



Confronting soils polluted with PFAS and other emerging persistent and mobile organic contaminants

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Nordrocs, Helsinki, September 15th 2026



NORDROCS 2026
-Crossing borders

The Flow



The rise of persistence substance pollution



Confronting the threat of accumulating persistent substances in soil

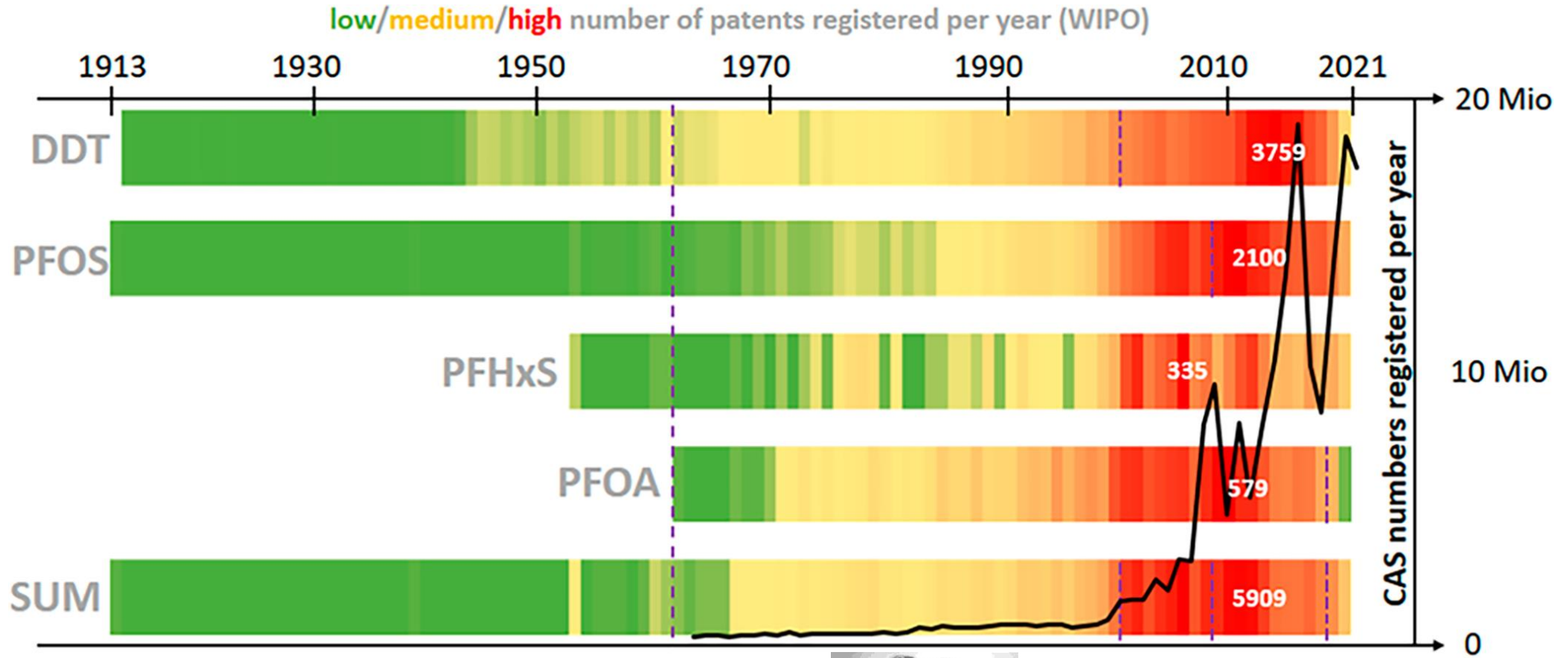




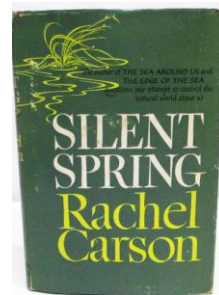
The rise of persistent substance pollution



Persistent synthetic chemicals rising



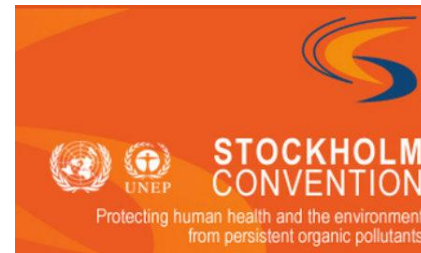
No. : MAX number of patents registered per stripe



Silent Spring
Rachel Carson

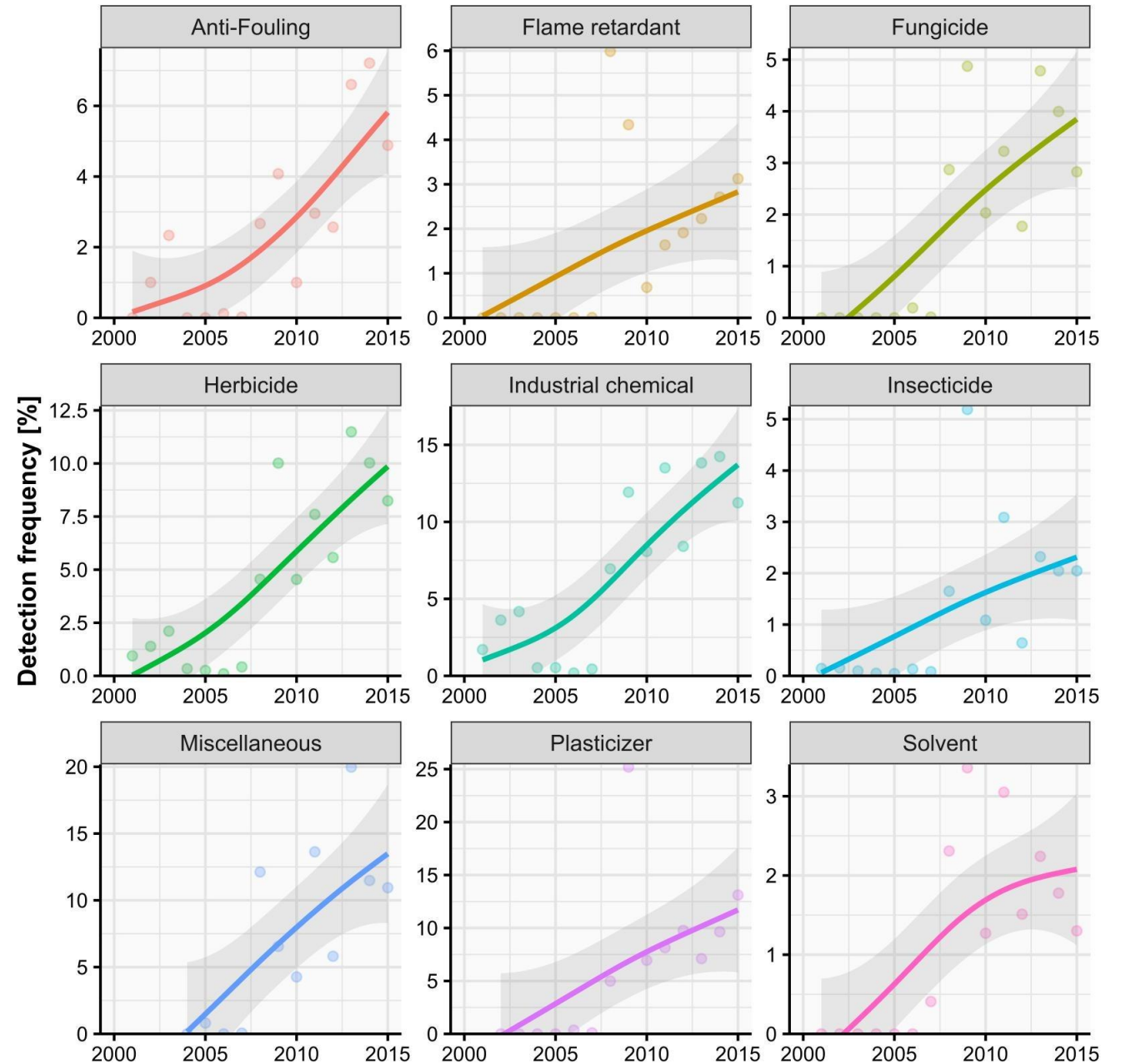


Stockholm convention
listing dates



European surface water burdened with increasing synthetic chemicals

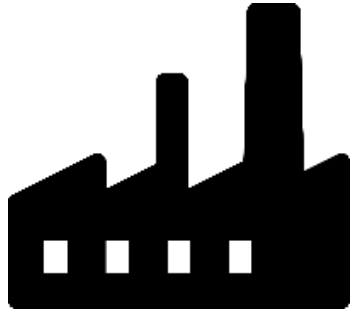
Would the Stockholm
Convention on Persistent
Organic Pollutants capture
these?



Wolfram et al. *Environment International*, 152, 106479.



Properties of a drinking water contaminant



Chemical Synthesis



Uses / Products



Transport through
the environment or
infrastructure



Water treatment
and production



Consumption

Persistent and Mobile

Toxic



New hazard classes introduced in Europe: PMT/vPvM

31.3.2023

EN

Official Journal of the European Union

L 93/7

COMMISSION DELEGATED REGULATION (EU) 2023/707

of 19 December 2022

amending Regulation (EC) No 1272/2008 as regards hazard classes and criteria for the classification, labelling and packaging of substances and mixtures

(Text with EEA relevance)



4.4. Persistent, Mobile and Toxic or Very Persistent, Very Mobile properties

4.4.1. Definitions and general considerations

4.4.1.1. For the purposes of Section 4.4 the following definitions shall apply:

“PMT” means a persistent, mobile and toxic substance or mixture that meets the classification criteria set out in Section 4.4.2.1.

“vPvM” means a very persistent and very mobile substance or mixture that meets the classification criteria set out in Section 4.4.2.2.

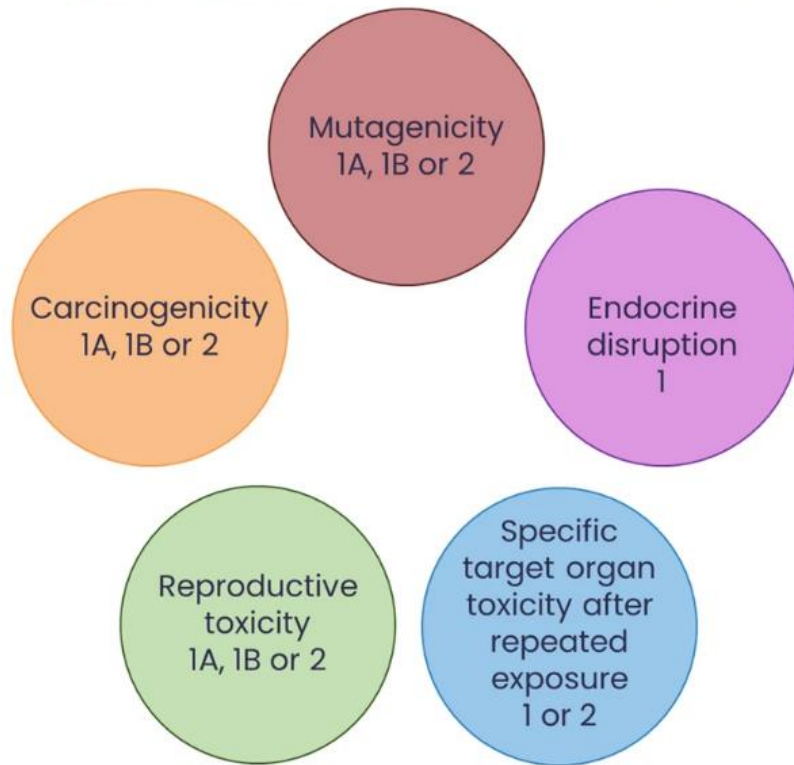
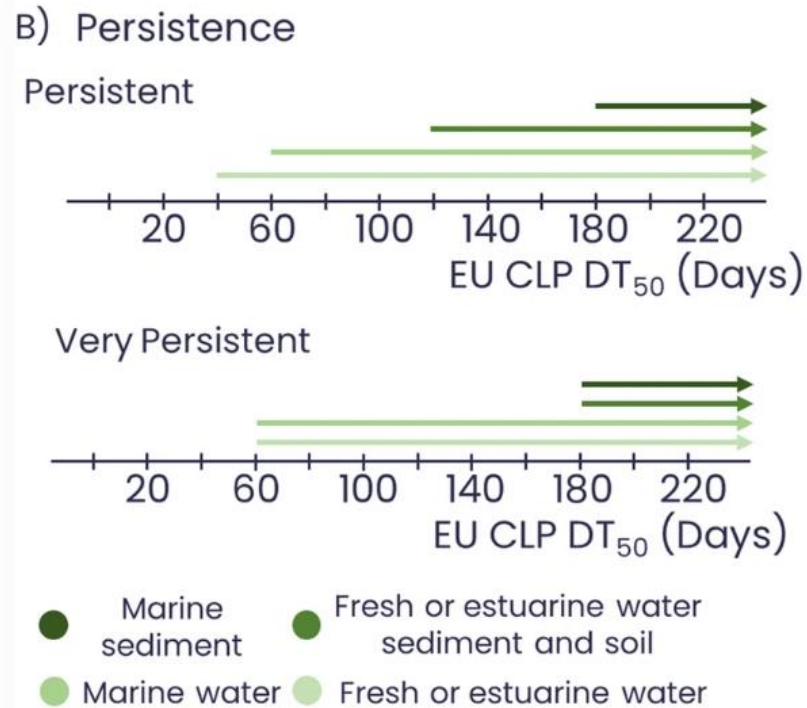
“log K_{oc} ” means the common logarithm of the organic carbon-water partition coefficient (i.e. K_{oc}).

