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*Enhancing Society Together*

# PFAS in the industrial water cycle

*A pragmatic approach on legislation, prevention and treatment*

*In collaboration with IWA*

Héloïse Thouément, Laura Piai & Marit Kroese

21 April 2026

# Webinar hosted by IWA and Haskoning



Learn – Publish – Communities - Events



*IWA* is a non-profit organization that connects knowledge, collaboration & impact to explore solutions for the world's most pressing water challenges

*Haskoning* is an independent consultancy and engineering firm supporting water, industrial, and environmental projects worldwide

# Welcome to the IWA webinar



**Héloïse Thouément**  
*Expert chemical pollution*



**Laura Piai**  
*Scientist PFAS removal from water*



**Marit Kroese**  
*Process Engineer Industrial Water*

**Haskoning** is an independent consultancy and engineering firm supporting water, industrial, and environmental projects worldwide



# Contents

10 min



## Introduction to PFAS

- What are PFAS?
- PFAS in the water cycle and monitoring
- Legacy and regulation

15 min



## Water technologies for PFAS

- Separation
- Destruction

20 min



## Real-world case studies

1. Approaches for PFAS in water from waste management operations
2. Dealing with PFAS in municipal wastewater & leachate
3. Managing PFAS-polluted sites caused by fire-fighting foam usage

15 min



## Outlook and Q&A

### Note:

Please post your questions in the chat and upvote questions you would like to see answered

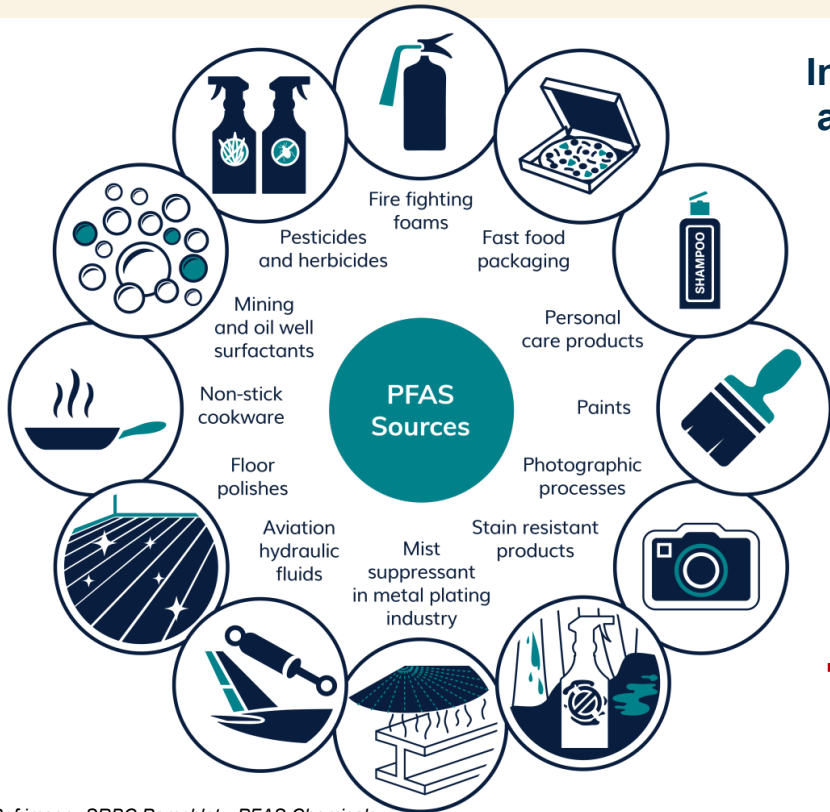


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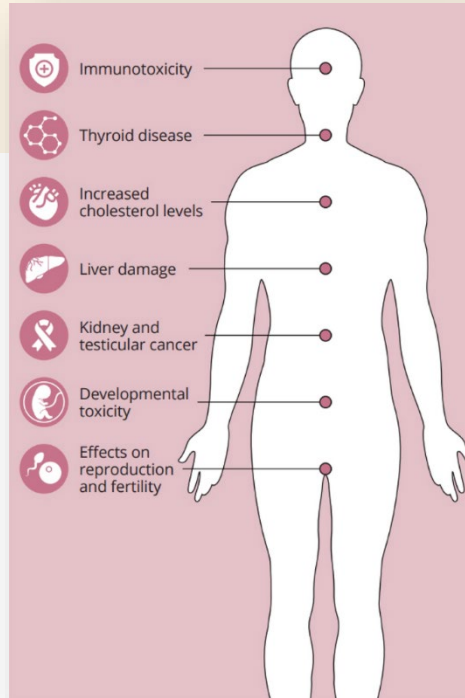
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# Introduction to PFAS in the water system

# PFAS have many applications



Intensive use from the 60s and *still* produced in 2026



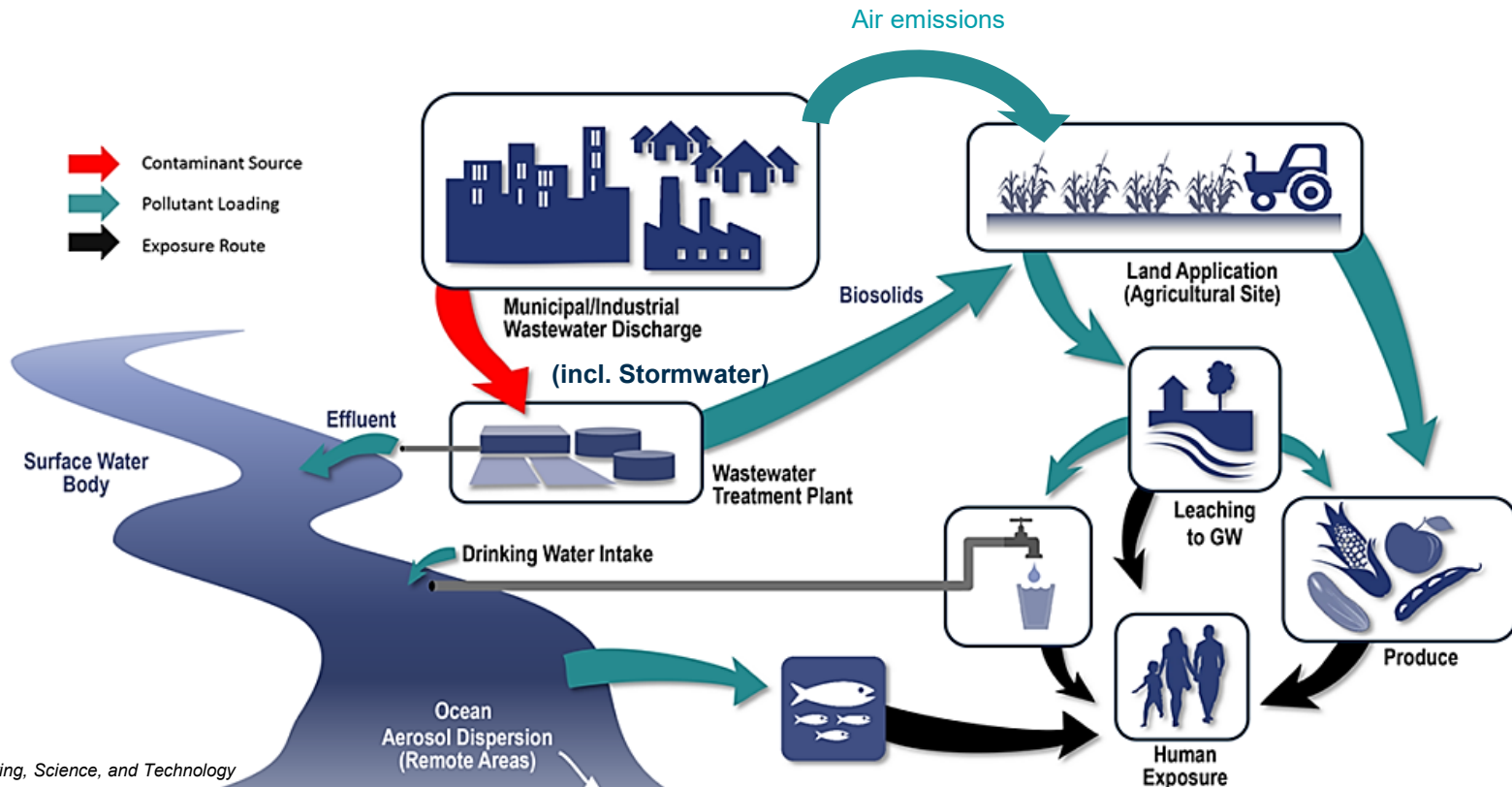
From Brunn et al. (2023) [2]

