

Preventing Recalcitrant Organic Mobile Industrial chemicals for Circular Economy in the Soilsediment-water system

Layman's Report



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101036449

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The Issue with Persistent, Mobile and Toxic Substances

By 2050, the Zero Pollution Action Plan envisions a "pollution-free" Europe, where air, water, and soil pollution are reduced to levels that no longer pose a significant risk to health and ecosystems.

Various chemicals stand in the way of achieving this goal. The widespread use of persistent, mobile, and potentially toxic substances (PM(T)), particularly **per- and polyfluoroalkyl substances** (PFAS) pose a significant threat to both human health and the environment. Their physiochemical properties - high persistency and mobility in the environment, among others - allow them to pass through subsurface environments, conventional drinking and wastewater treatment plants, making them ubiquitous in the soil-sediment-water system. These chemicals, still in daily use in industrial and consumer products (for example, fire-fighting foams, non-stick pans), continuously enter the ecosystem, contaminating soil, sediments, and the water cycle. Their persistence makes pollution difficult to reverse, endangering biodiversity and natural resources. It also undermines the principles of a circular economy, as recovered resources become unsuitable for reuse due to chemical contamination. PM(T) contamination is widespread, affecting the environmental compartments of wastewater, sewage sludge, landfill leachates, soils and sediments.



Per- and polyfluoroalkyl substances (PFAS) are synthetic chemicals with a special structure: They have a waterattracting head and a water-repelling tail made of carbon-fluorine bonds.

These strong bonds make PFAS extremely resistant, which is why PFAS are called "forever chemicals".

Through a survey conducted by PROMISCES, **84% of respondents, stakeholders from academia, industry and public authorities, expressed concern** over PM(T) substances, particularly PFAS, signifying the urgency of the problem. Respondents highlighted some challenges in manging PM(T)s, such as analytical difficulties and lack of available information on prevention and treatment. Effectively dealing with PM(T)s in the soil-sediment-water system requires effective regulatory and risk management strategies. However, obtaining the information needed to assess the risk to human health posed by these substances, with a wide range of chemical properties, is a challenge itself.







Grant agreement ID: 101036449

Project duration: 1 November 2021 - 30 April 2025

EU contribution: Approximately € 11,995,414 **Coordinator**: French Geological Survey - BRGM

Project Partners: 27 Countries involved: 9



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PROMISCES Circular Economy Routes

The overall aim of PROMISCES was to identify how industrial pollutants prevent the deployment of a circular economy in the EU and which strategies help overcome key bottlenecks to deliver the ambitions of the <u>European Green Deal</u>.

The main objective of the EU Green Deal is to achieve climate neutrality and zero pollution by 2050. Through the Green Deal, the EU created various action plans and strategies to achieve the stated objectives, such as the <u>Circular Economy Action Plan</u> and the <u>Zero Pollution Action Plan</u>. These EU initiatives require the effective and adequate management of PM(T)s.

To achieve the aim of the PROMISCES project, five circular economy routes were considered:

Semi-closed water cycles for drinking water supply at urban and catchment scale

B wastewater reuse for irrigation in agriculture

G groundwater remediation for safe reuse

nutrient recovery from sewage sludge





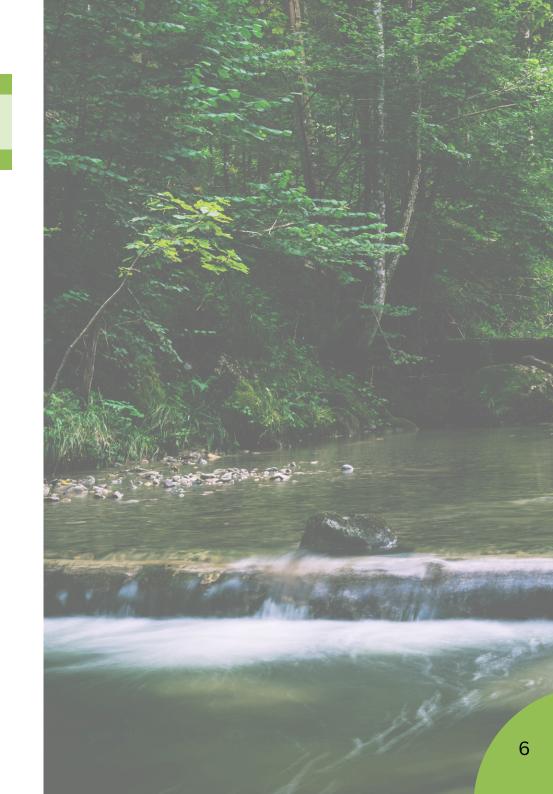
PROMISCES Objectives

To tackle the PM(T) issue, PROMISCES sought to...

