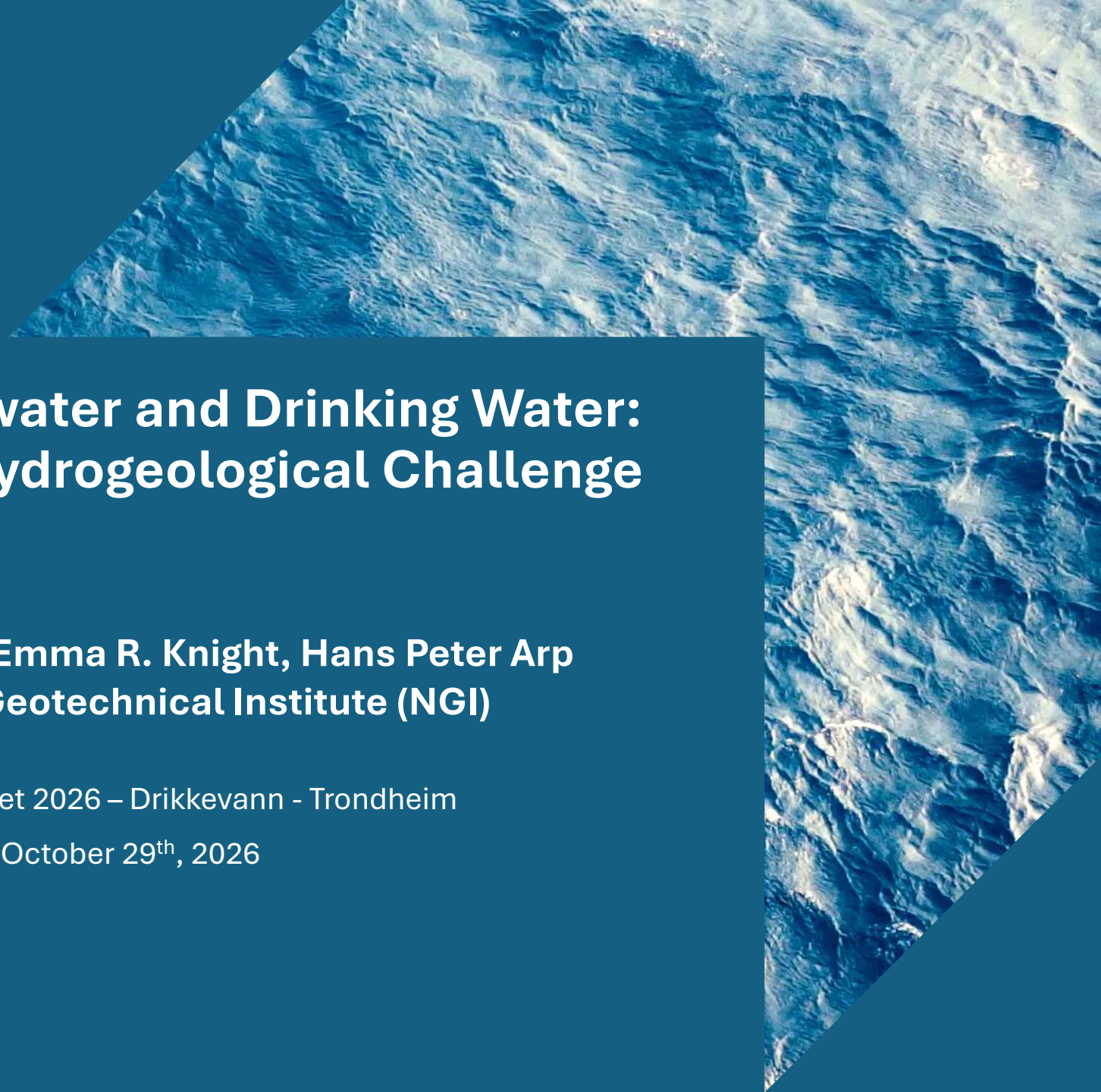
TFA in Groundwater and Drinking Water: An Emerging Hydrogeological Challenge

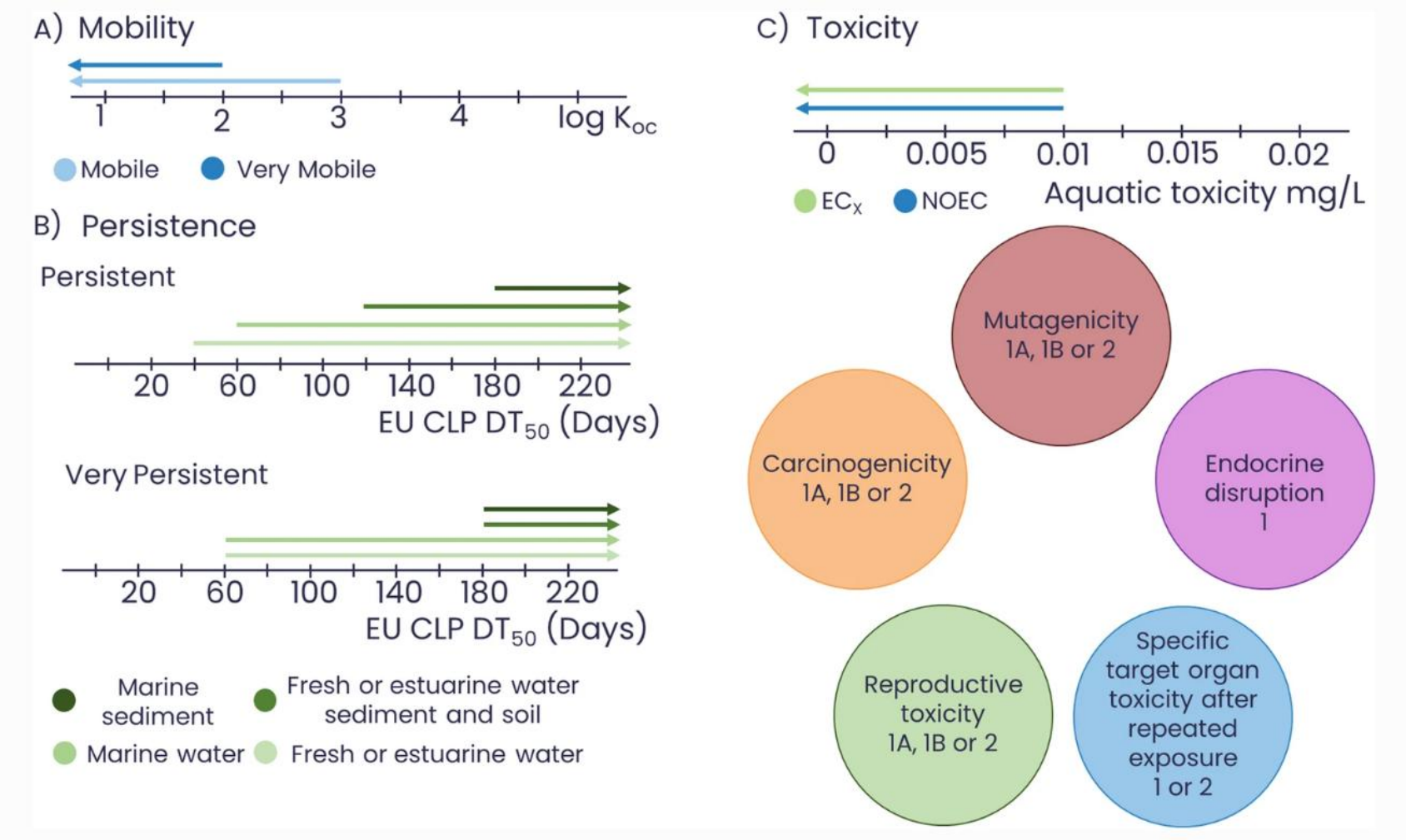
Francois Clayer, Emma R. Knight, Hans Peter Arp
Norwegian Geotechnical Institute (NGI)

IAHs Høstmøtet 2026 – Drikkevann - Trondheim

October 29th, 2026



Regulation and PFAS: PMT/vPvM Hazard Criteria



Per- and polyfluoroalkyl substances (PFAS)

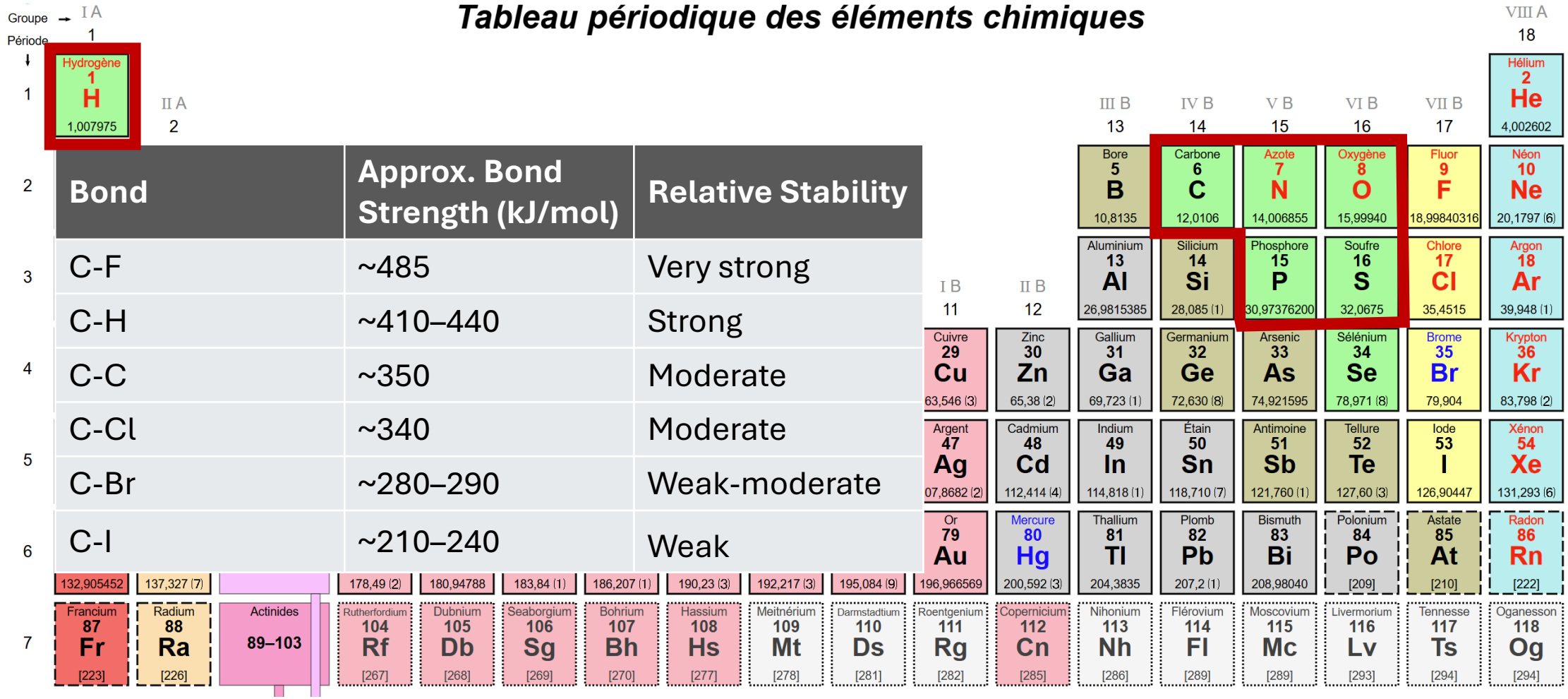
- fluorinated substances with:
  - >1 fully fluorinated methyl ($–CF_3$)
  - fully fluorinated methylene ($–CF_2–$)
- This group **must not** be attached to:
  - hydrogen (H)
  - chlorine (Cl)
  - bromine (Br)
  - iodine (I)

Classification, Labelling and Packaging (CLP) regulation enacted May 2023

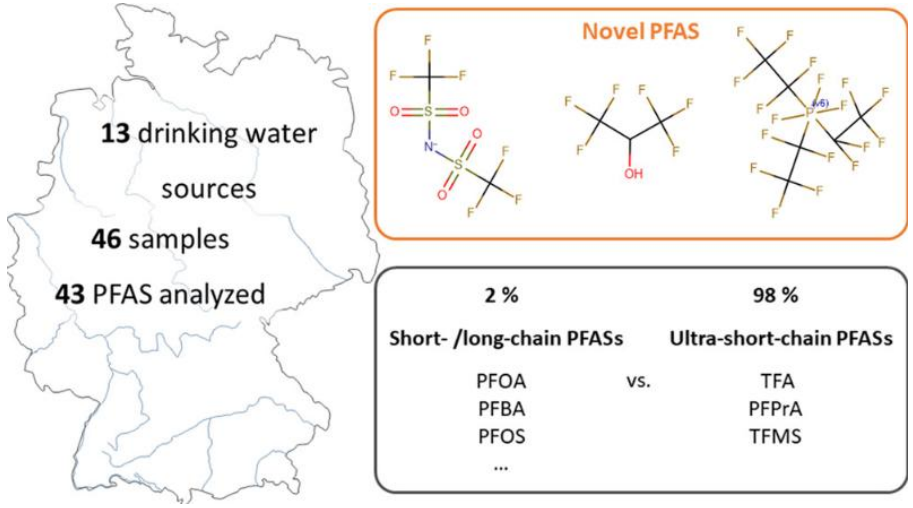
Chemistry and PFAS: why are PFAS so Persistent?