... but also many hazards

Current PFAS emissions to the environment :  
**75 000 000 kg/y in the EU** (Source: Forever pollution project)

Ref image: SRBC Pamphlet - PFAS Chemicals

# PFAS in the water cycle



Modified from EA Engineering, Science, and Technology

# “Together, forever”?

## No: there is a way

- PFOS and PFOA exposure decreased since phase-out (2000)
- Destruction techniques exist and are improving

## Yes: if we do not put effort into it

- Phasing out usage of *all* PFAS is slow and not worldwide
- Complete degradation requires energy  
**= very costly**
- Costs are for society, not manufacturers

Limiting PFAS exposure requires effort:  
Reduce emissions → reduce use & **limit discharge**

# Regulation: Monitoring, protecting and banning


## Example of the European Union approach :

### Monitoring (collecting evidence)

- Monitoring PFAS in urban wastewater, surface waters, groundwater, drinking water
- Increasing PFAS reporting obligations (industrial emissions portal regulation)

### Protecting (protection goals)

- Drinking water directive
- Water Framework Directive



Permits are discussed locally, based on protection goals on a case by case, risk-based approach

### Banning (closing the tap)

- Existing bans PFOS, PFOA, PFHxS (POP), PFHcxA, PFCA, refrigerants, firefighting foam, packaging
- To be voted on: complete PFAS restriction, including derogations (5-12 years) under obligations of PFAS management plan

*Reference for further insights about regulations: Per and poly-fluorinated chemicals (PFAS) | OECD*

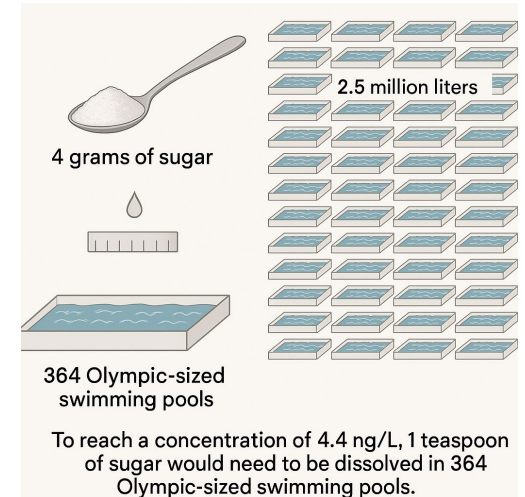
# Risk management in 2026

## Challenges (Reinikainen, 2024):

- Permitting based on food & drinking water protection
    - EU Drinking water threshold (2018) is not aligned with the food safety organisation (EFSA) recommendations (2020)
    - Methodology unclear
  - Protection goals for surface water (4.4 ng/L) and biota, based on EFSA recommendation, are already exceeded in many places
- ➔ Confusion and complex discussion for all stakeholders
- ➔ More conservative DW thresholds in Nordic countries
  - ➔ Impossible requests: measure under limits of quantifications
  - ➔ Protection goals < background concentrations

## Complex time for risk-based approaches - but management is necessary

- Combine rationality and sustainability
- ➔ Reality check:  
Take food consumption, background concentration into account
  - ➔ Precaution:  
No data does not mean no risk





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**PFAS sampling and analysis for:**  
**- PFAS concentrations in your effluent**  
**- Evaluation of treatment solutions**

# Special care for data quality

## Quality of your sampling and analysis impacts:

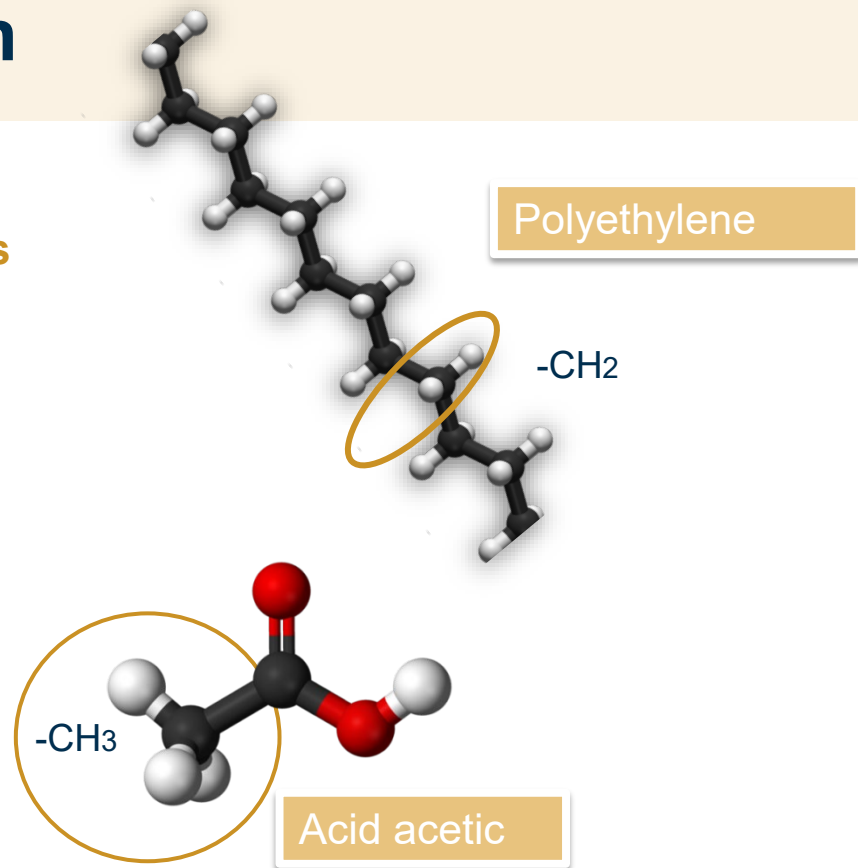
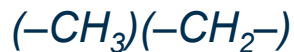
- Ability to draw conclusions (for treatment, for permitting)  
→ *beware of high limits of quantifications*
- Ability to conclude on treatment opportunities and related costs
- Insufficient data quality can lead to extra costs  
(*redo analysis, or bad treatment performance*)

**Most important:**  
Industrial water quality will  
impact analysis quality &  
treatment performance

# What are PFAS? Definition

PFAS: Per and Poly Fluoro Alky Substances

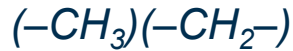
- Organic molecule in which the **hydrogen atoms** are attached to carbon backbone



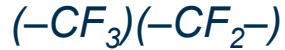
# What are PFAS? Definition

PFAS: **Per** and **Poly Fluoro Alky Substances**

- Organic molecule in which the **hydrogen atoms** attached to carbon backbone



- are **partly** or **entirely** replaced by **fluorine atoms**

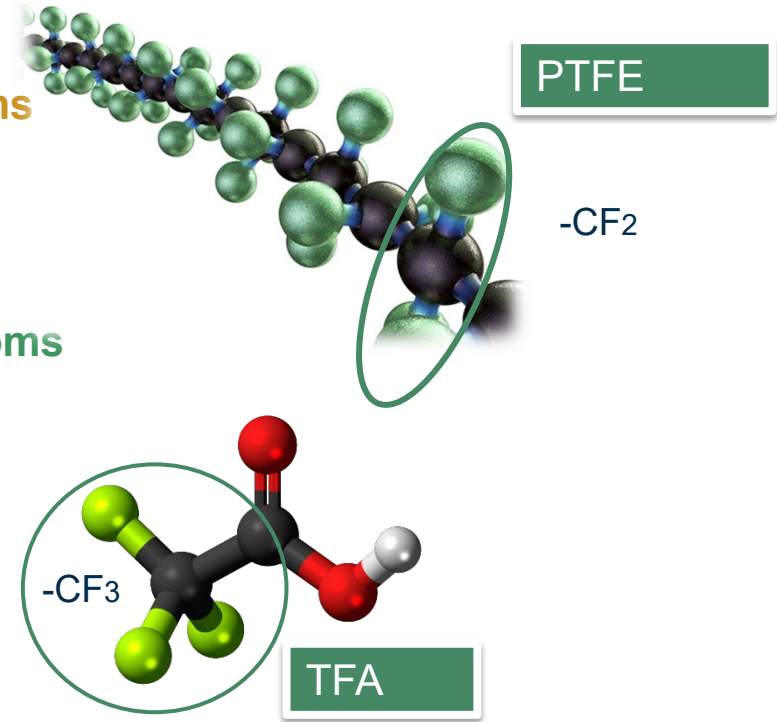


**Challenge:**

C – F bond is the strongest bond in chemistry

**Challenge:**

There are thousands of PFAS molecules, all with different structures and properties



