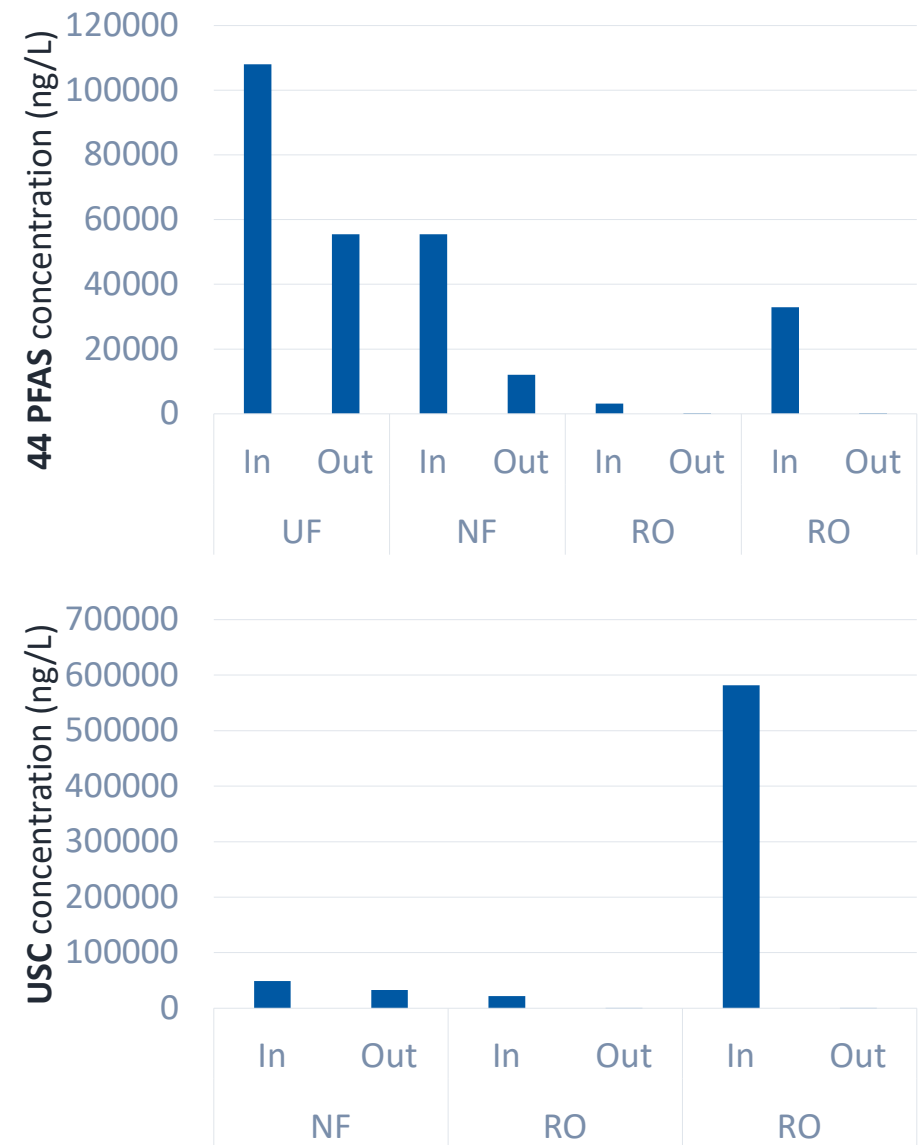
Reverse Osmosis

94 – 99% removal rate for 44 PFAS

98 – 99,95% removal rate for USC

Reverse osmosis has the best removal rate including USC

NF has an incomplete removal rate



* It has been considered that **no** USC had been removed by previous treatment step