F atoms are **small, highly electro-negative** resulting in very strong C-F bonds (~485 kJ/mol)

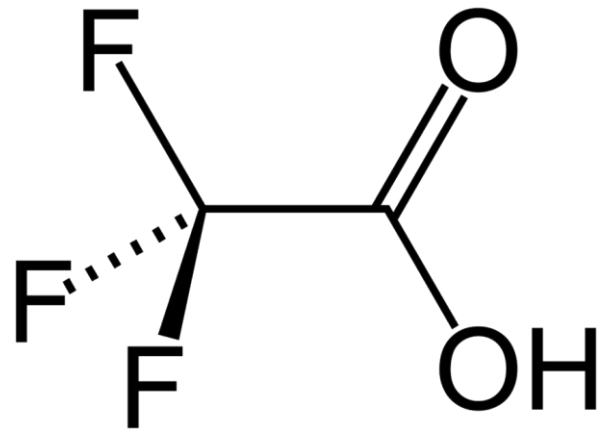
Bond	Approx. Bond Strength (kJ/mol)	Relative Stability
C-F	~485	Very strong
C-H	~410–440	Strong
C-C	~350	Moderate
C-Cl	~340	Moderate
C-Br	~280–290	Weak-moderate
C-I	~210–240	Weak

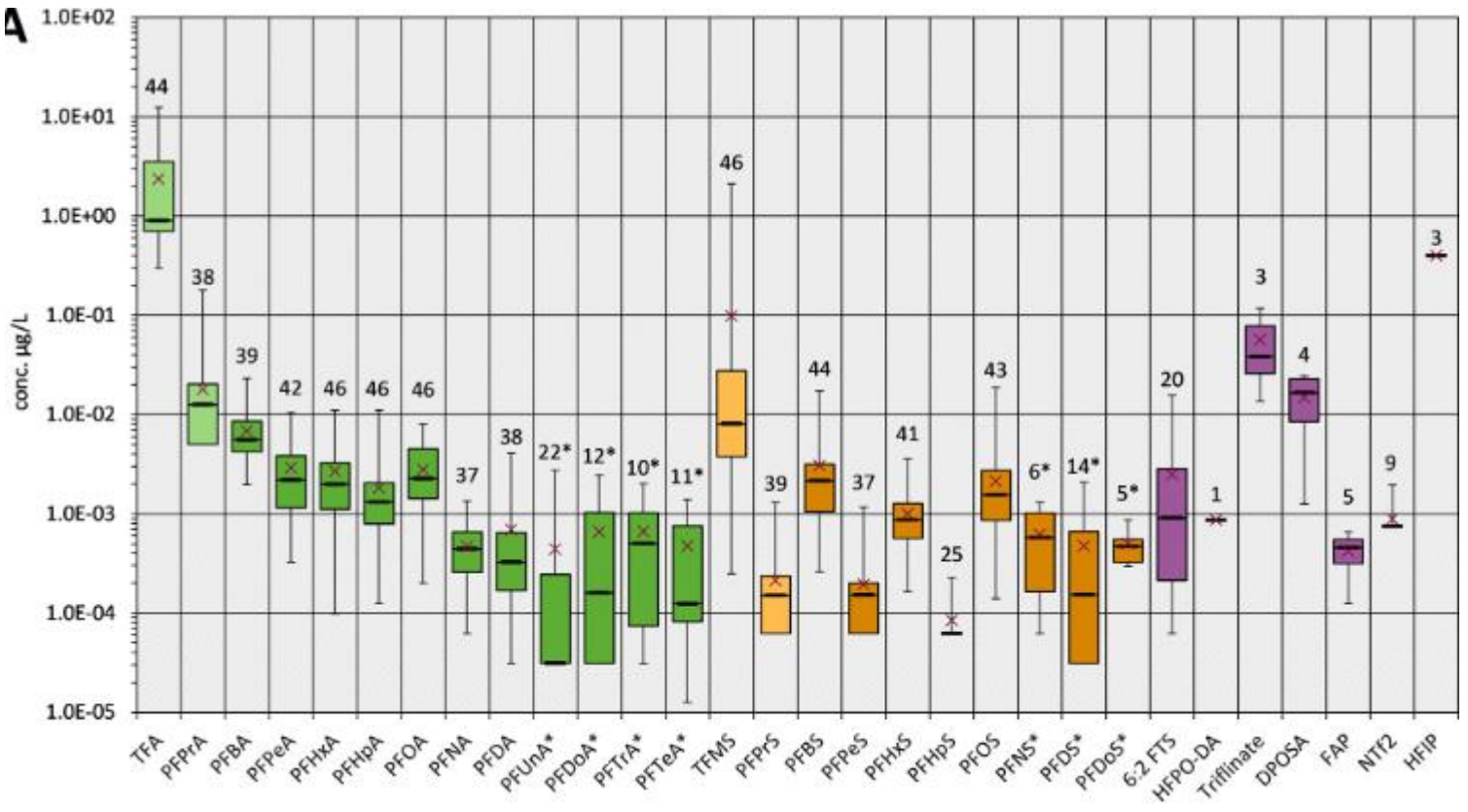


Which PFAS,meeting the vPvM criteria, is the most abundant?



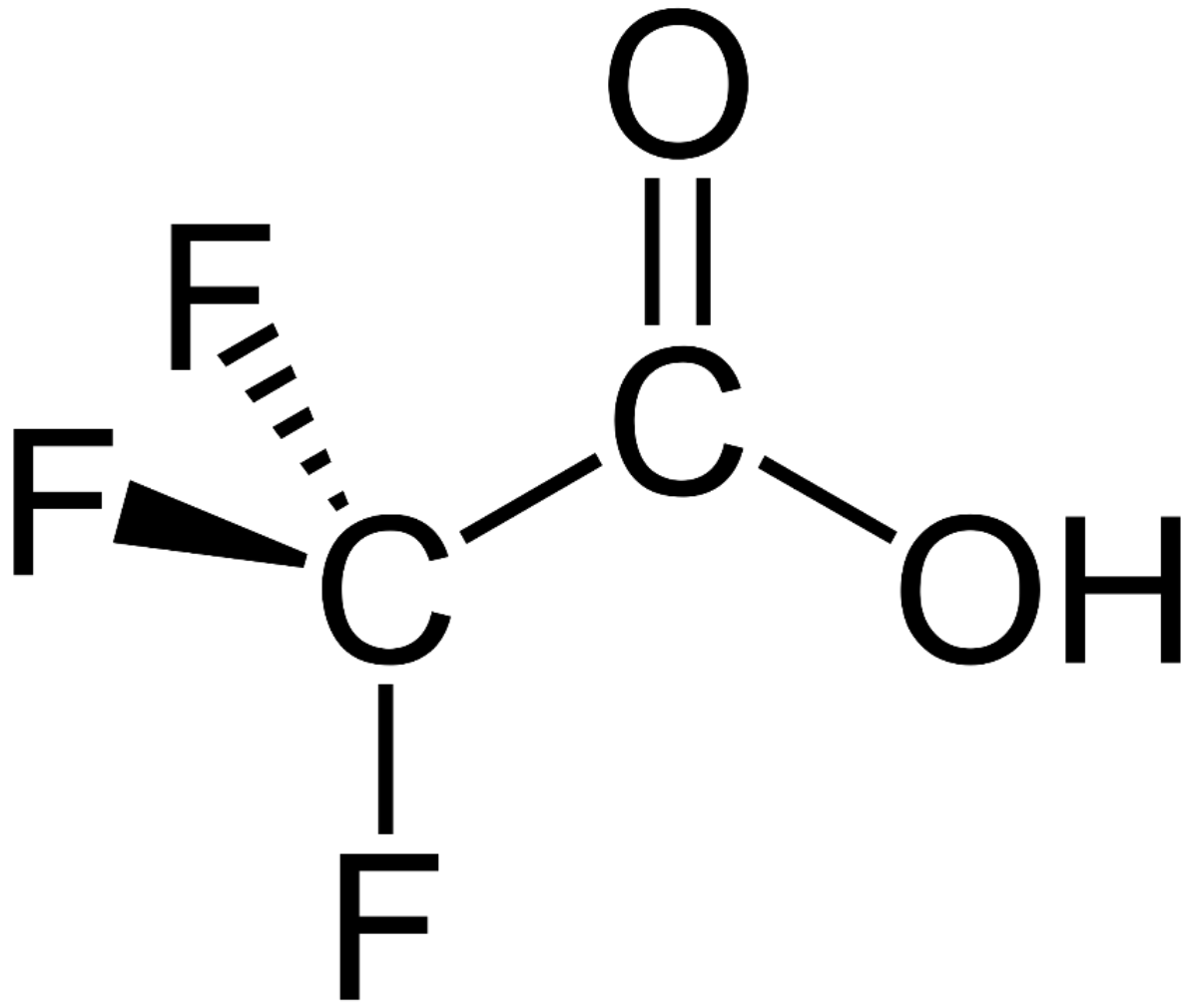
2 %		98 %
Short- /long-chain PFASs		Ultra-short-chain PFASs
PFOA	vs.	TFA
PFBA		PFPrA
PFOS		TFMS
...		



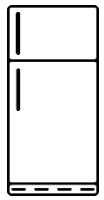


Environmental Science & Technology **2022** *56* (10), 6380-6390

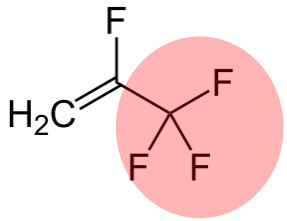
Why is this PFAS now everywhere?



Increasing sources of TFA since the 1990's

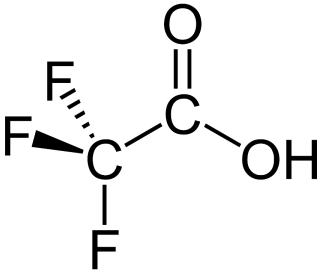


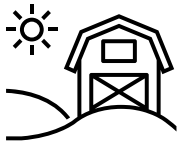
Refrigerants introduced by the **Montreal Protocol**



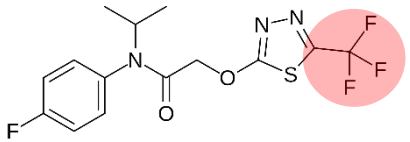
2,3,3,3-Tetrafluoropropene (µHFC-1234yf)

rain

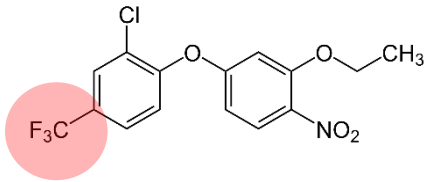




Pesticides

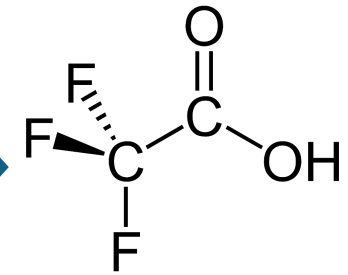


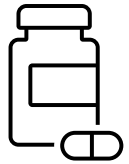
flufenacet



oxyfluorfen

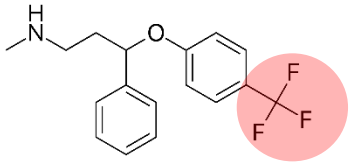
soil



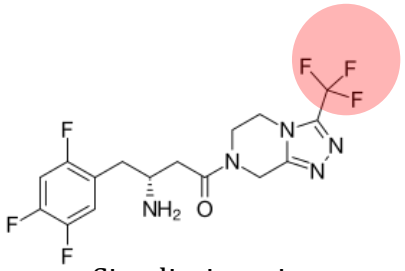


Pharmaceuticals

And Sedation Agents

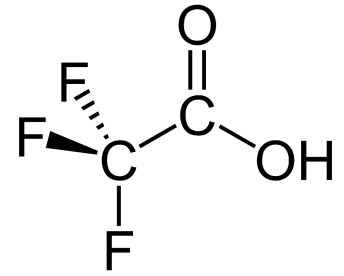


Fluoxetine (Prozac) - since1986 (Anti-depressant)