4.4.1.2 The hazard class Persistent, Mobile and Toxic or Very Persistent, Very Mobile properties is differentiated into:

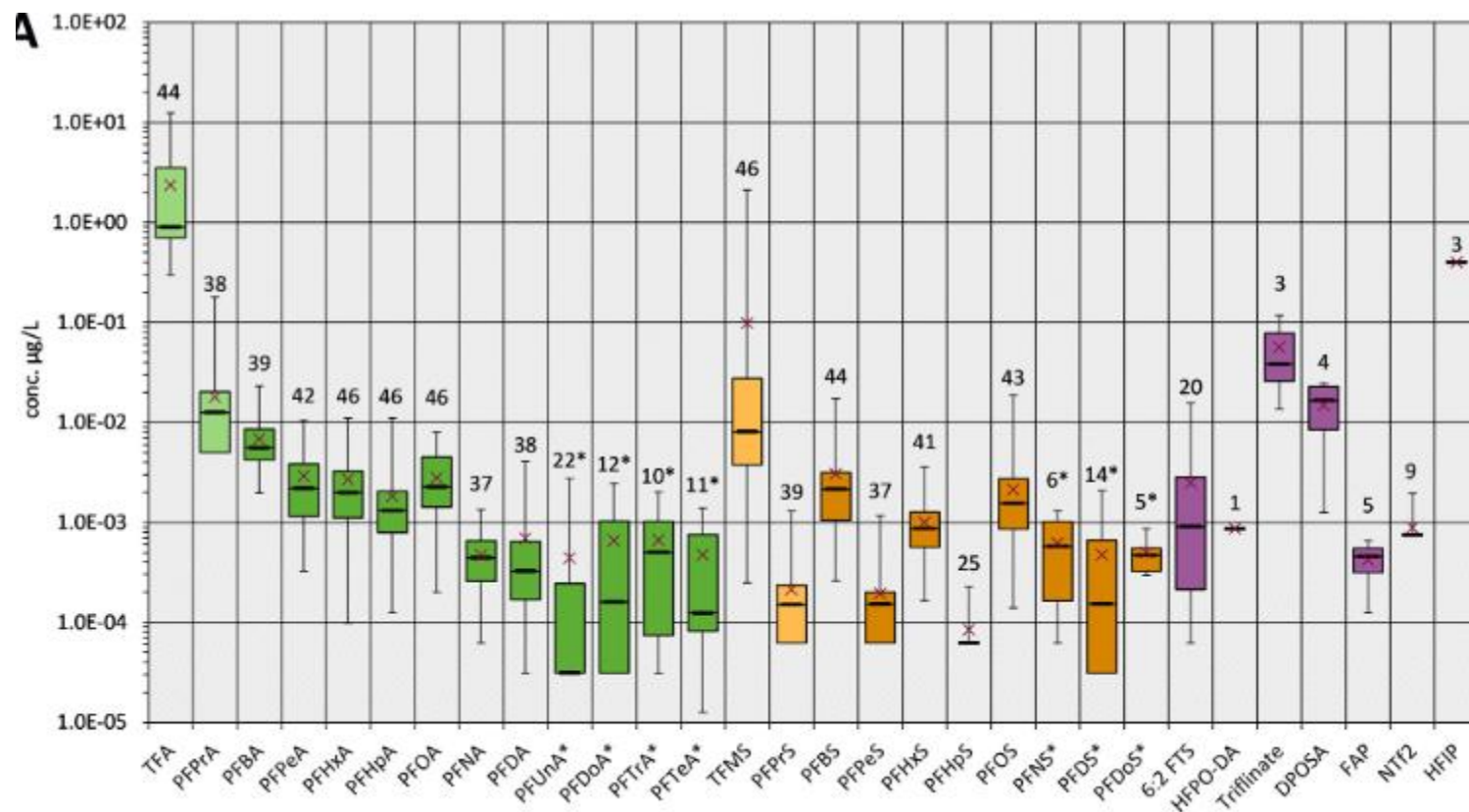
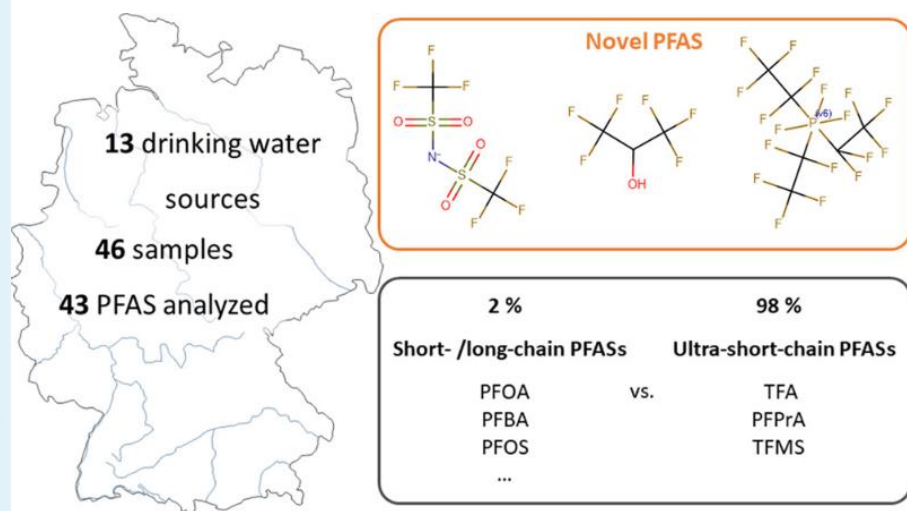
- PMT properties and,
- vPvM properties.

CLP regulation enacted May 2023

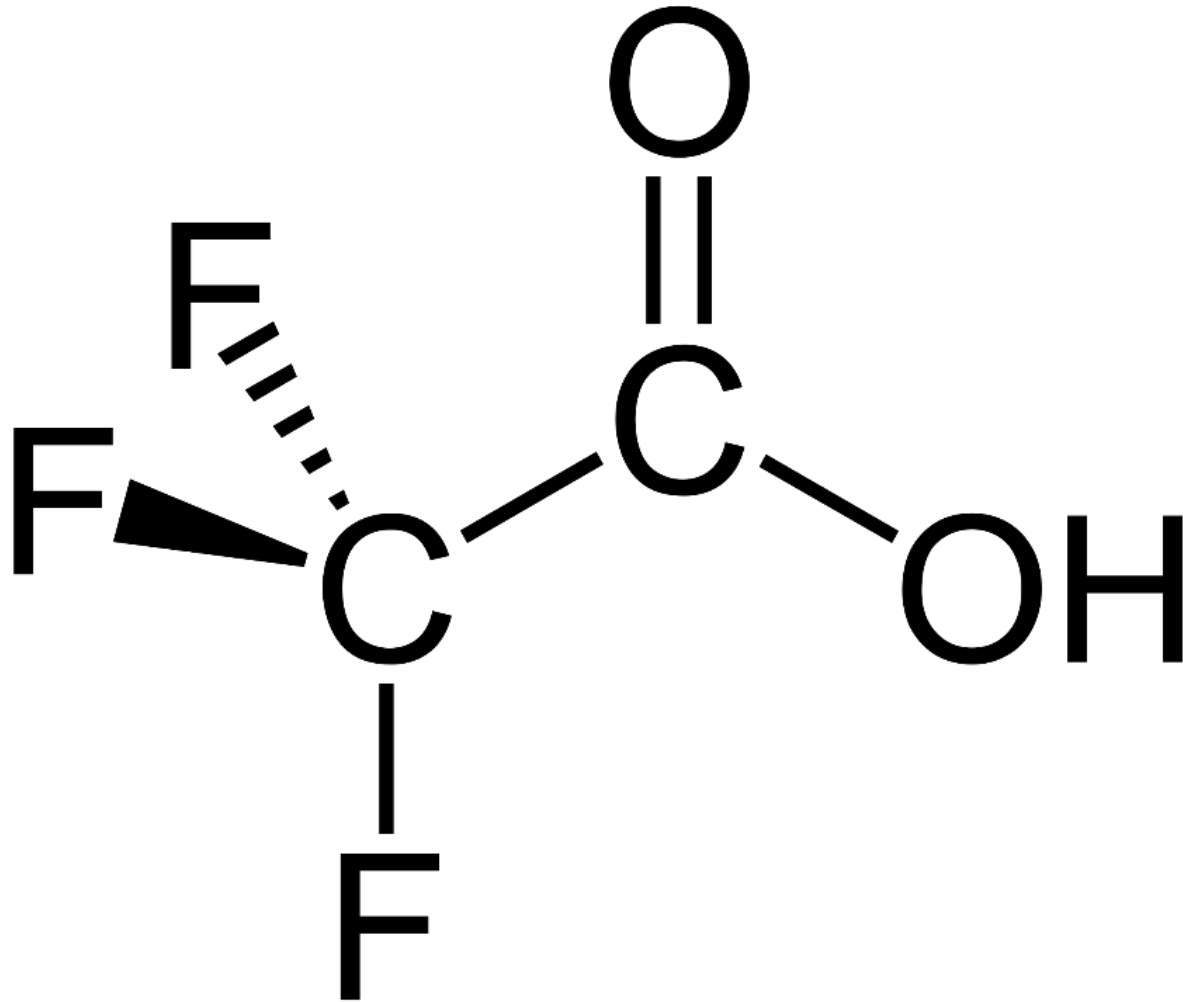
... a pathway to regulate PMT/vPvM substances in downstream regulation



What is the most abundant of the PFAS that meet the vPvM criteria?

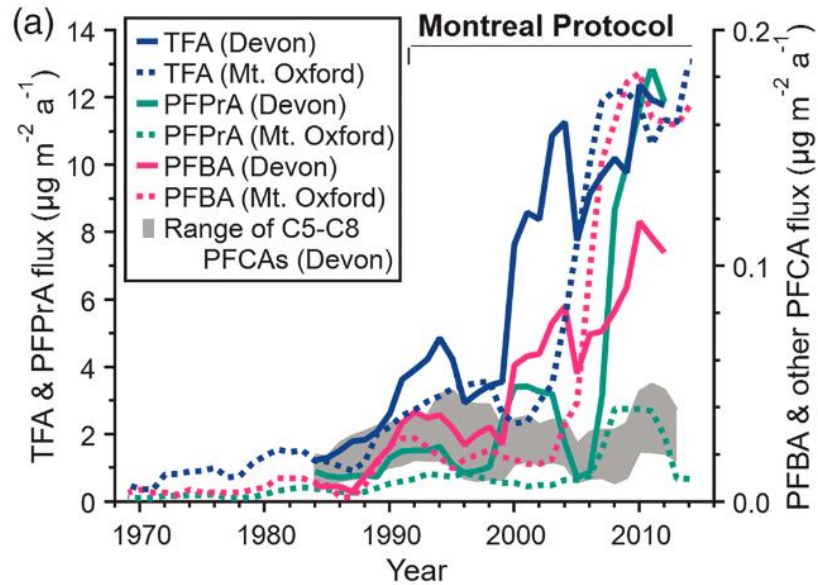


Why is this PFAS now everywhere?

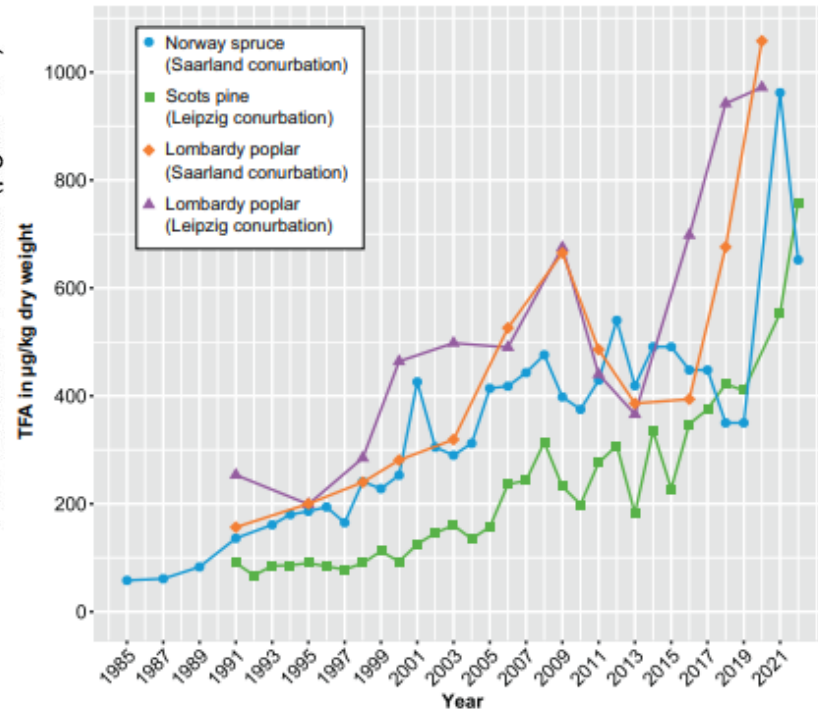


TFA is accumulating everywhere since the 190s, largely coinciding with F-gas use following the Montreal Protocol and use of PFAS-pesticides/pharmaceuticals

