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

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SUMMARY

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ATOLIX project

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Context

Widespread uses + 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

165 ISDND en France ouvertes en 2022

PFAS detected in both closed and active landfills due to disposal of PFAS-containing materials.

$$average\ concentration \sum \boldsymbol{PFAS_{lixiviat}} \in [1\ ;100\ 000\ ]\ ng/L$$

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

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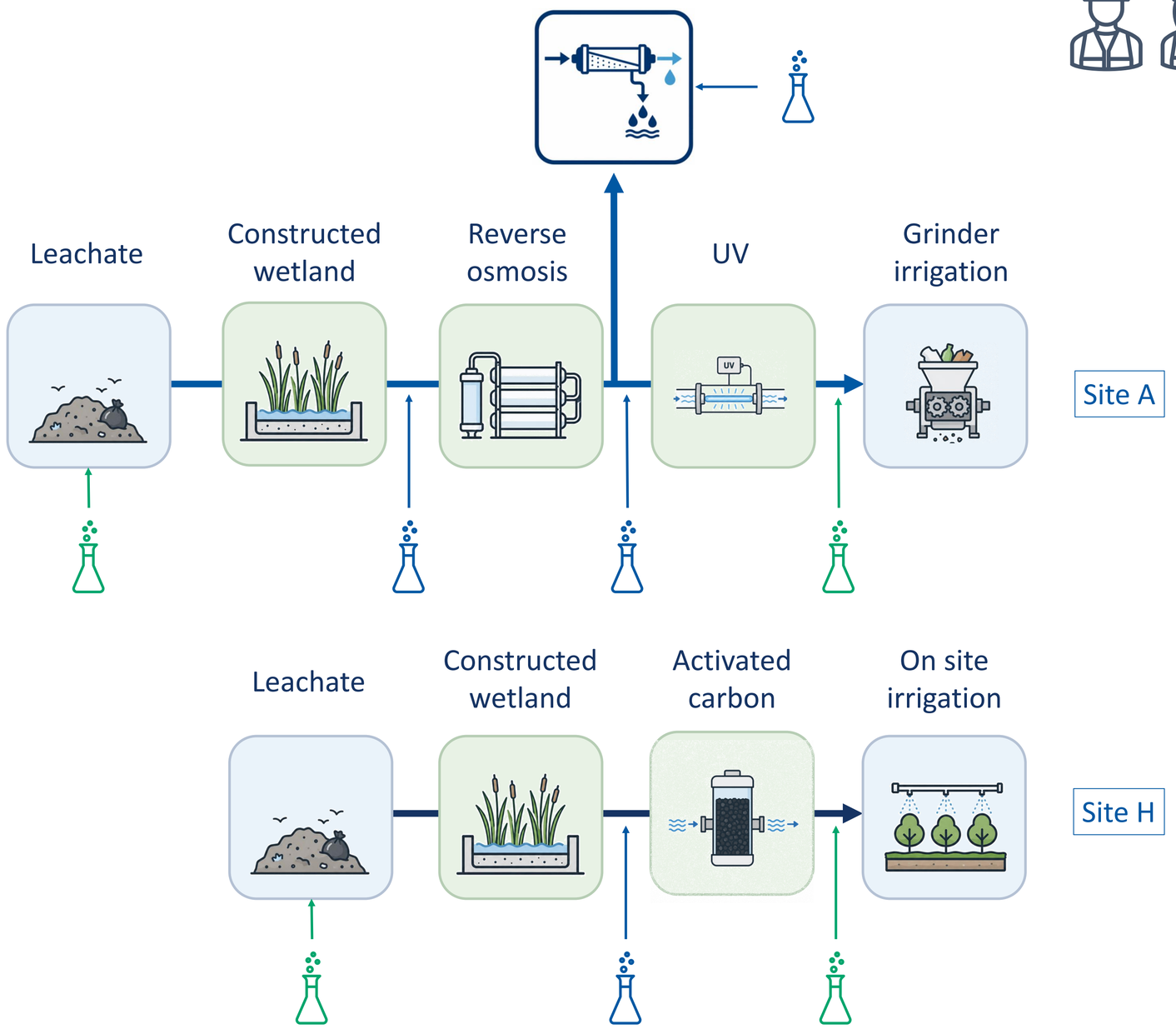
Sampling points



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 (COD)	140 - 152 000	98 – 5 250
Organic nitrogen (mg/L)	14 – 2 500	25 – 1 200
Chloride	150 – 4 500	235 – 1940