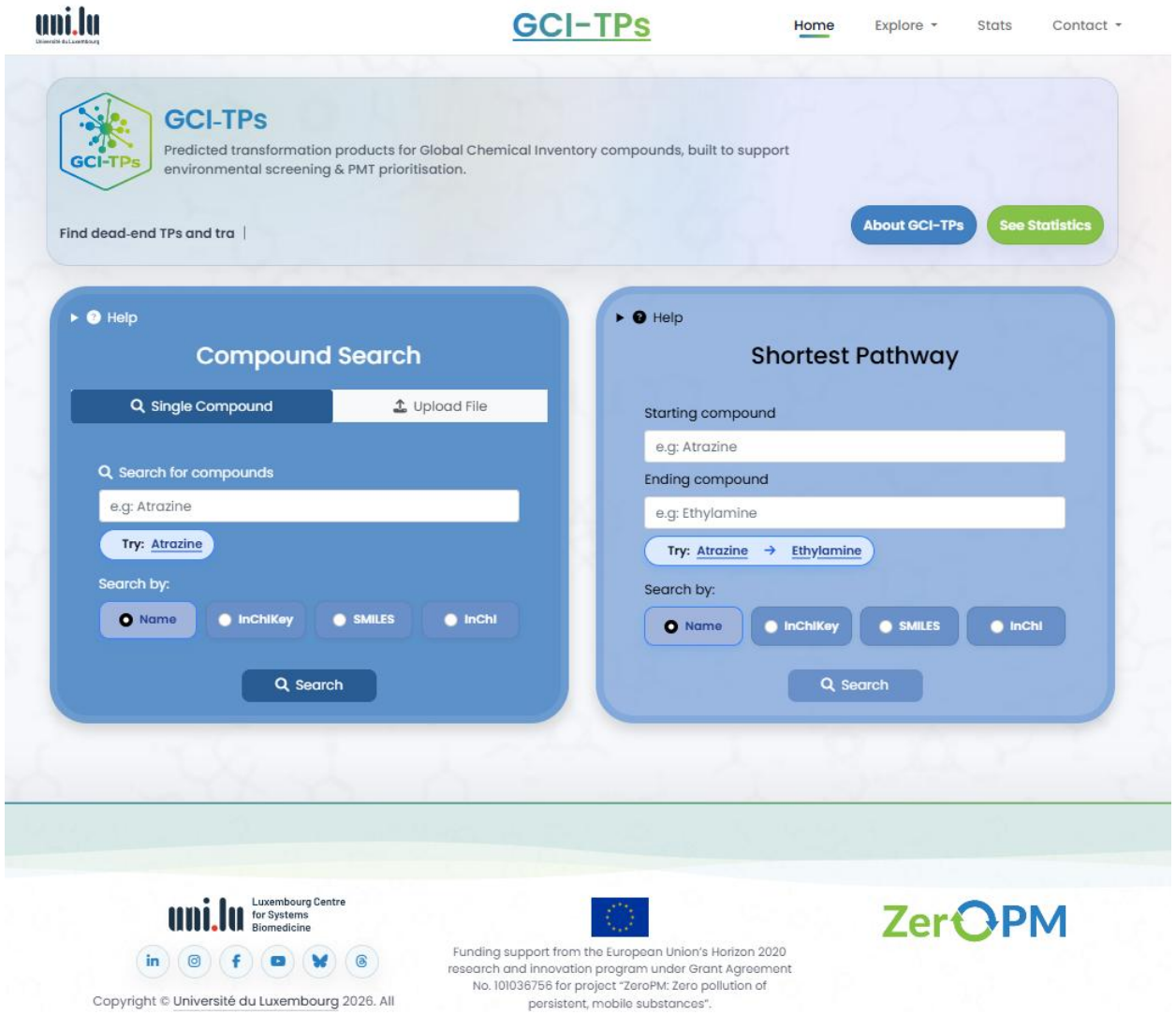


Sitagliptin – since 2006 (Anti-diabetic)

sludge/water



Predicting Dead End Transformation Products (TPs)



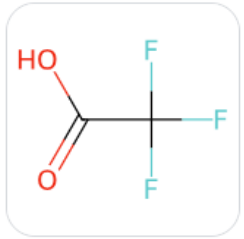
98 091 Original precursors
13 678 364 Transformation products
42 797 878 Reactions

https://gcitps.lcsb.uni.lu/

Palm et al. GCI-TPs: Identifying Potentially Hazardous Transformation Products of Global Chemical Inventory Compounds, https://chemrxiv.org/doi/full/10.26434/chemrxiv.15005019/v1

NGI

TARGET COMPOUND



Trifluoroacetic acid

Incoming reactions: 3,804	Outgoing reactions: 0
Direct predecessors: 2,431	Direct successors: 0
Dead-end in: 788	Dead-end out: 0

COMPOUND INFORMATION

INCHIKEY
DTQVDTLACAAQTR-UHFFFAOYSA-N

SMILES
C(C(F)(F)F)(O)=O

INCHI
InChI=1S/C2HF3O2/c3-2(4,5)1(6)7/h(H,6,7)

SYNONYMS
Trifluoroacetic acid; 76-05-1; Perfluoroacetic acid; Trifluoracetic acid; Trifluoroethanoic acid; 2,2,2-trifluoroacetic acid; Acetic acid, trifluoro-; Kyselina trifluoroctova; Acetic acid, 2,2,2-trifluoro-;...

Mass: 113.992867

PubChem: Open in PubChem

SELECTION

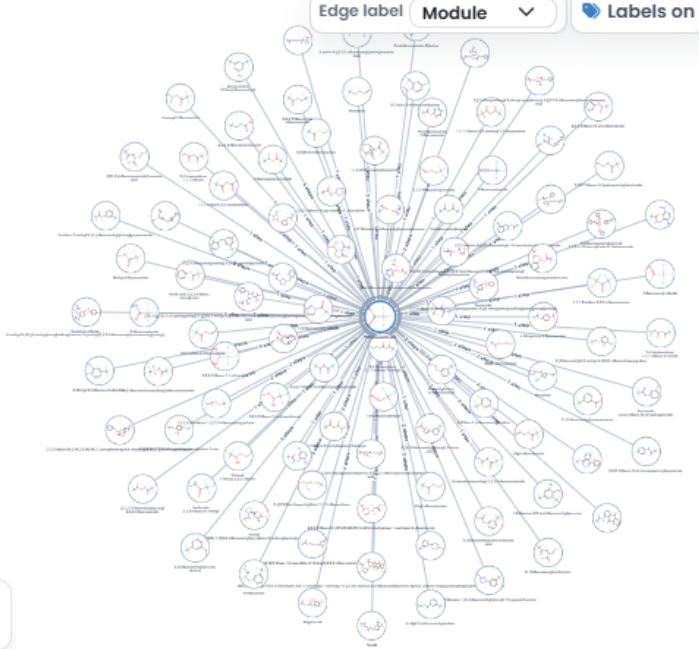
Click a node or an edge

Details will appear here.

← Original Precursors (100) | All Precursors (100) | Dead-Ends (0) | → All Successors (0)

Graph preview: 100 of up to 100 nodes shown.

Edge label: Module | Labels on | Titles on | Fit | Export

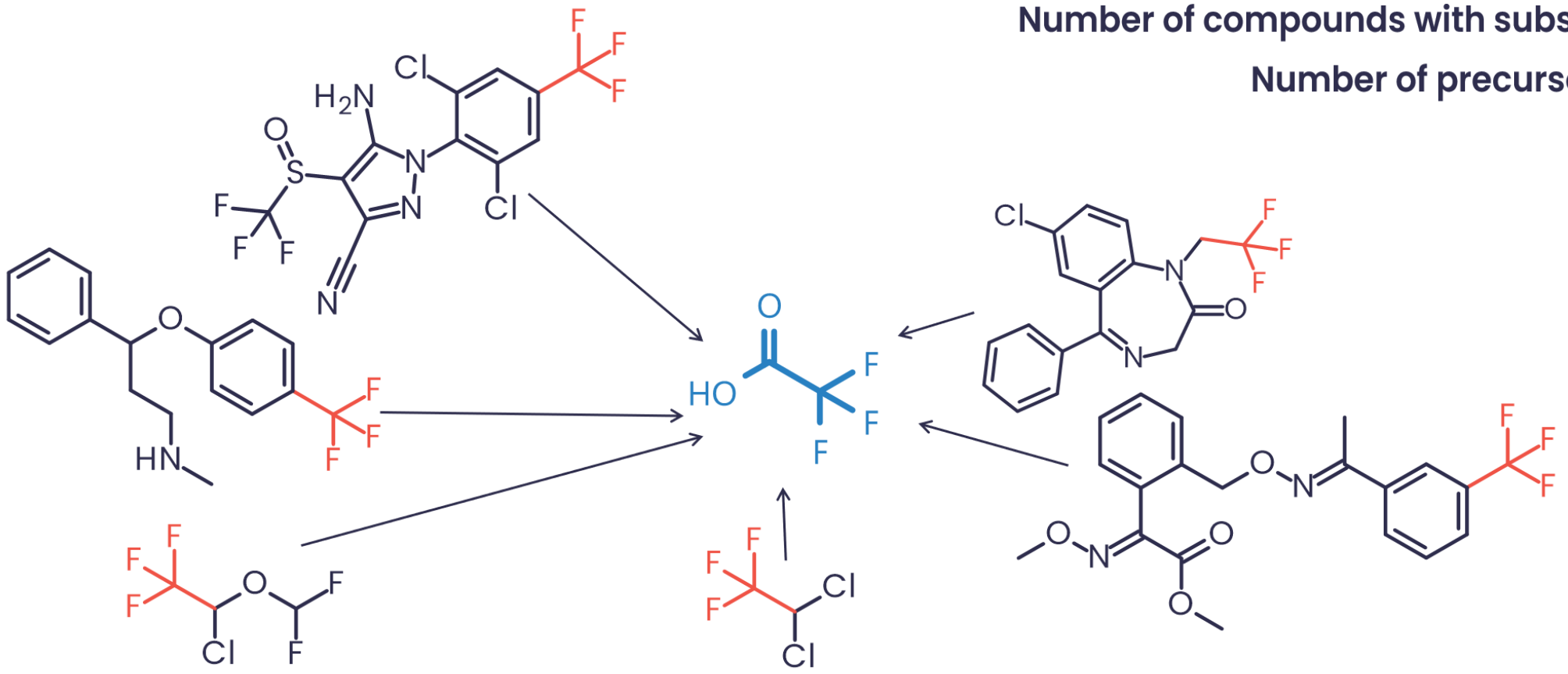


Graph preview: 100 of up to 100 nodes shown.