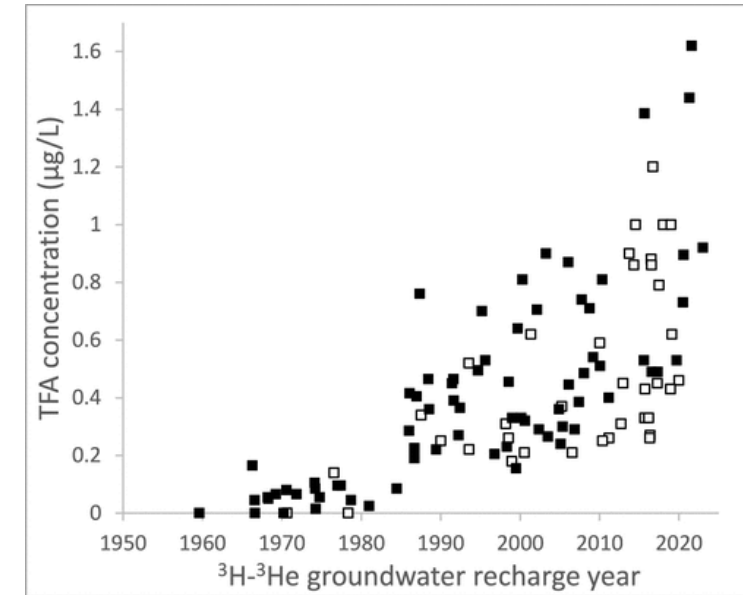
TFA accumulating in arctic ice cores



and in tree leaves



and in groundwater



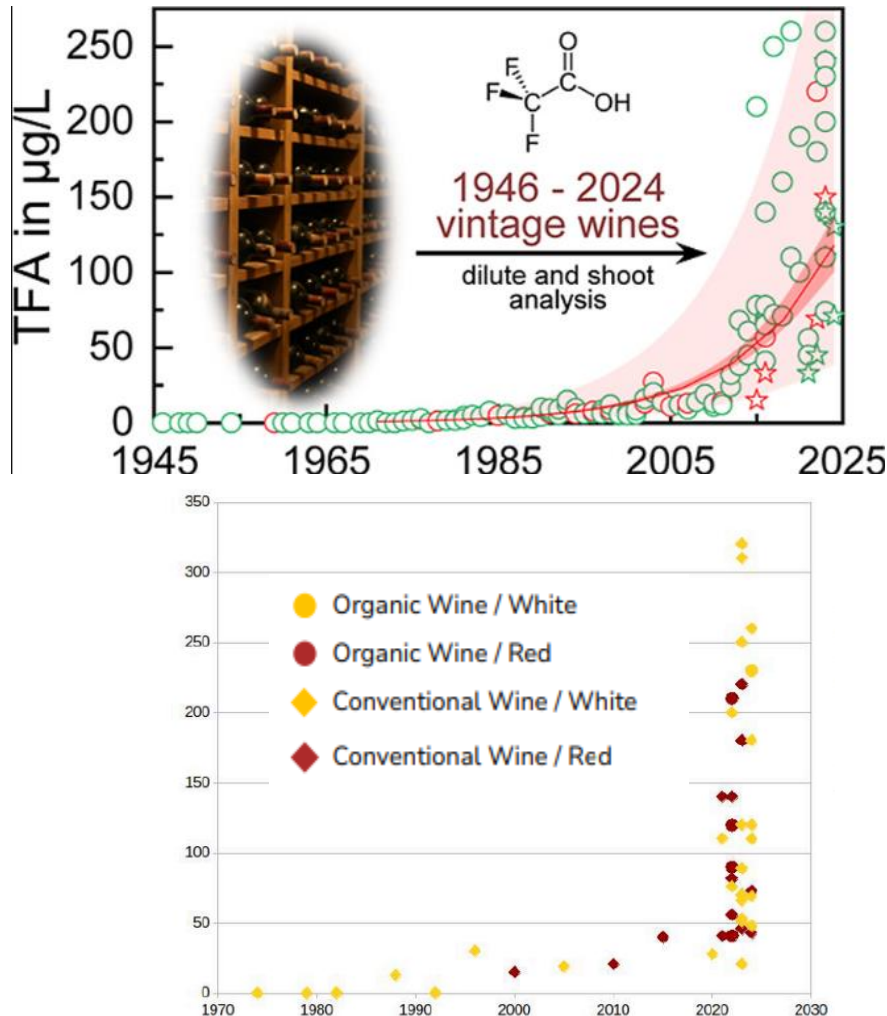
Pickard et al. Geophysical Research Letters (2020),47, e2020GL087535

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

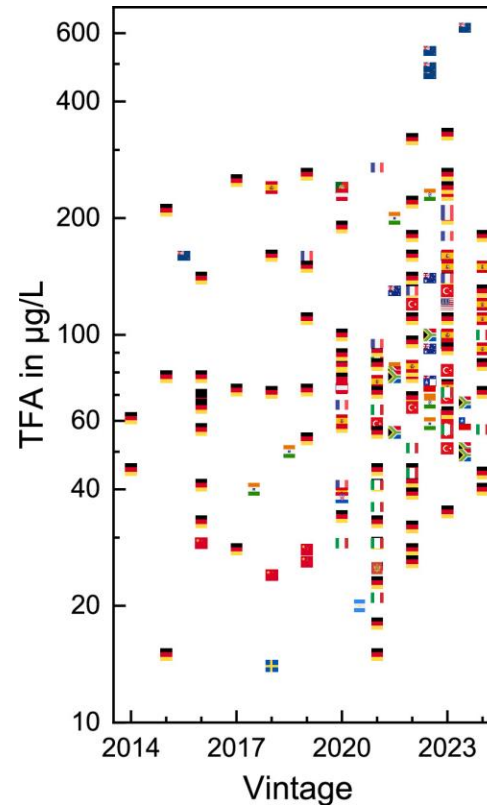
Albers and Sültenfuss, Environmental Science & Technology Letters 2024 11 (10), 1090-1095

TFA is increasing in all that we drink

...Wine



Up to 600 µg/L



Drinking water (median)^{1,2}

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

Tee (median): 2.4 µg/L²

Beer (median) 6.1 µg/L²

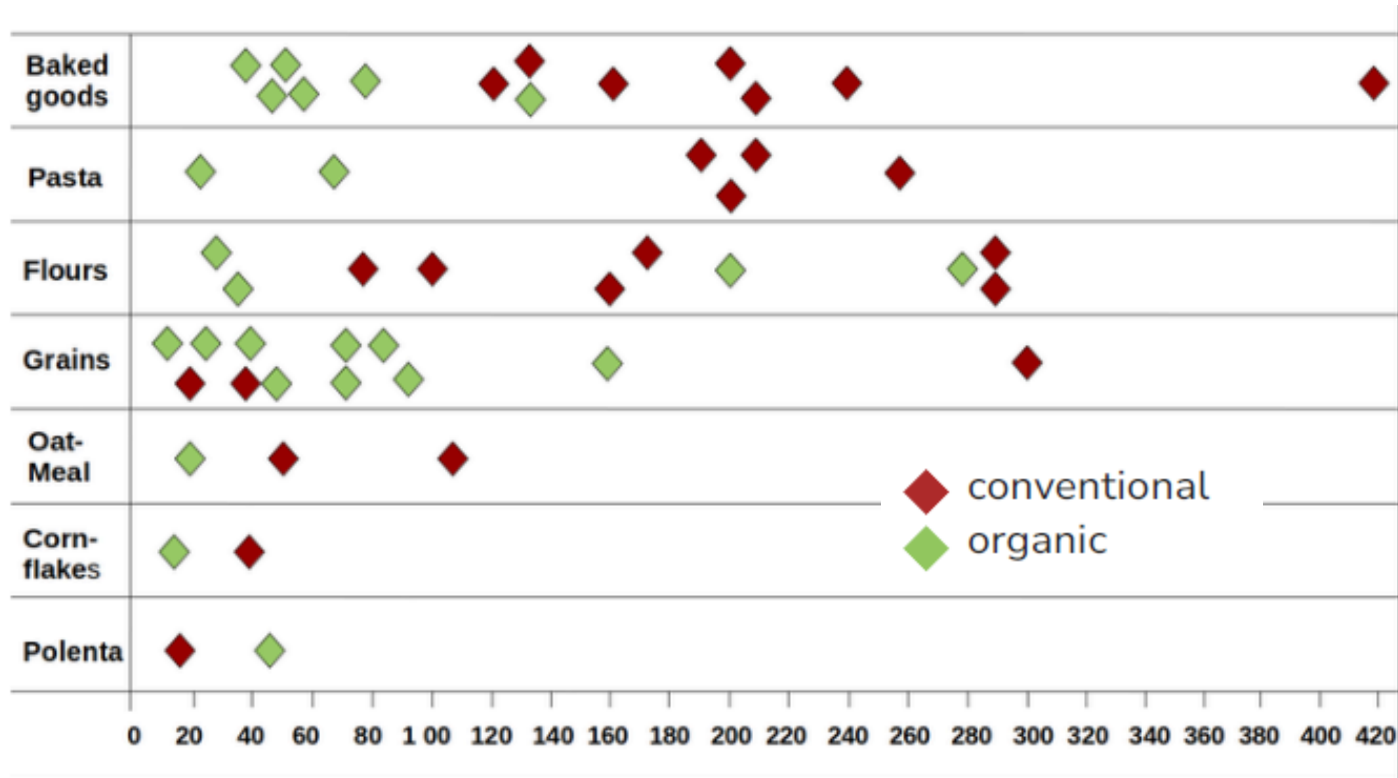
Orange juice (mean 34 µg/L)³

Apple juice (mean 6.2 µg/L)³

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

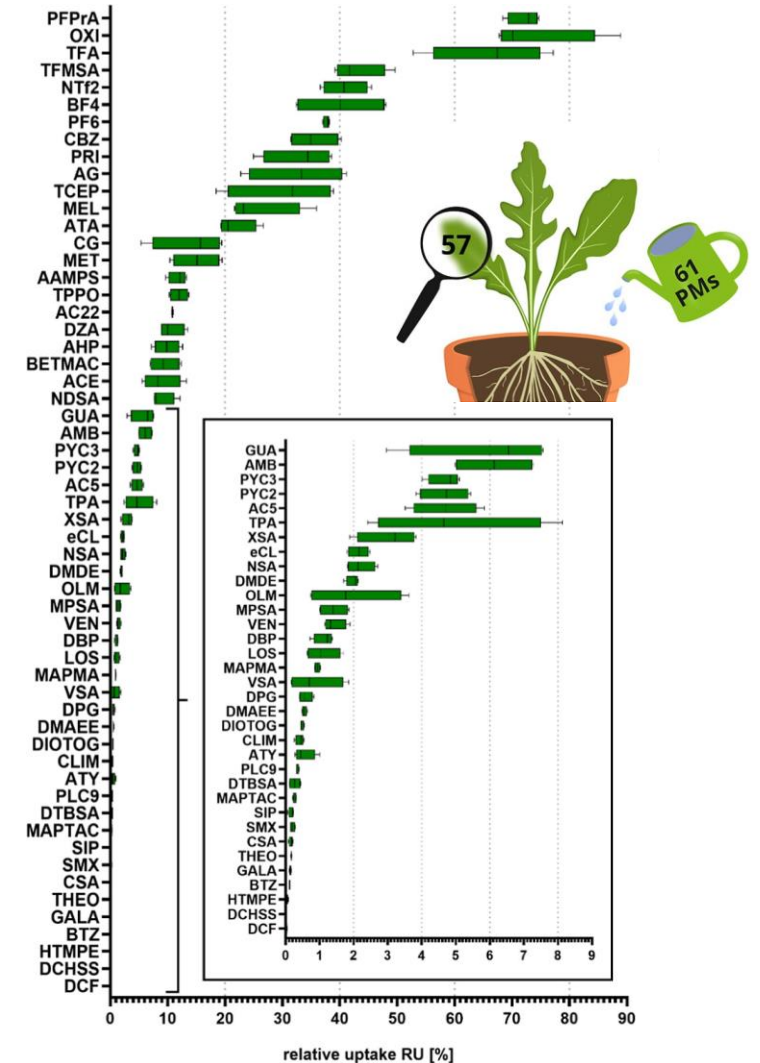
The Forever Chemical in our Daily Bread

The worrying rise of TFA in cereal products



µg/kg dw

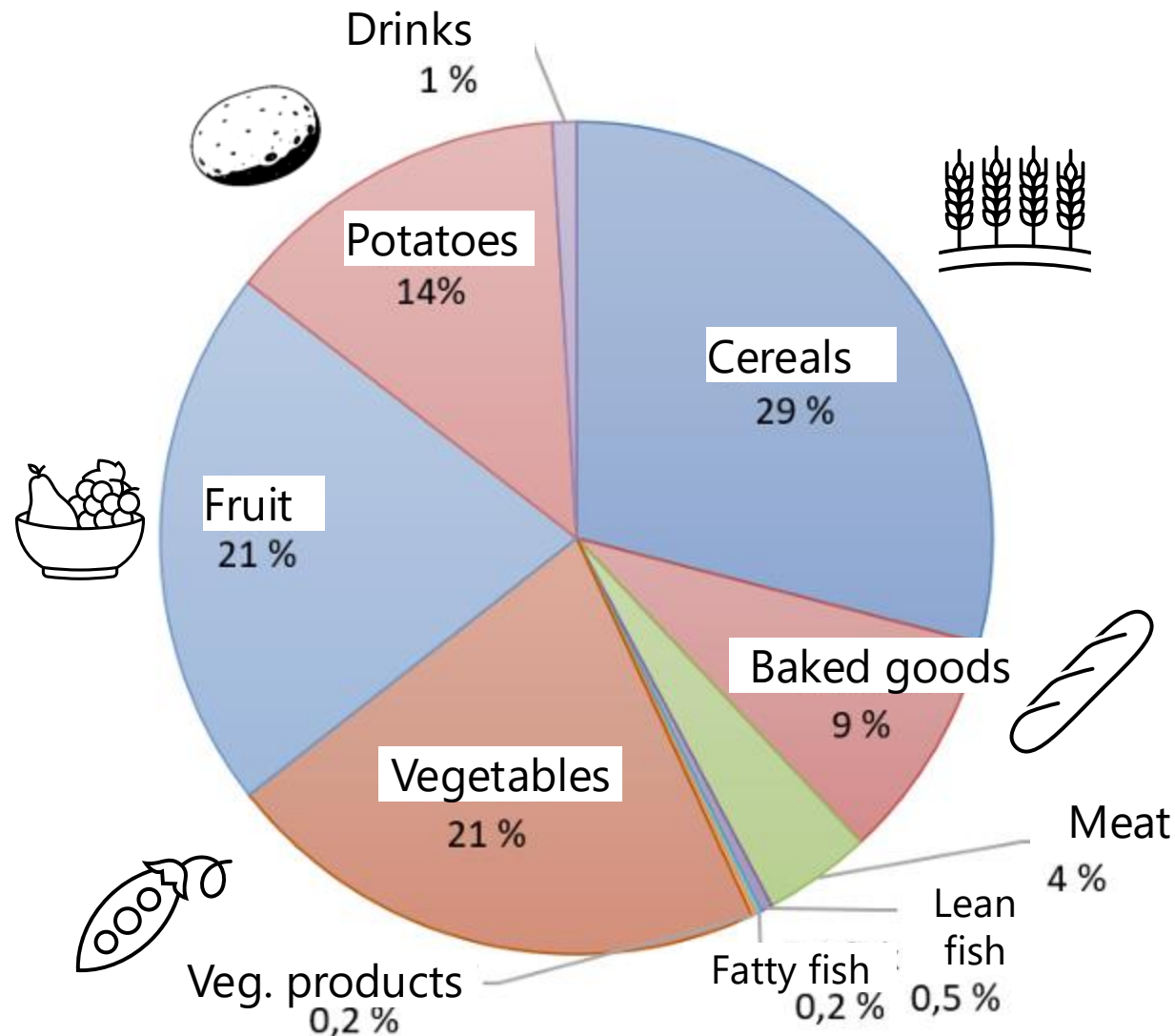
Many PMT/vPvMs can exhibit plant uptake



Seelig et al. *Environ. Sci. Technol.* 2025, 59, 18, 9265-9274

Intake of TFA from a typical Swedish Diet

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



Simple risk assessment:

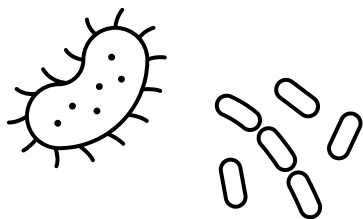
0.344 $\mu\text{g}/\text{kg}$ /day (70 kg/person)

= 2.5 % EFSA draft Acceptable Daily Intake for TFA of 14 $\mu\text{g}/\text{kg}/\text{day}$ (expressed as TFA)

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

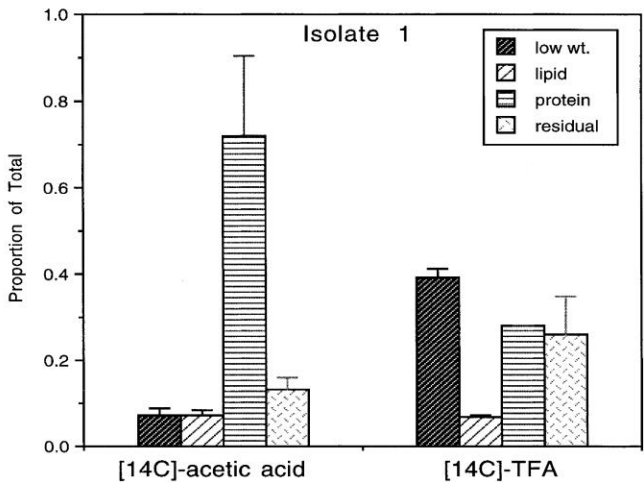
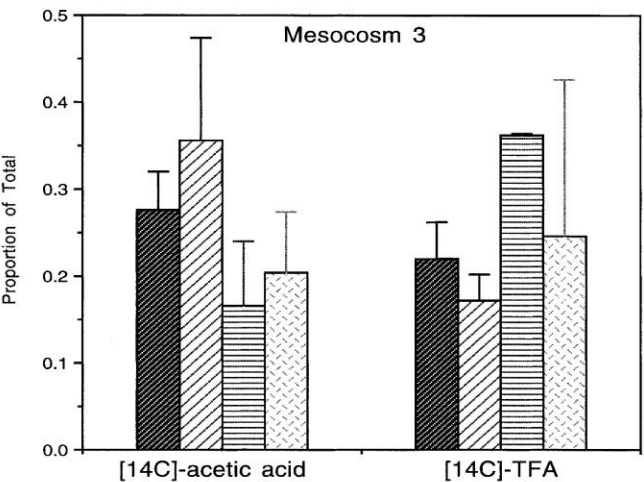
*Source: Gyllenhammar et al. (2026) «Halter av Trifluorättiksyra (TFA) och andra ultrakorta PFAS i Livsmedelsverkets Matkorgsstudie från 2022 »

TFA able to become part of the lipids and biomolecules inside microbes no follow-up since 1999



Trifluoroacetate, an Atmospheric Breakdown Product of Hydrofluorocarbon Refrigerants: Biomolecular Fate in Aquatic Organisms

LAUREL J. STANDLEY* AND THOMAS L. BOTT
Stroud Water Research Center, Academy of Natural Sciences of Philadelphia, 970 Spencer Road, Avondale, Pennsylvania 19311



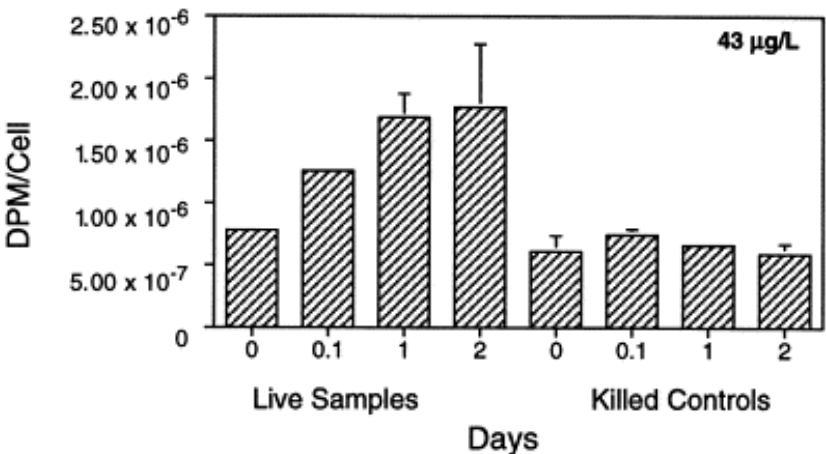
Water Research
Volume 33, Issue 6, April 1999, Pages 1538-1544



Research Note

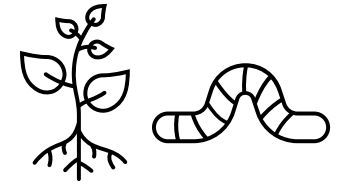
Incorporation of trifluoroacetate, a hydrofluorocarbon decomposition byproduct, by freshwater benthic microbial communities

Thomas L. Bott, Laurel J. Standley



If TFA covalently bonded with lipids, membranes, biomolecules, etc. they would ultimately be degraded to TFA... again

TFA toxicity to soil and terrestrial systems



Soils / terrestrial ecosystems

- ECHA REACH dossier: long term No observable effect concentration (NOEC) **0.83 mg/kg soil** (plant shoot growth)
- TFA readily bioaccumulates in plants/shoots from soil
- Effects on the soil pH, microbial respiration, bacterial abundance and litter decomposition were reported at TFA concentrations in soil in hotspots (**0.0013–2.4 mg/kg_{dw}**), above this problems related to TFA acidity can occur.
- **Soil concentrations at TFA hotspots already exceed these concentrations which decrease soil quality**
- **Lack of long exposure studies on terrestrial and agricultural systems**



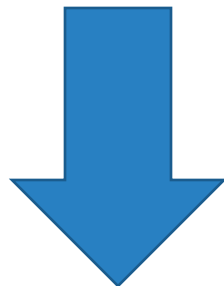
[Jan Kopřiva](#)

Xu et al. Concentration-Dependent Response of Soil Parameters and Functions to Trifluoroacetic Acid. *Eur. J. Soil Sci.* 2022, 73 (4),

No. e13266. Chen et al. *Environ. Sci. Technol.* **2018**, 52 (15), 8263– 8271

Technological and cost limitations

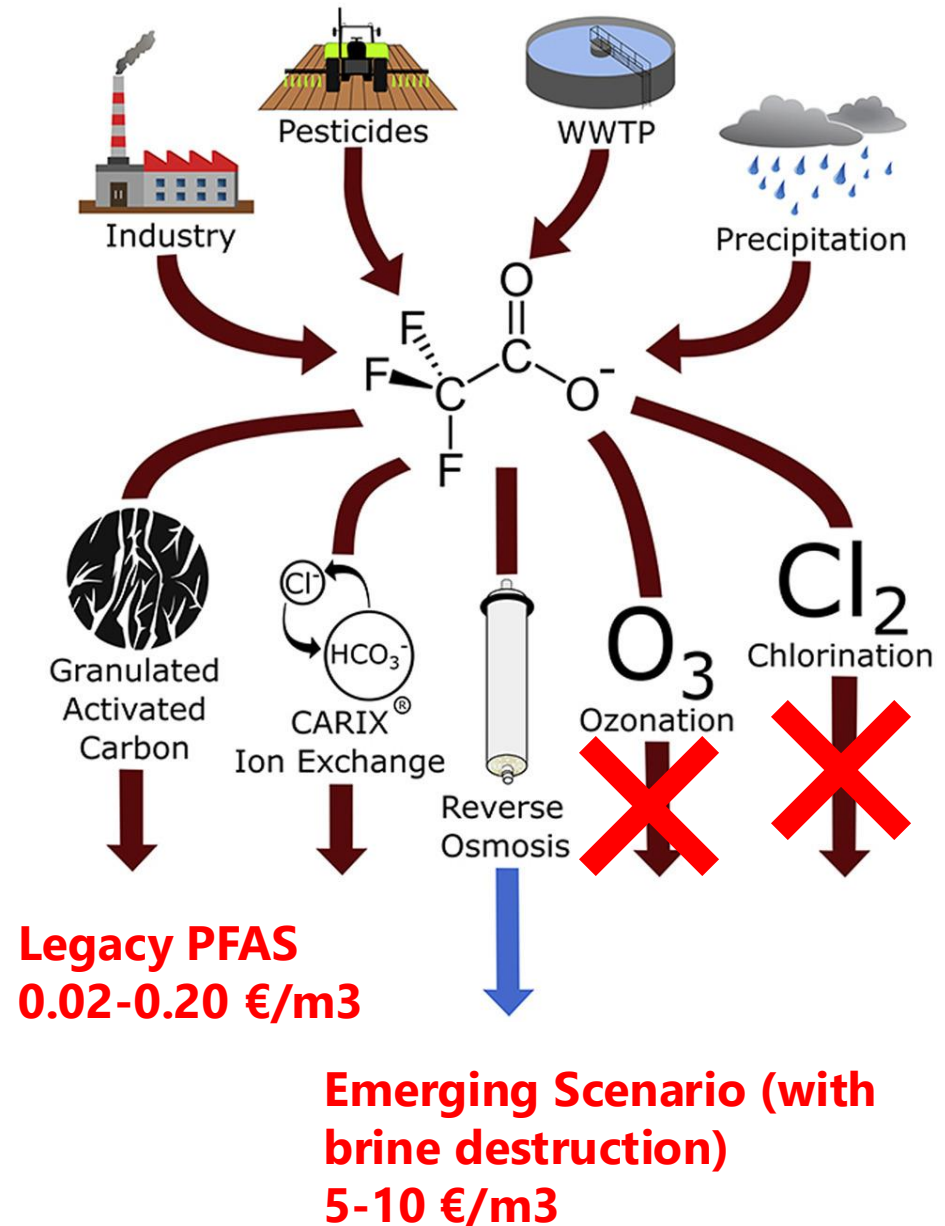
- TFA removal from water is Reverse Osmosis followed by Supercritical water oxidation (ca 8 €/m³)



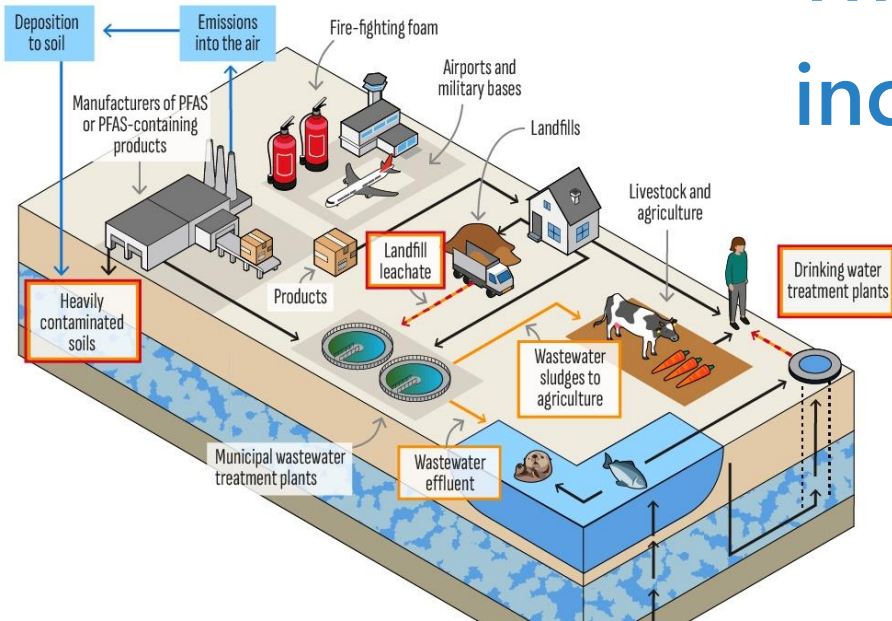
Upscale to all water from
PFAS contaminated sites

ca. 100 billion € /year

- + *all water synthetic*
- + *huge impact from green house gas emissions*
- + *Infrastructure upgrade not realistically plausible*



The EU costs of PFAS removal increases it spreads



Legacy scenario (e.g. EFSA PFAS):

- **Health costs by 2050** (costs of inaction): **438 billion €** (European Commission, 2025)
- **Remediation** (next 20 years): **38 - 100 billion €**

Emerging Scenario (with TFA)

- **Remediation** (next 20 years): : **€2 trillion €**

LES DÉCODEURS • PFAS

PFAS: Less than 2% of emissions could be removed from environment, even with massive investments

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

Environmental
Science
Processes & Impacts

ROYAL SOCIETY
OF CHEMISTRY

PAPER

Published on 06 July 2026
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Check for updates

Cite this: Environ. Sci.: Processes
Impacts, 2026, 28, 2092

PFAS remediation across Europe: costs and limited impacts

Alison L. Ling, ^a Raphaëlle Aubert, ^b Eurydice Bersi, ^c Stéphane Horel^b
and Hans Peter H. Arn^d

Planetary Boundary Threat of Persistent Synthetics

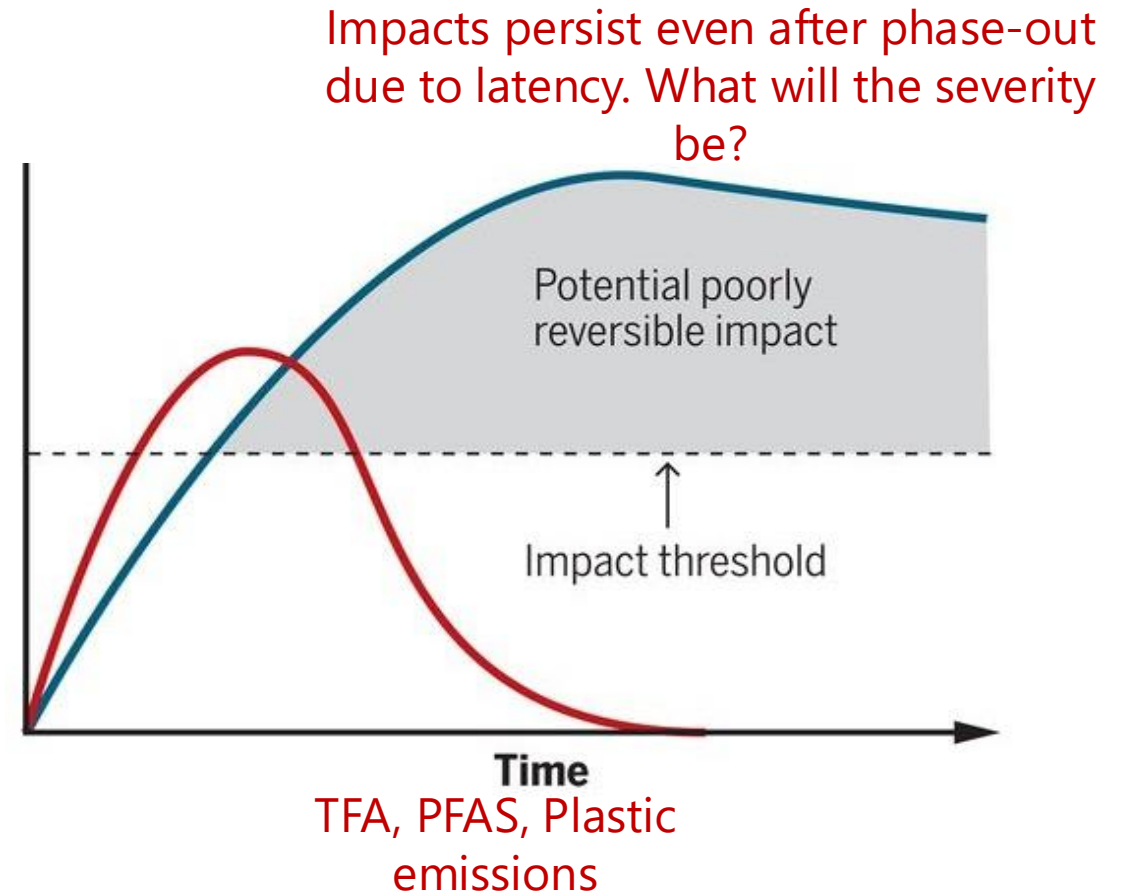
Disturbances to the «homeostasis» or of earth processes. Exceed this, Earth would leave the Holocene where humans evolved.