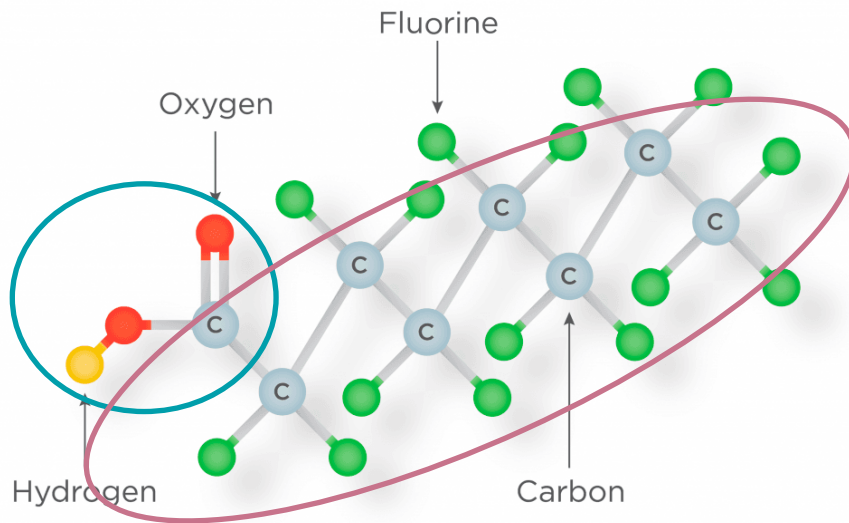
# What are PFAS? Example with PFOA

## Hydrophilic head group

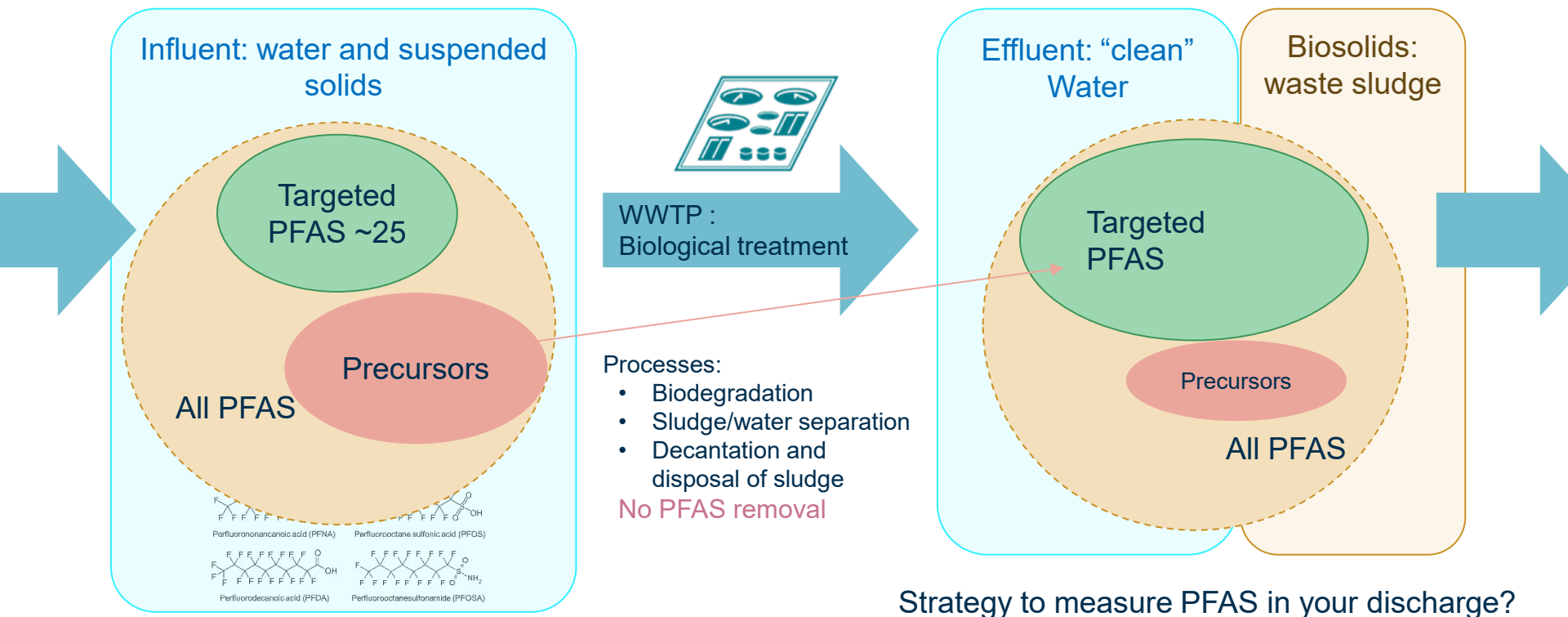
➤ favours water and rejects air/oil

## Hydrophobic fluorinated chain

➤ rejects water and favours air/oil



# PFAS in conventional wastewater treatment plants

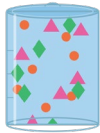


# Create an efficient sampling and analysis protocol

Know your water, be aware of the following aspects:



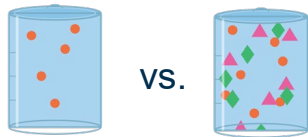
and



- ❖ Large concentration differences between PFAS (100-fold)

*solution → additional dilution before analysis*

- ❖ Different types of PFAS require different analytical methods



vs.

- ❖ Other components present in matrix besides PFAS

*note: especially salts interfere with analysis techniques*

*solution → discuss with lab for best analytical method*

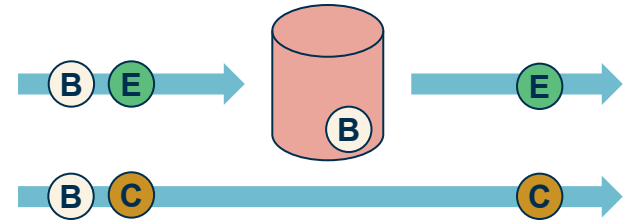
*solution → treat water before you apply PFAS treatment*

Be aware of  
PFAS  
interference  
compounds

# Create an efficient sampling and analysis protocol

## Quality data starts at the sampling stage:

- Avoid cross-contamination → use as little equipment as possible
- Avoid PFAS desorption or adsorption → choose PFAS free equipment and adapted sampling material *(no recycled plastic or glass)*
- Take multiple samples if needed:
  - ⓔ experiment sample
  - ⓑ blank sample *(check for contamination)*
  - ⓒ control sample *(check for degradation or interference)*
- Proper reporting of the sampling procedure



Communication  
between process  
engineer and  
laboratory is key

Sampling and  
analysis is a key part  
of your research, not  
an afterthought



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# PFAS removal technologies

# Concentrate, then degrade

PFAS removal: energy input is determined by treated volume, not by mass PFAS removed  
→ inverse relation:  $\text{€/m}^3 \propto \text{€/kg}$



## Separation / Concentration

Large volume, relatively low energy consumption

- Adsorption
  - Activated carbon
  - Ion exchange
  - Cyclodextrins
  - Metal Organic Frameworks
  - Pillararenes
- Membrane filtration (NF/RO)
  - Foam fractionation
  - Etc.

## Degradation

Small volume, relatively high energy consumption

- Incineration
- Advanced reduction
- Plasma discharge
- Electron beam
- Ball milling
- Electrochemical oxidation
- Hydrothermal Alkaline Treatment
- Super Critical Water Oxidation

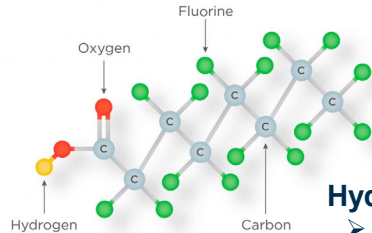
# Adsorption

Choice for best adsorbent depends on:

- Matrix
- Space limitations ( $\neq$  contact times)
- Other requirements (pharmaceuticals removal?)