Campaigns between February and April of 2026 → rainy conditions

Atolix leachates are within the common ranges for landfill leachates

2

PFAS in raw leachates

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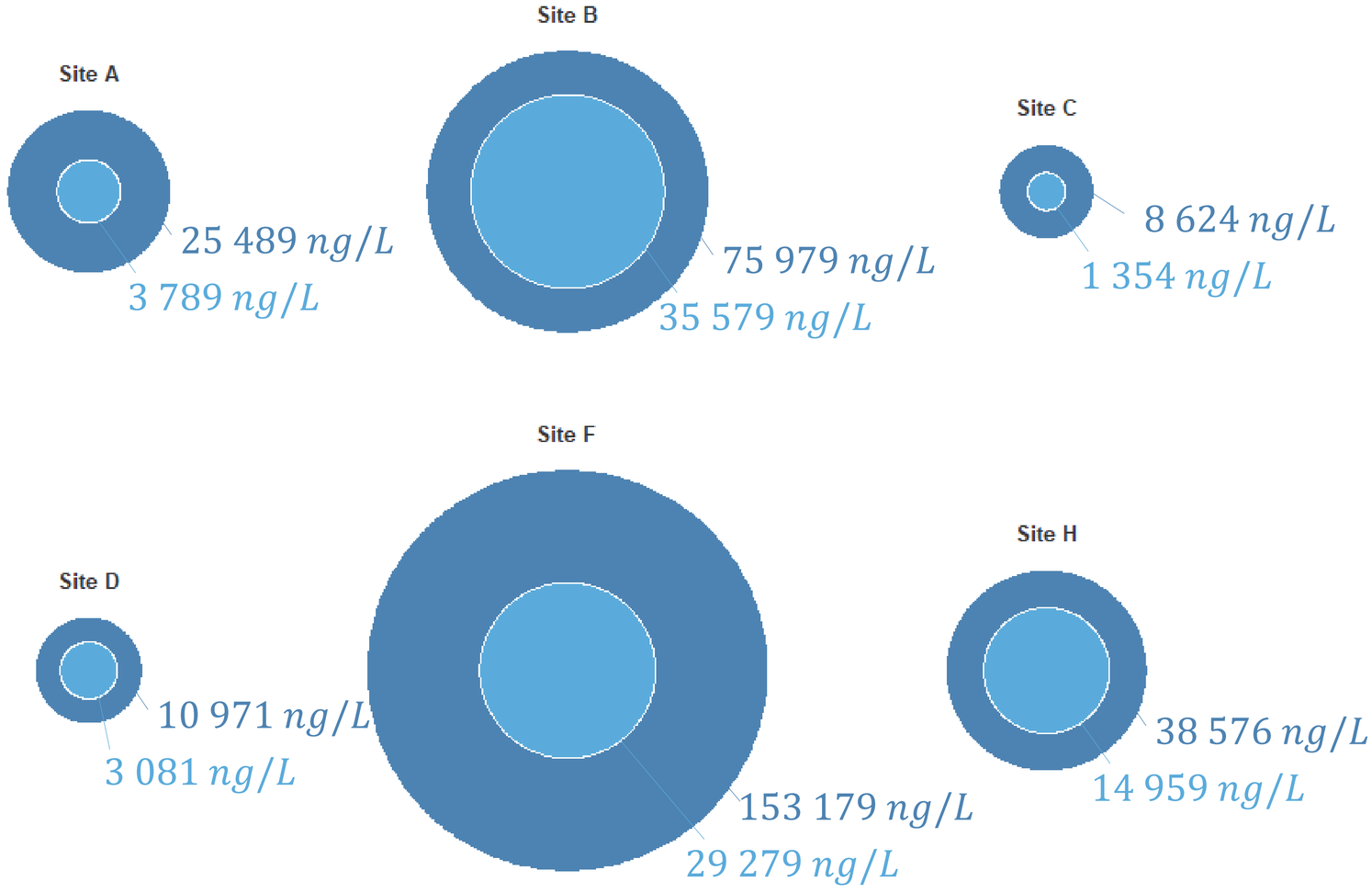
PFAS in raw leachates



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

Sites C & D closed

Significant variability across sites
USC are predominant in raw leachate
Closed sites present lower PFAS concentrations