Conditions for novel entities:^{1,2}

Condition 1: pollution disrupts a vital earth system process of which we are ignorant.
TRUE: impacts at hotspots occur now, ignorant of impacts from life-long intergeneration exposure (ignorant)

Condition 2: disruptive effect is not discovered until ...manifested at a global scale
TRUE: Concentration increases globally

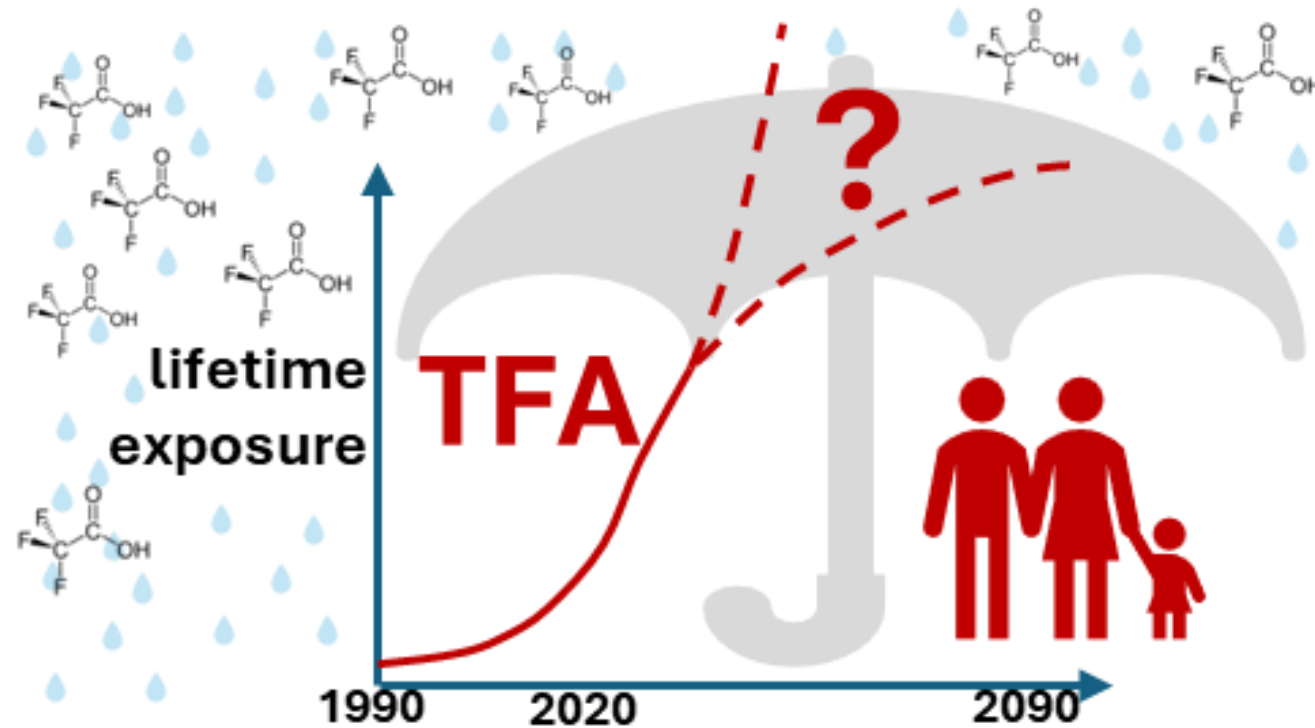
Condition 3: impacts are poorly reversible because level of global pollution cannot be readily reduced
TRUE: Stockpiles of sources exist and degrade slowly. Most PFAS and TFA and many plastics we emit will exist in water for the future of earth



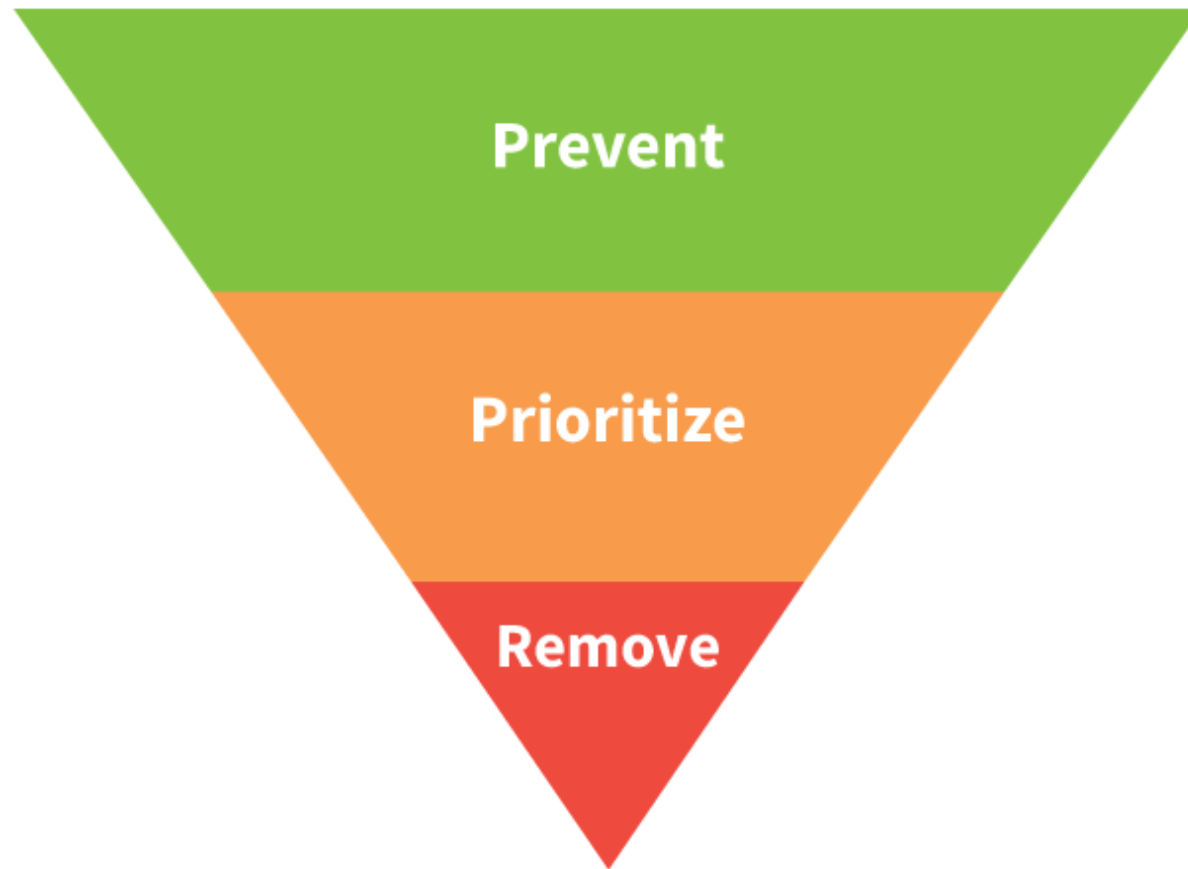
1. Persson et al. *Environ. Sci. Technol.* **2013**, 47 (22), 12619– 12622

2. MacLeod et al. *Science* 373,61-65(2021)

Confronting the threat persistent synthetics



Toxic-Free Hierarchy

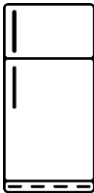


Prevent



Solution to F-gases used as refrigerants

Fifth generation of F-gases in the Montreal Protocol can be free of TFA precursors



Refrigerants and blowing agents

Refrigeration



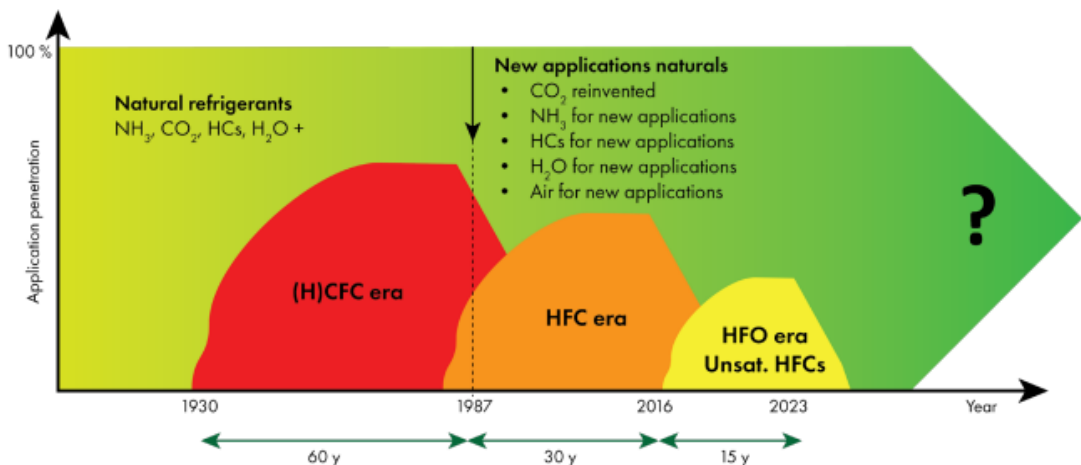
Indoor Climate



Miscellaneous



	CO ₂	Ammonia	Propane	Isobutane	Others
Domestic refrigeration				X	
Stand-alone refrigeration systems in commercial stores	x	x	X	x	x
Multipack centralized refrigeration systems in commercial stores	X	x	x		
Industrial refrigeration	x	X			
Transport refrigeration of goods	x		x		x
Ultra-low and low temperature freezers		x	x		x



Environmental
Science
Processes & Impacts



CRITICAL REVIEW

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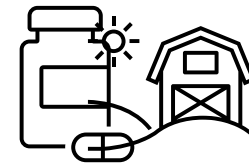
Cite this: Environ. Sci.: Processes
Impacts, 2024, 26, 1955

**Finding non-fluorinated alternatives to fluorinated
gases used as refrigerants†**

Juliane Glüge,^a Katharina Breuer,^a Armin Hafner,^c Christian Vering,^b
Dirk Müller,^b Ian T. Cousins,^d Rainer Lohmann,^e Greta Goldenman^f
and Martin Scheringer^a

Petter NEKSÅ
DOI: 10.18462/iir.gl2024.1295
Full conversion to natural refrigerants -
Feasible and likely to happen?

Solution to TFA from Pesticides and Pharmaceuticals



The Danish Environmental Protection Agency has withdrawn the approval of 8 more pesticides that contain PFAS active substances. They can form and leach TFA into the groundwater. Pesticides approved for use in Denmark must not pose a risk to groundwater. In June, they already banned 25 other products. PFAS pesticides that have not yet been directly linked to TFA are still allowed in Denmark. The Danish Nature Conservation Organisation applauds the decision but calls for a swift ban of the other PFAS pesticides, especially the very harmful insecticide lambda-cyhalothrin.



