Strategies towards zero pollution from PFAS: Insights from the ZeroPM project

Hans Peter Arp, Norwegian Geotechnical Institute

hans.peter.arp@ngi.no

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036756.

Zero pollution of persistent, mobile substances

- ZeroPM will interlink and synergize three strategies to protect the environment and human health from persistent, mobile substances: **Prevent**, **Prioritize** and **Remove**.

Project period:
October 2021 to September 2026
Project budget: 11.6 million Euro

The EU's Chemicals strategy for sustainability (CSS)

CHEMICAL POLLUTION IN NATURAL ENVIRONMENT

The Commission will:

- propose new hazard classes and criteria in the CLP Regulation to fully address **environmental toxicity, persistency, mobility and bioaccumulation;**
- introduce **endocrine disruptors, persistent, mobile and toxic** and **very persistent and very mobile substances** as categories of substances of very high concern;

PFAS[62]

The Commission will:

- ban **all PFAS** as a group **in fire-fighting foams** as well as in **other uses**, allowing their use only where they are essential for society;
- address PFAS with a **group approach**, under relevant legislation on water, sustainable products, food, industrial emissions, and waste;
- address PFAS **concerns on a global scale** through the relevant international fora[63] and in bilateral policy dialogues with third countries;
- establish an EU-wide approach and provide financial support under research and innovation programmes to identify and develop **innovative methodologies for remediating PFAS contamination** in the environment and in products;
- provide research and innovation funding for safe **innovations to substitute PFAS** under Horizon Europe.

- ZeroPM is rooted in the CSS

- define **criteria for essential uses**[44] to ensure that the most harmful chemicals are only allowed if their use is necessary for health, safety or is critical for the functioning of society and if there are no alternatives that are acceptable from the standpoint of environment and health. These criteria will guide the application of essential uses in all relevant EU legislation for both generic and specific risk assessments;

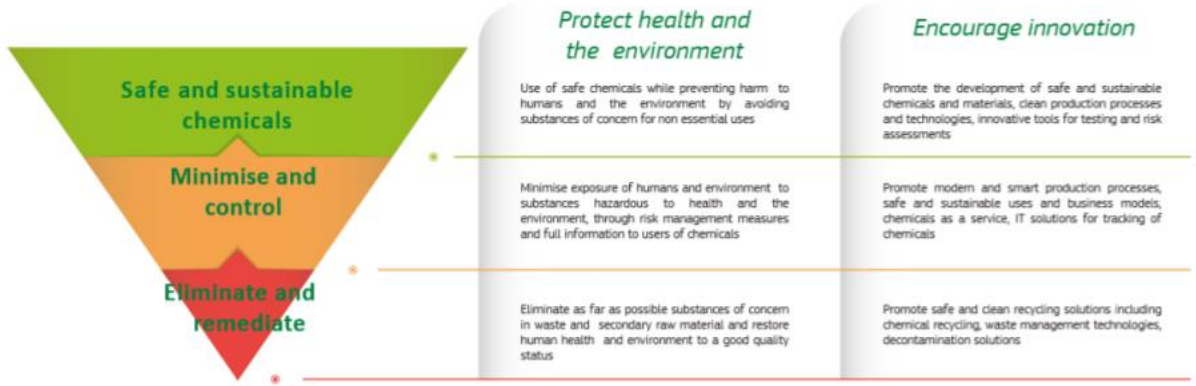
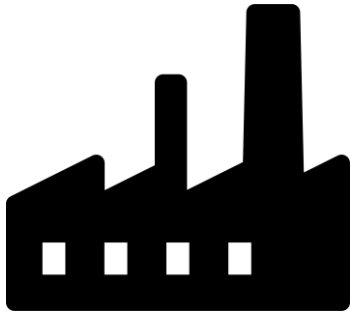


Figure: The toxic-free hierarchy – a new hierarchy in chemicals management

What is a PMT/vPvM substance

Persistent and Mobile



Chemical Synthesis

Transport through the environment or infrastructure

Water treatment and production

Consumption

Uses / Products

Toxic

PMT/vPvM hazard classes in the CLP regulation

EUROPEAN COMMISSION

Brussels, 19.12.2022

COM(2022) 748 final

2022/0432(COD)

Proposal for a

REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

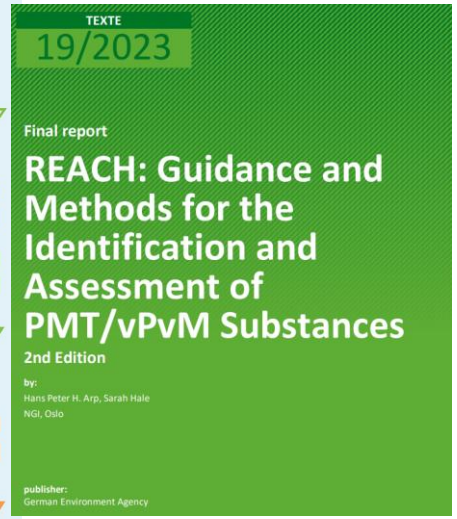
amending Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures

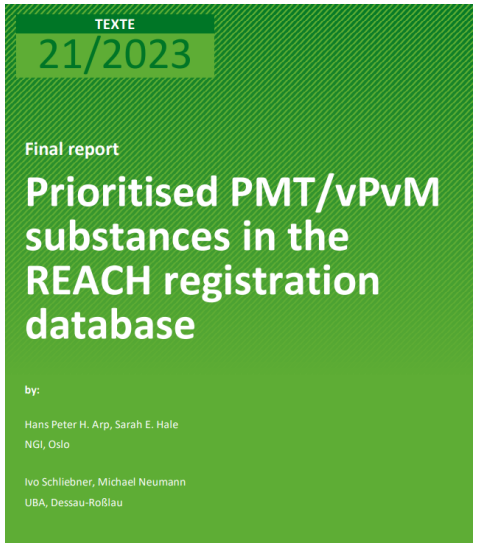
..added definitions and scientific and technical criteria to enable substances and mixtures that have endocrine disrupting ('ED'), persistent, bioaccumulative and toxic ('PBT'), very persistent and very bioaccumulative ('vPvB'), ***persistent, mobile and toxic ('PMT'), or very persistent and very mobile ('vPvM') properties to be classified into established hazard classes***.

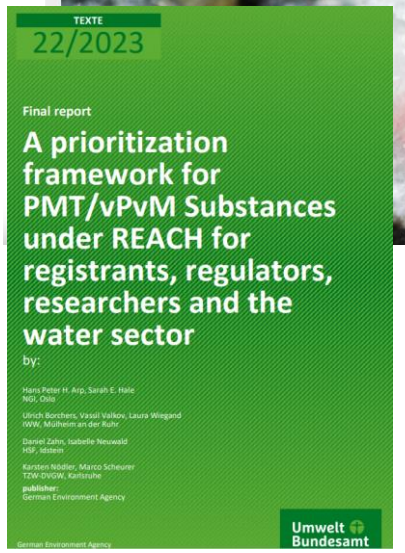
... European Chemical Manufactures now need to do PBT/vPvB and PMT/vPvB substance evaluation/labelling to bring them on the European market.

Four new UBA reports on PMT/vPvM substances

- Published Sept 05, 2023
- Lists of PMT/vPvM substances detected and registered under REACH
- Strategies for prioritization