PFAS in raw leachates

Ultra Short Chains

TFA → 40 – 75 %

Ubiquitous presence

One order of magnitude higher than others

$average[TFA]_{raw\ leachate} = \mathbf{30\ 080}\ ng/L$

PFMeS → 2 – 10 %

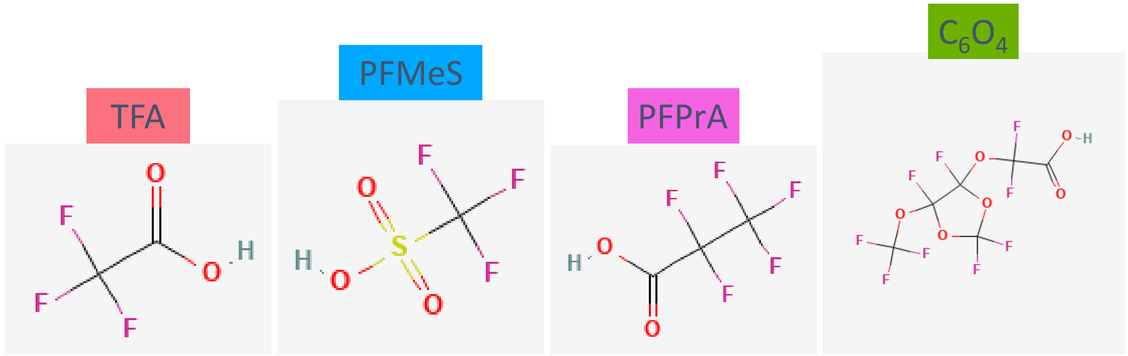
PFPrA → 1 – 7 %

Presence in firefighting foams

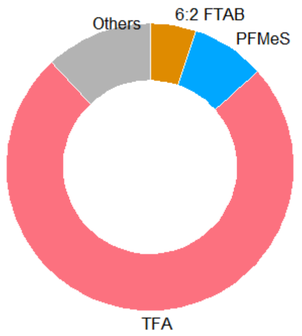
C_6O_4

Syensquo fluorosurfactant

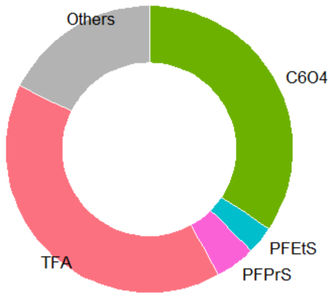
PFOA substitution



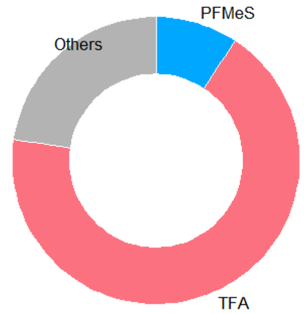
Site A



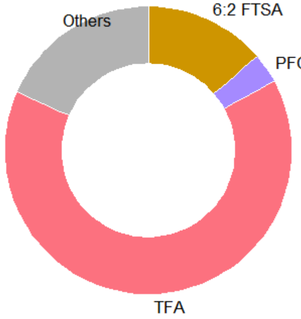
Site B



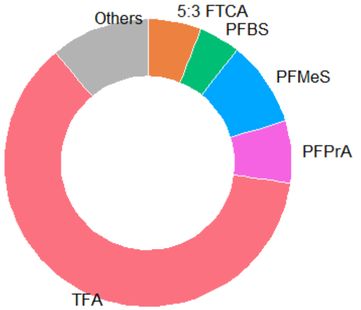
Site C



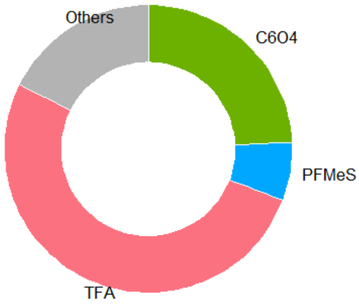
Site D



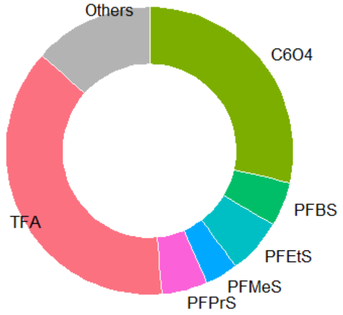
Site F



Site H



Site I



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