PERSISTENT POLLUTANTS

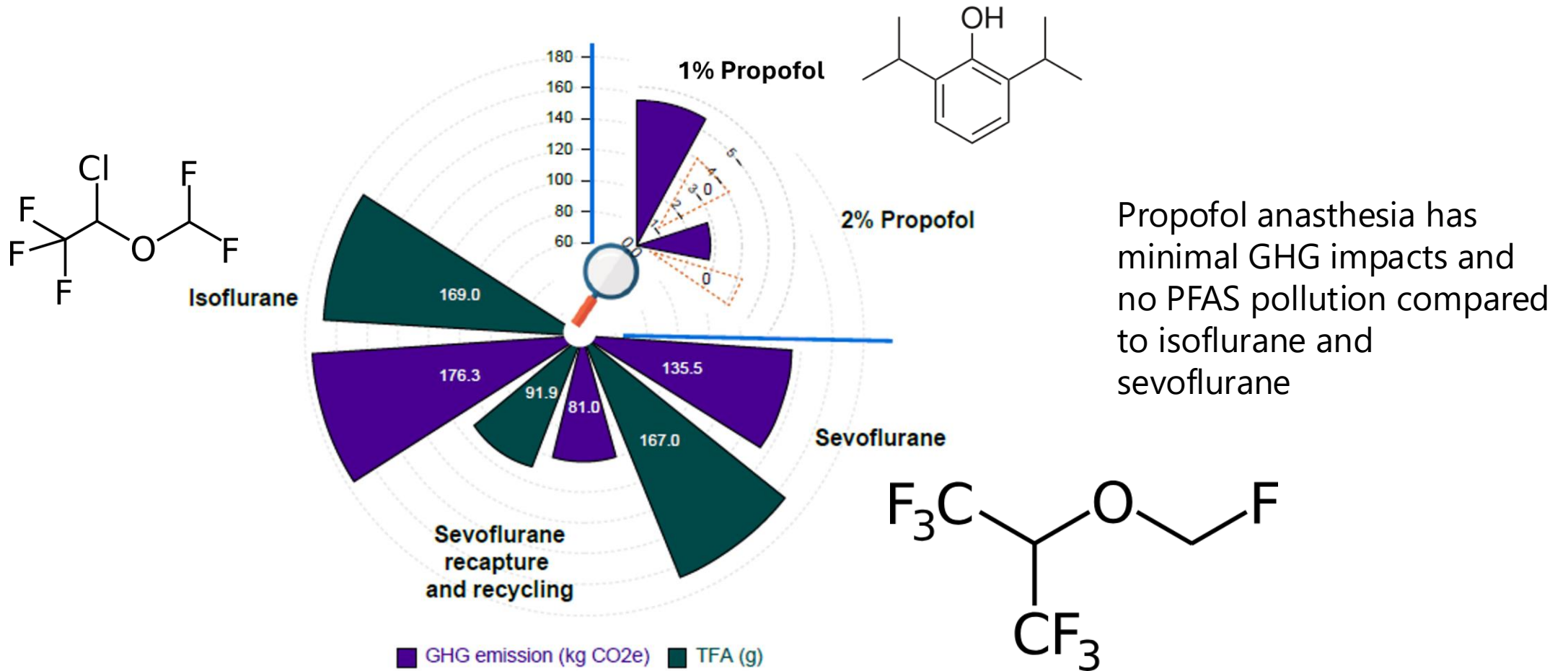
Are fluorinated drugs PFAS?

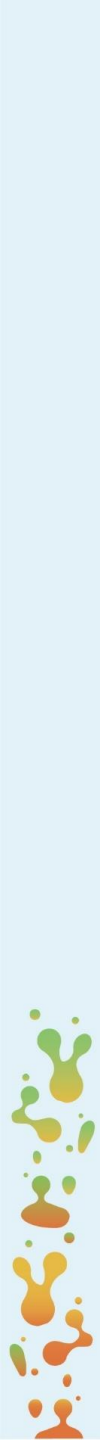
Proposed regulations in the European Union present an uncertain future for pharmaceuticals and agrochemicals—and motivation to design greener ones

BRIANNA BARBU, C&EN STAFF

- Biodegradable, non-fluorinated drugs an active area of «green pharmacy» innovation
- Evaluate switching to PFAS free alternatives when recommending medications

When two treatments give the same patient outcomes, choose the most environmentally friendly one





Prioritize

Updated Prioritized PFAS monitoring lists and recommended thresholds

- TFA included in surface water regulation (max 2.2 µg/L)
- 43 PFAS included for monitoring in EU Soil Monitoring and Resilience Directive
- Need clarity on national thresholds



ARAGORN coordinates expert recommendation on Monitoring of PFAS in Europe's soils

News

New expert recommendations coordinated by ARAGORN and ZeroPM support the EU's Soil Monitoring Directive with practical, cost-effective methods to detect and prevent toxic chemical pollution.



pubs.acs.org/journal/estlcv

Highlight

Urgency to Propose Normative Soil Limits for Per- and Polyfluoroalkyl Substances Targeting PFOA and PFOS

Sébastien Sauvé* and Hans Peter H. Arp*

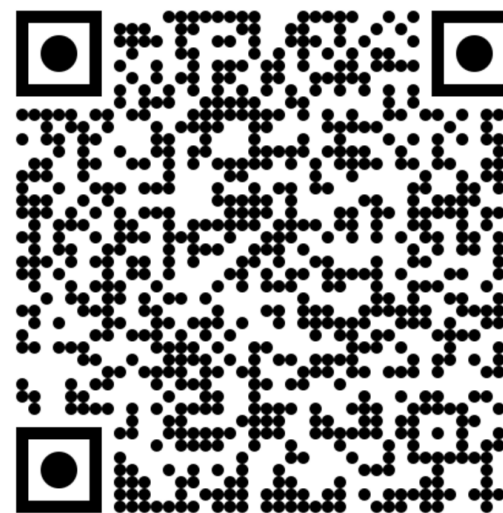


Environ. Sci. Technol. Lett. 2026, 13, 862–864

Link: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32026L0805>

New PMT/vPvM substances on the SIN List

Name	Reason for inclusion
Benzotriazole	PMT; vPvM
Methyl-1H-benzotriazole	PMT
Cyanuric acid	vPvM
1,3,5-trinitro-1,3,5-triazinane	PMT
Cyanoguanidine	vPvM
2,4-dinitrophenol	PMT; vPvM
1,3-dioxolane	PMT
Benzoguanamine	PMT; vPvM
Bis(2-dimethylaminoethyl)(methyl)amine	vPvM
Trichloroacetic acid	vPvM
Cyanuric chloride	vPvM
Acryloyldimethyltaurates (AMPSA)	vPvM
1,3-dichlorobenzene	PMT
5,5-dimethylhydantoin	vPvM
Dapsone	PMT
Dichlorodifluoromethane	vPvM
Melamine Cyanurate	PMT; vPvM
Methenamine	vPvM



Toxic-Free Heirarchy



Remove at source, rather than downstream

- PFAS/PMT emission monitoring and removal should be focussed on industrial sites and hotspots and landfills
- More downstream is more inefficient

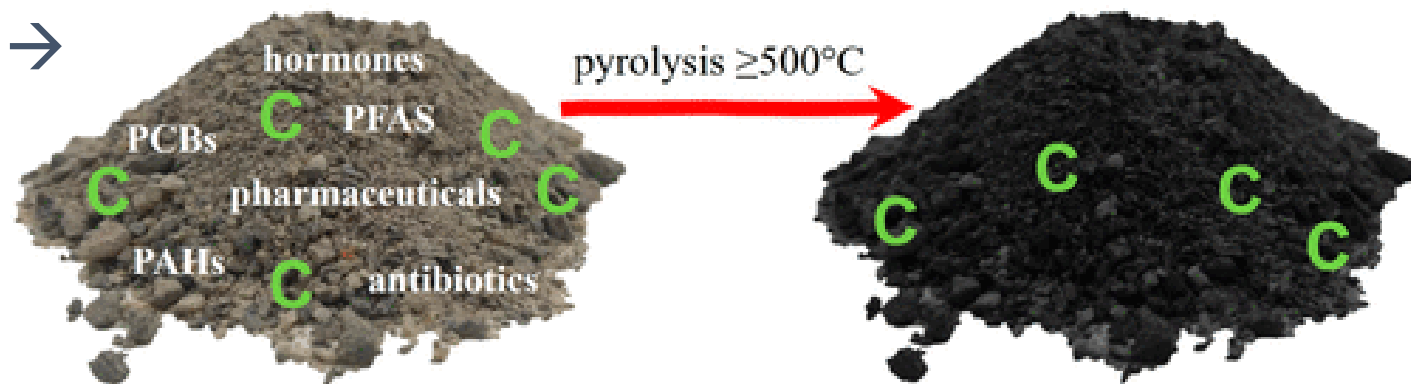


Lo stabilimento Miteni di Trissino, in provincia di Vicenza (Foto Federico Bevilacqua)

https://lavialibera.it/it-schede-2139-pfas_in_europa_40_anni_di_inquinamento_ma_il_profitto_vince_su_tutto

“Pyrolysis solves the issue with organic contaminants in sewage sludge”¹

Boiling points deciding factor → volatilized or decomposed²

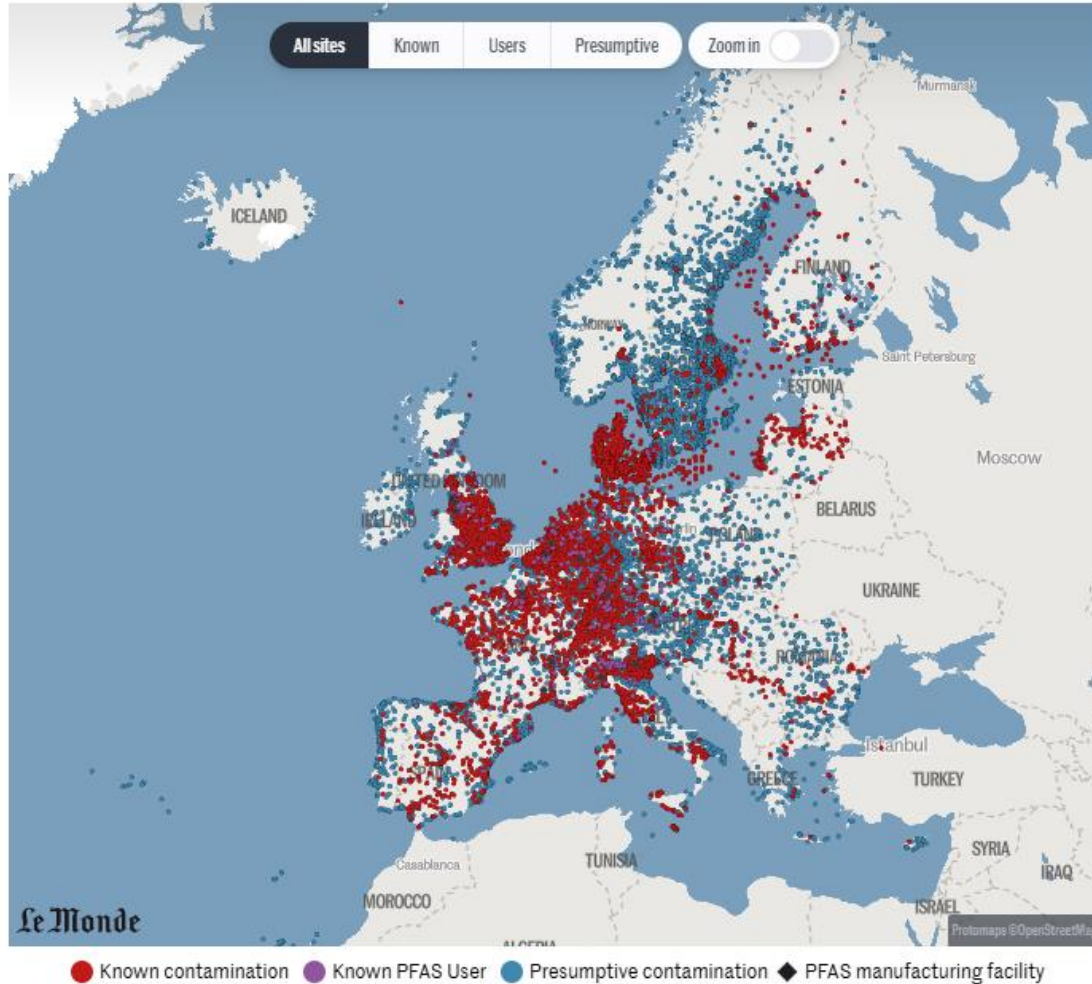


Is this really true for PFAS and other persistent contaminants?

Figure: Buss (2021) ACS Sust Chem. Eng.
<https://doi.org/10.1021/acssuschemeng.1c03651>

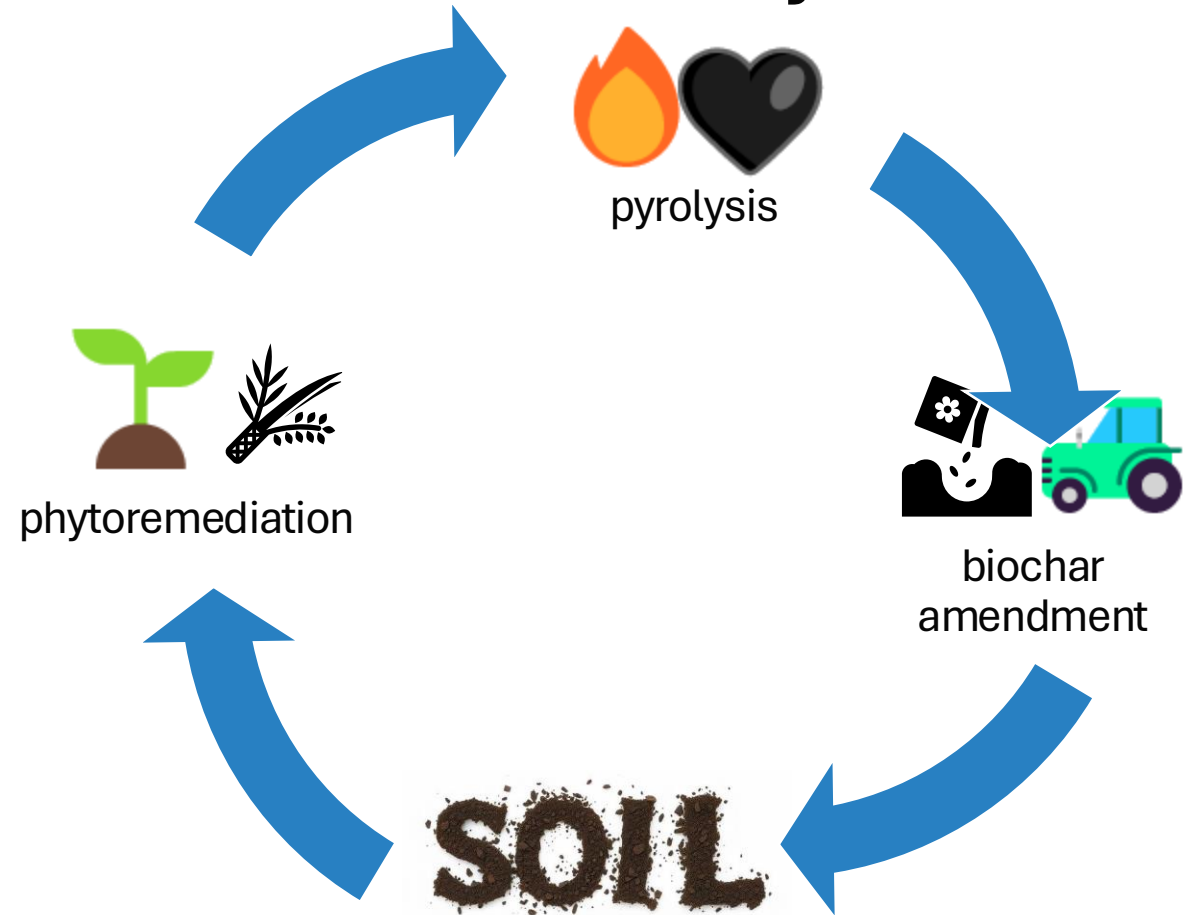
- 1) Buss (2021) ACS Sust Chem. Eng. <https://doi.org/10.1021/acssuschemeng.1c03651>
- 2) Moško et al (2021) Chemos <https://doi.org/10.1016/j.chemosphere.2020.129082>