## Hydrophilic head:

- Electrostatic interactions
- Ion Exchange
- Shorter chains



## Hydrophobic tail

- Adsorption to activated carbon
- Longer chains

## IEX (& specialized adsorbents) vs. GAC

- Higher throughput ( $>$  BVs treated)
- However, also consider:
  - Cost & CO<sub>2</sub> footprint adsorbent
  - Regeneration or disposal adsorbent (GAC reactivation also functions as PFAS-degradation step)

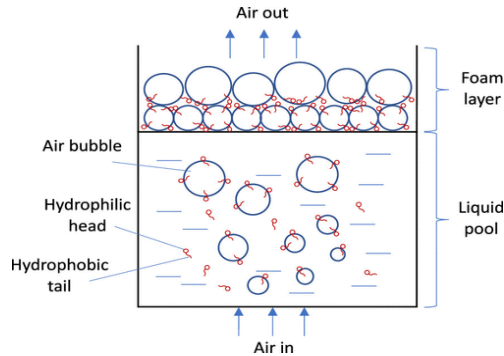
## Challenge: the water matrix

- PFAS: ng/l
- Other pollutants:  $\mu$ g/l
- Background organic matter: mg/l



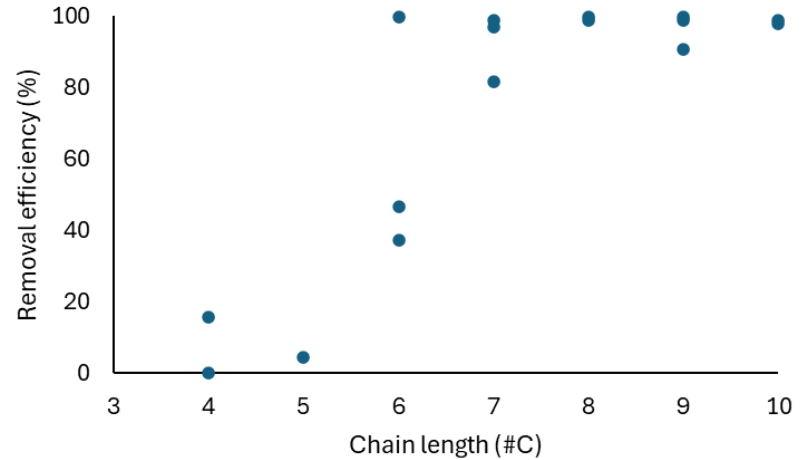
# Foam fractionation

- PFAS that have surfactant properties accumulate in foam
- Less sensitive to water matrix compared to adsorption and membrane filtration
- Suitable for reducing the volume of PFAS-containing stream > 1,000 x
- Reported energy consumption 0.65 – 0.80 kWh/m<sup>3</sup> (Burns et al. 2022)
- Polishing needed to reach very low concentrations



Morrison et al. 2023

**Challenge:**  
 Effectiveness for short-chain PFAS is low. Co-surfactants may help, but ecotoxicity is a concern.



Source of data: Burns et al. 2021 & 2022

# PFAS degradation technologies

- Development of various technologies based on:



## Thermal

- Combustion
- Pyrolysis



## Chemical

- Oxidation
- Reduction



## Biological

- Aerobic
- Anaerobic

### Challenge: very energy intensive

- PFAS degradation: 10 – 1000 kWh/m<sup>3</sup>
- Pharmaceuticals: ~ 0.1 kWh/m<sup>3</sup>

### Challenge:

Most technologies still have a low TRL

### Degree of destruction: (currently)

Thermal > Chemical > Biological

- Degree of destruction depends on chosen technology, type of PFAS and water matrix

Complete degradation:

😊 HF, F and CO<sub>2</sub>

Partial degradation:

☹️ Intermediate by-products

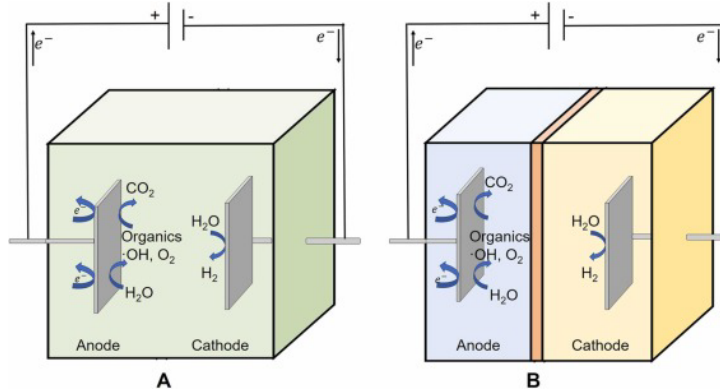
### Challenge:

Formation of recalcitrant short-chain PFAS

# Commercially available destructive technologies

## Electrochemical oxidation

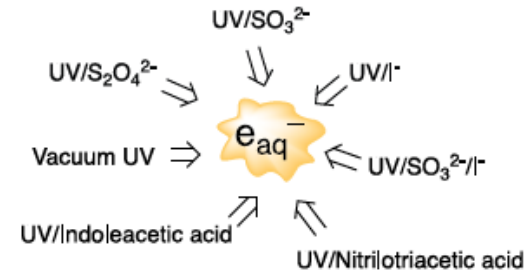
- Direct oxidation via electron transfer or indirect oxidation via radicals
- Type of electrode is a key aspect (also where development is focused)
- Point of attention → Formation of  $\text{ClO}_3^-$  and  $\text{ClO}_4^-$



Veciana et al. 2022

## Advanced reduction

- Reactive species: hydrated electrons ( $e_{\text{aq}}^-$ )
- Common combination with  $\text{UV}/\text{SO}_3^{2-}$
- Sensitive to dissolved oxygen and  $\text{NO}_3^-$



Fennel et al 2024

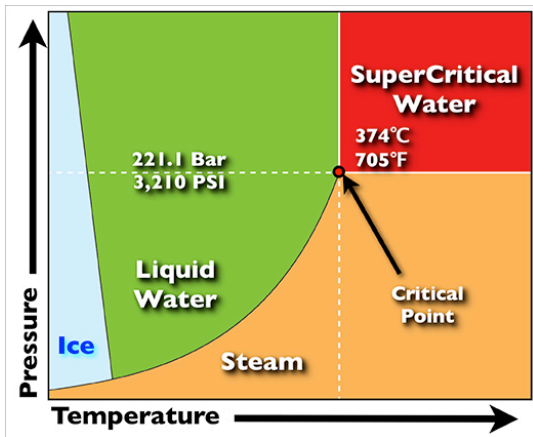
# Commercially available destructive technologies

## Super Critical Water Oxidation (SCWO)

- Above supercritical point of water
- Challenges: salts precipitation, corrosion, safety aspects

## Hydrothermal alkaline treatment (HALT)

- Below supercritical point of water
- Challenges: pH correction needed after treatment, corrosion, safety aspects



170-350°C



20-220 bar



pH > 14

High potential for mineralization

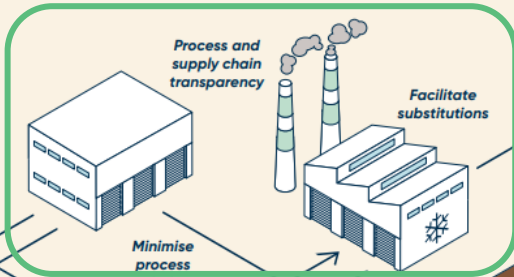


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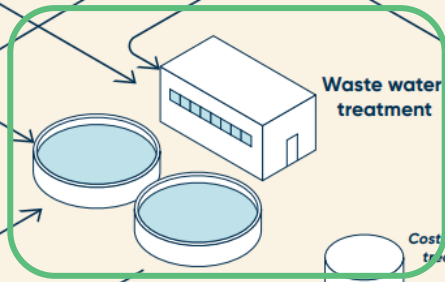
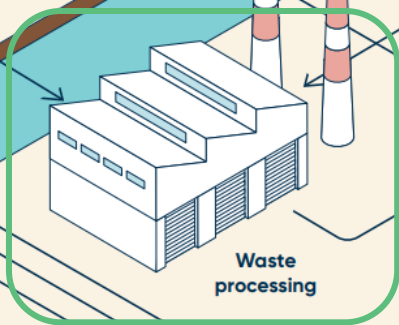
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# Real-world case studies

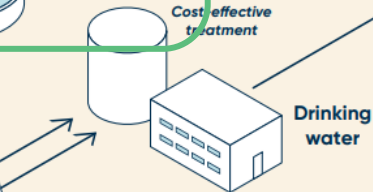
3. Managing PFAS-polluted sites caused by fire-fighting foam usage



1. Approaches for PFAS in water from waste management operations



2. Dealing with PFAS in municipal wastewater & leachate



Accidental spills

Groundwater

Surface water

Waste processing

Waste water treatment

Cost effective treatment

Development of new technologies

Authorities and legislation  
Compliance with regulations

Drinking water



# Managing PFAS in water and waste

## Case 1



Key message: do not blend it

# Case study: PFAS management plan

Client requested an overview of PFAS

## What did we do?

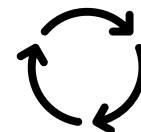
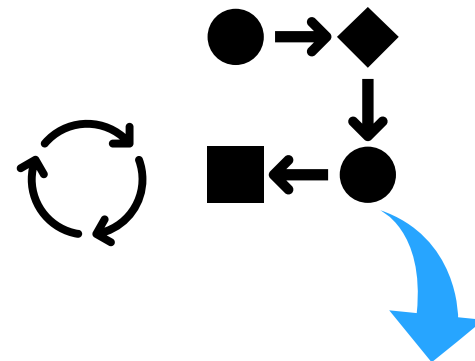
- Generate a **PFAS mass balance** for each step
- **Evaluate** the quantities of PFAS in product and in the waste