Leachates treatment efficiency

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Focus – site B

Method

Raw leachate

Vertical constructed wetland

∑ 28 PFAS

46%

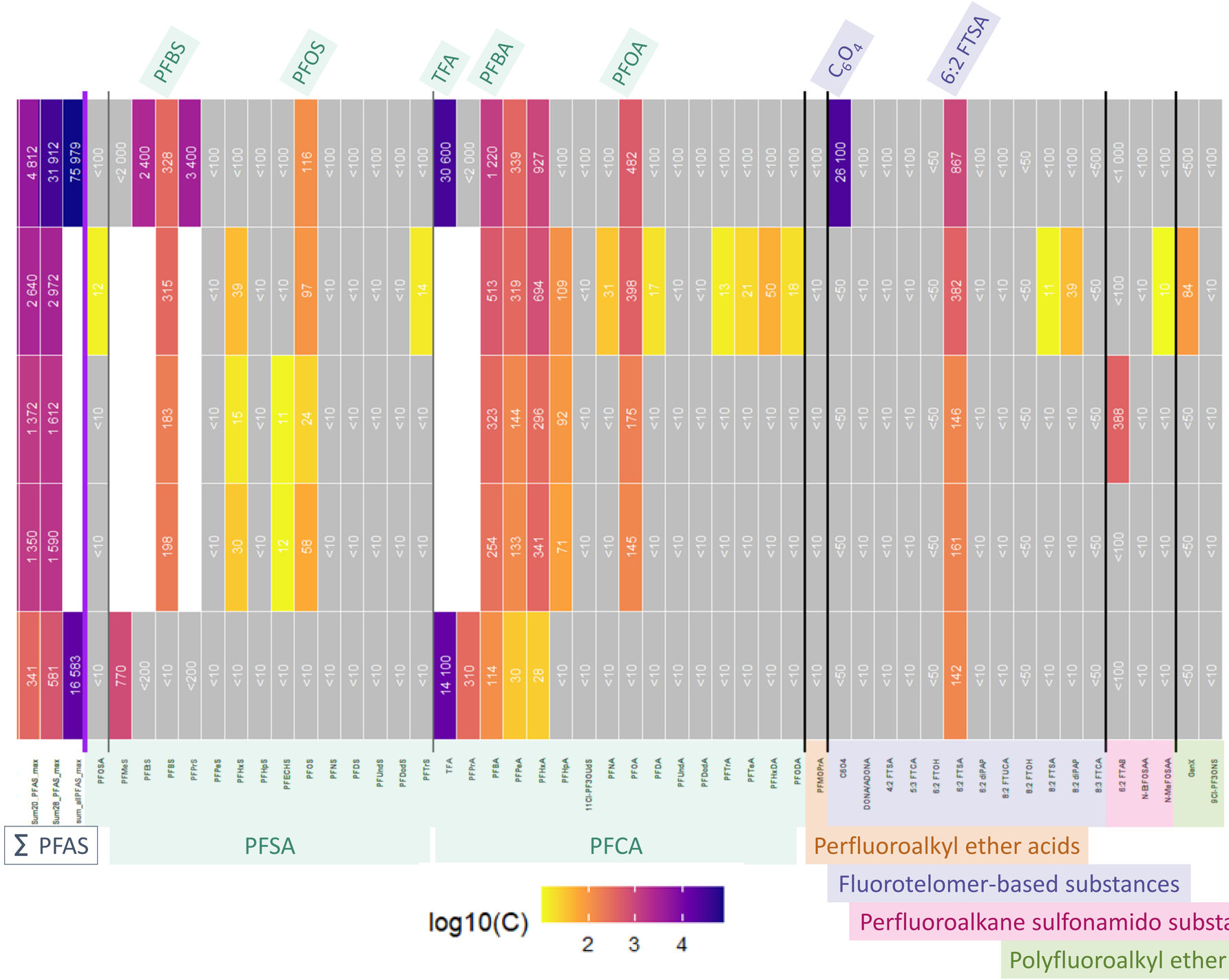
Horizontal constructed wetland

1%

Vertical constructed wetland

63%

Treated leachate – Activated carbon



Treatment efficiency

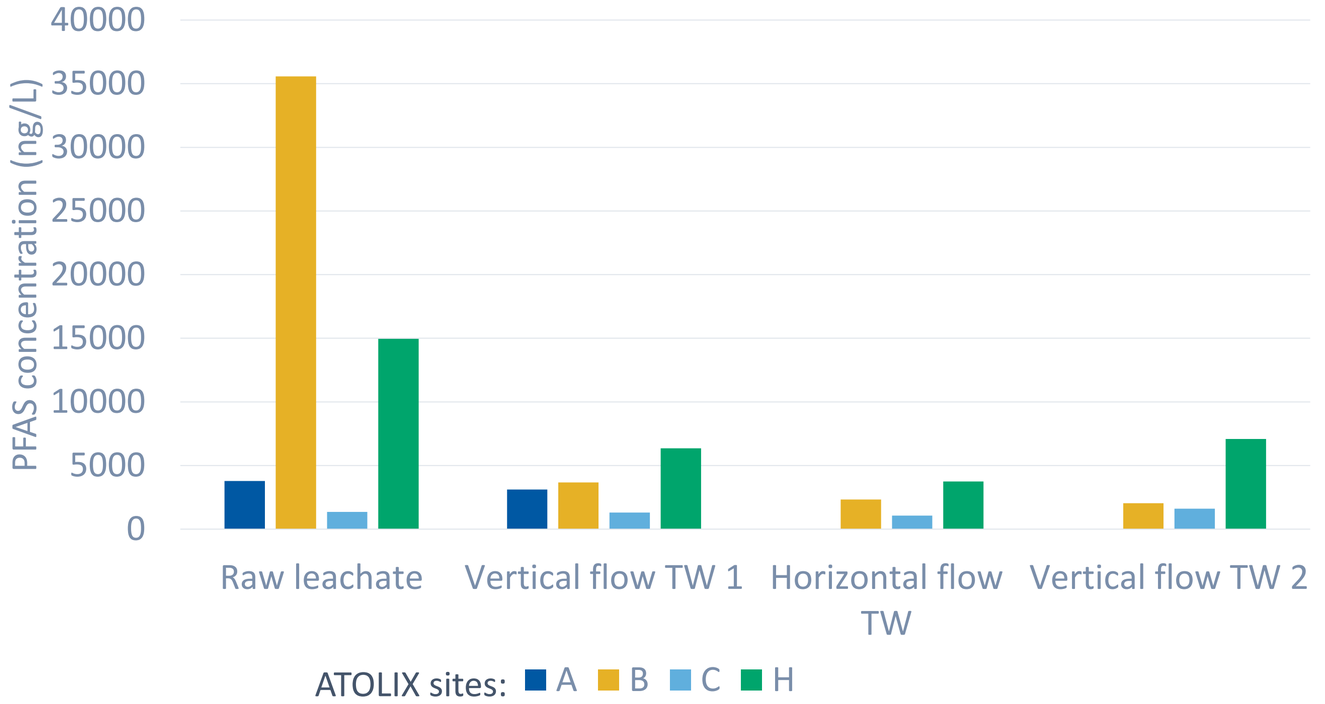
Treatment Wetlands (TW)

Treatment wetlands with vertical and horizontal flows.
Overall efficiency between 0 and 94 %.

Great removal of C_6O_4

$$\left[PFOS_{VFTW\ gravel}\right] = 8{,}82\ \mu g.kg\ M.S.^{-1}$$

USC not analyzed



Polyfluoroalkyl substances degraded. Ex: C_6O_4, 5:3 FTC and N-MeFOSAA
PFCA removal rate > PFSA removal rate

Treatment efficiency

Biological treatment

Removal for only:

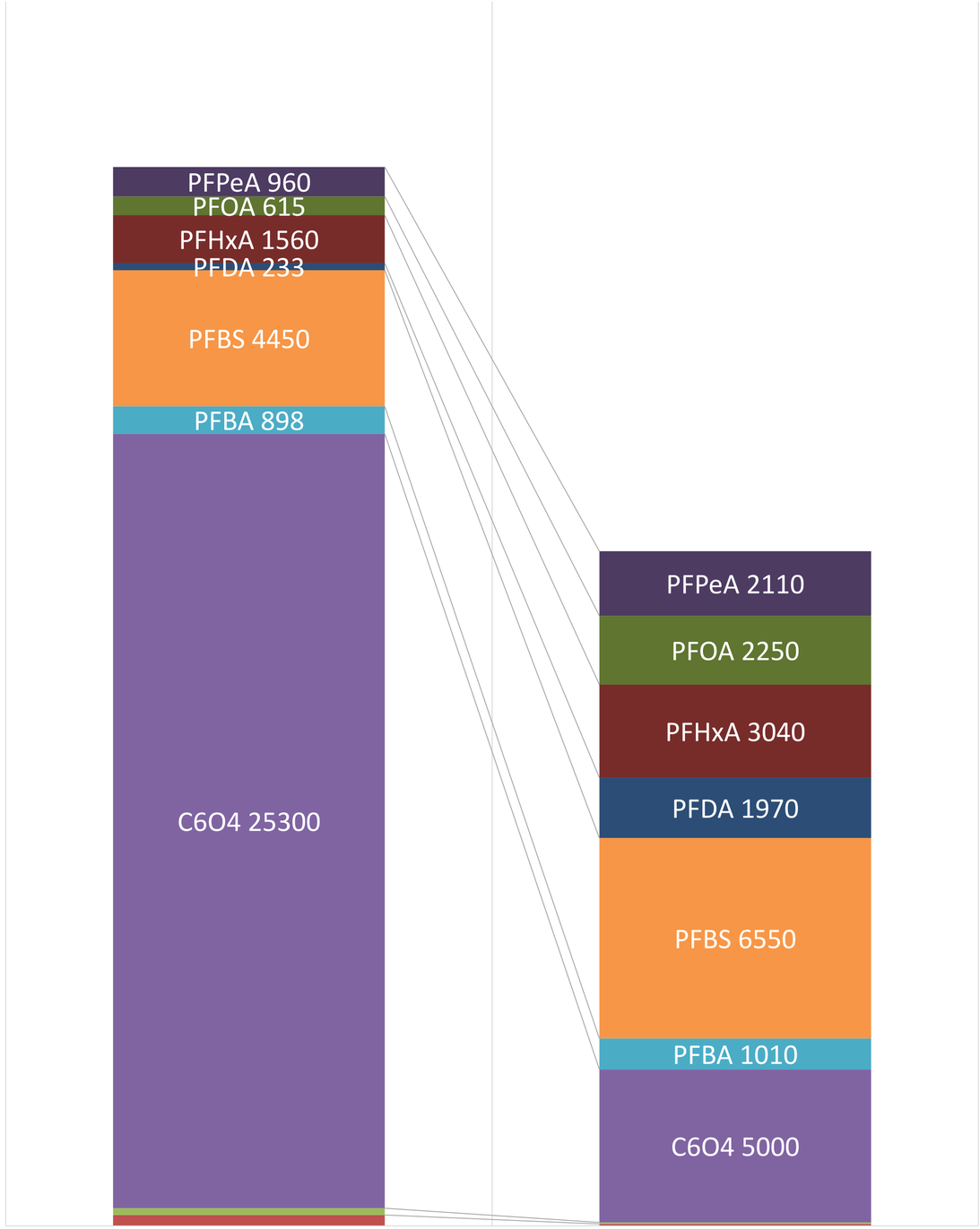
- 6:2 FTOH
- 8:2 FTOH
- C_6O_4

Overall removal of PFAS of 36% *

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

Aerobic + anaerobic bioreactor generates short and long chains perfluoroalkyl

Degradation of volatile and biodegradable compounds



* 6:2 FTAB has been removed from the data

Treatment efficiency

Coagulation - Flocculation

$FeCl_{3+}$ + $Ca(OH)_2$ + Anionic flocculant

No effect of PFAS removal **with USC**

Coagulation – flocculation has no effect on the removal of PFAS

Treatment efficiency

Activated carbon

Activated carbon removal efficiency

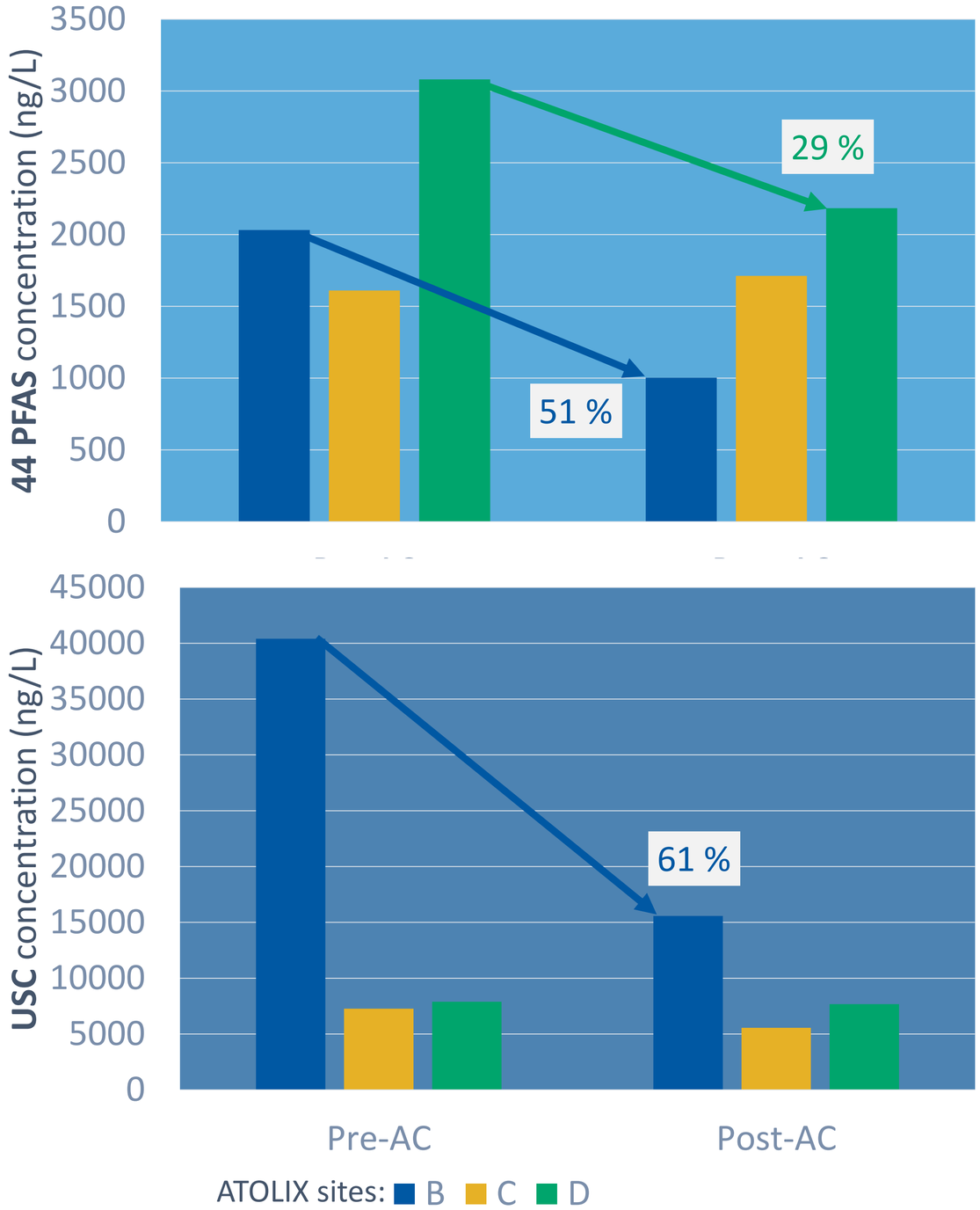
Between 0 and 51% for **44 PFAS**

Between 3 and 61 % for **USC** *