Pyrolysis and soil pollution



Large number PFAS contaminated soils, including agricultural areas

The virtuous cycle



JOURNAL OF
AGRICULTURAL AND
FOOD CHEMISTRY

pubs.acs.org/JAFC

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Viewpoint

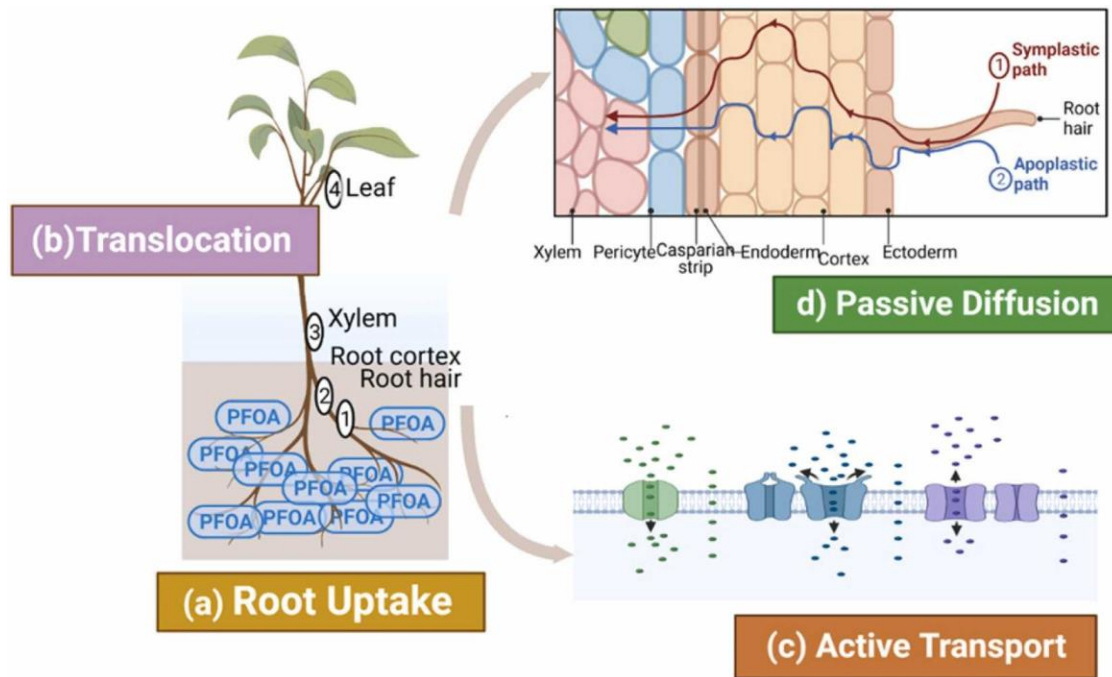
A Virtuous Cycle of Phytoremediation, Pyrolysis, and Biochar Applications toward Safe PFAS Levels in Soil, Feed, and Food

Gerard Cornelissen,* Nathalie Briels, Thomas D. Bucheli, Nicolas Estoppey, Andrea Gredelj, Nikolas Hagemann, Sylvain Lerch, Simon Lotz, Daniel Rasse, Hans-Peter Schmidt, Erlend Sormo, and Hans Peter H. Arp

Cite This: *J. Agric. Food Chem.* 2025, 73, 3283–3285

Read Online

Step 1: Plant Uptake of PFAS (Phytoremediation)

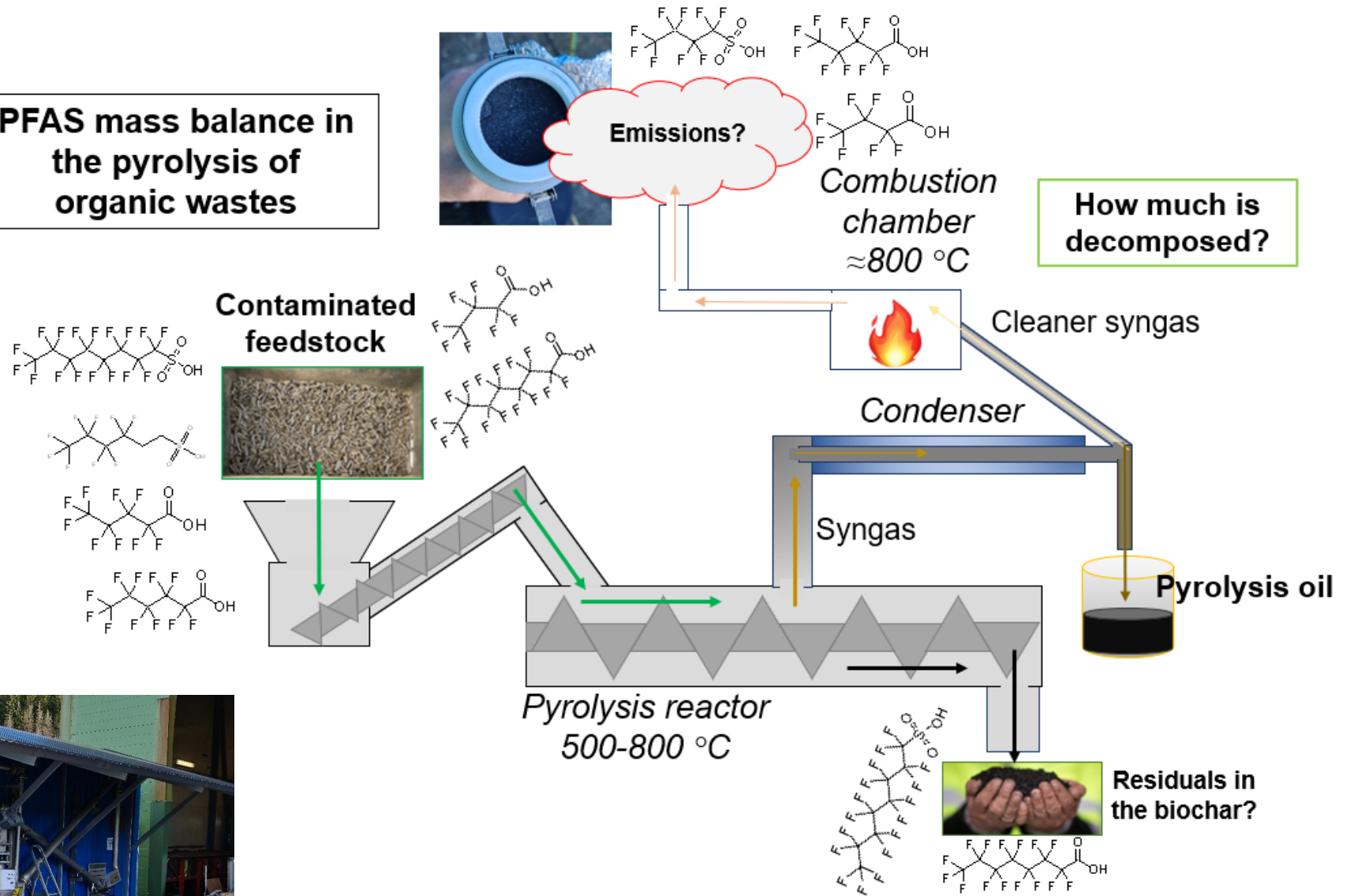


NGI field trial at a PFAS factory site in Belgium

Adu et al. (2023) J. Haz. Mat.130805 <https://doi.org/10.1016/j.jhazmat.2023.130805>
Mei et al. (2021) Env. International. 106642
<https://doi.org/10.1016/j.envint.2021.106642>