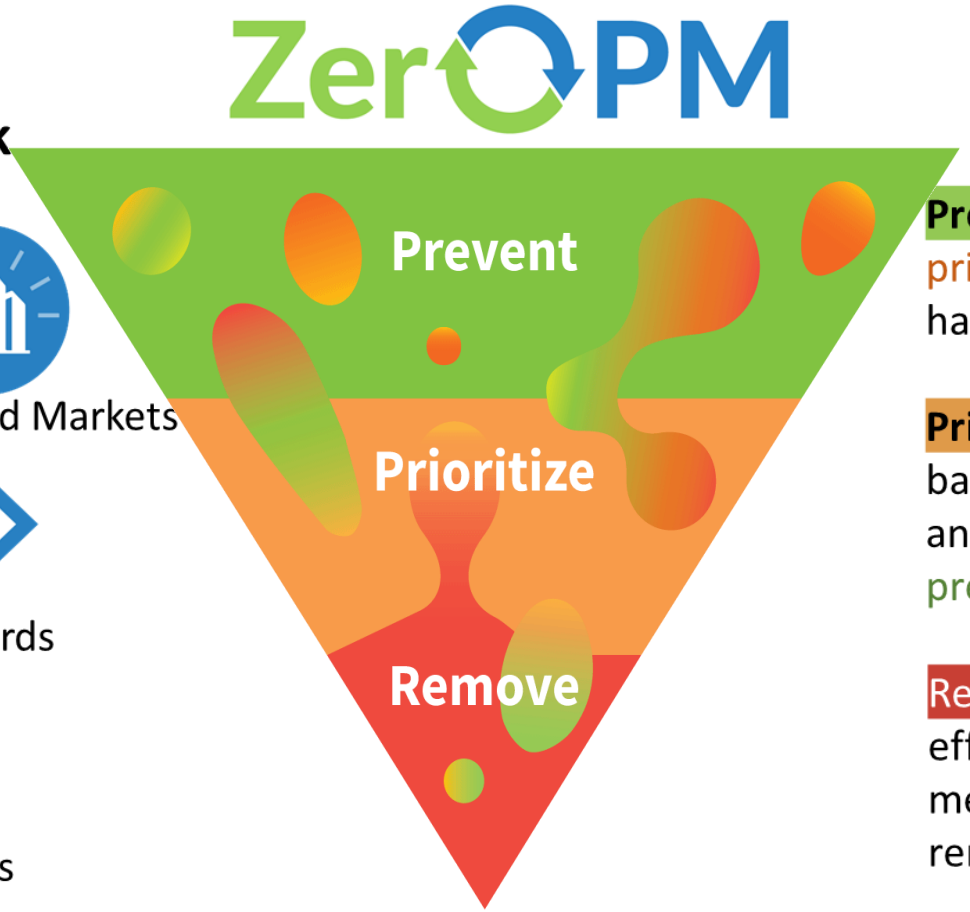
ZeroPM's concept

Multilevel framework

Chemical Technology, Policy and Markets

Water Exposure and Hazards

Remediation and Impacts



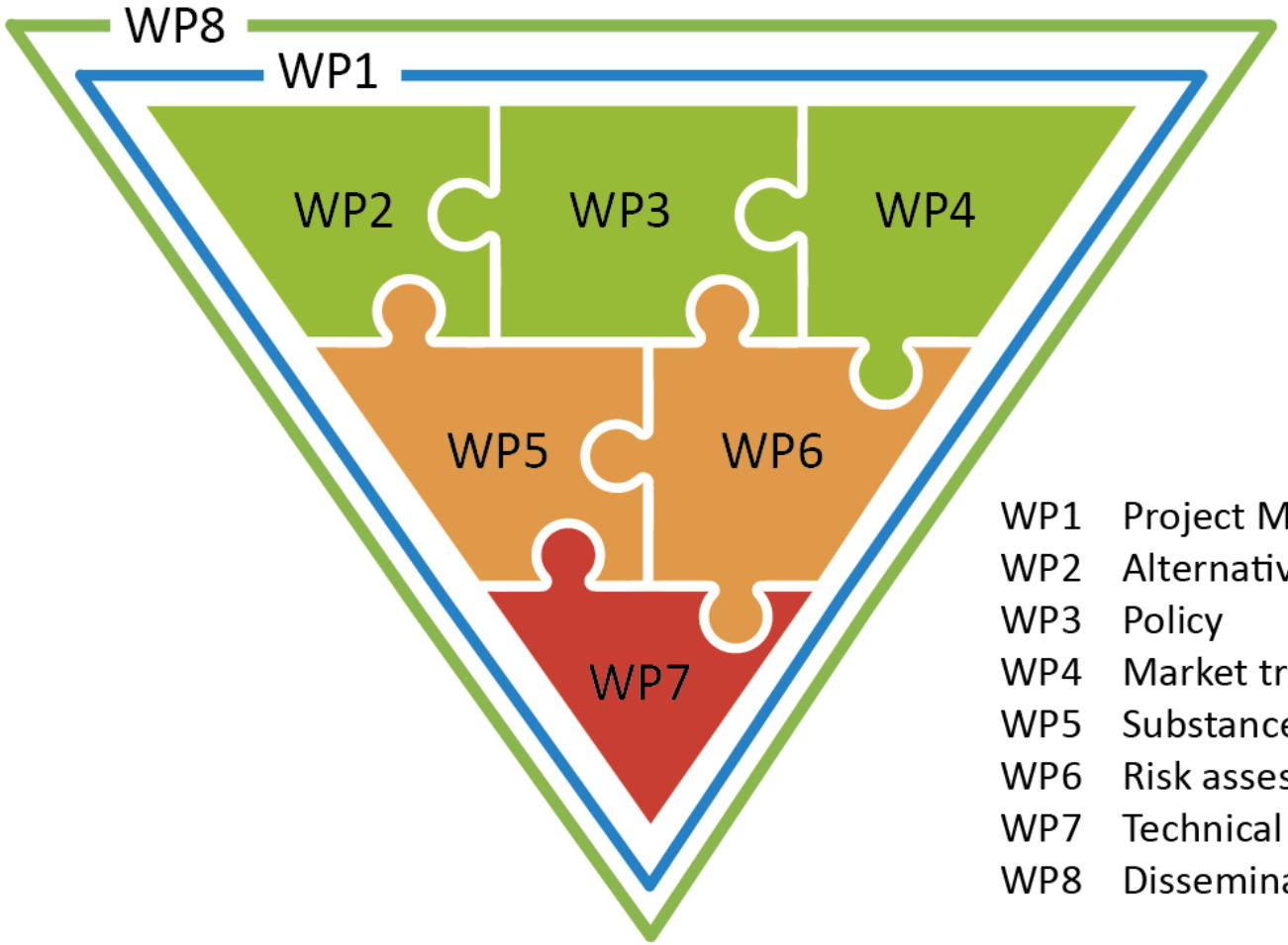
Interlinked Strategy

Preventing regrettable substitution for prioritized PM substances, by assessing hazards, sustainability, exposure and removal.

Prioritizing PM substances and groups based on intrinsic properties, exposure, and hazard to select those substances to prevent and remove most urgently

Removing prioritized PM substances via effective, sustainable and safe remediation methods, that prevent unfocused remediation effort

ZeroPM's work packages



WP1	Project Management
WP2	Alternatives Assessment
WP3	Policy
WP4	Market transition
WP5	Substance grouping
WP6	Risk assessment
WP7	Technical solutions
WP8	Dissemination & Communication

WP2 Alternatives Asessment

Lead: Ian Cousins,
Stockholm University

Objective: to provide **safer chemical alternatives to non-essential uses** of PM substances

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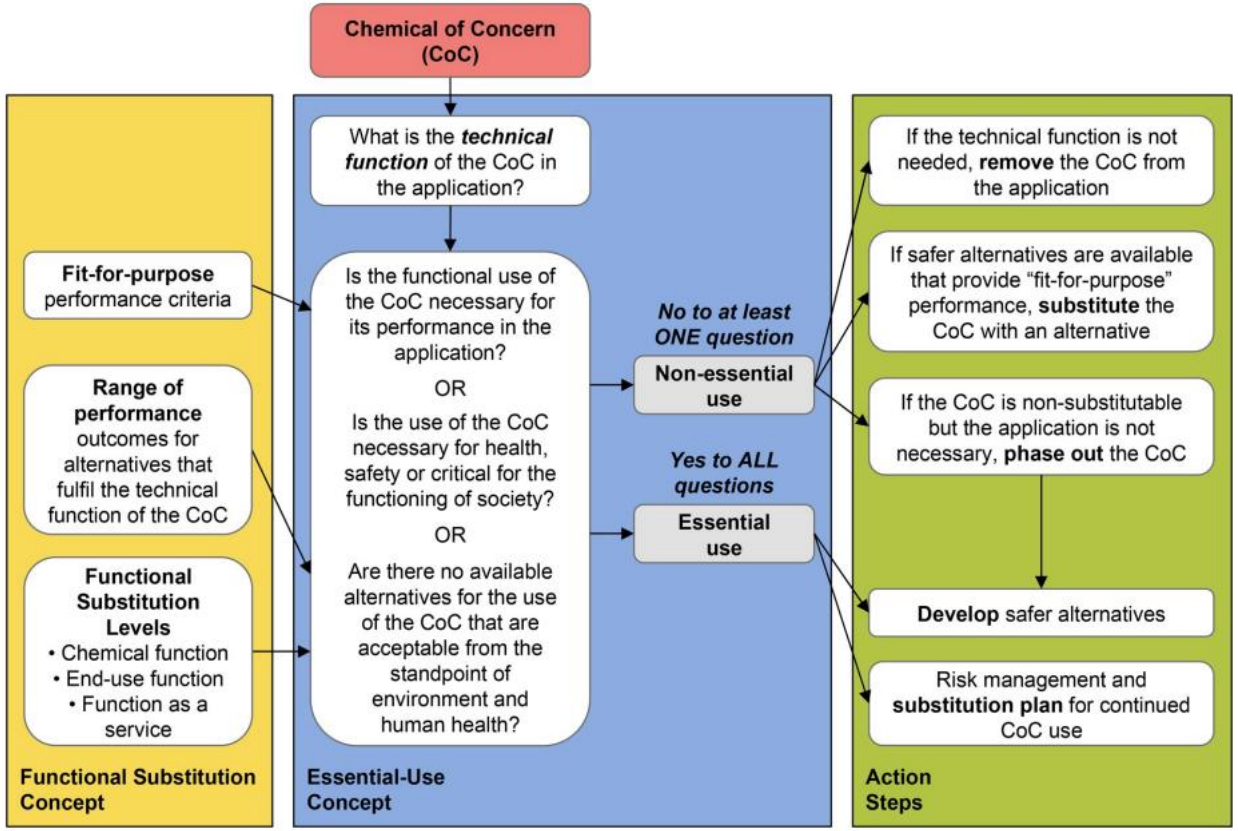
WP2

The combination of the essential-use and functional substitution concepts



Source: Roy et al. (2022)

Environmental Science & Technology
pubs.acs.org/est
Viewpoint

Combined Application of the Essential-Use and Functional Substitution Concepts: Accelerating Safer Alternatives

Monika A. Roy, Ian Cousins, Elizabeth Harriman, Martin Scheringer, Joel A. Tickner,* and Zhanyun Wang

Assess:

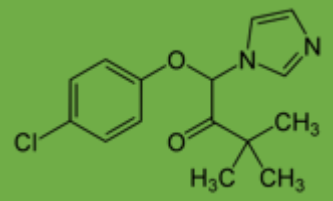
1) Technical function necessary for performance?
2) Safer alternatives available?
3) Necessary for health, safety or critical functioning of society?

WP2

Definition of the technical function for cosmetic products

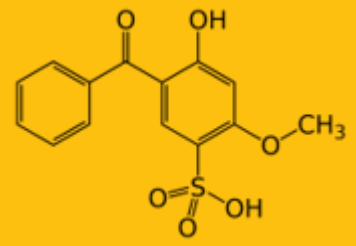
CLIMBAZOLE

CAS Number: 38083-17-9
Technical function: Preservative and anti-seborrheic agent
Type of products: Shampoos (as anti-dandruff agent)



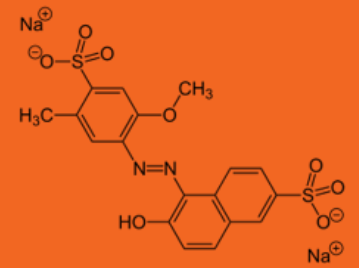
BENZOPHENONE-4

CAS Number: 4065-45-6
Technical function: UV filter and UV absorber
Type of products: All types of cosmetic products



ALLURA RED

CAS Number: 25956-17-6
Technical function: Pigment
Type of products: All types of cosmetic products



Van Dijk, J. et al, Managing PMT/vPvM substances in consumer products through the concepts of essential-use and functional substitution: a case-study for cosmetics, Environ. Sci.: Processes Impacts, 2023