Time of use	COD (mgO_2/L)
2 months	206
11 months	110
5 months	98

Removal efficiency of AC depends on time of use

Removal in spite of high COD



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

Treatment efficiency

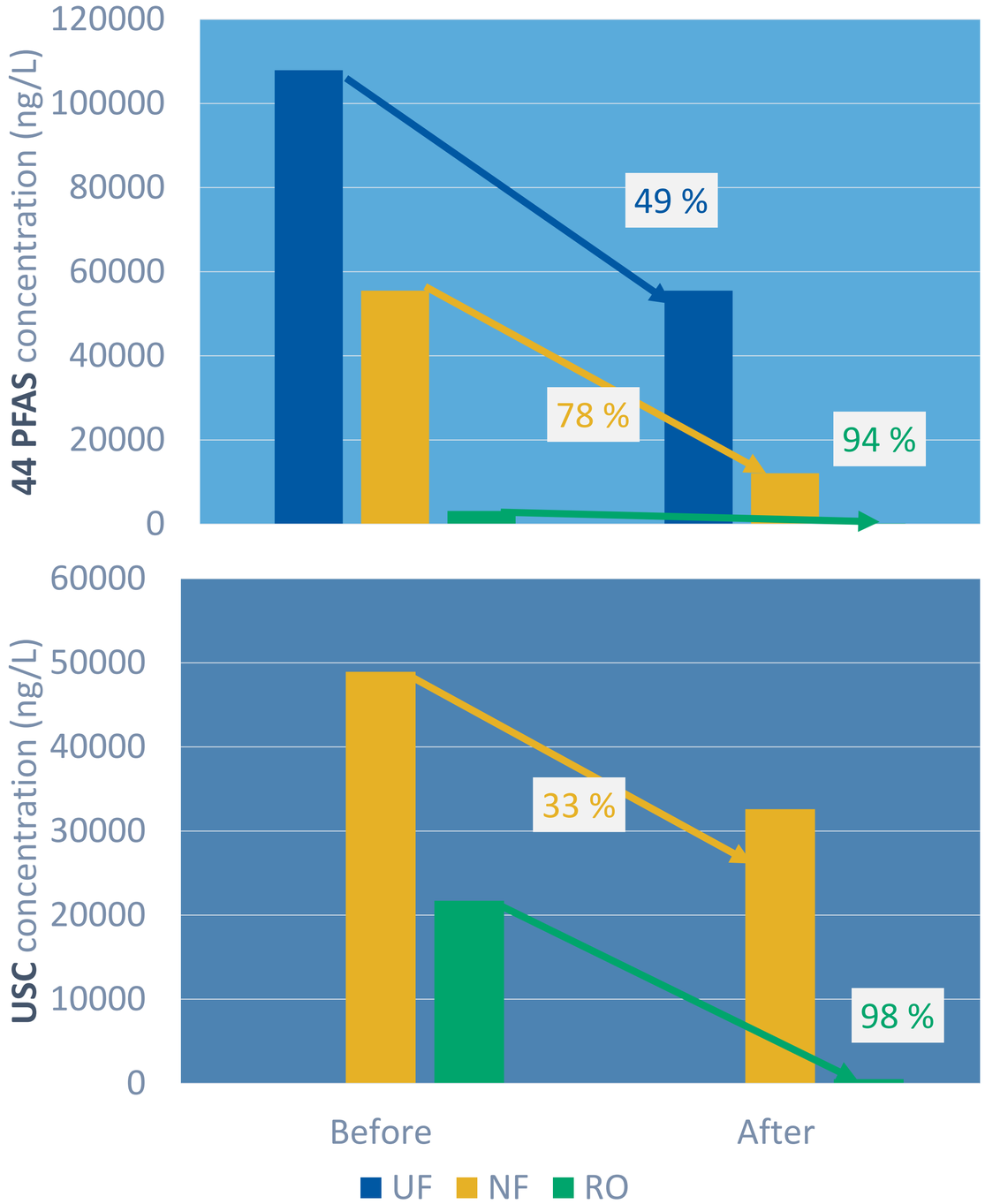
Reverse osmosis, ultra & nanofiltration

Ultrafiltration Membrane with mean pore size of 30 nm
UF removal rate linked to PFAS adsorbed on organic matter or membrane

Nanofiltration membrane with mean pore size of 0,42 nm
- 78% removal rate for 44 PFAS
- 33% removal rate for USC

Reverse Osmosis
- 94% removal rate for 44 PFAS
- 98% removal rate for USC

Reverse osmosis has the best removal rate including regarding USC
NF has a incomplete removal rate