Substructure Groups: TFA

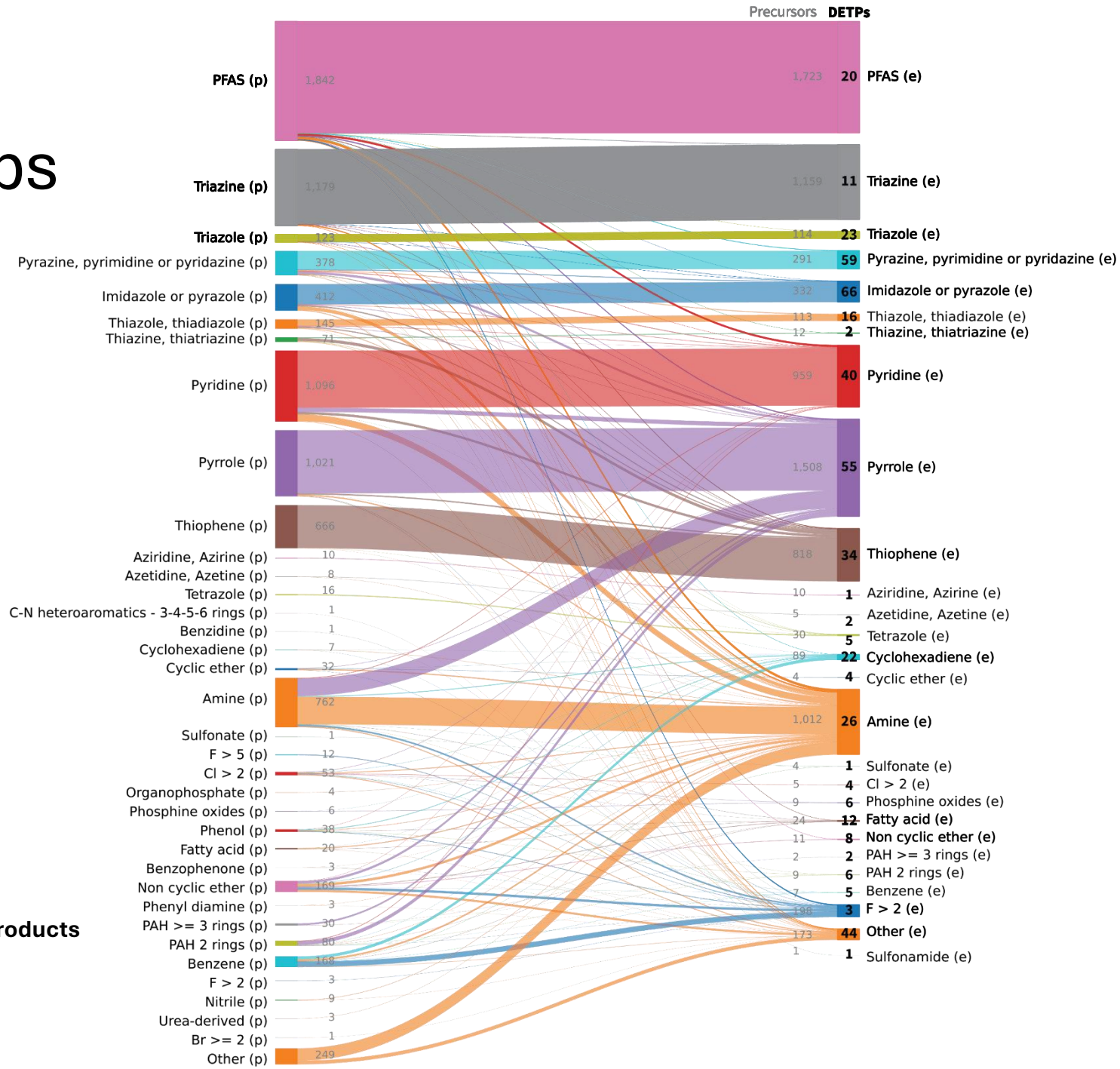
Number of compounds with substructure: 2153

Number of precursors: 788 (37%)



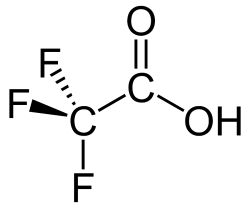
PFAS are one of many (v)P(v)M/PMT groups

- Expert-based structural grouping
- 45 classes – ranked in decreasing order of MP probability
- Do the Dead-End Transformation Products remain in the same class?
  - If Yes – Strong indication of Persistency

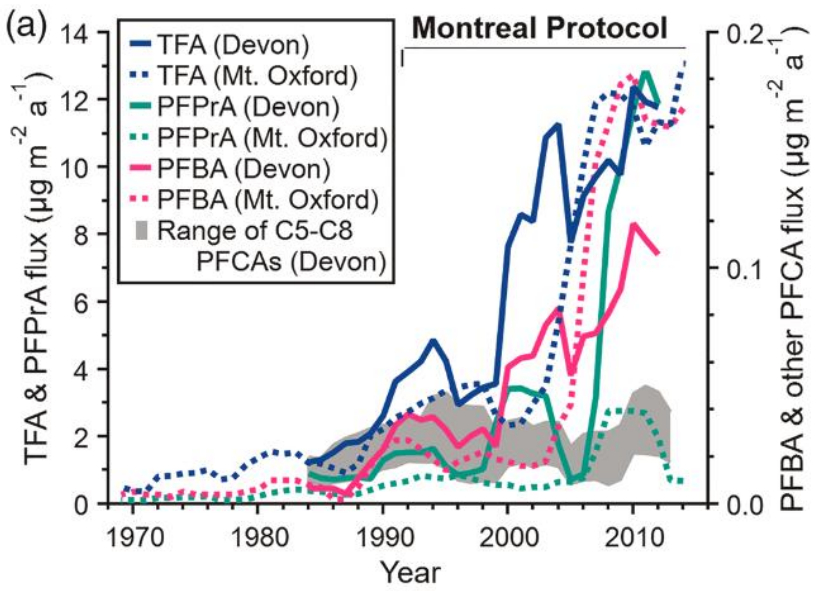


Mapping precursors and dead-end transformation products (DETPs) through expert priority classes

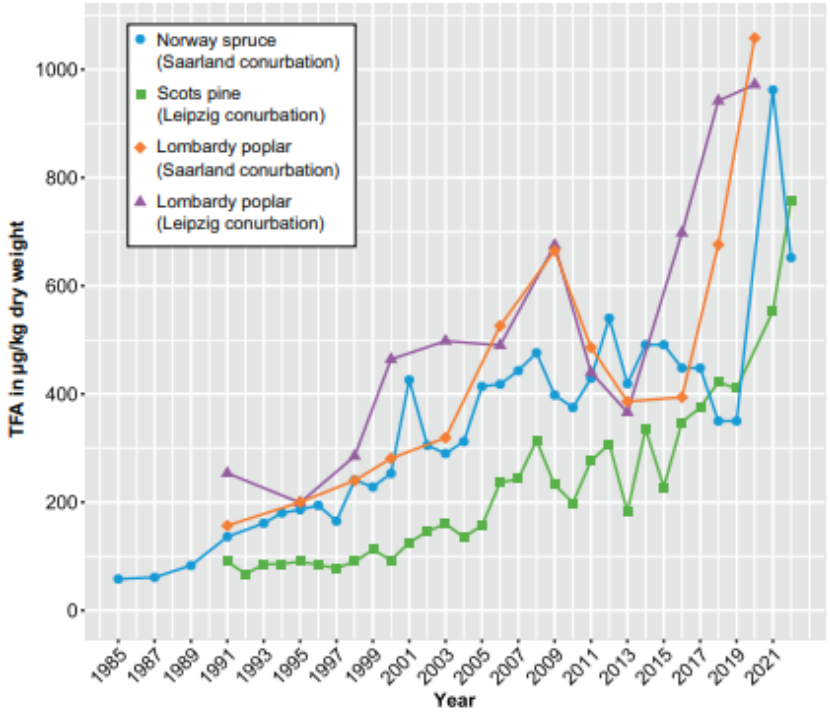
TFA is accumulating everywhere



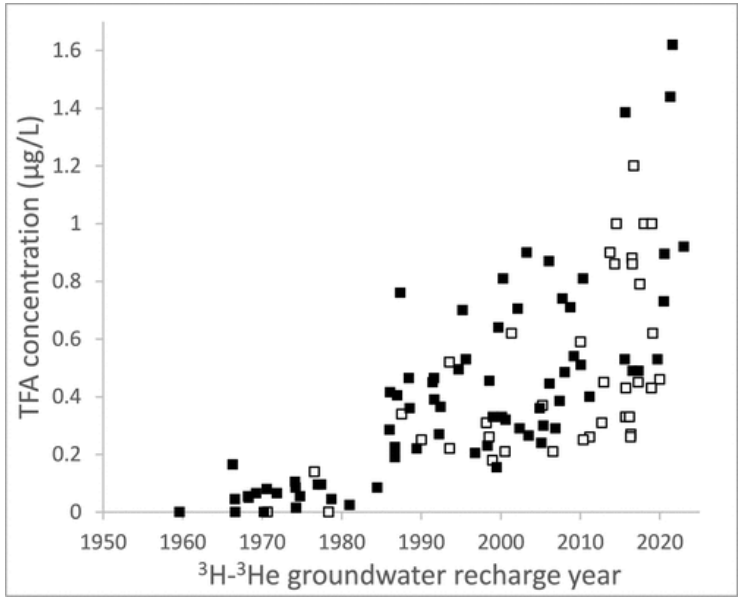
TFA accumulating in arctic ice cores



and in tree leafs



and in groundwater (Denmark)



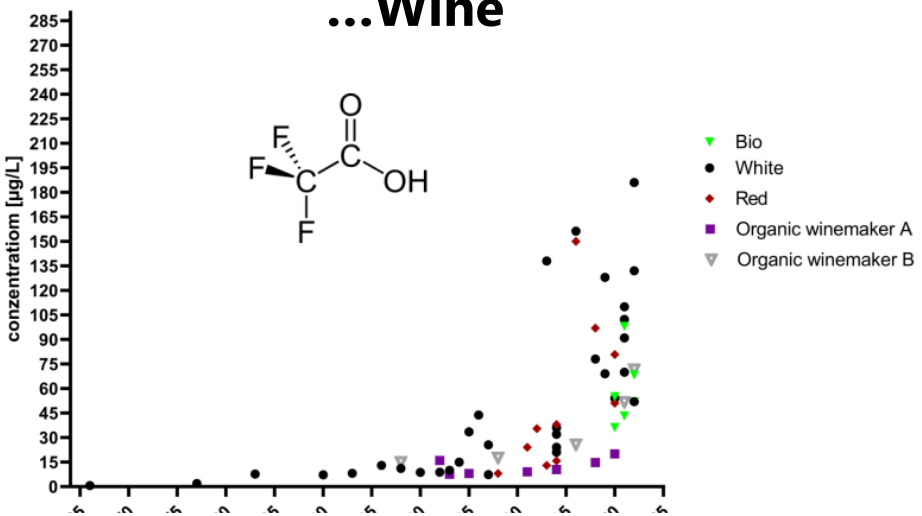
Pickard et al. Geophysical Research Letters (2020),47, e2020GL087535

Freeling and Björnsdotter, Current Opinion in Green and Sustainable Chemistry 2023, 41:100807

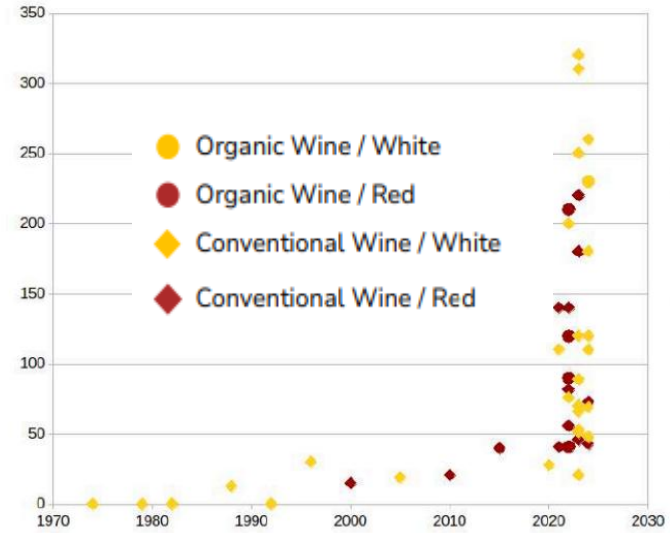
Albers and Sültenfuss, Environmental Science & Technology Letters 2024 11 (10), 1090-1095

TFA is accumulating everywhere

...Wine







Up to 300 µg/L

Unpublished data: Michael Müller. Uni. Freiburg
michael.mueller@pharmazie.uni-freiburg.de (used with permission)

Wine image: Sai Balaji Varma Gadhiraju



PAN Europe: Message from the Bottle – The Rapid Rise of TFA Contamination Across the EU

Drinking water (median)[1,2,3]

- France: 0.78 µg/L
- Germany: 1.5 µg/L
- 19 Countries: 0.23 µg/L

Tee (median): 2.4 µg/L[3]