## Reality on site:

- Small streams containing PFAS mixed with the wastewater
- Waste management companies not aware that PFAS are in the waste stream

## Solutions:

- Where possible, create a separated waste stream (dedicated containment tanks)
- Add a recycling program



# Take away message – not blending PFAS

## What can you do?

- Find out where the PFAS are:
  - Check the Safety data sheets of the substances used, Bill of materials, ...
  - Biocides, detergents, lubricants, used on site
- Generate the mass balances
- Communicate
  - in the supply chain
  - with your waste management
- Cost benefit analysis to prevent dilution vs treatment
- Get support where needed



# Dealing with PFAS in municipal wastewater & leachate

Case 2



# PFAS in wastewater effluent

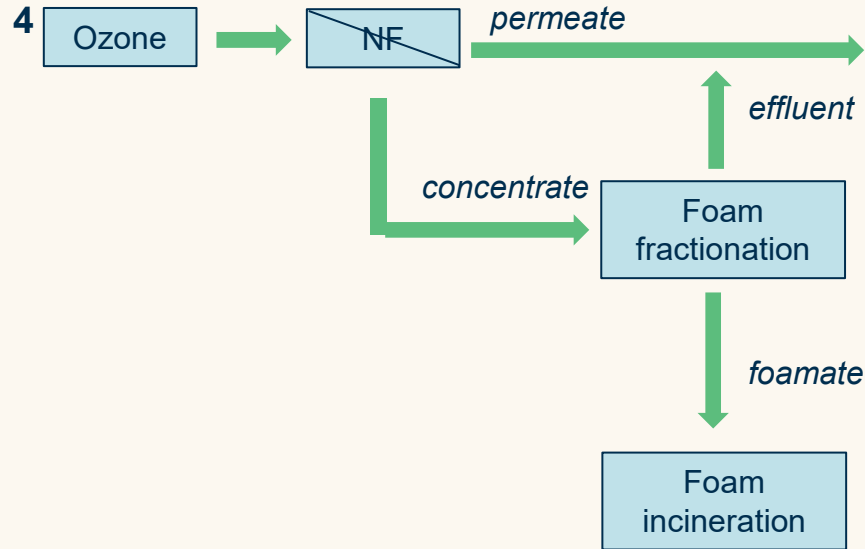
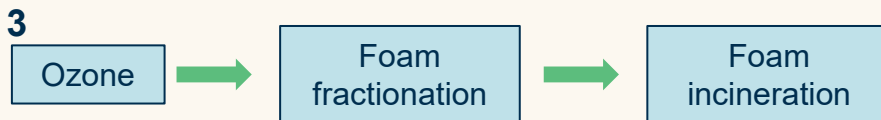
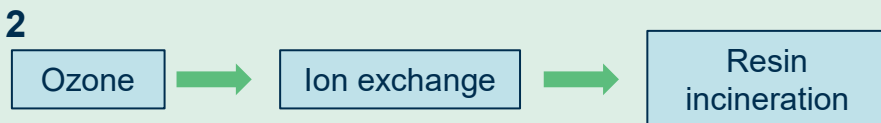
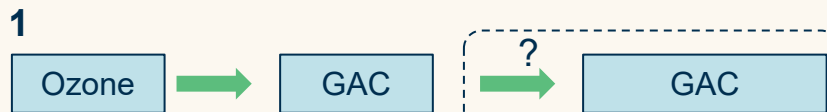


## New WWTP in design phase

- PFOS: 0.4 ng/L
- PFOA<sub>eq</sub> ( $\Sigma 24$  PFAS): 4.9 – 7.3 ng/L

## System selection

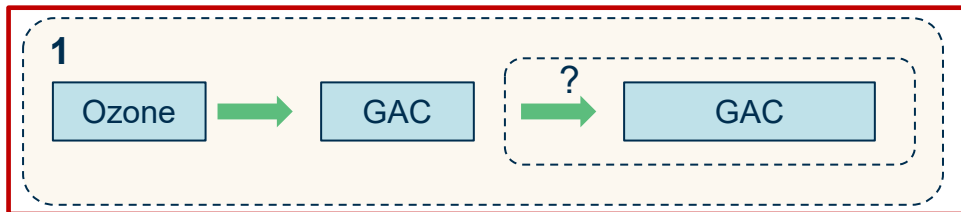
- Technology Readiness Level (TRL)  $\geq 9$
- Applicable to large flows ( $>4,000$  m<sup>3</sup>/h)



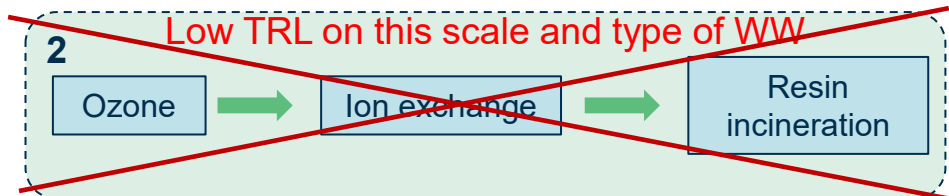
# PFAS in wastewater effluent



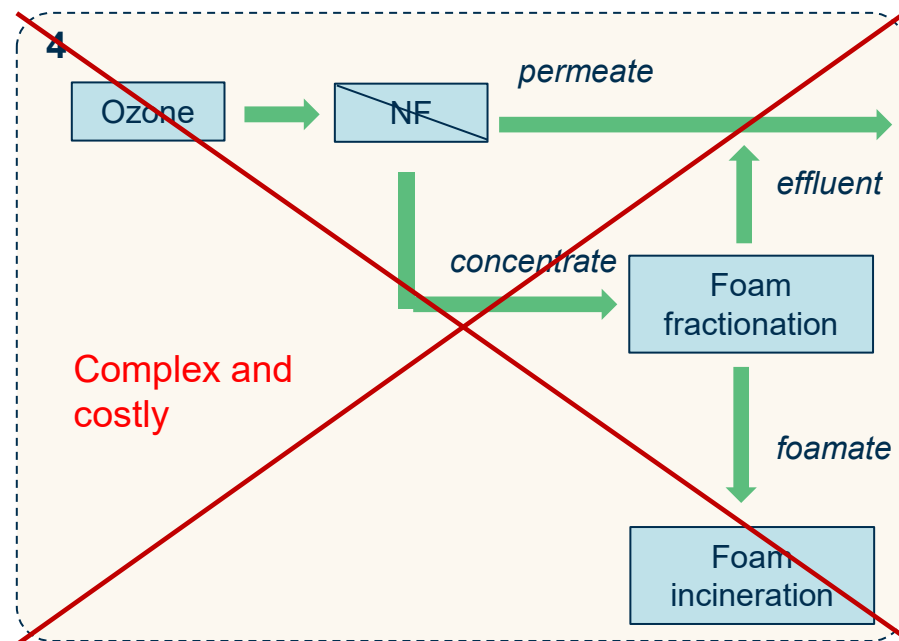
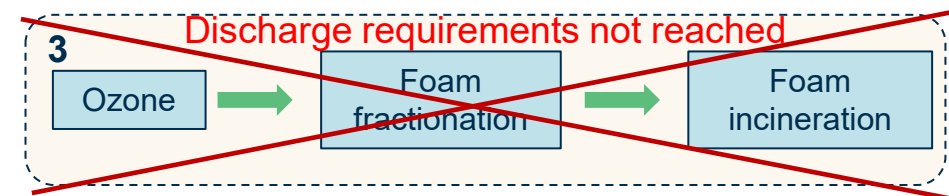
Selected option