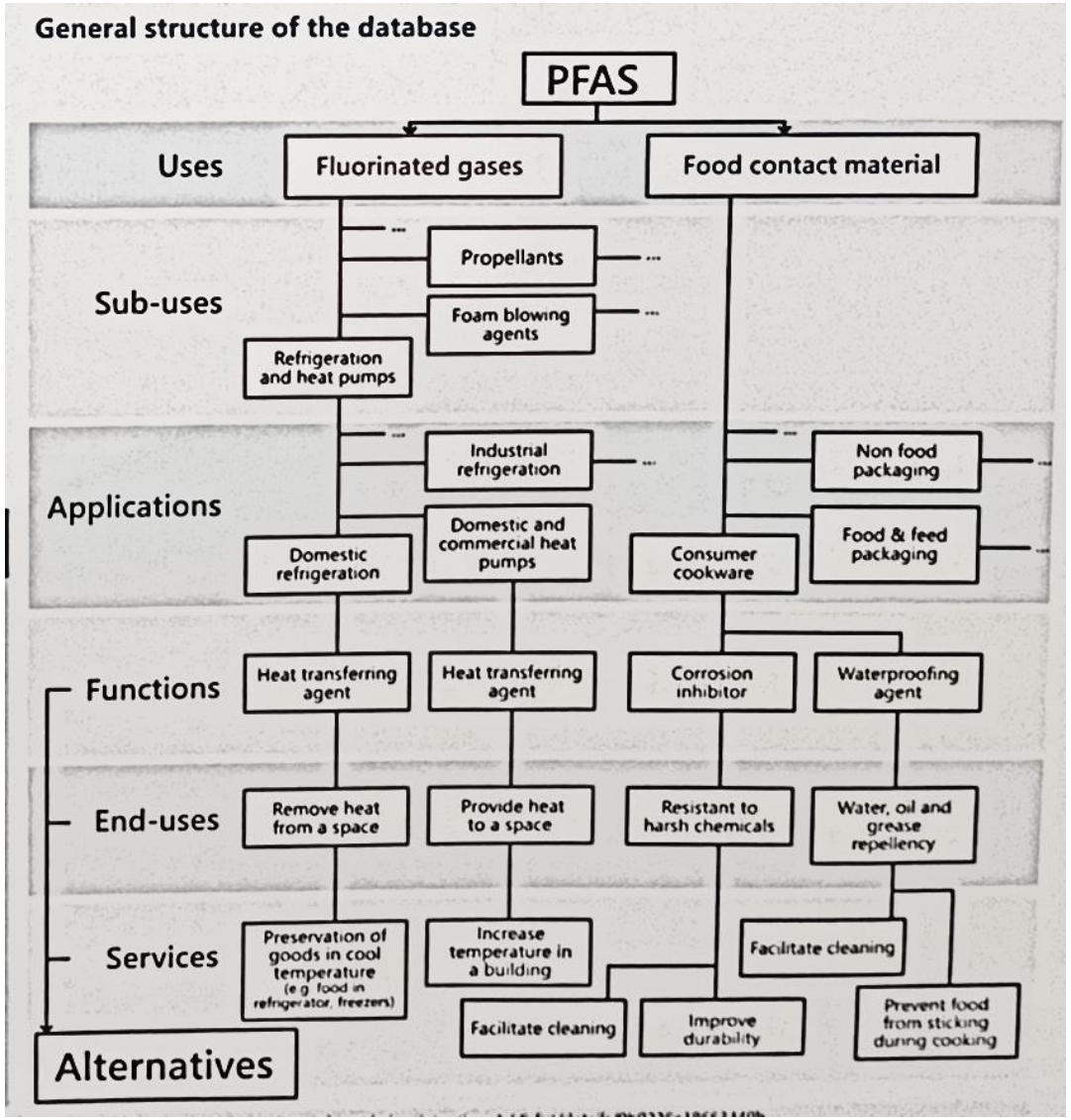
WP2

Comparison of the alternatives

- Comparison of alternatives with Multicriteria Decision Analysis (MCDA) methods based on hazard profile
  - Heat map
  - MAUT
  - ELECTRE III
- ***Safer alternatives available for all case study***

Use case	Chemical name	Ranking		
		Heatmap	MAUT	ELECTREIII
Pigment	**Allura red**	**3**	**4**	**3**
	Malvidin chloride	6	2	2
	Beetroot red	**1**	**1**	**1**
	Pigment red 51	3	5	5
	Pigment red 68	2	6	3
	Acid red 180	**7**	**7**	**7**
	Pigment red 122	5	3	5
UV- filter	**Benzophenone-4**	**2**	**4**	**3**
	Ensulizole	**1**	**1**	**1**
	Benzylidene camphor sulfonic acid	**5**	**5**	**7**
	Bisdisulizole disodium	2	3	5
	Bemotrizinol	4	2	2
	Bornelone	7	6	5
	Phenylemenis-diphenyltriazine	6	7	3
Anti-seborrheic	**Climbazole**	**6**	**6**	**5**
	Octanoic acid	**3**	**2**	**1**
	Caprylylglycine	**2**	**3**	**2**
	Shikimic acid	**1**	**1**	**4**
	Ciclopirox olamine	**4**	**4**	**2**
	Hexamidine diisethionate	5	5	6

Alternative Assesment Database to PFAS



Considers Food contact materials/packaging

Fluorinated gases

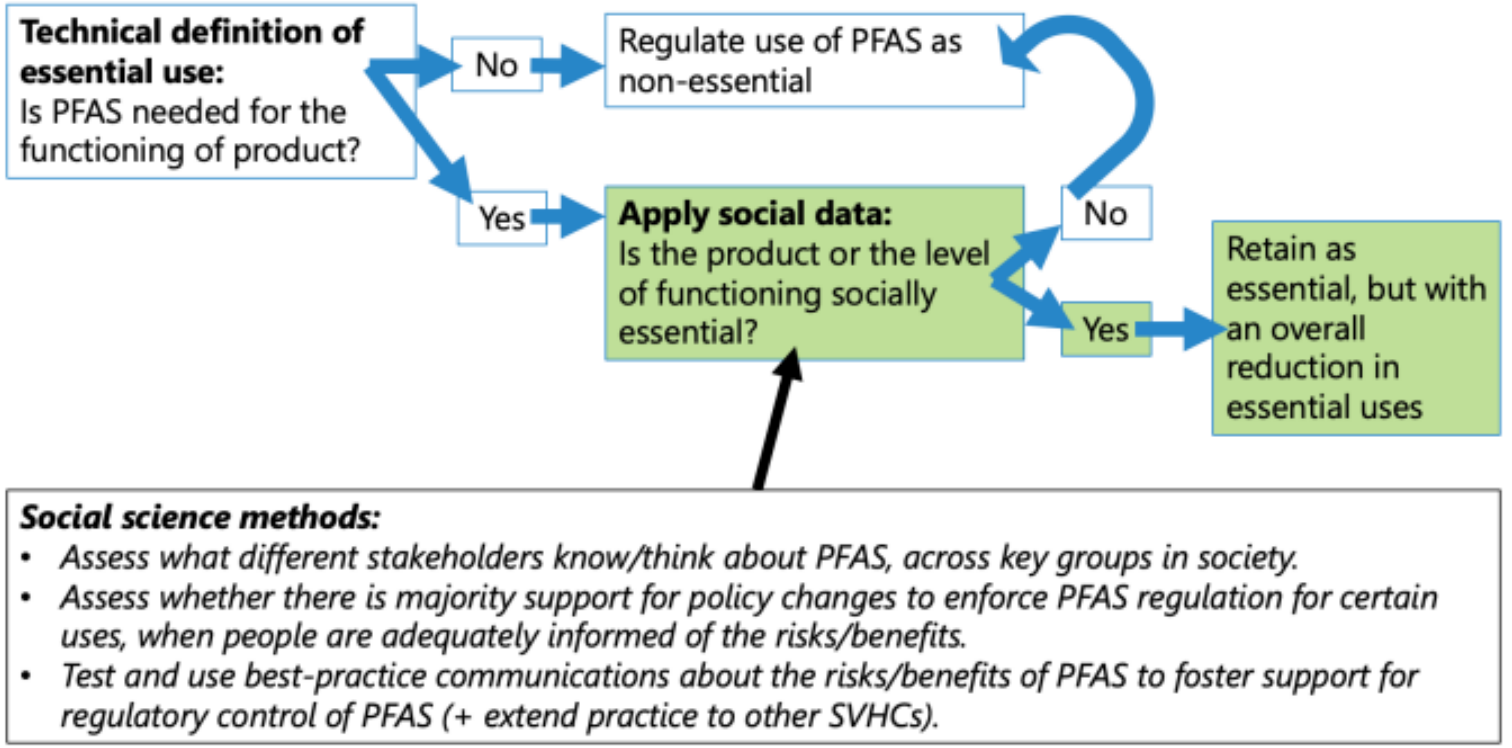
Will be submitted to ECHA for the Sept. 25 restriction proposal

Coming soon to zeropm.eu!

WP2

Considering Social Perceptions

- An extra layer of essentiality beyond technical function
- Relevant for assessing diverse stakeholder perspectives (industry, general public, policy)



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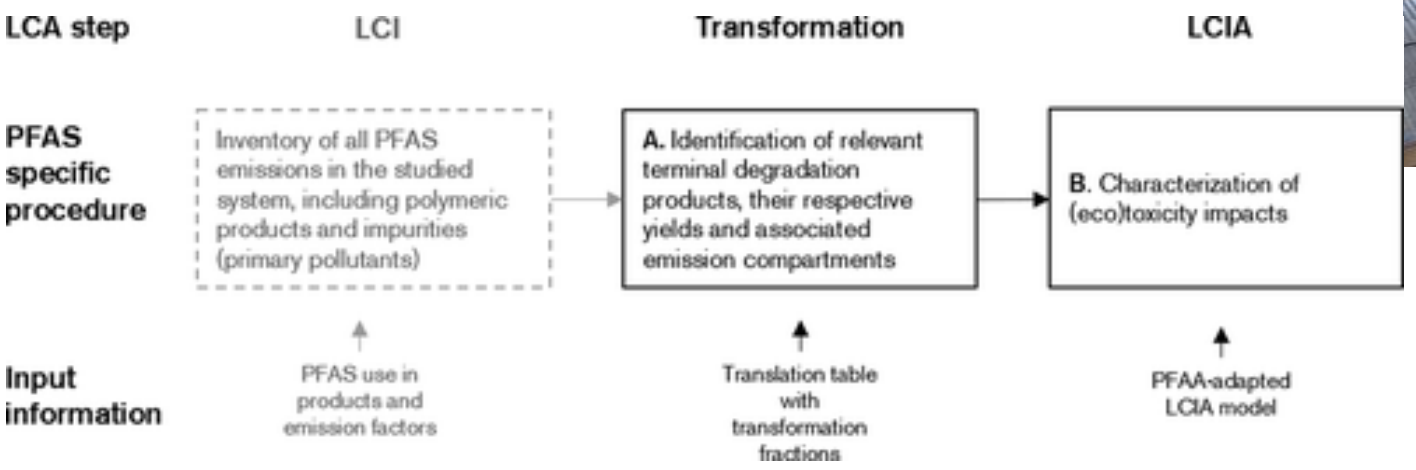
WP2

Overall Sustainability Considerations

- Consider life cycle impact analysis with alternatives assessment
- Also consider technology and impacts of water removal technology



Holmquist et al. Environ. Sci. Technol. 2020, 54, 10, 6224-6234

Energy intensive reverse osmosis facility to eliminate PFAS at the Rastatt test site to make drinking water potable

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WP2

WP3 Policy

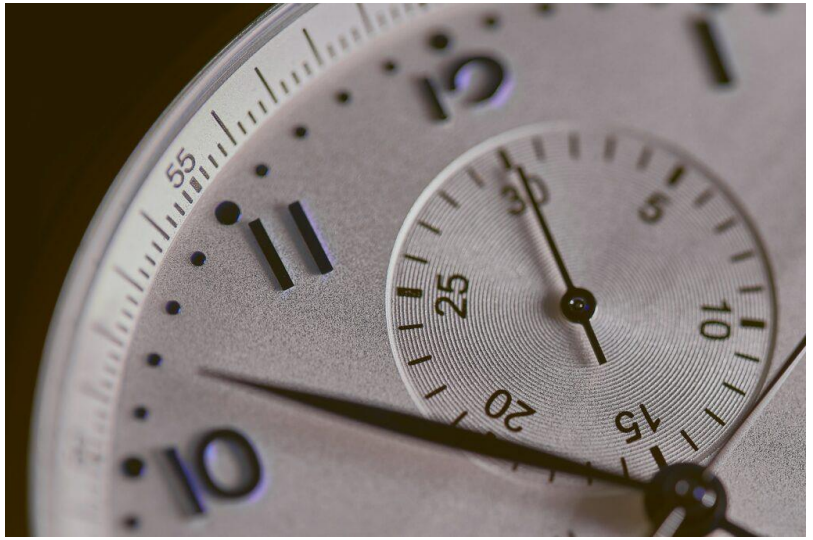
Lead: Lise Oules
Milieu Law and Policy Consulting

Objective: to stimulate and support policy changes to more effectively tackle PM substances.