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PFAS in treated leachate

PFAS in treated leachates

Overall concentrations

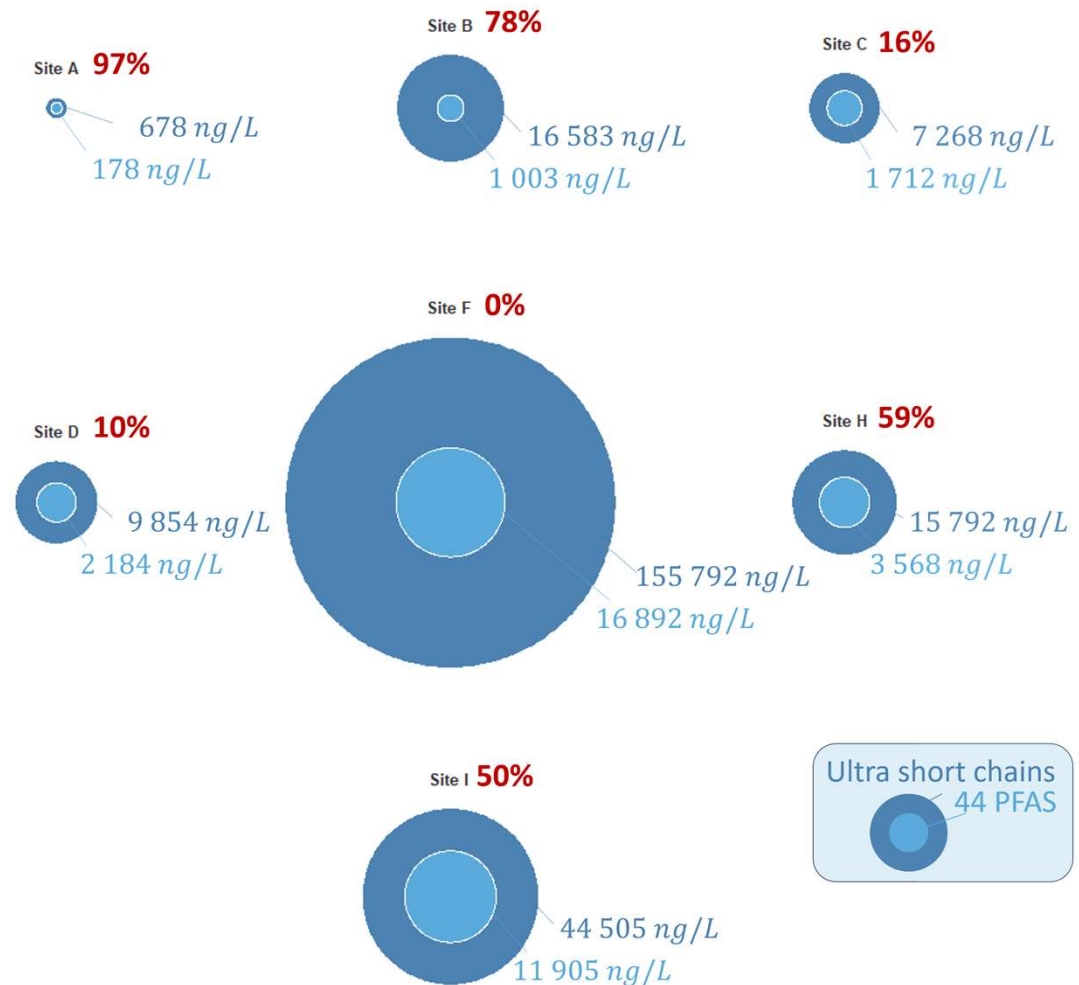
Range in treated leachates for 7 landfills:
178 – 155 792 ng/L

Sites B & C treated leachates to surface water
Sites F & I treated leachates to sewage
treatment plant