Low TRL on this scale and type of WW



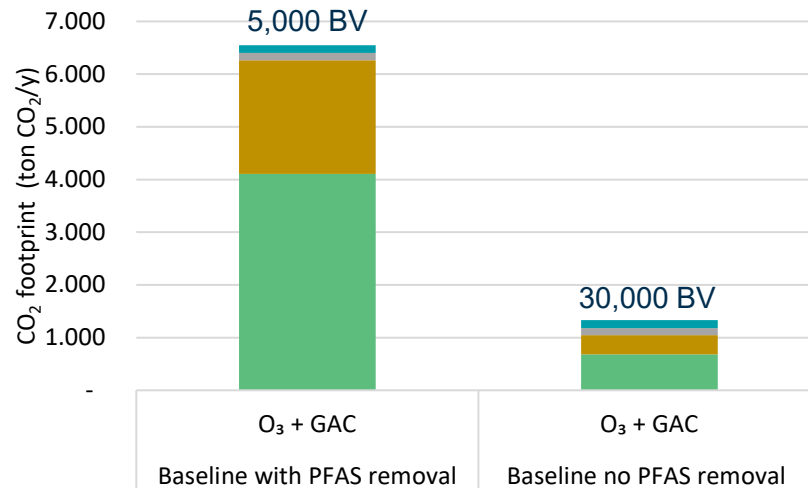
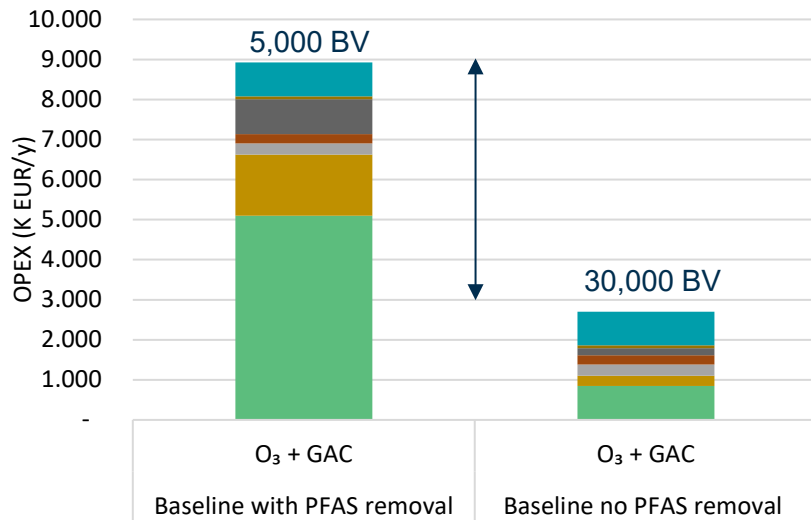
Discharge requirements not reached



# PFAS in wastewater effluent



## OPEX & CO<sub>2</sub> footprint for PFAS removal



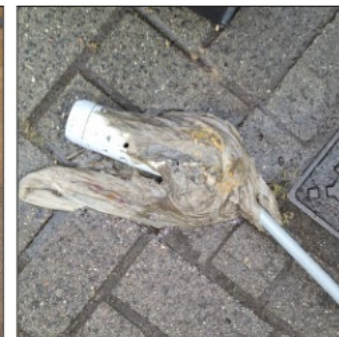
- GAC reactivated
- GAC fresh
- Oxygen
- Electricity
- CO<sub>2</sub> tax
- Manpower
- Maintenance

- GAC reactivated
- GAC fresh
- Oxygen
- Electricity

# Tracing PFAS in WW influent – the Dutch approach



- **Goal:** trace sources of PFAS in WWTP where influent concentrations are higher than average
- **What was achieved?**
  - Narrowed down most relevant sources in effluent catchment area
  - Passive samplers suitable for sewer systems identified and tested
  - Defined monitoring strategy
    - Sampling rounds, from downstream to upstream
    - Duration of 7 days



*This project was developed by STOWA, Ministry of Infrastructure and Water Management, Water Authority of Zuiderzeeland and municipality of Lelystad*

*Source: [Bronnen van PFAS opsporen via metingen in de riolering: methodiek en toepassing in Lelystad](#)*

# PFAS in leachate - Foam fractionation in activated sludge



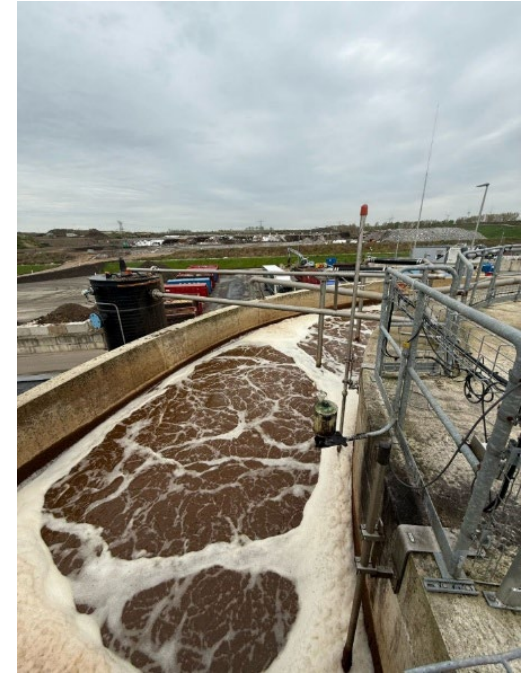
**TU**Delft

Foaming in aeration tank → from problem to solution

- Foam forms in aeration tank
  - **Current practice** → dose anti-foaming
  - **Goal** → stop dosing anti-foaming, collect and remove foam

## Pragmatic Approach:

- Design foam collection system
- Foam contains biomass – effect on sludge performance?
- Suitable technology for PFAS degradation in foam (with high solids content)?



# Managing PFAS-polluted sites caused by fire-fighting training

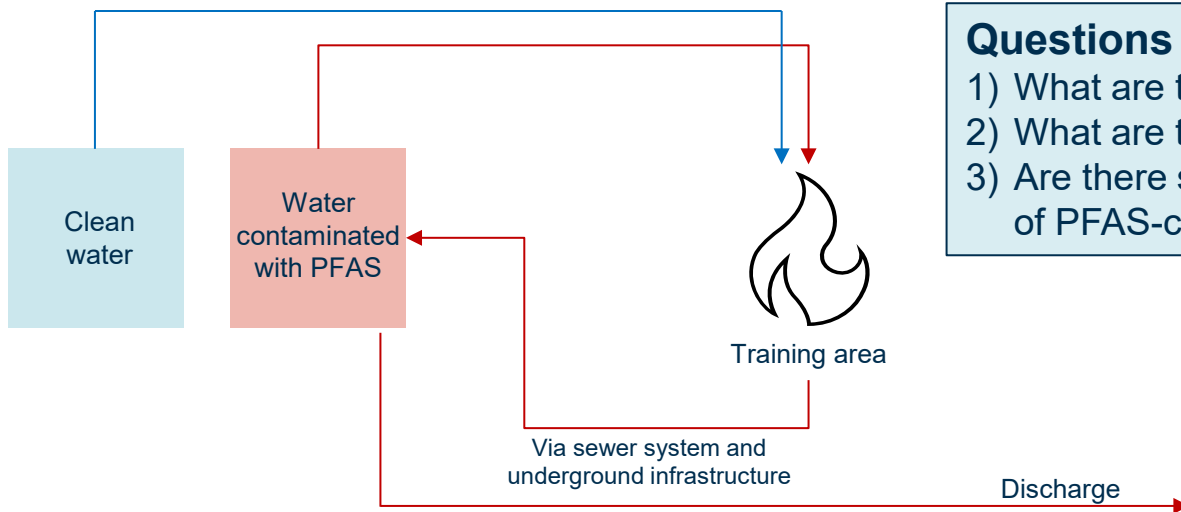
Case 3



# PFAS in water after fire fighting training



**Case:** Fire fighting training area, use of PFAS-containing foam until 2020  
Fresh clean water + recirculated water used in training  
PFAS found in recirculated water stream



## Questions

- 1) What are the most effective measures?
- 2) What are the sources of PFAS in the area?
- 3) Are there safety concerns regarding reuse of PFAS-containing water

# Question 1 – What are most cost-effective measures?



## End-of-pipe treatment

- Only technologies with high TRL considered  
→ degradation technologies other than incineration excluded
- Treat water until source of PFAS is depleted

### Challenge

Duration of end-of-pipe treatment?  
How long until source is depleted?

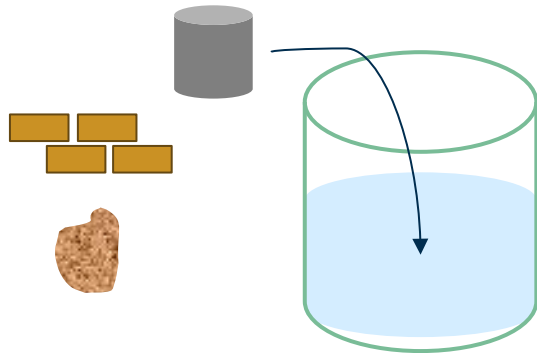
## Intervention at the source

- Identify sources
- Determine suitable measures
  - Treat concrete to stop leaching → effectiveness in the long-term?
  - Replace materials in paved surface
  - Reline tanks and gutters

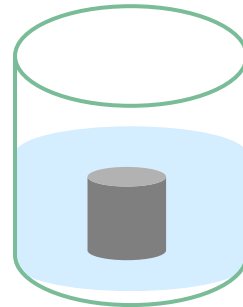
### Challenge

Can we identify all sources?