WP3

Examples of Policy Action

- ZeroPM Regulatory Watch
- policy actions tailored to groups of PM/PFAS substances, uses or sectors facilitating a transition towards zero pollution from PM substances
- Design roadmaps for groups of PM substances, uses or sectors
- To promote implementation of PM substance assessment into EU legislation engaging all relevant stakeholders



https://zeropm.eu/regulatory-watch/

- Biodiversity Strategy (COM(2020) 380 final)
- Chemicals Strategy for Sustainability (COM(2020) 667 final)
- Circular Economy Action Plan (COM(2020) 98 final)
- European Green Deal (COM/2019/640 final)
- Europe's Beating Cancer Plan (COM(2021) 44 final)
- Farm to Fork Strategy (COM(2020) 381 final)
- Industrial Strategy for Europe (COM(2020) 102 final and COM(2021) 350 final)
- Pharmaceutical Strategy (COM(2020) 761 final)
- Renovation Wave for Europe (COM(2020) 662 final)
- Soil Strategy for 2030 (COM(2021) 699 final)
- Strategy for Plastics in a Circular Economy (COM(2018) 28 final)
- Sustainable Blue Economy Strategy (COM(2021) 240 final)
- Sustainable and Circular Textiles Strategy (COM(2022) 141 final)
- Zero Pollution Action Plan (COM/2021/400 final) and SWD 'Towards a monitoring and outlook framework for the zero pollution ambition' (SWD(2021) 141 final)

WP4 Market Transition

Lead: Anna Lennquist
ChemSec

Objective: to ***catalyse a market transition away from harmful PM substances***.

chemsec
INTERNATIONAL CHEMICAL SECRETARIAT

WP4

ChemSec PFAS movement and business group

PFAS Movement

- Coorperations who pledged to transition away from PFAS

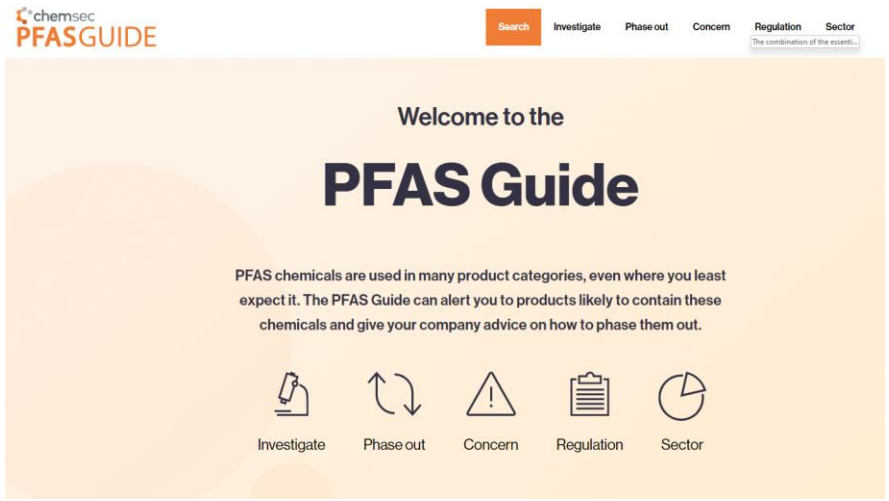
ChemSec business group

- Regular discussions about transitioning to safer chemicals

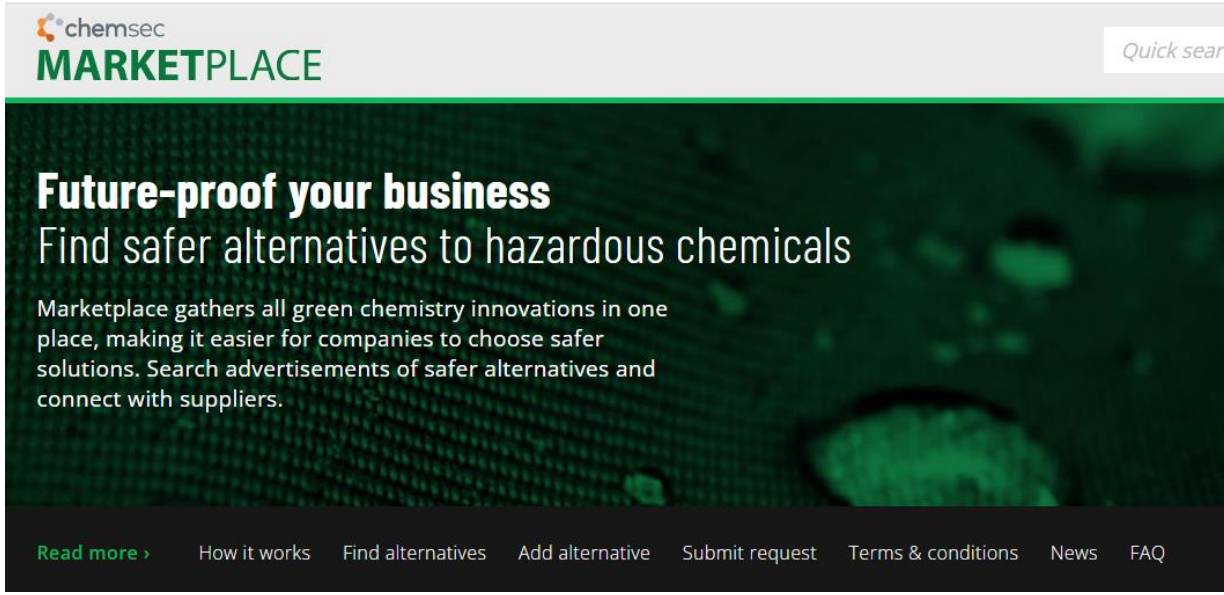
adidas
Boots
coop
DELL
EurEau
H&M Group
IKEA
KINGFISHER
LEGO
Shaw
SKANSKA
SONY

WP4

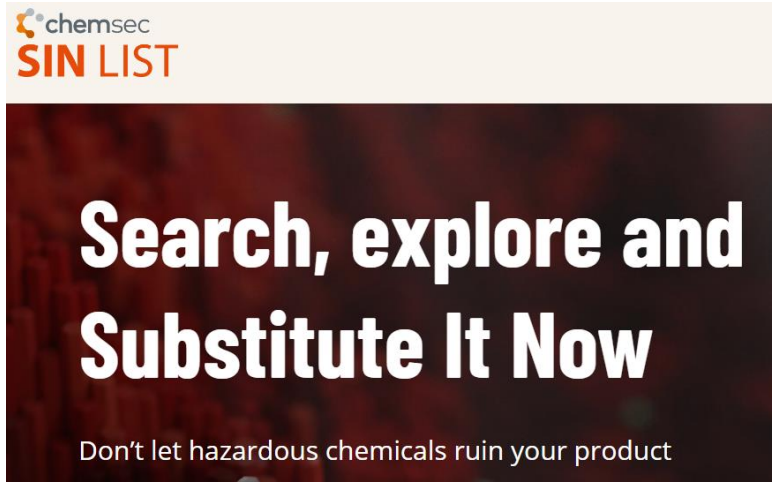
Tools developed for Market Transition



https://pfas.chemsec.org/



https://marketplace.chemsec.org/



SIN List helps you identify the most relevant PFAS and other hazardous substances to start substituting (before regulators make you)

https://sinlist.chemsec.org/

WP4

WP5 Substance Grouping

Lead: Hans Peter Arp
NGI

Objective: ***To prioritize PM substances and substance groups on the global chemical market for prevention and removal***

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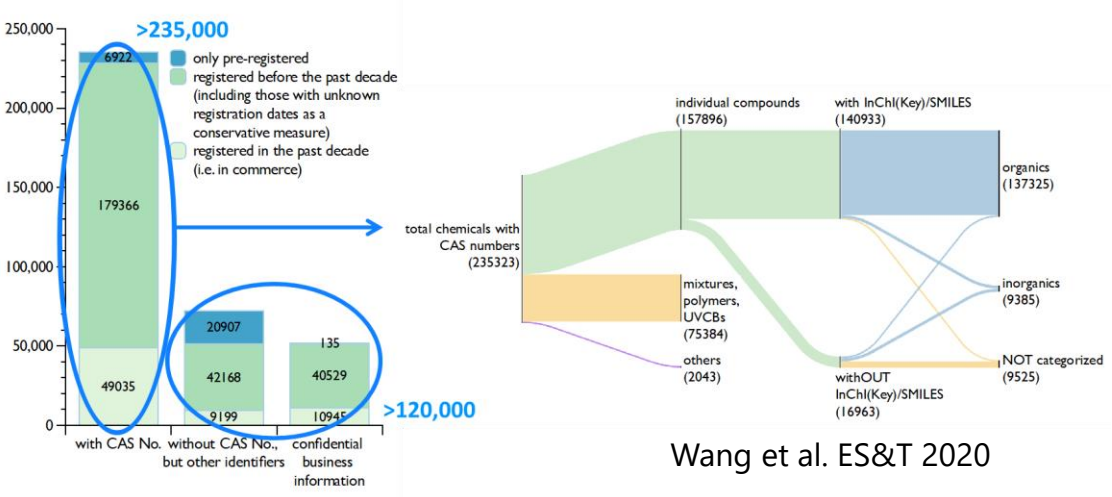
Materials Science and Technology

WP5

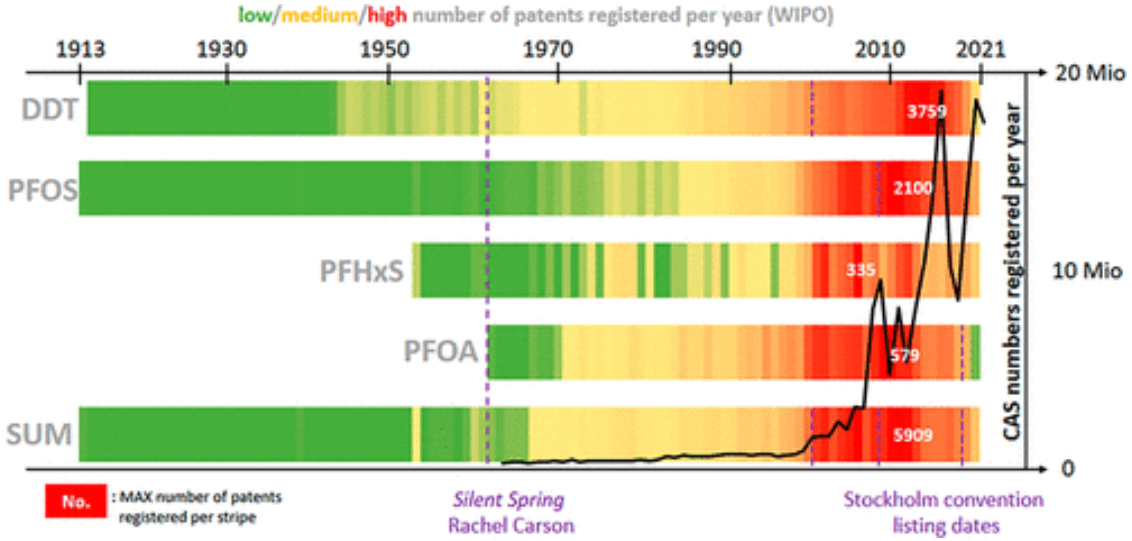
Cheminfomatics at the core

- **Global Chemical Inventory –**
  database all chemicals registered for production/import on the globe for prioritization based on persistence and mobility (beta version)