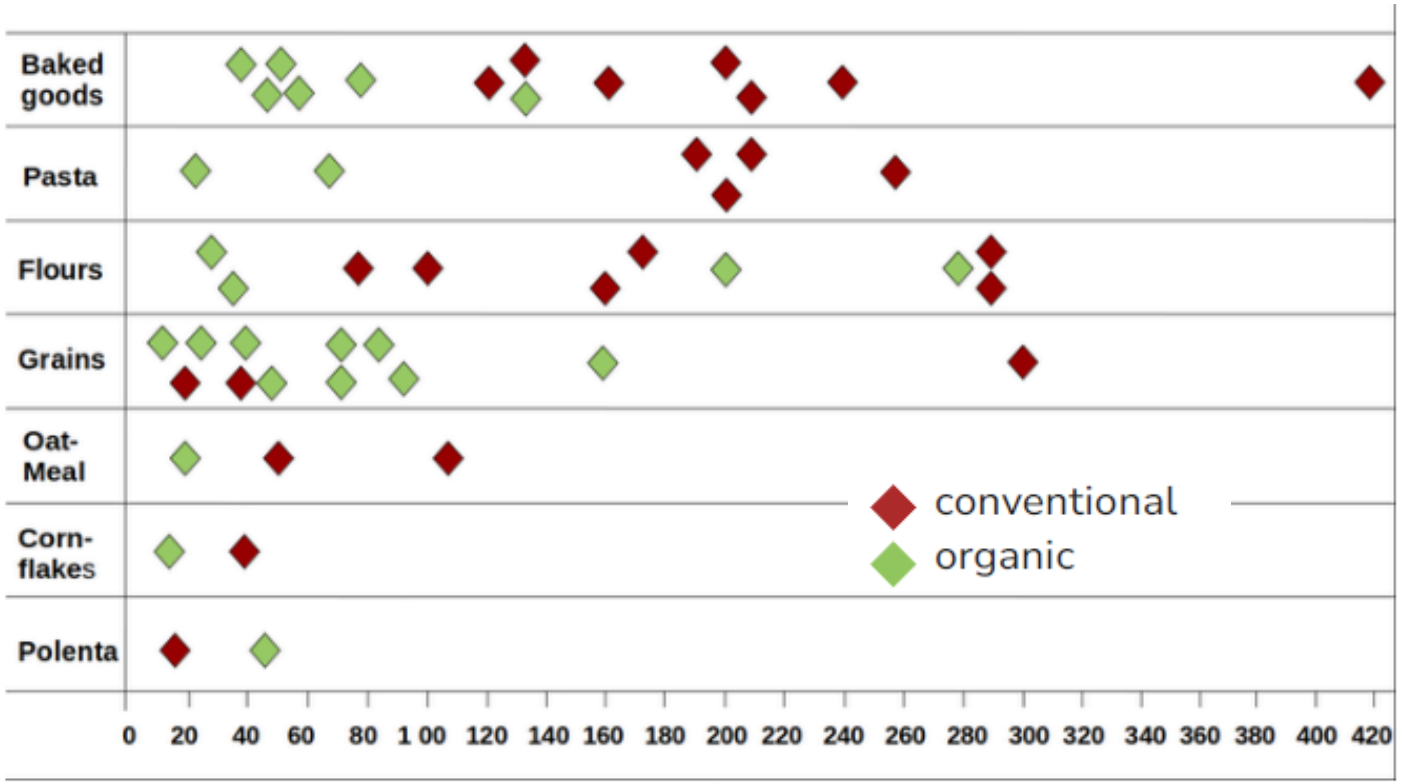
Beer (median) 6.1 µg/L[3]

Orange juice (mean 34 µg/L)[4]

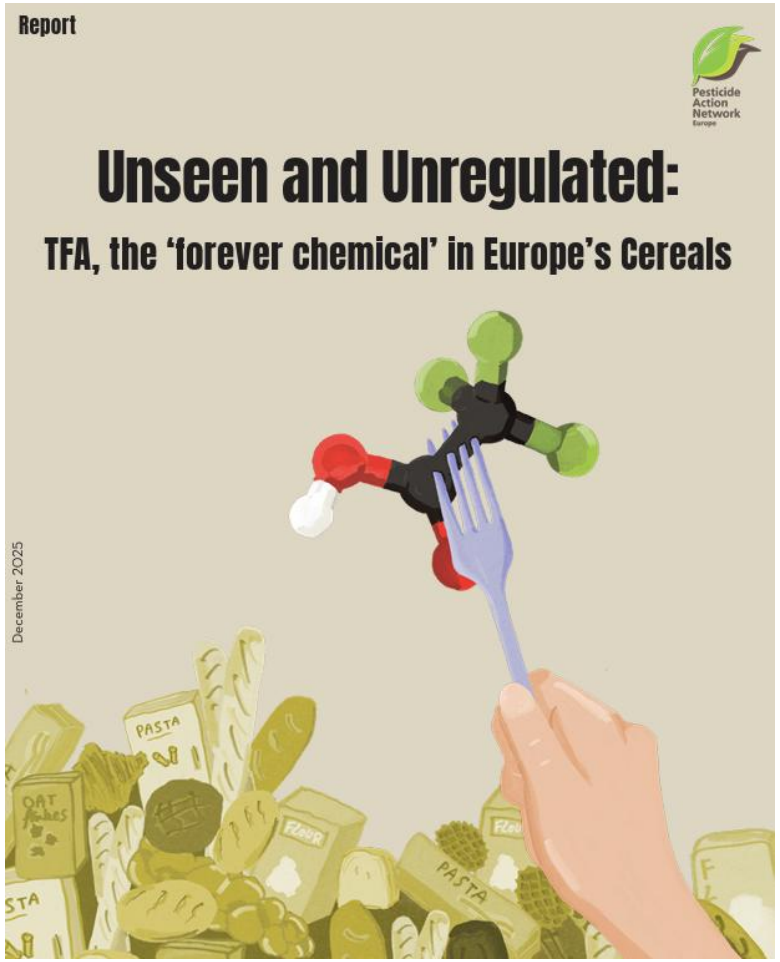
Apple juice (mean 6.2 µg/L)[4]

1. Anses (2025)
2. Neuwald et al. *Environmental Science & Technology* **2022** *56* (10), 6380-6390
3. Scheurer & Nödler. *Food Chemistry*, *351*, 129304.
4. Van Hees et al. https://cdnmedia.eurofins.com/european-east/media/uxcnaa2c/eurofins_tfa_tfms_juice_24_final.pdf





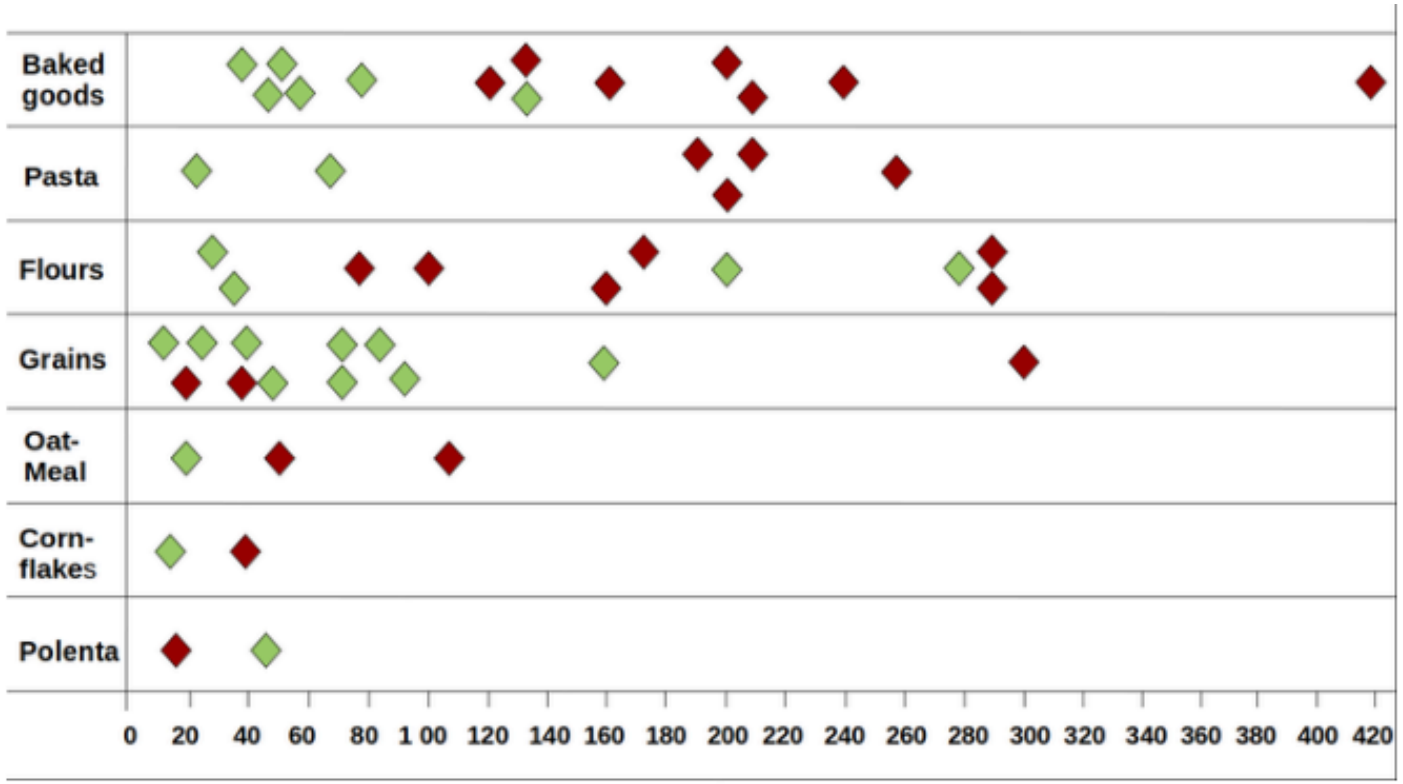
µg/kg dw



210 µg/kg in a French Baguette



and in blood



µg/kg dw

https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/Report_03062025_TFA



Chinese blood 97% detection
Median 8.5 µg/L



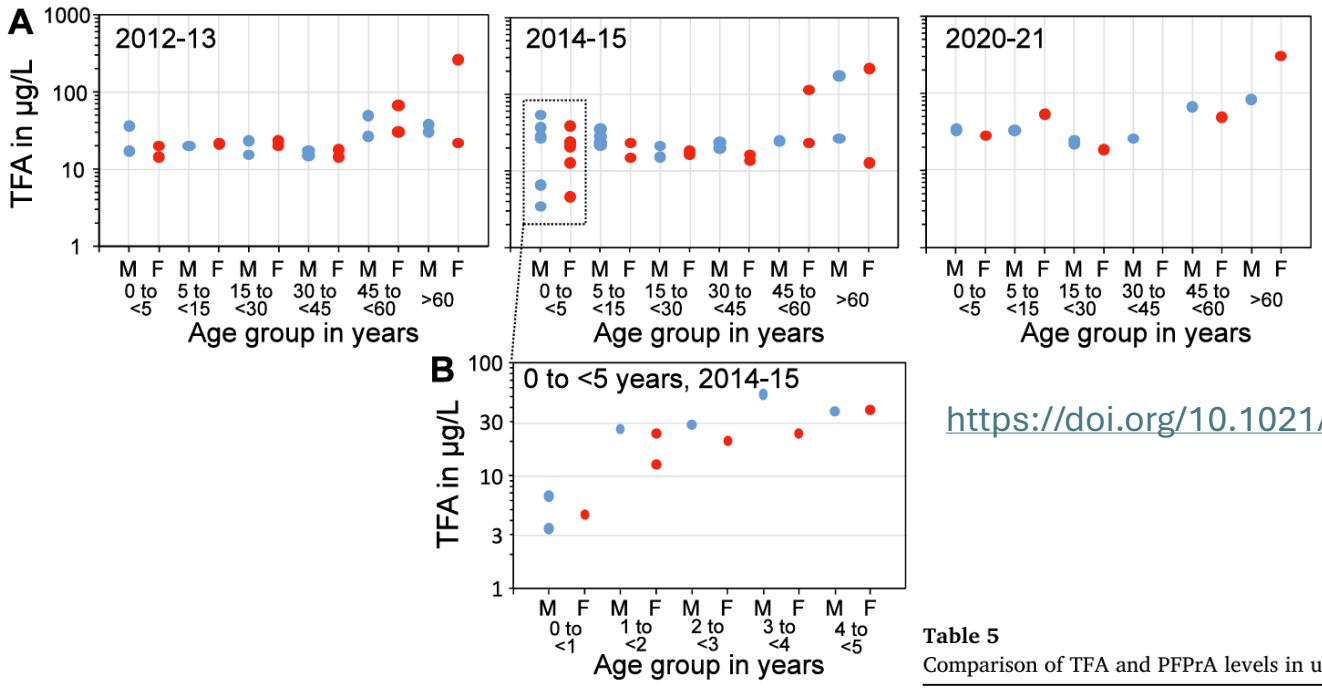
USA blood serum 74% detection
Median 6.0 µg/L

What levels of TFA will be in the blood of future generations?