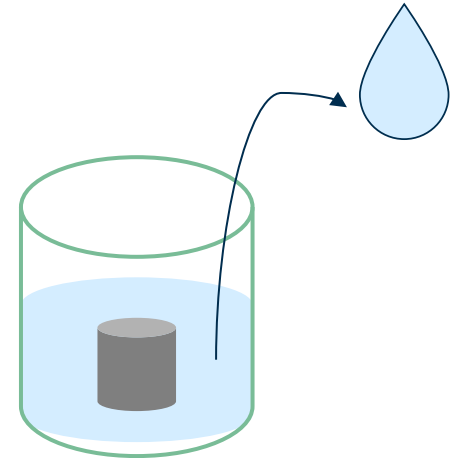
## Question 2 – What are the sources of PFAS in the area?



Concrete/sand/brick + water



Wait

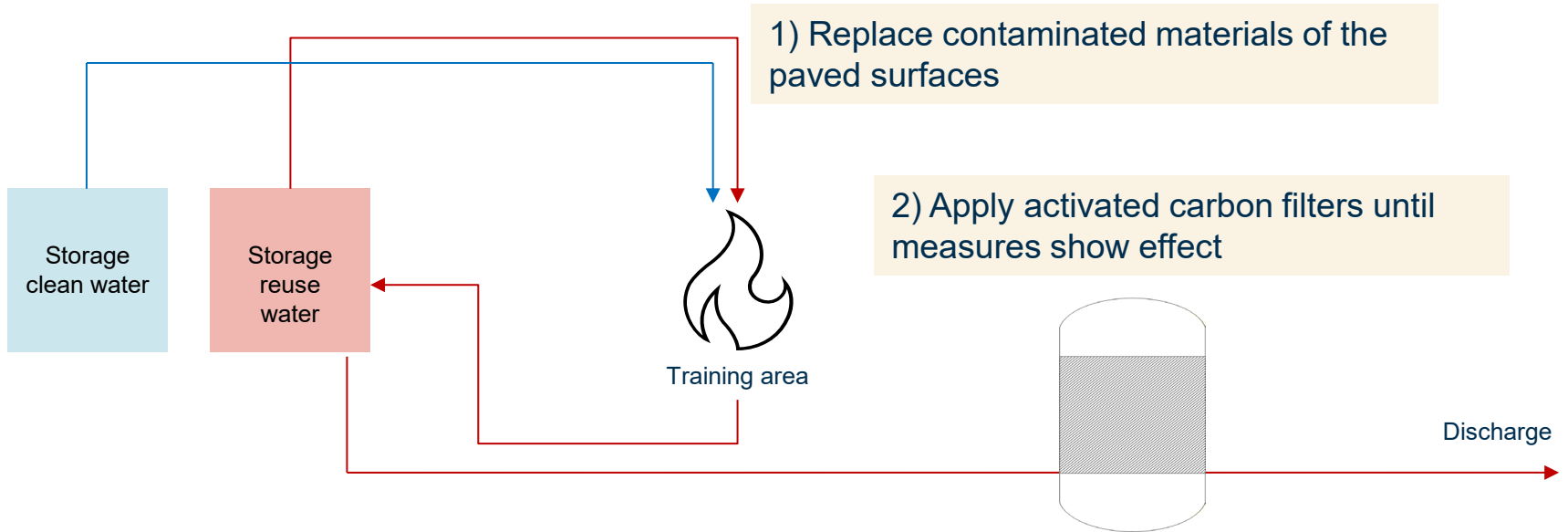


Measure PFAS in water

### Challenge

No established protocol for leaching test with organic contaminants in construction material, so protocol for inorganic contaminants was applied

# Advise



1) Replace contaminated materials of the paved surfaces

2) Apply activated carbon filters until measures show effect

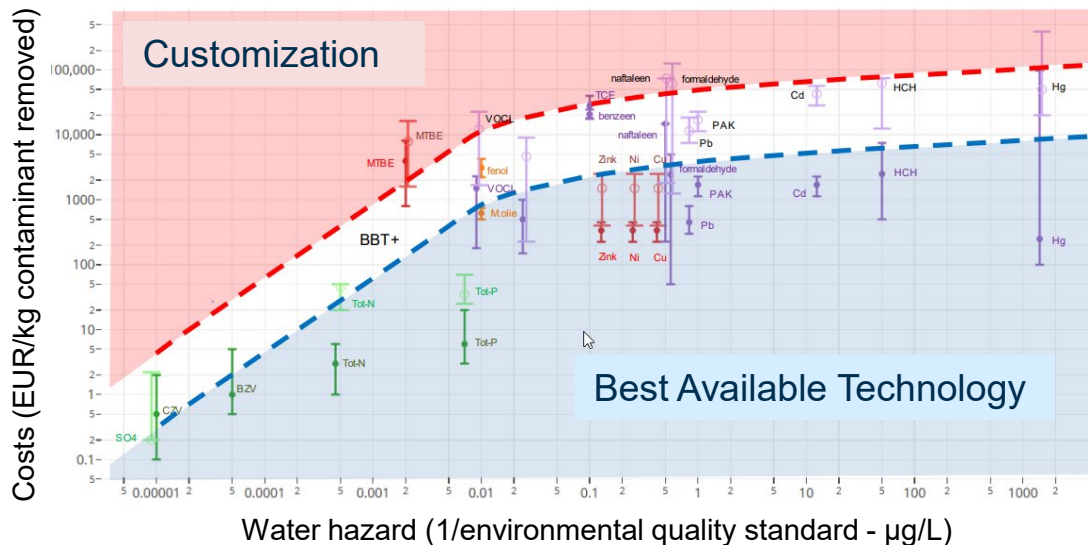
3) Reline underground infrastructure (also effective to prevent infiltration from and to groundwater)

# Cost-effectiveness end-of-pipe treatment



- Expected costs based on activated carbon → 750 – 950 k€/kg PFAS
- Threshold for cost-effective measures → 100 – 150 k€/kg PFAS

Discussions with permitting authority to define next steps



Source: Ministry of Infrastructure and Water Management, the Netherlands ([Kosteneffectiviteit/BBT+ en de KE-RWS tool](#) | [Informatiepunt Leefomgeving](#))



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# Outlook

# How to move forward pragmatically?

Sustainable solution = continue with the staged phasing-out of PFAS usage, implement emission control and organize an answer to PFAS legacy

## For industry

- Survey PFAS in your products and processes
- Keep being competitive on your products but *collaborate* on environmental challenges like PFAS
  - Open the conversation with your local government
  - Reach out to external parties who have the expertise
  - Implementation will drive technological progress (iterative process)



## For local government

- A good relation and open communication is important to build trust
- Consider effort-based and risk-based permitting
- Consider that treatment costs are higher than cost-effective thresholds
- Identify knowledge gaps internally & connect with stakeholders



# Outlook: events

Interested in more? Join us at:

- IWA WIN conference 2026  
*Click [here](#) for more information*
- ChemCon conference 2026  
*Click [here](#) for more information*



**Registration is now open –  
Join me at WIN2026**

# Get in touch

*Feel free to contact us later for more information or project-specific questions*



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**Additional info**

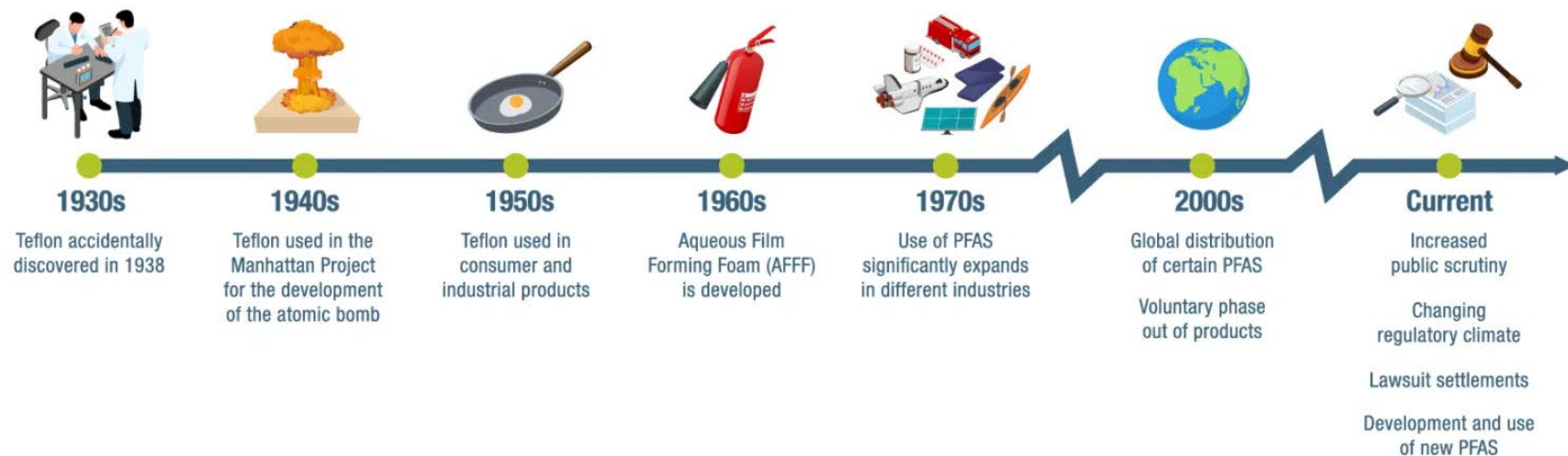
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- **PFAS regulation for risk management:** Reinikainen, J., Bouhoulle, E., & Sorvari, J. (2024). Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment. *Environment international*, 186, 108614.
- **PFAS regulatory landscape overview (OECD country resources):**  
<https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/per-and-poly-fluorinated-chemicals.html>