**Significant variability across sites (depending
on initial concentration & technology)**

**Notable PFAS concentrations in treated
leachates**

USC predominant still



PFAS in treated leachates

Target analysis

Ultra Short Chains

TFA → 15 – 85 %

Ubiquitous presence

One order of magnitude higher than others

average[TFA]_{treated leachate} = 24 027 ng/L

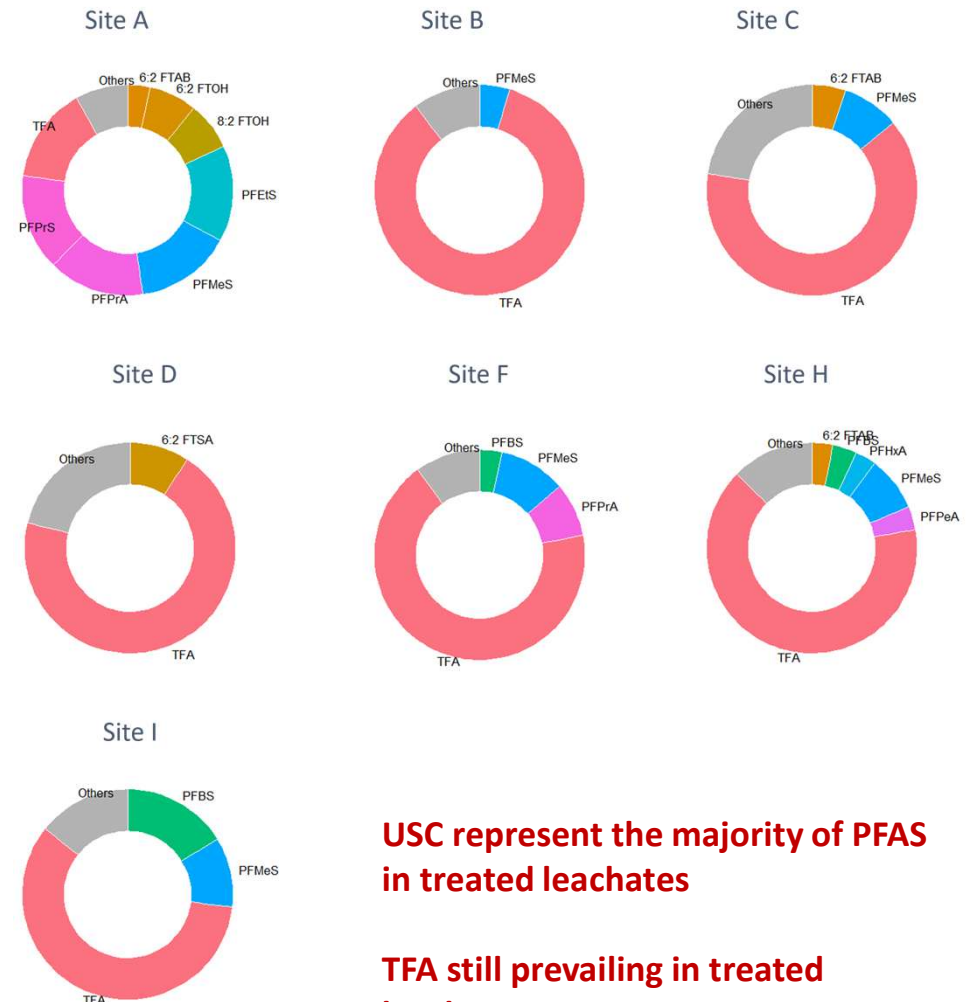
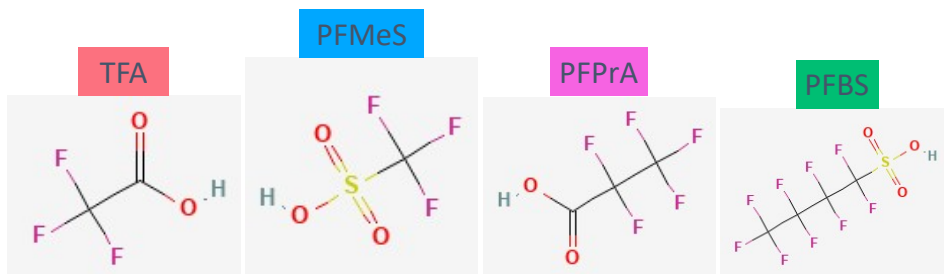
PFMeS → 2 – 15 %

PFPrA → 1 – 15 %

Short chain

PFBS

C₆O₄ → 99,95% removed



USC represent the majority of PFAS in treated leachates

TFA still prevailing in treated leachates

PFAS in treated leachates

Fluxes

Site flux variation for the sum of 28 PFAS (regulatory ICPE)
without USC

Between 173 and 3 g/year

Site flux variation for the sum of 49 PFAS (USC + 28 ICPE PFAS + 16 other PFAS)
including USC

Between 2 246 and 18 g/year

Average for ATOLIX sites = 573 grams/year including USC

Estimation: 100kg of PFAS released from active landfills every year in France



Conclusions

ATOLIX

Conclusions



ATOLIX project: 7 landfills studied

Raw leachates (49 PFAS): 8 624 - 153 179 ng/l

Treated leachates: (49 PFAS): 678 - 155 792 ng/l

Ultra short chains prevalence in both raw and treated leachates: TFA, one order of magnitude higher than others

Leachate treatments efficiency on PFAS:

Reverse osmosis – 97% removal overall

Nanofiltration – 57% removal overall

Biological treatment – increase for several PFAS

Coagulation flocculation – no effect

Activated carbon – removal depends on media saturation

Flux:

Average 573 grams of PFAS emitted annually

French national roadmap:

Reduce PFAS emissions by 70% by 2027 and 100% by 2030

Treatment trains tests to be carried out with “**Concentrate & destroy**” strategy

Thank you for your attention

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