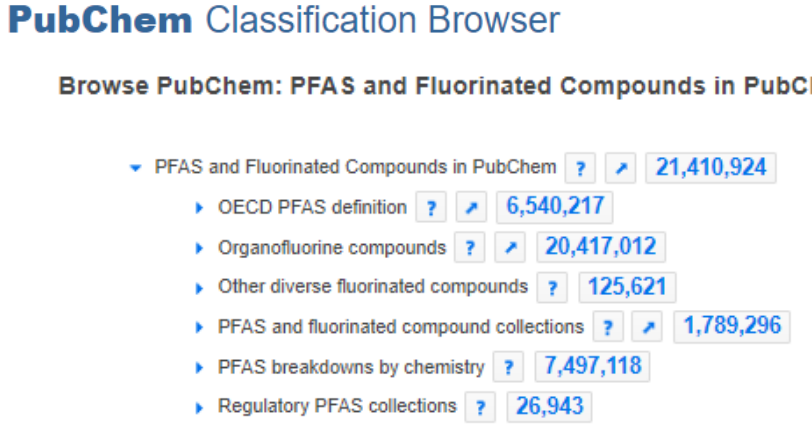


Wang et al. ES&T 2020

Chemical Stripes to visualize trends

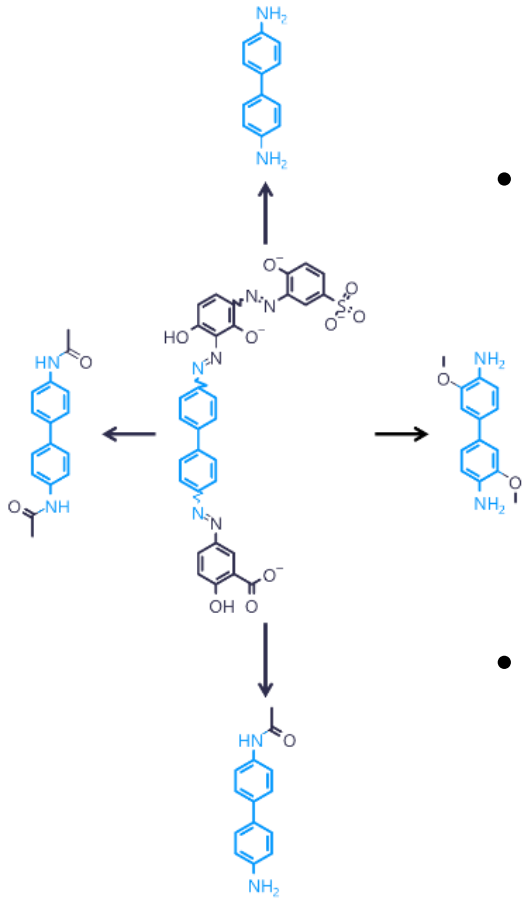


- **PFAS Tree to navigate PFAS on Pubchem** (>7 million!)
  https://pubchem.ncbi.nlm.nih.gov/classification/#hid=120

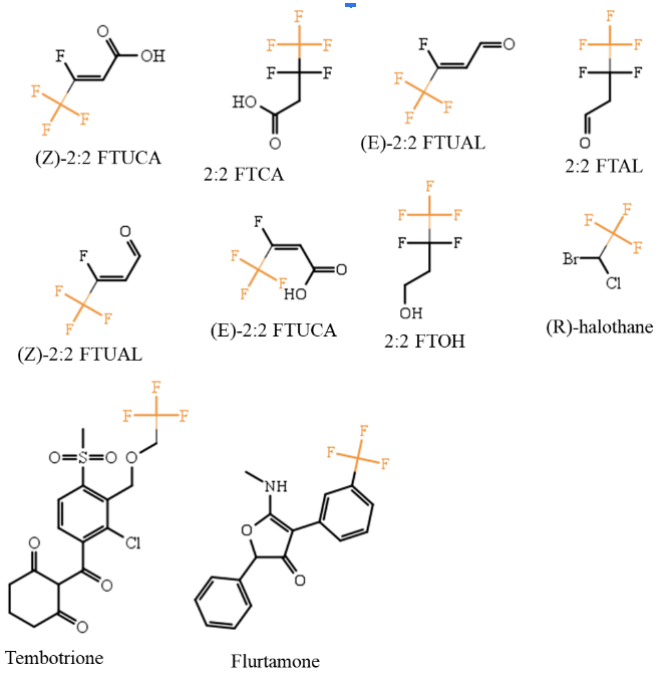


WP5

Substance grouping #1: Common transformation products (persistent moiety)



- **Transformation products** from photooxidation, hydrolysis and metabolism **more mobile** than parents
- **Methods:**
  - Literature transformation pathways
  - BioTransformer (predicts metabolites through rule-based and machine learning models)
  - EnviPath (machine learning models)
- Use cheminformatics to identify **common, preserved moieities** (e.g. common end products)

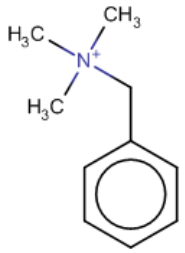


E.g.: «TFA precursor group» precursors of the vPvM substances Trifluoroacetic acid (TFA)

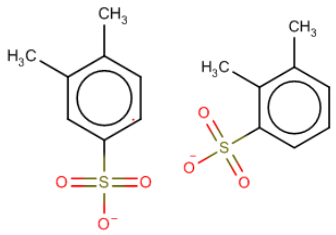
WP5

Substance grouping strategy 2: look for common moeities of persistent and mobile substances

Benzyltrimethyl ammonium

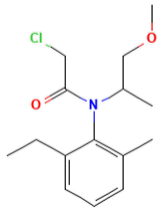


Dimethylbenzene sulfonic acid 0.01-1 µg/L

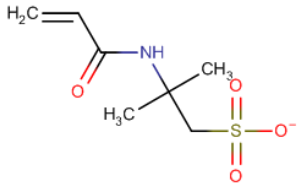


Trifluoromethane-sulfonic acid Up to 3 µg/L

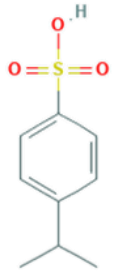
metaolachlor Up to 0.5 µg/L



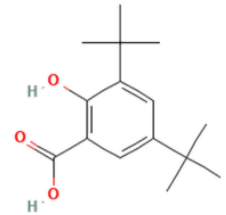
2-Acrylamido-2-methylpropane sulfonic acid 10-1000 µg/L



p-Cumenesulfonate

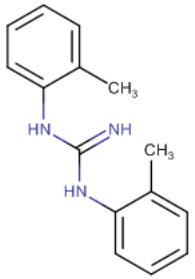


3,5-Di-tert-butylsalicyliate 0.1 – 1 µg/L

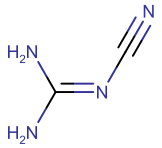


Diazabicyclooctane 0.01 – 1 µg/L

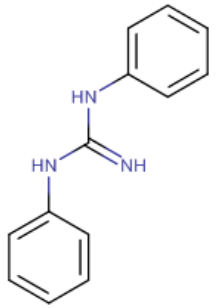
1,3-Di-*o*-tolylguanidine



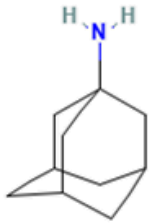
Cyanoguanidine 0.1 – 10 µg/L



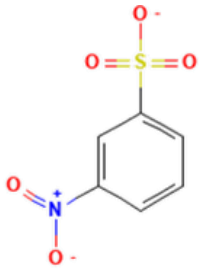
1,3-Diphenyl guanidine



Adamantan-1-amine Up to 0.01 µg/L

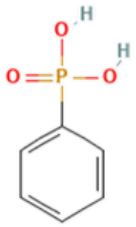


3-Nitrobenzene sulfonate Up to 10 µg/L



2,5-dichloro-benzenesulfonic acid Up to 100 ng/L

Phenyl phosphonic acid Up to 0.05 ng/L



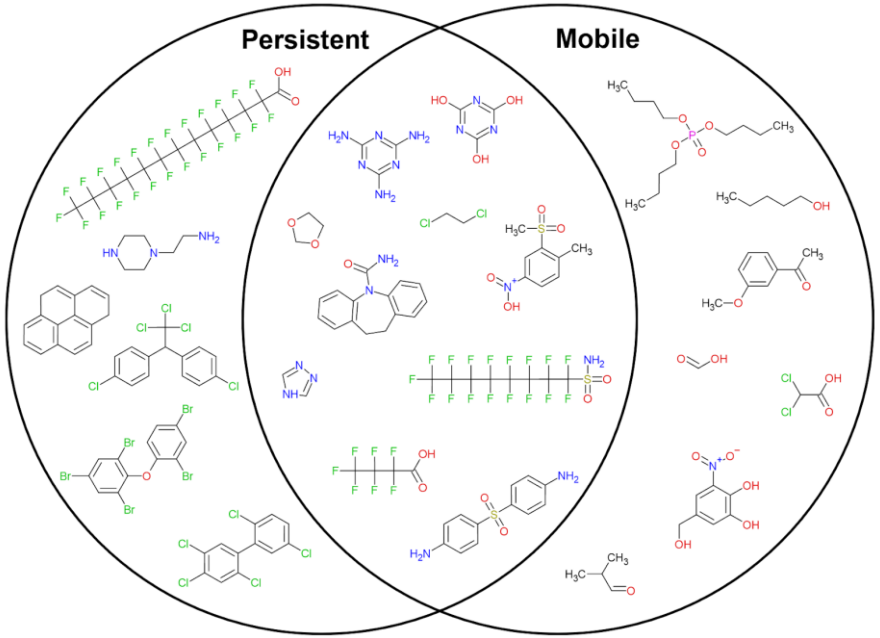
Triisopropanolamine borate Up to 40 ng/L

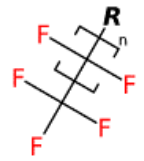
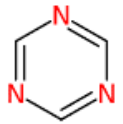
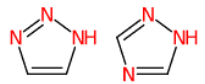
-Strong bonds (C-F, C-Cl, cyclic, highly branched)
-ionic or highly polar
-small in size

Neuwald et al. ES&T 2022
Kiefer et al. Water research 196 (2021) 116994
Schulze et al. Water research 153 (2019): 80-90.
Neuwald et al. Water Research 204 (2021) 117645

WP5

Prioritizing PM substance groups



PREVENT (WPs 2, 3, 4)	PRIORITIZE (WPs 2, 5 6, 7)			REMOVE (WPs 5, 6, 7)
Stakeholders concerns	**PM substance group - *based on substructure***		**Hazards Indicated**	**Removal is difficult**
Phase 1 (Months 1 – 30) Pre-selected PM substance groups				
Substances: mobile PFAA (PFBS, TFA); - cyclic PFAS (PFECHS); - small perfluoroethers (GenX) *Uses*: fluoropolymer processing aids, emulsifiers, flame retardants, others[39 A]	**PFAS**	 small PFAS, n=0-7	- PFBS and GenX recently categorized as SVHC under REACH - many known and unknown PFAS with unknown hazards	Monitored in test site areas (Figure 1.3) and drinking water globally[40] Removal requires expensive treatment like reverse osmosis or next generation technologies.
Substances: melamine, cyromazine, cyanuric acid *Uses:* melamine resins, biocides	**Triazines**	 s-Triazines	- Triazines interact to form nephrotoxic complexes. - Melamine STOTRE2 classification - found in banned herbicides, like atrazine	Monitored in pan-European and American water surveys[41,42] Permeable to most water remediation technology (e.g. activated carbon filtration).
Substances: benzo-1,2,3-triazoles, 1,2,4-triazoles *Uses:* anticorrosive agents, fungicides	**Triazoles**	 1,2,3- & 1,2,4-Triazoles	- Chronic effect concentrations (aquatic species) reported in low µg/L - alternatives available with unknown hazards	Benzo-1,2,3-triazoles monitored in surface water, sludges and drinking water globally;[43] 1,2,4-triazoles appearing more frequently in surveys[44] Water treatment methods are ineffective.[43,44]
Phase 2 (Month 30-60) Alternatives to Phase 1 groups and new PM substance groups				
Proposed safer and sustainable alternatives to pre-selected substances	Production, use, PM assessment and monitoring database investigated for finding alternatives or further grouping of additional priority PM substances.		Hazard and sustainability assessed for substances and by-products from water treatment or environmental transformation	Exposure modelled, and remediation technology performance assessed to indicate suitability as alternatives or PM substance grouping.
Extended list of Priority PM Substances and Substance Groups and their Alternatives				