Duan et al. (2020) Environ Int 134:105295.
Zheng et al. (2023) ES&T 2023, 57, 15782-15793
Arp et al. ES&T 2024, 58, 45, 19925-19935

TFA in human urine: Australia and Germany

Australia



https://doi.org/10.1021/acs.estlett.5c00678

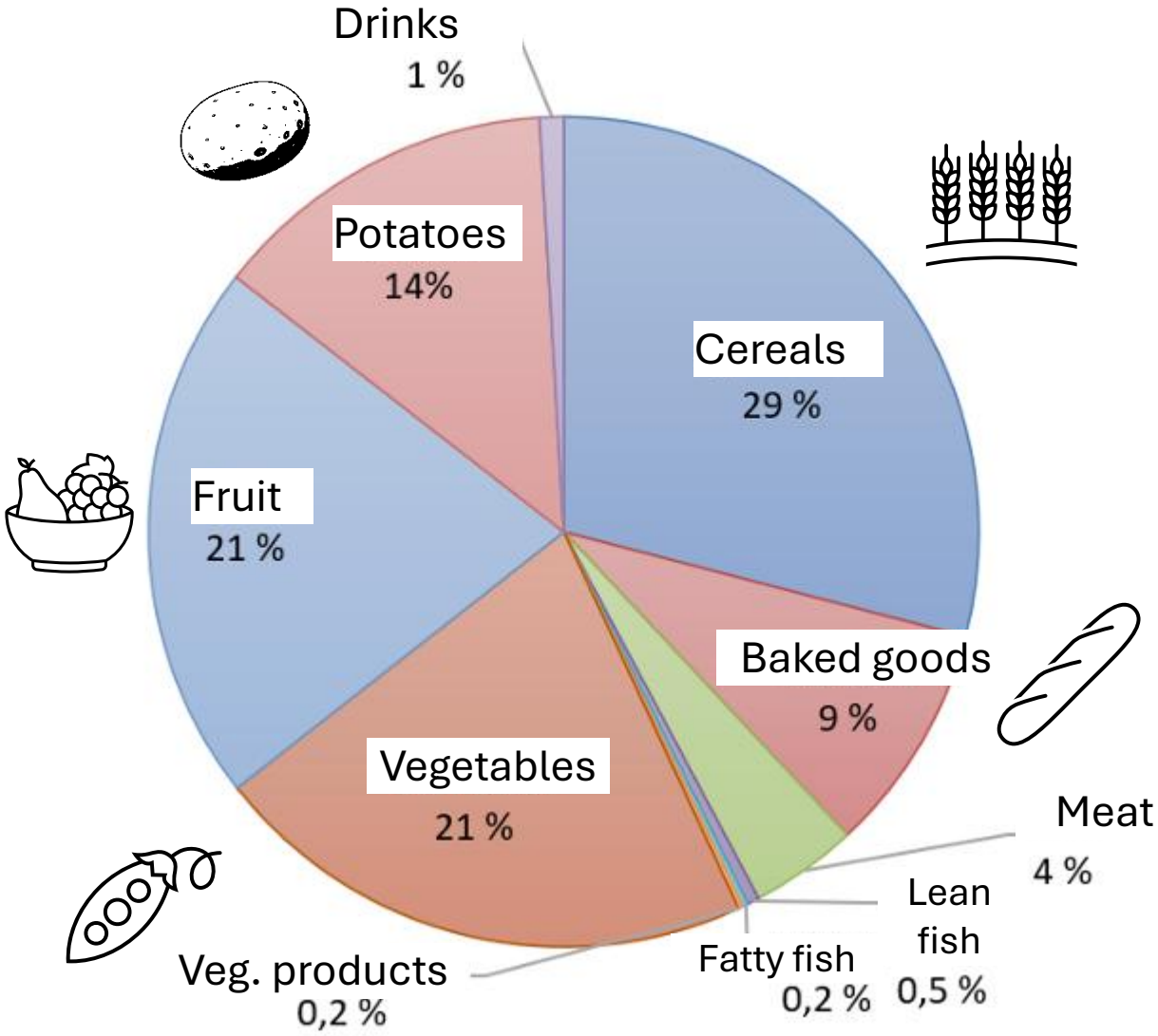
Germany

Table 5
Comparison of TFA and PFPrA levels in urine (µg/L) from the NAKO cohort with levels determined in other studies.

Study, Region	NAKO[a] Germany	NAKO[a] Germany	Australia[b]	Australia[b]	Australia[b]	USA[c]	FLEHS IV[d] Belgium
Year	2015–2019	2020–2024	2012–2013	2014–2015	2020–2021	2020	2017–2018
Age	20–69 y	20–69 y	15–>60 y	15–>60 y	15–>60 y	25–88 y	14–15 y
N	150	150	24[e]	22[e]	12[e]	81[f]	83
TFA:							
% > LOQ	100	100	100	100	100	31	30[g], 64[h]
Median	22,5	27,2	21	23	33,5	<LOD	NC
Max	110	1312	270	220	300	290	NC
PFPrA							
% > LOQ	0	0	NA	NA	NA	56	NA
Median	<LOQ	<LOQ	NA	NA	NA	0.051	NA
Max	<LOQ	<LOQ	NA	NA	NA	6.8	NA

Intake of TFA from a typical Swedish Diet

(total 24.1 µg TFA/person/day in 2022)*



Simple risk assessment:

0.344 µg/kg /day (70 kg/person)

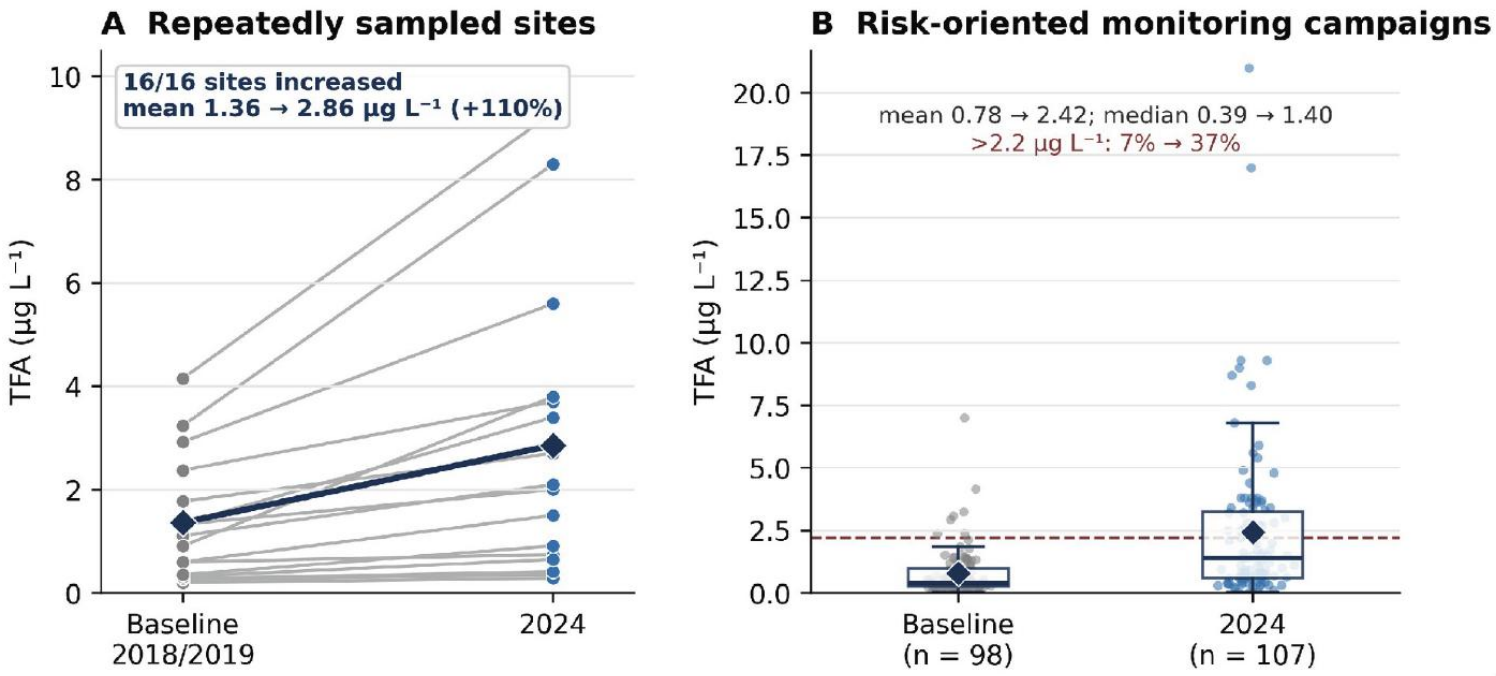
= 1.4% EFSA draft Acceptable Daily Intake for TFA of 25 µg/kg/day (expressed as TFA)

= 110% of the EFSA TWI of 0.0044 µg/kg/week $PFOA_{equivalents}$ based on immunotoxicity (using an RPF of 0.002) of 0.314 µg/kg/day

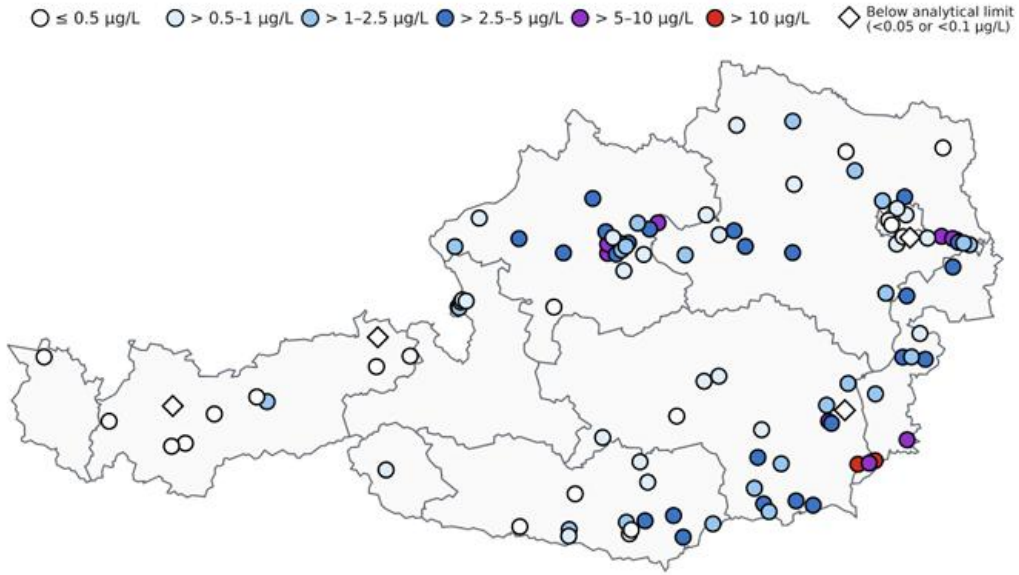
*Source: Gyllenhammar et al. (2026) «Halter av Trifluorättiksyra (TFA) och andra ultrakorta PFAS i Livsmedelsverkets Matkorgsstudie från 2022 ”