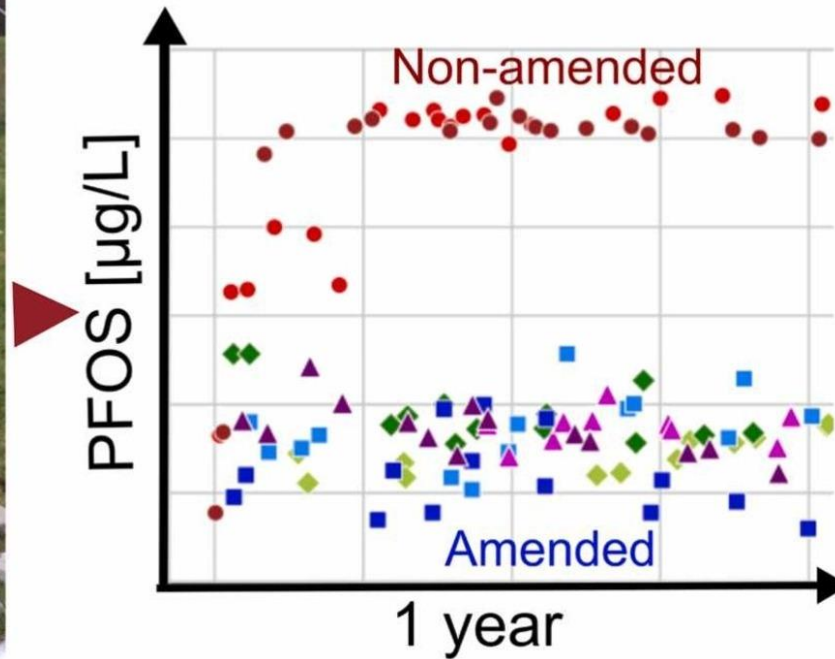
Pyrolysis to mineralize > 96% of PFAS

PFAS mass balance in the pyrolysis of organic wastes





Step 3: Field testing of biochar



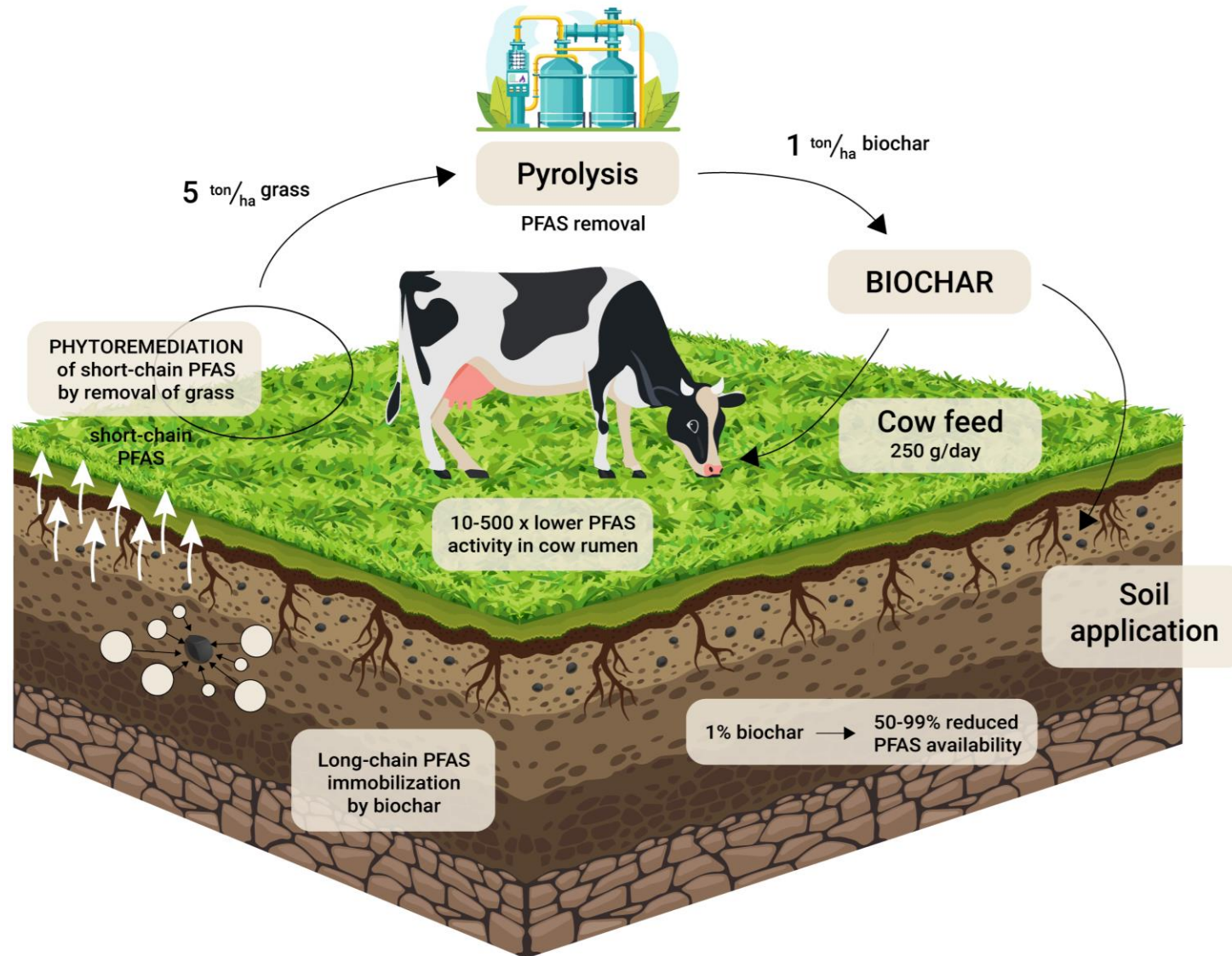
No biochar

PFOS leached in less than 1 year

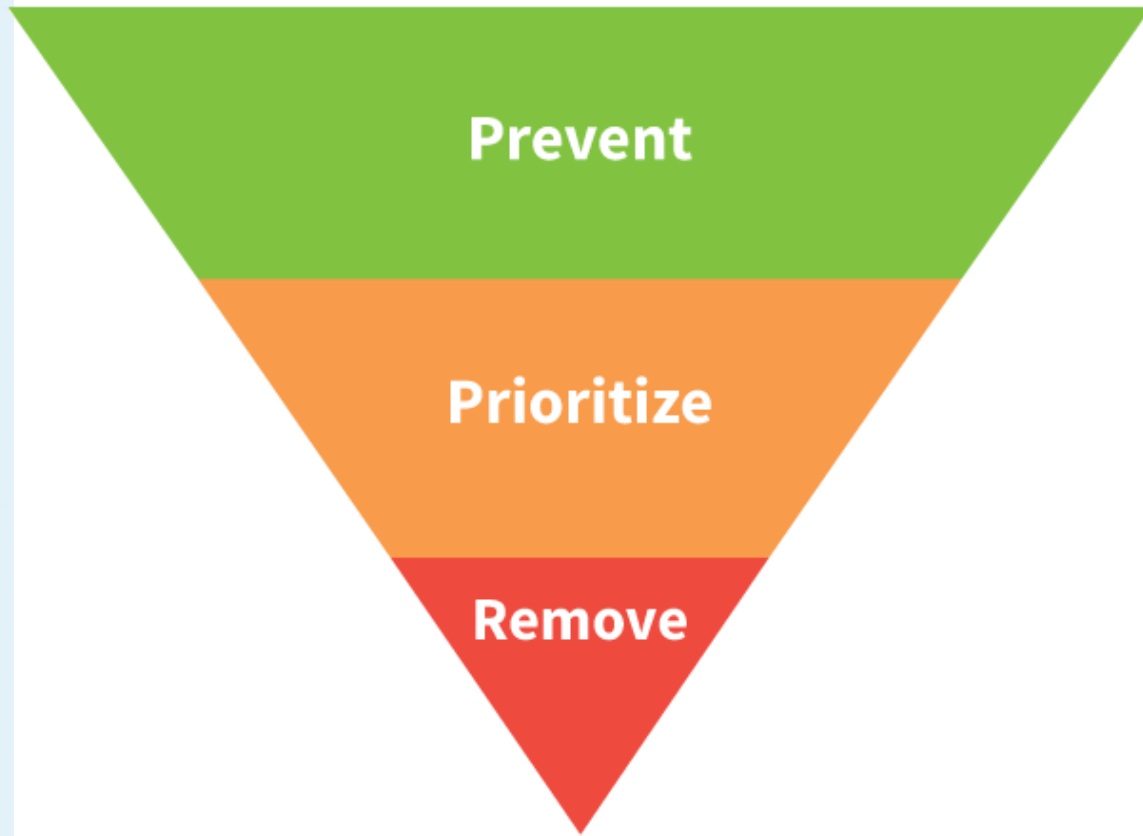
With Biochar

PFOS immobile in soil for > 100 years

Repeating the cycle to turn contaminated land to arable land



How to confront the threat of persistent synthetic substances



All you need is love
and regulatory clarity to:

- Focus preventing uses associated with emissions and circular management routes
- Identify persistent substances producing at the largest volumes and posing the most risk uses
- Remediate at the point of emissions and hot spots with sustainable methods rather than downstream



Thank you!



Eco-toxicological and climate change effects of sludge thermal treatments: Pathways towards zero pollution and negative emissions

Marjorie Morales^{a,*}, Hans Peter H. Arp^{b,c}, Gabriela Castro^{b,d}, Alexandros G. Asimakopoulos^b, Erlend Sørmo^{c,e}, Gregory Peters^f, Francesco Cherubini^a



A Virtuous Cycle of Phytoremediation, Pyrolysis, and Biochar Applications toward Safe PFAS Levels in Soil, Feed, and Food

Gerard Cornelissen^{*}, Nathalie Briels, Thomas D. Bucheli, Nicolas Estoppey, Andrea Gredelj, Nikolas Hagemann, Sylvain Lerch, Simon Lotz, Daniel Rasse, Hans-Peter Schmidt, Erlend Sørmo, and Hans Peter H. Arp



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VOW - Valorization of Organic Waste
SLUDGEFFECT - mitigate hazardous substances



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Immobilization of PFAS by use of biochar (CONTAIN) – a project collaboration between University of Copenhagen, NGI and NMBU

What about plastics?

SPECIAL SECTION

PLASTICS

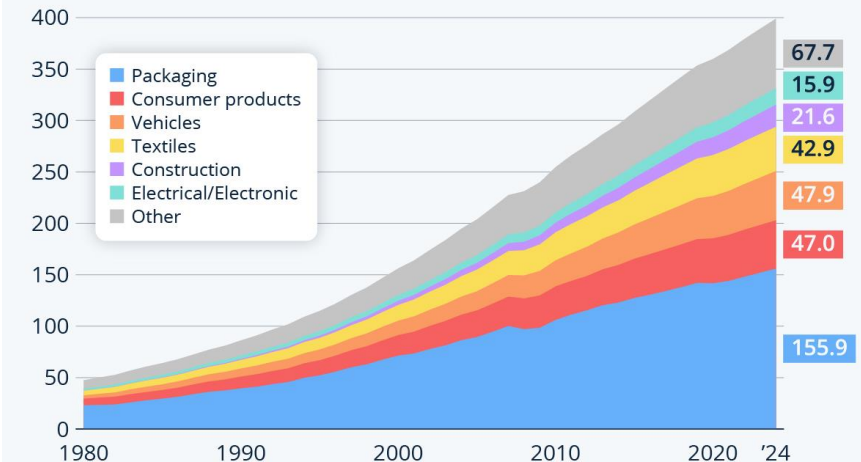
REVIEW

The global threat from plastic pollution

Matthew MacLeod^{1*}, Hans Peter H. Arp^{2,3*}, Mine B. Tekman^{4*}, Annika Jahnke^{5,6*}

The World Is Flooded With Plastic Waste

Global plastic waste production by application (in million tonnes)*



* Forecast from 2020 onwards

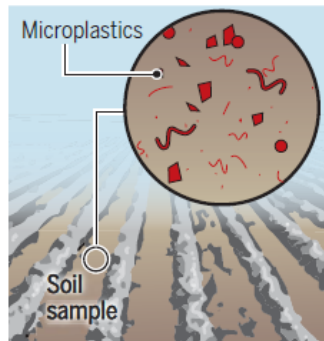
Source: OECD



statista

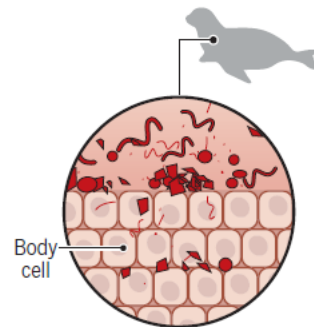
D Soils

Plastic applied to cropland as mulch and with contaminated compost accumulates and may be slowly released as weathered microplastic.



E The body

Ingested or inhaled particles can accumulate in body cavities, release fragments and chemicals, and potentially penetrate epithelial layers and tissues.



Science **373**, 61–65 (2021) 2 July 2021

Analysis | [Open access](#) | Published: 09 July 2025

Mapping the chemical complexity of plastics

[L. Monclús](#) , [H. P. H. Arp](#), [K. J. Groh](#), [A. Faltynkova](#), [M. E. Løseth](#), [J. Muncke](#), [Z. Wang](#), [R. Wolf](#), [L. Zimmermann](#) & [M. Wagner](#) 

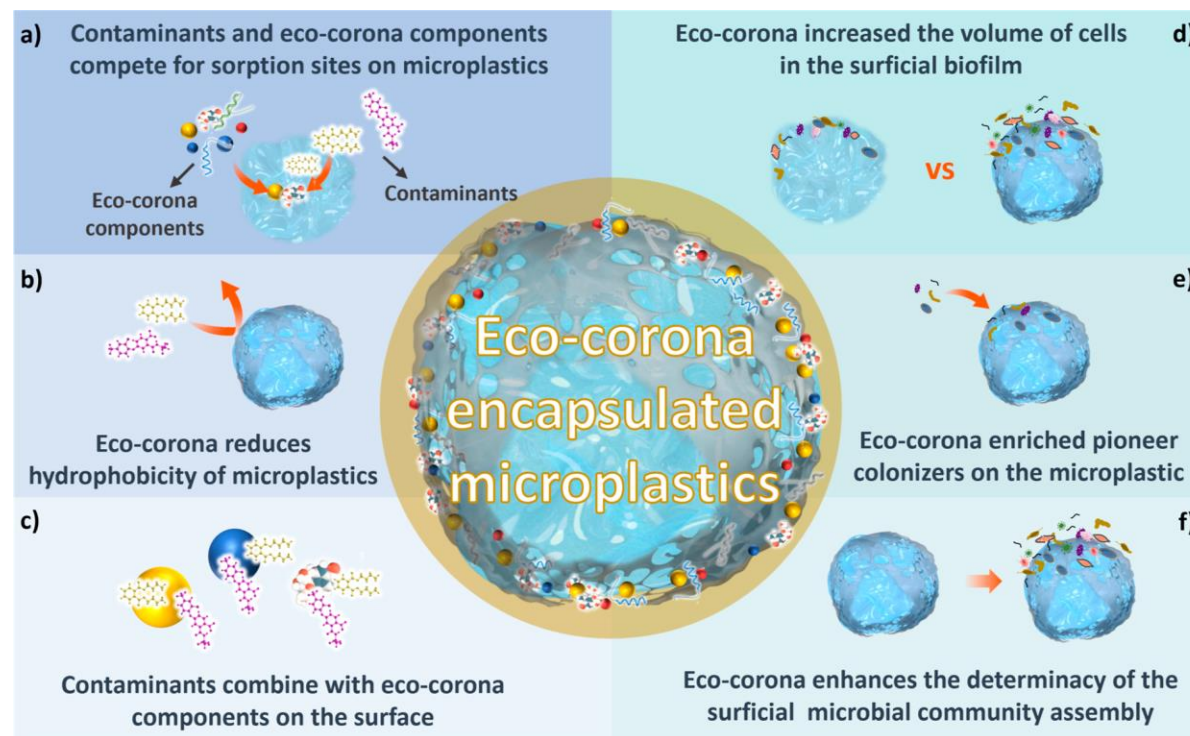
[Nature](#) **643**, 349–355 (2025) | [Cite this article](#)

Plastic as an entity associated with chemicals and changing soil microbiology



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Soil Metabolome Impacts the Formation of the Eco-corona and Adsorption Processes on Microplastic Surfaces

Shi Yao, Xiaona Li, Tao Wang, Xin Jiang, Yang Song,* and Hans Peter H. Arp

Cite This: *Environ. Sci. Technol.* 2023, 57, 8139–8148

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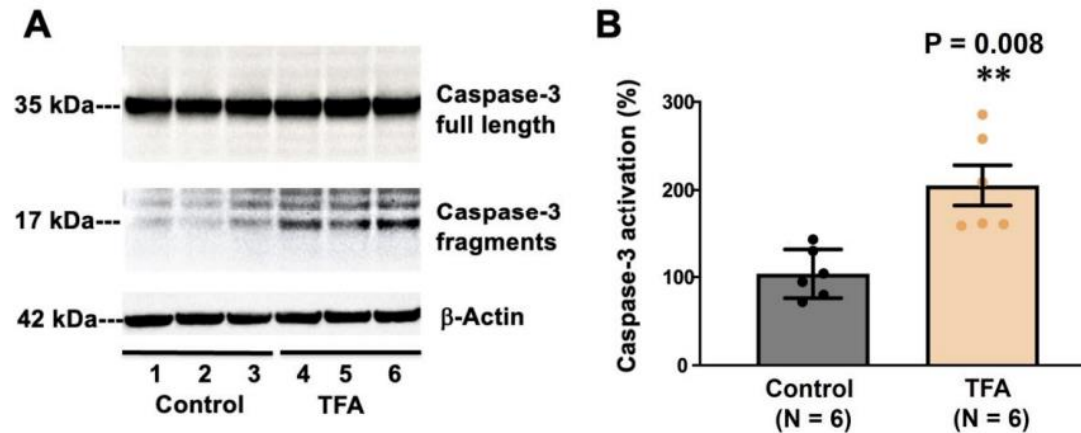
Metrics & More

Article Recommendations

Supporting Information

Collaboration with Yang Song
Institute of Soil Science, Chinese Academy of Sciences

Link to neurotoxicity with TFA-binding to proteins (differently than acetic acid)



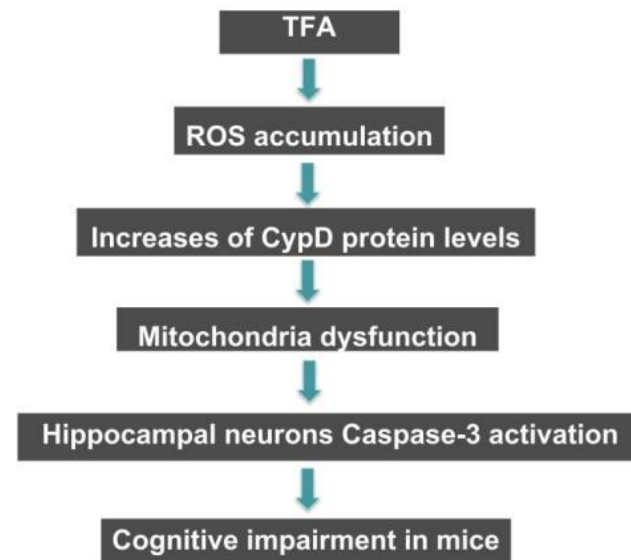
Aging and Disease
www.aginganddisease.org

Early access date: February 26, 2025
<http://dx.doi.org/10.14336/AD.2024.1430>

Original Article

Trifluoroacetic Acid Induced a Cyclophilin D-Dependent Cognitive Impairment in Mice

Yun Li^{1,2#}, Yichi Xu^{1,3}, Yuanlin Dong¹, Christa J. Nehs⁴, Zhongcong Xie¹, Yiying Zhang^{1*}



EFFECTS OF TRIFLUOROACETIC ACID, A HALOTHANE METABOLITE, ON C6 GLIOMA CELLS

T. G. Ma, Y. H. Ling, G. D. McClure, M. T. Tseng

Department of Anatomical Sciences and Neurobiology,
University of Louisville, Louisville, Kentucky

Commodity vs Functional plastics

Commodity Plastics

- Materials with high volume, low cost, high reuse,
- Increase design and sorting criteria for mechanical recycling
- easily mechanically recyclable/reusable like steel, glass, etc.



<https://silverspurcorp.com/hdpe-vs-pet-plastic-bottles/>

Functional Materials Plastics

- Additives are essential for a specific technical function; Bauhaus design would permit only essential ones.
- High-chance of being outside of circular economy if cannot be reused (safely)



Creator: Joaquin Traverso Traverso | Credit: Shutterstock
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Commodity vs Functional plastics

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