# PFAS use – a timeline

## PFAS Development ...

## ...and Evolution



Ref image: *What Are PFAS and What Can You Do About Them?* | Kimley-Horn

# PFAS: Risk and regulation

Source	Value	Comment Reinikainen, 2024	Meaning
Drinking water directive (DWD 2018)	PFAS total < 0.5 µg/L Sum of PFAS (dw) < 0.1 µg/L	Scientific background not clear, not aligned with EFSA recommendation	The risk associated to exposure at such concentration is unclear
Tolerable weekly intake (EFSA 2020) – in discussion	<b>4.4 ng/kg/week</b> – 4 PFAS	Recommendation only. Precautionary approach related to reduced vaccine response.	New studies might change this recommendation
Biota Environmental quality standards (2026) - new	<b>77 µg/kg<sub>ww</sub></b> (sum 24 PFAS, PFOA equivalent)	Conservative (115 g fish/day)	Other risk-based approach could change the result. Fishes usually above this limit
Surface water EQS (2026) - new	<b>4.4 ng/L</b> (sum 24 PFAS, PFOA equivalent)	Higher than earlier defined, not aligned with Biota-EQS, based on drinking water	Commonly exceeded in EU surface waters
PFOA equivalent		Good for screening, not yet scientifically convincing	Might change

# Definition of PFAS

There are over thousands to millions of different PFAS molecules (Schymanski et al. (2021)).

## Classification #1: Fluorination

- **Perfluoroalkyl** = fully fluorinated
- **Polyfluoroalkyl** = partly fluorinated

## Classification #2: Head group

- **-COOH**, **-PO4H** or **-SO3H**  
→ determines strength and acidity

## Classification #3: Tail length

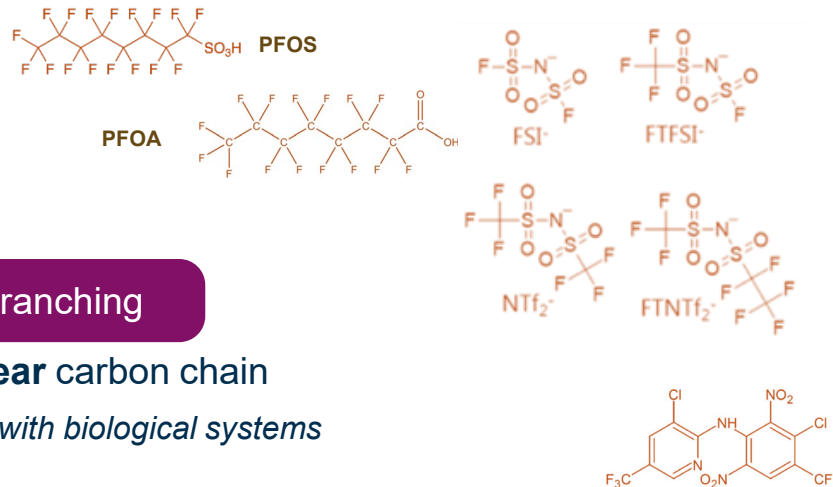
- **Short** (<6-C) or **long** (> 7-C)  
→ determines mobility and toxicity

## Classification #4: Branching

- **Branched** or **linear** carbon chain  
→ affect interaction with biological systems

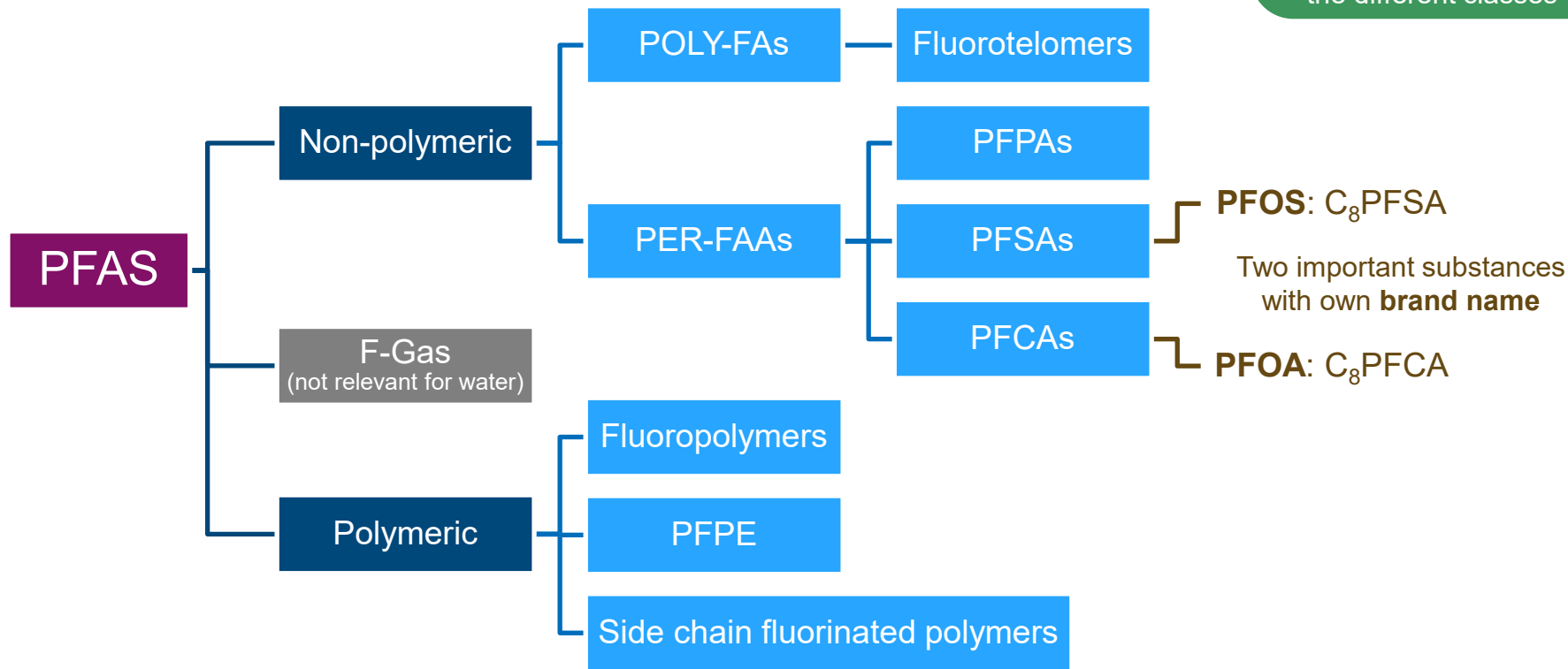
## Classification #5: Polymer

- **Non-polymer** (<C20) or **polymer**  
→ non polymer is more mobile and bio-accumulating



# PFAS – classification tree

Tip: don't learn PFAS names by heart, but familiarize yourself with the different classes



# PFOA equivalent

**PFOA equivalent:** an umbrella parameter to regulate PFAS (similar to CO<sub>2</sub> equivalent)

- Concentration specific PFAS \* RPF = **Concentration in PFOA<sub>eq</sub>**
- **RPF** = **Relative Potency Factor** (toxicity molecule compared to PFOA)
- **∑PFAS** = Sum of different PFAS expressed in PFOA toxicity equivalent
  
- Example:

PFAS	Concentration (ng/L)	RPF	Concentration in PFOA <sub>eq</sub> (ng/L)
TFA	10	0.002	0.02
PFOS	10	2	20
PFOA	10	1	10

**Challenge:**  
different PFAS molecules are difficult to regulate



**Approach:**  
Use PFOA equivalent