TFA in Groundwater - Austria

Groundwater in Austria



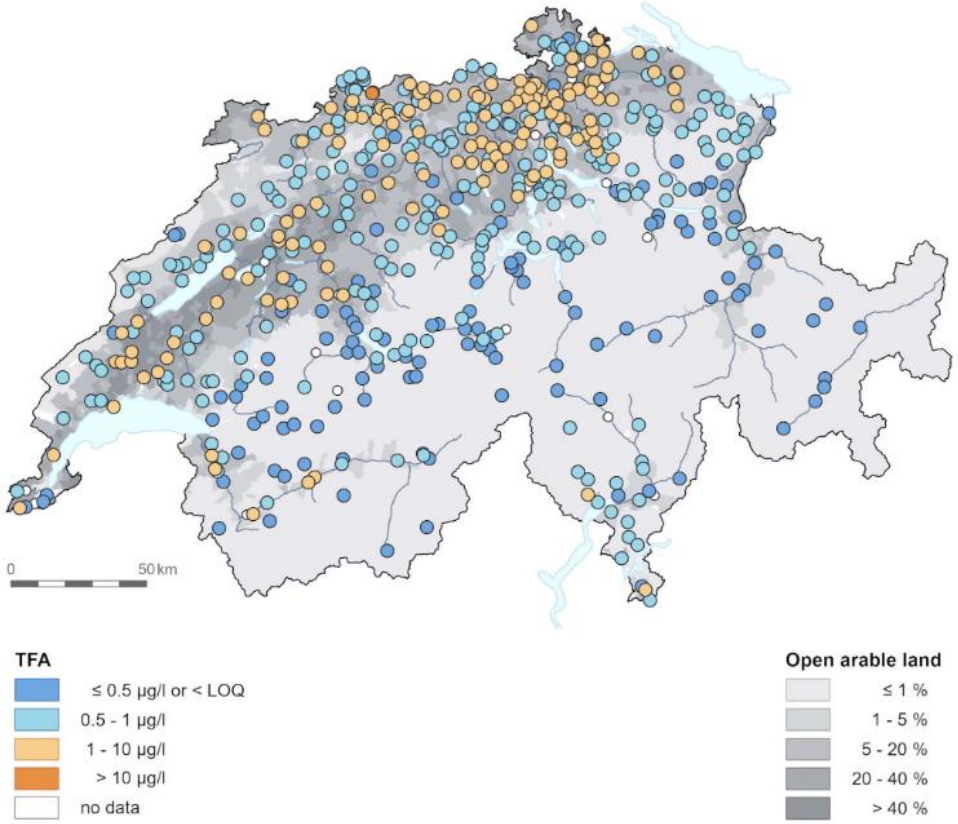
In 2024



https://doi.org/10.26434/chemrxiv.15008752/v1 (Preprint)

TFA in Groundwater - Switzerland

Groundwater in Switzerland



TFA in groundwater. Data: NAQUA 2022/2023

- TFA in precipitation averaged around 0.6 µg/L
- In aquifers above 1000 masl around 0.6 µg/L
- In Lakes and Rivers, locally higher up to 1.0 µg/L

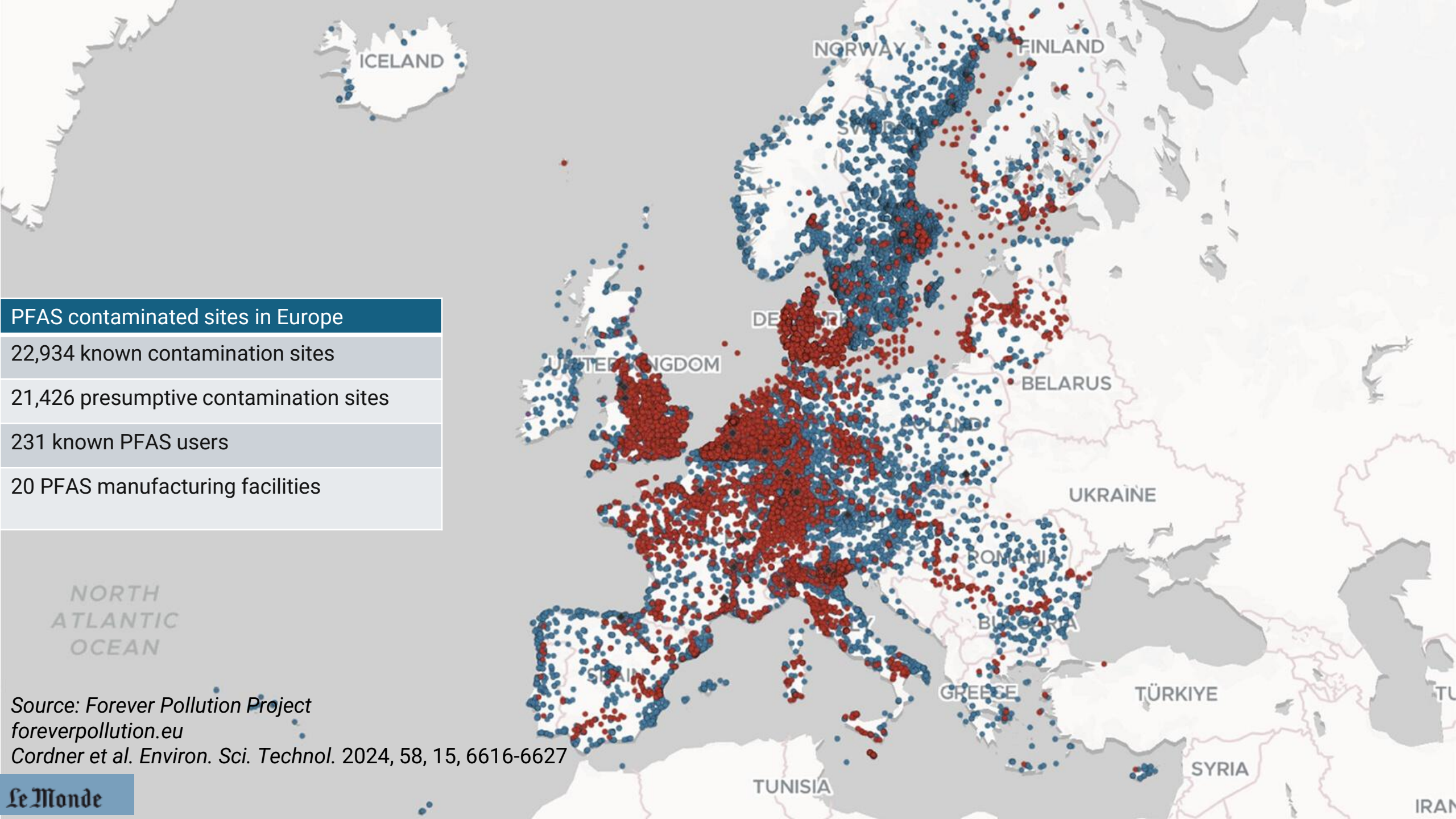
Other aquifers (near urban and agricultural areas)

- On average 1.2 µg/L and up to 5-10 µg/L

TFA from precipitation: **0.6 kg/(km^2 yr)**
TFA from Agriculture (plant protection products): **1.7 kg/(km^2 yr)**

https://doi.org/10.5194/acp-25-18157-2025
Federal Office for the Environment FOEN

NGI

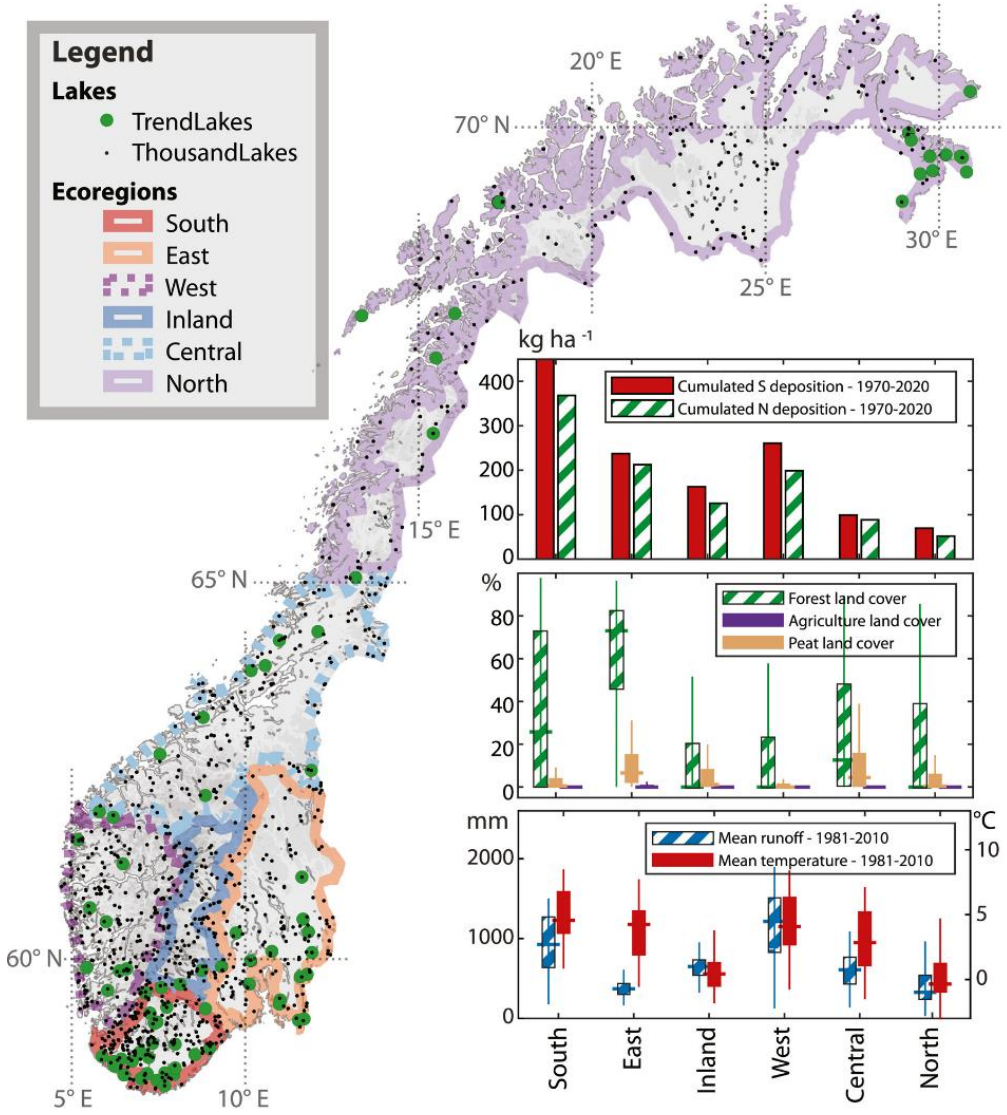


PFAS contaminated sites in Europe
22,934 known contamination sites
21,426 presumptive contamination sites
231 known PFAS users
20 PFAS manufacturing facilities

Source: Forever Pollution Project
foreverpollution.eu
Cordner et al. Environ. Sci. Technol. 2024, 58, 15, 6616-6627

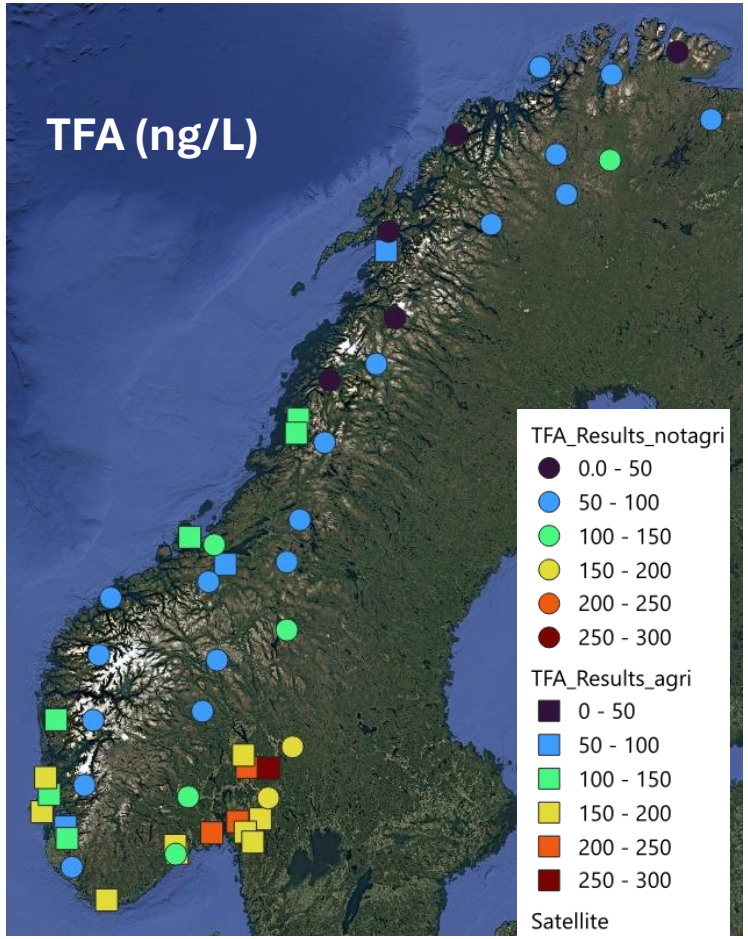
Le Monde

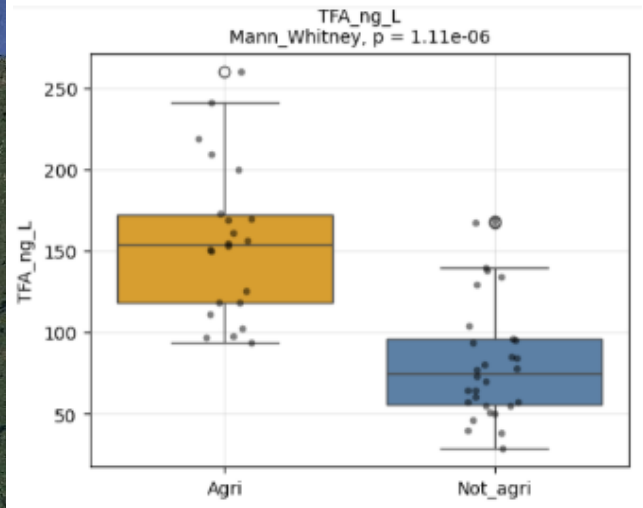
TFA in a subset of 1000 lake samples (2019) – Norway