WP6 Risk Assessment

Lead: Timo Hamers
VU Amsterdam

Objective: To characterise and quantify impacts of PM substances on human health and the environment

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TG ENVIRONMENTAL RESEARCH

Fraunhofer ITEM

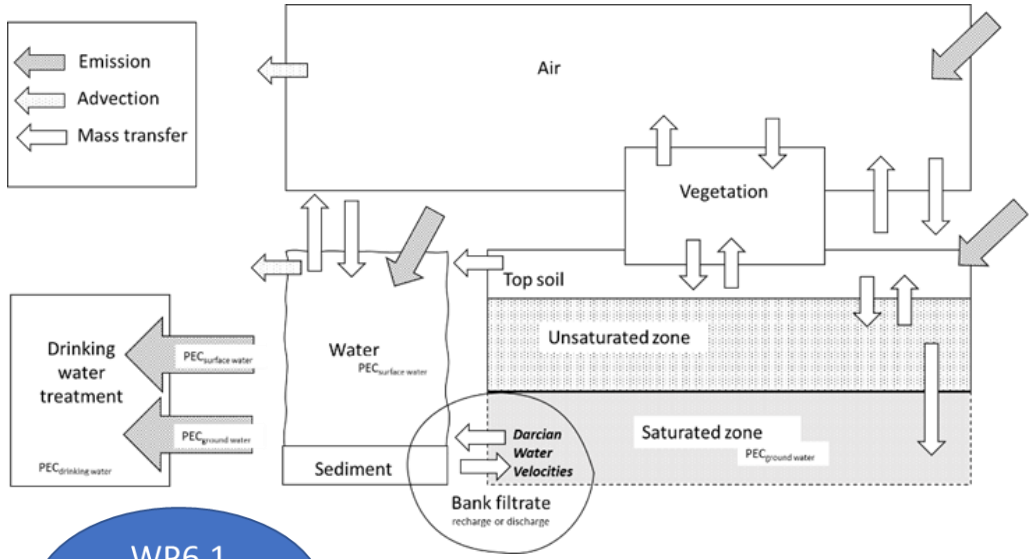
DVGW TZW Technologiezentrum Wasser

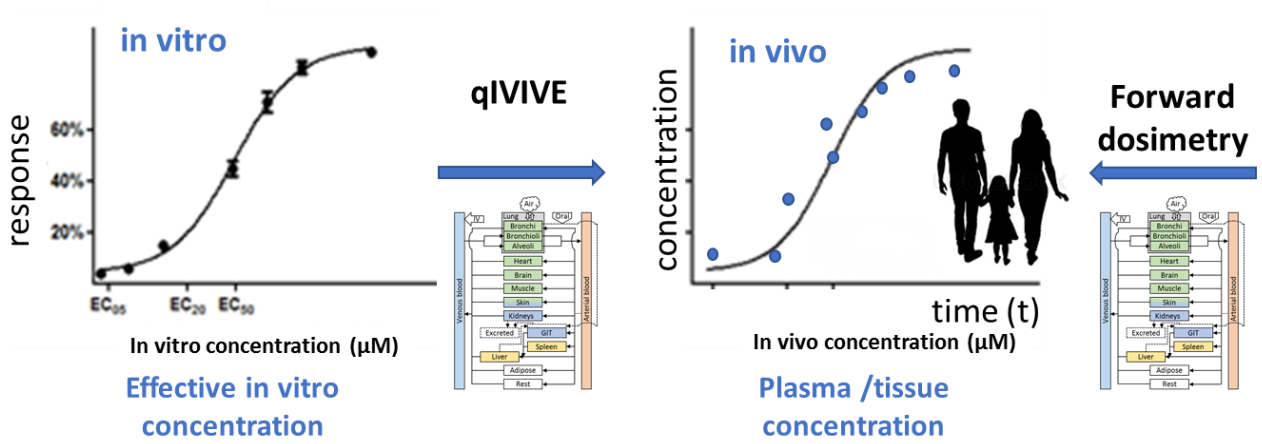
NGI

WP6

External and Internal Exposure

- multi pathway exposure models
- pharmacokinetic (PBPK) models



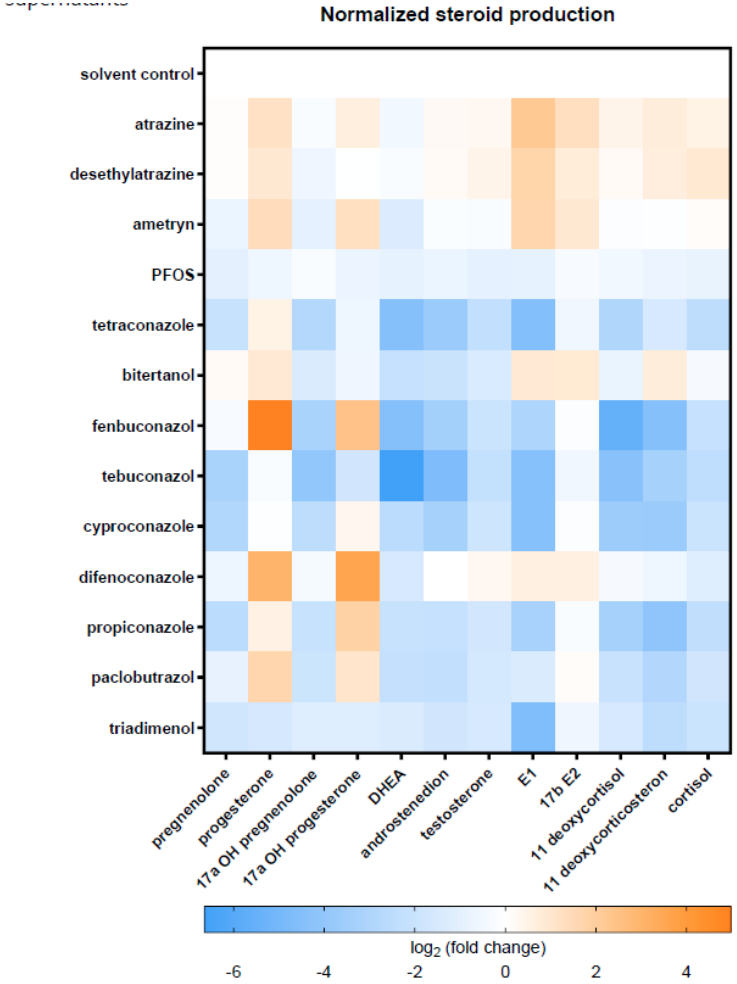


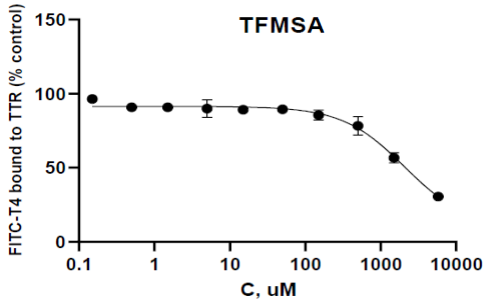
TG ENVIRONMENTAL RESEARCH

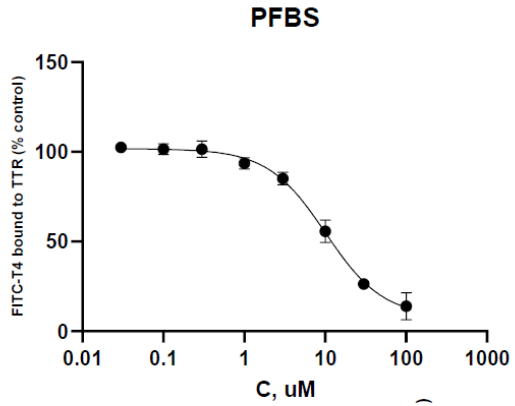
Fraunhofer ITEM

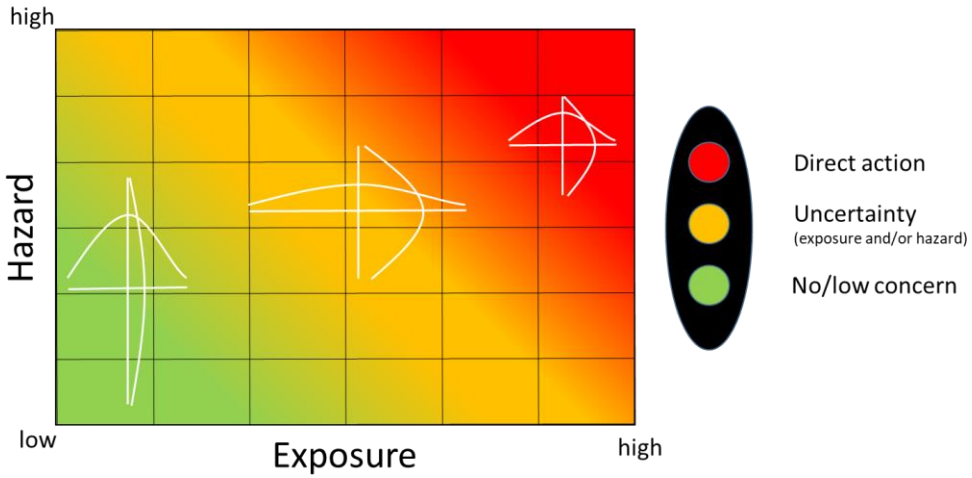
WP6

Hazard assessment toolbox and risk matrix







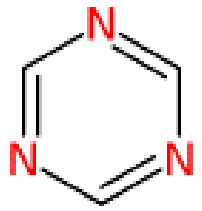


WP6

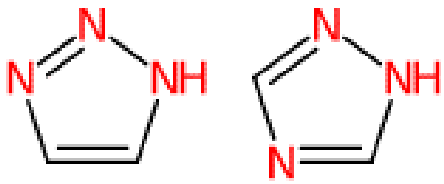
Prioritization of triazines and triazoles as groups

Triazines and Triazoles can be recognized as persistent and mobile by both methods:

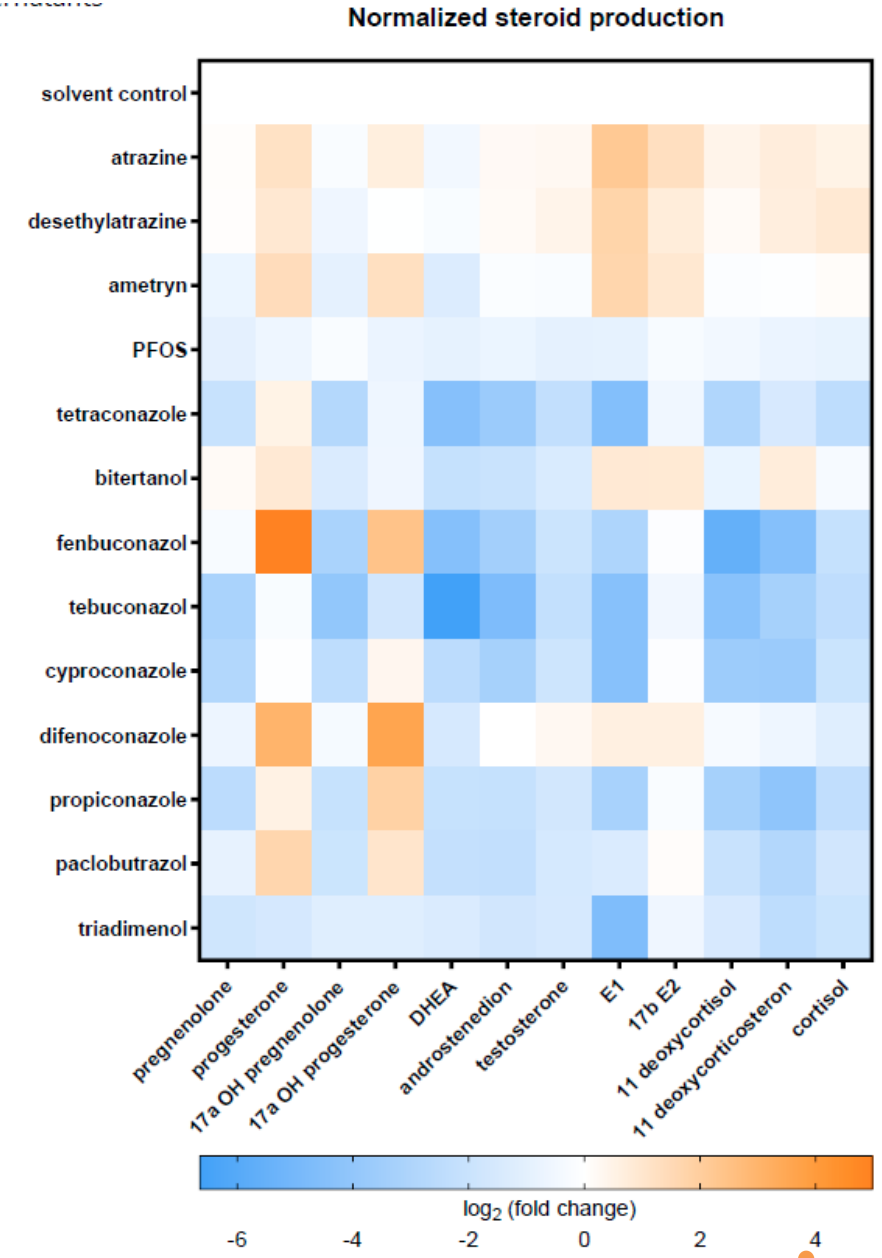
- Stable triazine end product – melamine (STOTRE 2)
- Tetraconazole, Bitertanol, Fenbuconazole & Tebuconazole metabolize to 1,2,4-triazole
- Melamine and 1,2,4-triazole found ubiquitously in water
- EDR effects of some triazines and commonly amongst triazoles



s-Triazines



1,2,3- & 1,2,4-Triazoles



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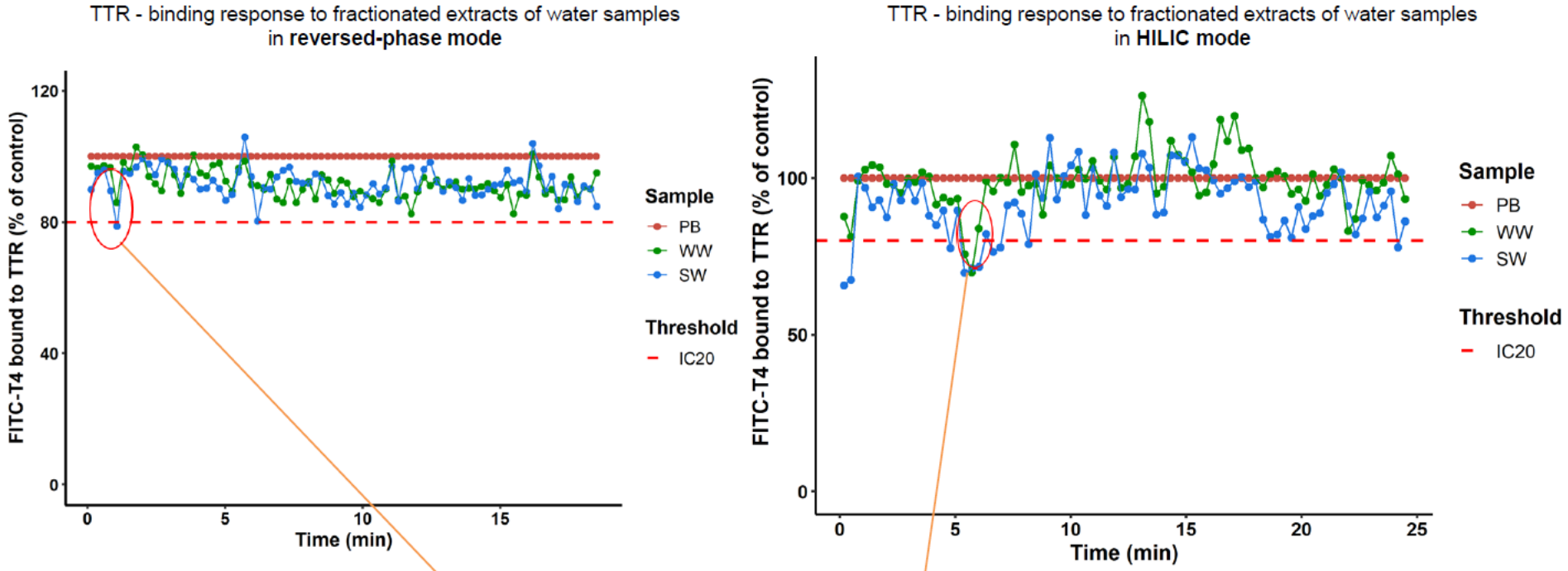
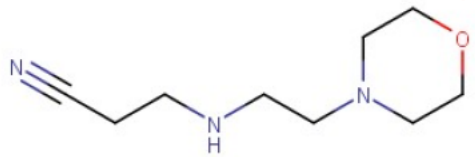
Maxim Carlier, VUA

WP6

Identify emerging PM substances using Effect Directed Analysis





3-[(2-morpholin-4-ylethyl)amino]propanenitrile

Only suspect

Timur Baygildiev, VUA

WP6

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WP7 Technical Solutions

Lead: Marcel Riegel
DVGW-TZW

Objective: to demonstrate how and if legacy and prioritized PM substance pollution can be remediated

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NIVA Norwegian Institute for Water Research

UNIVERSITY OF THE AEGEAN

CHALMERS UNIVERSITY OF TECHNOLOGY

WP7

Developing passive sampler for PFAS and PMT/vPvM monitoring

POCIS 

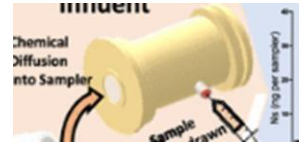
Sorbent sandwiched between two membranes (~ 40 cm^2)

MPT 

Sorbent enclosed in microporous PE tube (15 cm^2)

DGT 

Hydrogel/PES membrane & sorbent gel layer (3.14 cm^2)

G-TIP 

Sampling cell with small opening for sampling (~ 3 cm^2)

Testing for ultra-short chain and total PFAS

37181-39-8 & 1493-13-6	Perfluoromethanesulfonate (TFMeS)
108410-37-3 & 354-88-1	Perfluoroethanesulfonate (PFEtS)
110676-15-8 & 423-41-6	Perfluoropropanesulfonate (PFPrS)
45187-15-3	Perfluorobutanesulfonate (PFBS)
76-05-1	Trifluoroacetic acid (TFA)
422-64-0	Perfluoropropanoic acid (PFPrA)
375-22-4	Perfluorobutanoic acid (PFBA)

[EVOLUTE® EXPRESS ABN (biotage.com)]

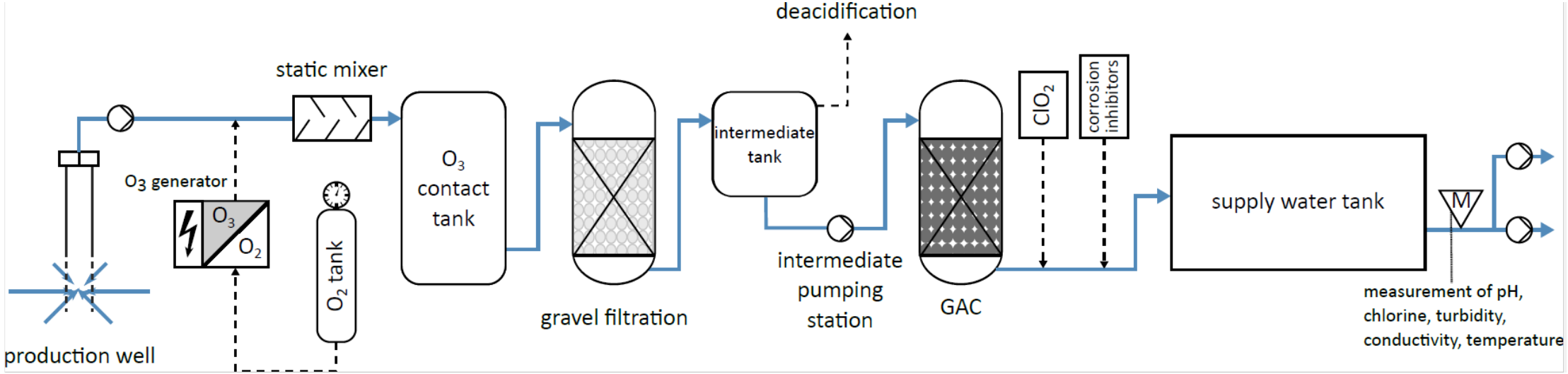
NIVA
Norwegian Institute for Water Research

Ian Allan, Emma Knight

WP7

Report coming soon!