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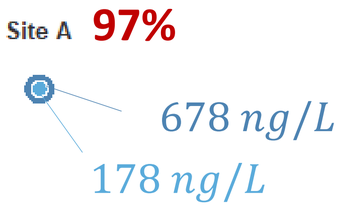
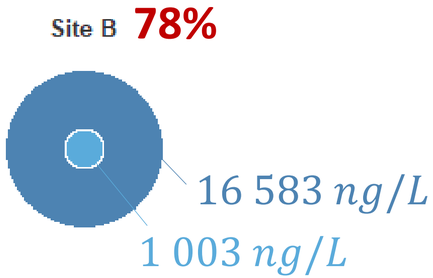
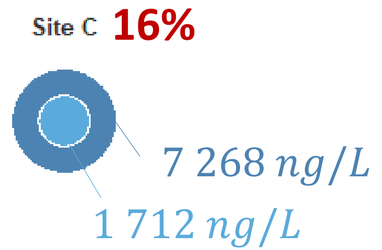
PFAS in treated leachate

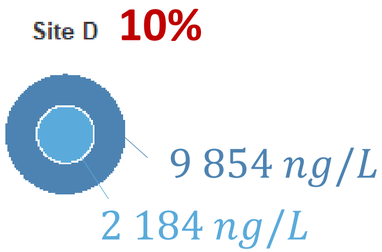
PFAS in treated leachates

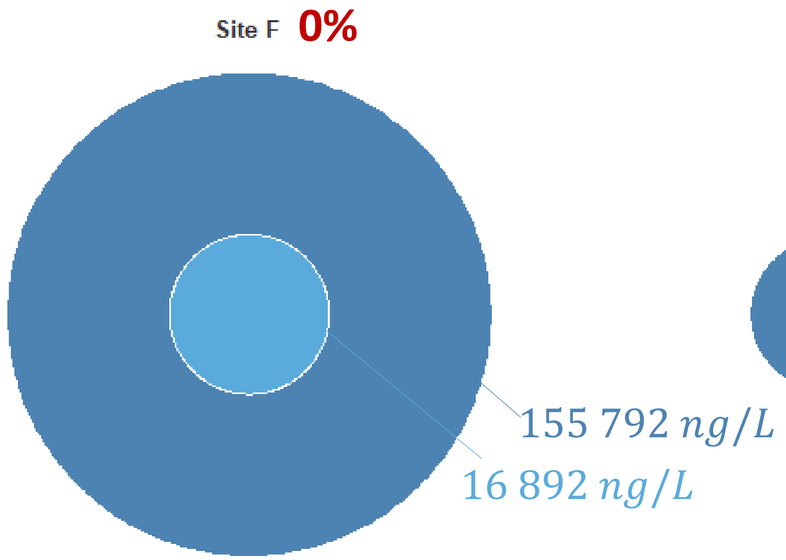
Overall concentrations

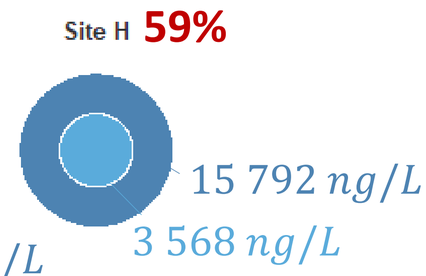








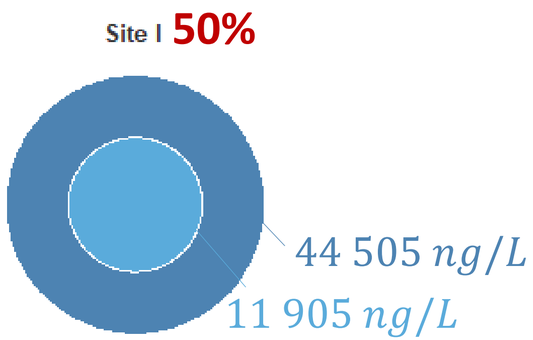


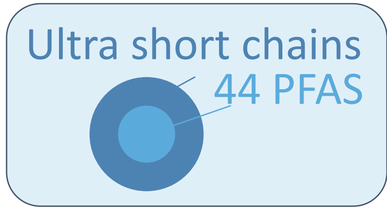


Range in treated leachates for 7 landfills:
178 – 155 792 ng/L

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

Notable PFAS concentrations in treated leachates
Significant variability across sites
USC predominant still