De Wit et al. (2023)
https://doi.org/10.1029/2022GB007509

- 1000 lakes sampled in 2019 by helicopter – statistically representative of **>134 000 Norwegian lakes** (> 4ha; NVE 1995)
- Subselection of 22 lakes in "Agricultural" watershed, and 30 lakes across Norway (Lon-Lat gradient)





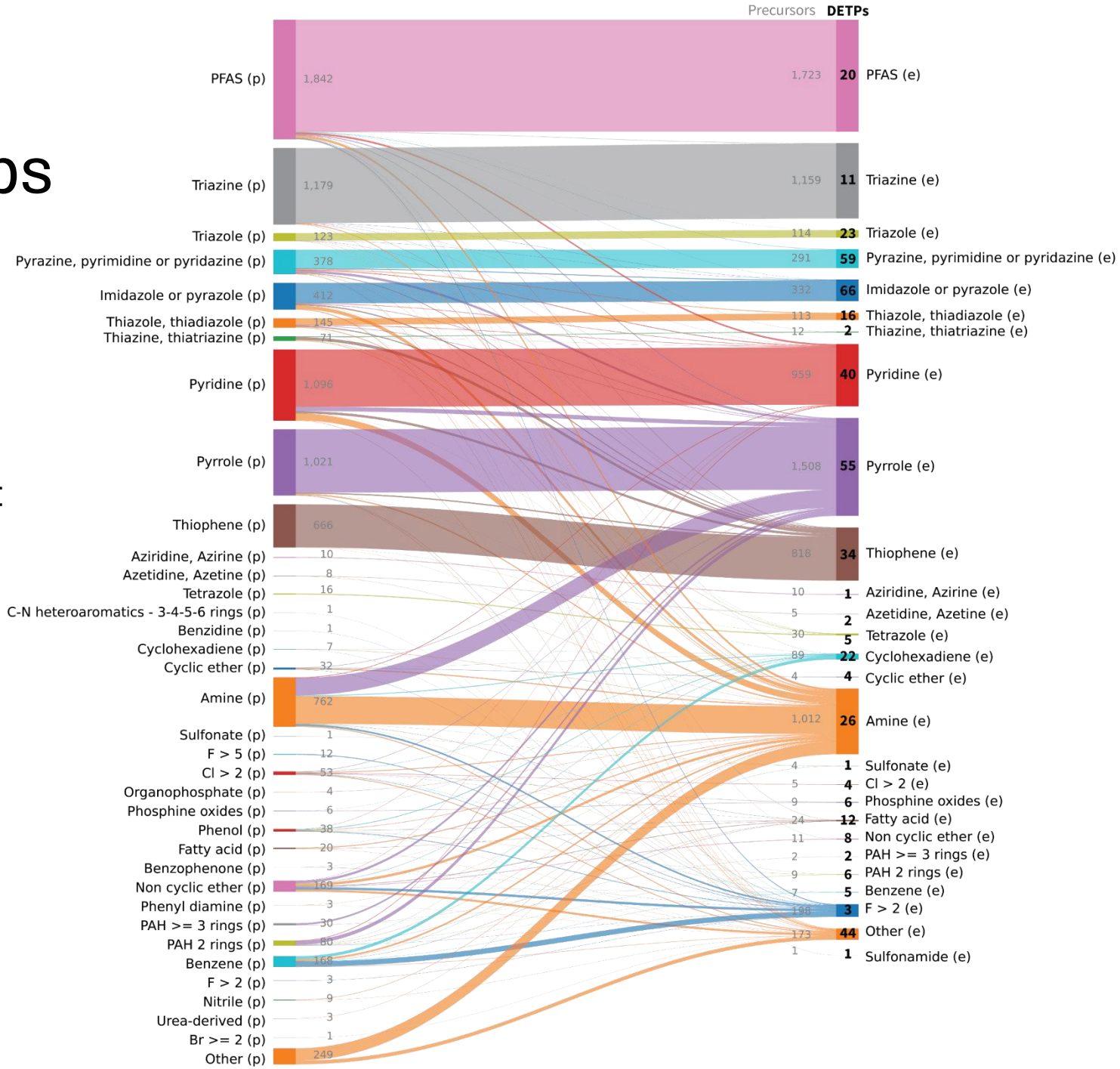
Drinking water in Oslo (2026):
0.3 µg/L

PFAS are one of many (v)P(v)M/PMT groups

- Drinking Water is probably a negligible TFA exposition pathway for human
- TFA is increasing fast and everywhere because it is ubiquitous and persistent

BUT

- There are many other groups that are raising concern
- Some can degrade over longer timescales which is a source of uncertainty…



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Emma R. Knight



Thank-you!

ZeroPM

Prevent

Prioritize

Remove

2021-2026

Thanks to funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036756



SETAC Keynote 2022 (Youtube)



Final ZeroPM workshop (ZeroPM: LinkedIn)



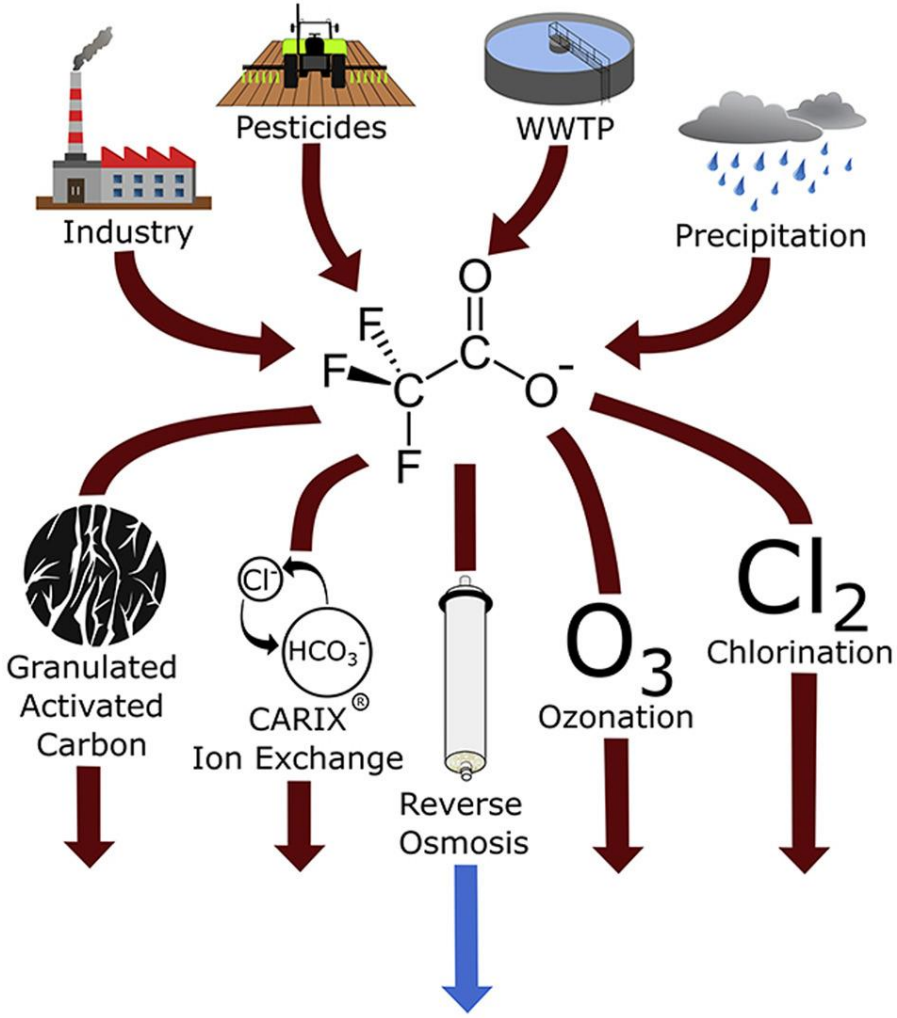
ZeroPM Breaking News

Welcome to ZeroPM - ZeroPM

Water treatment ineffective at removing TFA, ….or can form TFA

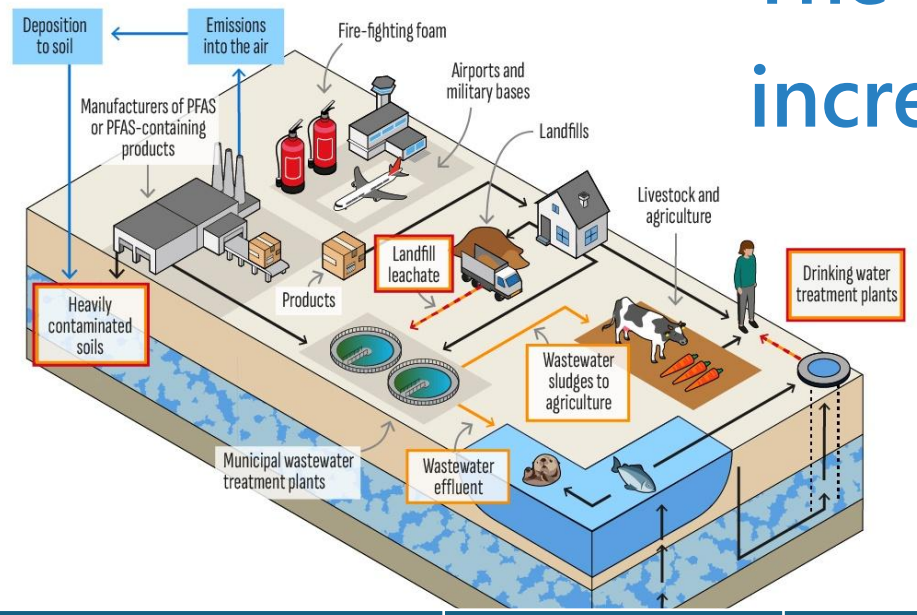
PFAS remediation

- **Enhanced degradation techniques** (ozonation, chlorination, photolysis, electrolysis, incineration, pyrolysos etc.) **can lead to TFA formation from precursors** (along with other PFAS, F-gases)
- Sorption techniques (activated carbon, ion exchange resins) -> **do not filter TFA**
- **Reverse osmosis** only technique that works for TFA, but requires an expensive destruction step for brines



Scheurer et al. (2017). *Water research*, *126*, 460-471.

The costs of PFAS removal increases it spreads



Costs of removal in the EU using best available technology (BAT)	Legacy Scenario	Emerging Scenario
	Targeting long-chain PFAS	Targeting all PFAS, including TFA
Heavily contaminated soils	1-5 B €/year	5-30 B €/year
Drinking water	0.2-0.7 B €/year	16-65 B €/year
Landfill leachate	0.0004-0.01 B €/year	0.02-0.7 B €/year
Wastewater effluent	Not included	20-70 B €/year
Wastewater sludges to agriculture	Not included	8-20 B €/year

- **Health costs by 2050 – €438 Billion Euro** (European Commission, 2025)
- **Remediation Legacy PFAS –** only treat legacy PFAS (e.g. PFOS) and assume emissions stopped
  €38 - 100 billion over 20 years
- **Emerging Scenario for TFA –** short chain PFAS and TFA continue to be emitted:
  €2 trillion over 20 years

Emerging Scenario removes < 1 % of PFAS per year in Europe (1-20 tons removed vs 150 000 tons emitted, based on ECHA data)

Ling et al. https://doi.org/10.26434/chemrxiv.10001503/v1