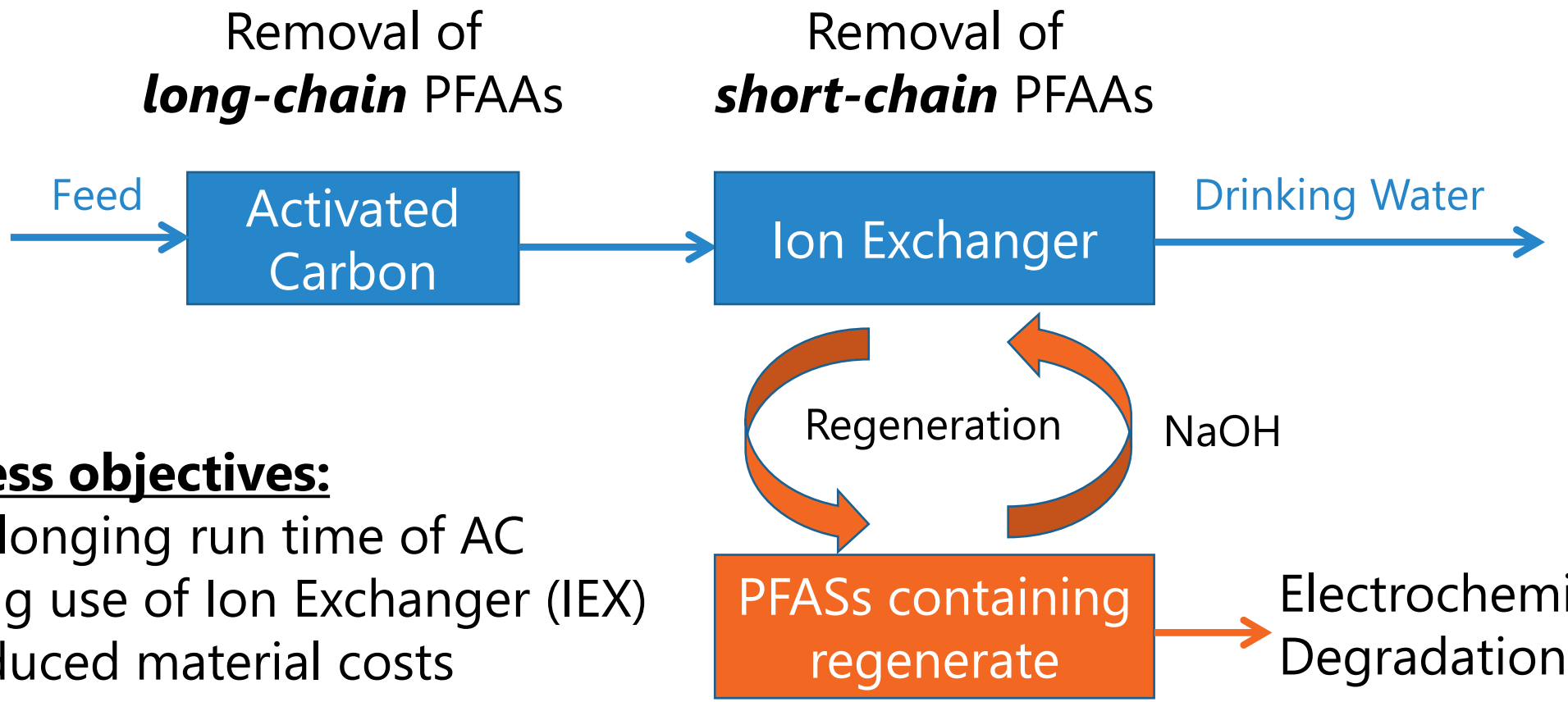
Pilot scale testing of water treatment solutions to PFAS and PMT substances



Rauental, Germany WTP

WP7

Coupled AC with regenerative ion-exchange and electrochemical degradation



Process objectives:

- Prolonging run time of AC
- Long use of Ion Exchanger (IEX)

→Reduced material costs

→Avoid toxic by-products

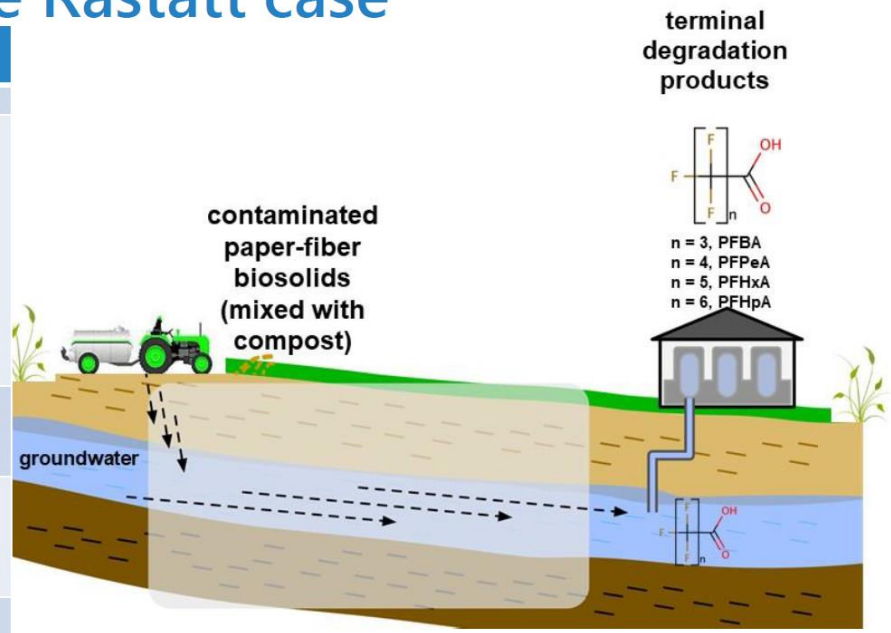
→Compare with ozonation, reverse osmosis, nanofiltration

WP7

Investigating soil sites

Test Site 1: The Rastatt case

Location	Rastatt/Baden-Baden, Southern Germany
Area	> 1000 ha
Media contaminated	Agricultural fields: soil, groundwater that is used for irrigation and drinking water production, agricultural plants, fish (fishing by anglers is forbidden in some lakes), human blood (residents show up significantly higher PFAS levels in blood.)
Pollutant	Short- and long-chain PFASs (as well as pesticides and their metabolites)
Source of pollution	Soil amendment with PFAS contaminated paper-fiber biosolids (mixed with compost) on agricultural land
Scale of problem	Local



Göckener *et al.*
Environmental Sciences Europe (2022) 34:52
https://doi.org/10.1186/s12302-022-00631-1

Environmental Sciences Europe

COMMENT Open Access

Digging deep—implementation, standardisation and interpretation of a total oxidisable precursor (TOP) assay within the regulatory context of per- and polyfluoroalkyl substances (PFASs) in soil

Bernd Göckener[1*], Frank Thomas Lange[2], Lukas Lesmeister[2], Emine Gökçe[3], Hans Ulrich Dahme[3], Nicole Bandow[4] and Annegret Biegel-Engler[4]

Abstract
Over the past decades, thousands of different per- and polyfluoroalkyl substances (PFASs) have been produced and

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- PFAS analytics of soils
  - Influence of drying and milling
  - TOP assay
  - Source of groundwater/drinkingwater

WP7

Sludge Treatment for PFAS/PMT removal using hydrothermal carbonization (HTC)

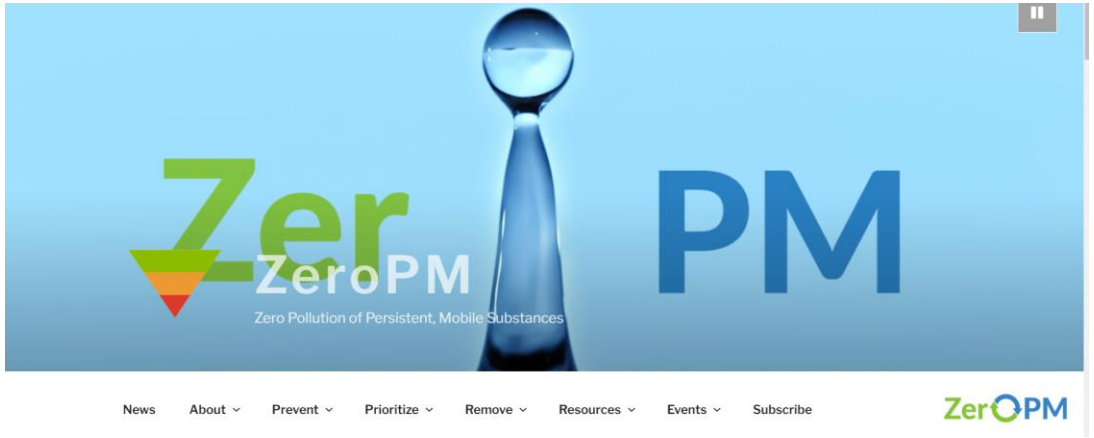
https://youtu.be/3zSUVvLuvNE?si=K4l8N6PdoByMws94

Developing a pilot hydrothermal carbonization plant in Mytilene Greece

WP7

WP8 Dissemination & Communication

Lead: Sarah Hale
DVGW-TZW



- Webinars
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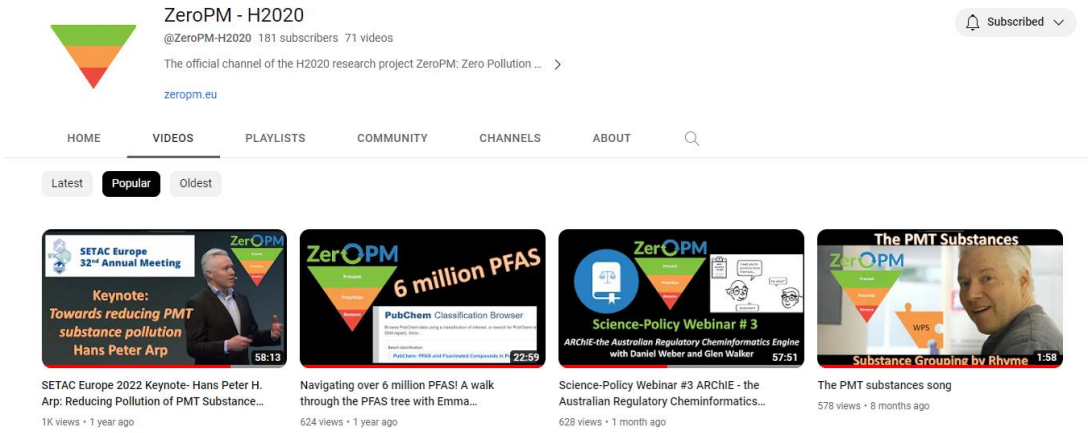
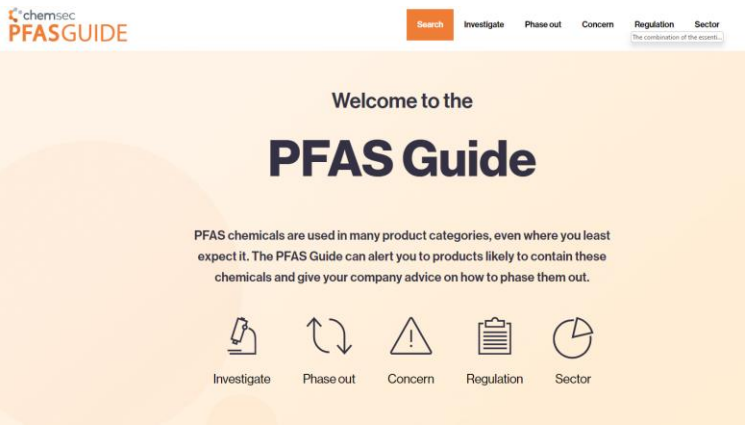


Webinar announcement

Anna Lennquist

Jonatan Kleimark

More info and registration: https://zeropm.eu/news/



Thank-you!!

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Contact: hans.peter.arp@ngi.no