PFAS in treated leachates

Target analysis

Ultra Short Chains

TFA → 15 – 85 %

Ubiquitous presence

One order of magnitude higher than others

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

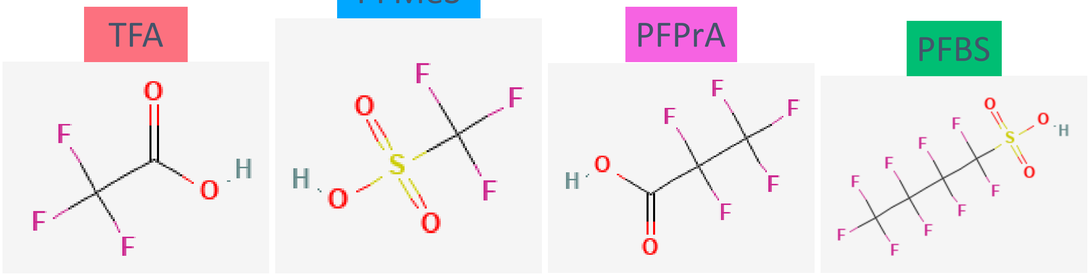
PFMeS → 2 – 15 %

PFPrA → 1 – 15 %

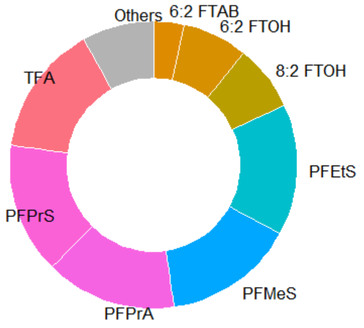
Short chain

PFBS

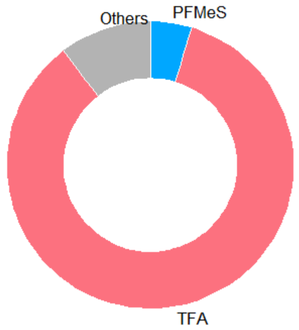
C_6O_4 → 99,95% removed



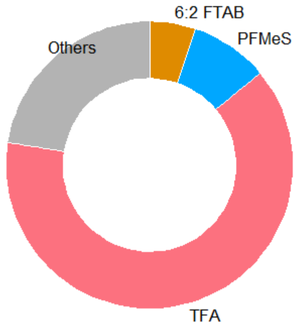
Site A



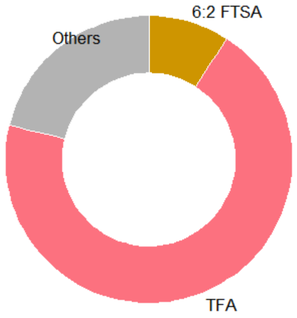
Site B



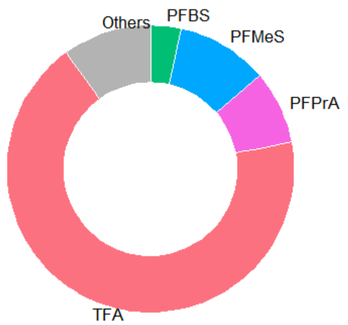
Site C



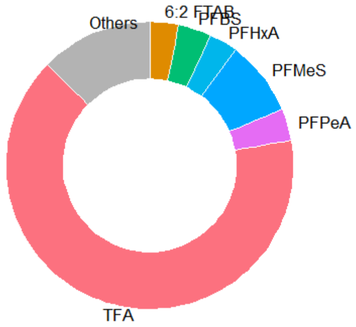
Site D



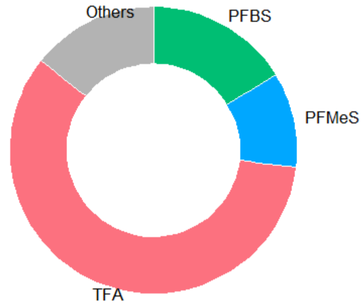
Site F



Site H



Site I



TFA still prevailing in treated leachates
USC represent the majority of PFAS in treated leachates

PFAS in treated leachates

Fluxes

Site flux variation for the sum of 49 PFAS including USC:
Between 2 246 and 18 g/an

Site flux variation for the sum of 28 PFAS:
Between 173 and 3 g/an

Starting 1st of September 2026 in France:
100€ fee for every 100 grams of PFAS emitted every year

Average for ATOLIX sites = 573 grams/year
***Estimation*: 95kg of PFAS released from landfills every year in France**

Conclusion

ATOLIX

Conclusion

ATOLIX project:

7 landfills included

Raw leachates:

$$\left[\sum_{49} PFAS\right] \subset [8\,624\,;153\,179]\,ng/L$$

Treated leachates:

$$\left[\sum_{49} PFAS\right] \subset [678\,;155\,792]\,ng/L$$

Ultra short chains prevalence in both raw and treated leachates:

TFA, one order of magnitude higher than others, PFMeS, PFPrA

Leachate treatments efficient for PFAS removal:

Reverse osmosis – 97% removal overall

Nanofiltration – 57% removal overall

Biological treatment – increase for several PFAS

Coagulation – flocculation – no effect

Flux:

Average 573 grams of PFAS emitted annually

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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