- Enhance the ability to detect and monitor iPM(T)s
- 2 Improve the **predictability of persistency** and mobility of iPM(T)s
- 3 Improve assessment and management of human health risks associated with the exposure to PFAS and iPM(T)
- Provide risk management solutions
- Provide **innovative approaches** to prevent and manage the occurrence of iPM(T)s in circular economy routes

iPM(T) stands for industrial persistent, mobile and potentially toxic substances





PROMISCES Case Studies



As part of our efforts to enhance the understanding and management of persistent and harmful substances, the project achieved several key breakthroughs. These results contribute to the development of effective strategies to mitigate environmental risks associated with PFAS and PM(T) substances.

The project was driven by seven representative case studies (CS) from six European countries, tackling challenges linked to chemical pollution. These case studies targeted the reduction of the environmental impacts on water systems (surface water, groundwater, urban runoff, and wastewater), contaminated soils and brownfields, as well as dredged sediments from rivers and seaports.



Tracking How Chemicals Move and Stay in the Environment



Enhance the ability to detect and monitor iPM(T)s.

PROMISCES developed new tools and guidelines to identify, quantify and assess iPM(T) substances in the environment.

Measuring PFAS in the environment comes with a variety of challenges. Although these persistent and mobile chemicals are ubiquitous, concentrations are often very low, requiring highly sensitive analytical techniques. In addition, each matrix (drinking water, sediment or sludge) in which PFAS are to be monitored presents its own challenges due to other substances present in the sample.

Therefore, PROMISCES developed **10 advanced quantitative methods** for the **detection and measurement of 57 PFAS**. To ensure reproducibility and comparability of test results, PROMISCES also improved Standard Operating Procedures (<u>D1.1</u>). As there are thousands of different PFAS, global methods have been developed to complement the targeted analysis of PFAS by detecting a wide range of organic fluorinated chemicals (<u>D1.3</u>). This allows even unknown PFAS to be included in monitoring. In parallel, PROMISCES deployed screening approaches (D1.4) in order to prioritize the most relevant iPM(T), on which to develop quantitative analyses (<u>D1.2</u>).



The results provide best practices for tracking PM(T)s, supporting regulatory frameworks and guiding future environmental protection efforts.



The effectiveness and utility of these methods in real-world environments was demonstrated through their implementation in the PROMISCES CSs. A key focus was the use of passive samplers for PFAS monitoring in urban water systems (CS#1), which provided a practical and scalable approach to field monitoring. Lessons learned from the CSs were instrumental in evaluating and refining monitoring strategies for PFAS.



Understanding Harmful Chemicals in Our Environment

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Improve the predictability of persistency and mobility of iPM(T).

PROMISCES developed new methods for the detection of these harmful substances in water, soil, and other materials, making monitoring more effective.

PROMISCES developed a collection of models to assess the fate and transport of PFAS and PM(T)s across local and regional scales, considering conditions such as urban runoff, bank filtration, the unsaturated zone, and groundwater.

PROMISCES gathered a comprehensive dataset on the sources and environmental pathways of iPM(T)s and PFAS. Exposure data from case studies assessing PFAS fate and transport under different conditions were used to validate modeling tools, such as 3D models for soilgroundwater interaction or emission models at the catchment scale. These tools are useful for providing robust predictions for PFAS migration and supported the development of management strategies (D2.3 and D2.4).





The results provide valuable insights on how to predict toxicity and exposure, supporting future environmental protection efforts.



Protecting Human Health from Hazardous Substances



Improve assessment and management of human health risks associated with the exposure to PFAS and iPM(T)s.

PROMISCES updated the derivation of health-related indicator values and developed new approaches for environmental exposure and risk assessment for several circular economy routes.

PROMISCES improved toxicity assessment methodologies using **cell-based** (*in vitro*) and **computational** (*in silico*) testing approaches, both alone and in combination.

For this purpose PROMISCES selected a panel of about 40 PFAS and 20 PM(T)s. Thereby 15 different **toxicity endpoints** associated with PFAS exposure were identified, providing valuable insights into the potential effects of these compounds on human health (<u>D1.5</u>).

QSAR (Quantitative Structure Activity Relationship) tools and advanced artificial intelligence and machine learning models were assessed for the prediction of the aquatic toxicity of organic PM(T)s, including PFAS, across various aquatic species. This set of tools are applicable to a large group of PFAS/PM(T)s.

Based on the toxicity assessment, PROMISCES proposed a new endpoint for thyroid effects and corresponding **health-related indicator values** for newly identified PFAS in drinking water. These findings were then used to improve concepts for toxicity-based quality benchmarks for assessing drinking water and environmental media (D1.6).



The results provide best practices for using products from formerly polluted recovered resources, focusing on the safety of the products for humans.



Toxicity endpoints are key health effects that can be used to establish toxicity thresholds, below which adverse effects are not seen.

To assess the human exposure to PM(T)s in circular economy routes, PROMISCES developed a risk-based human health exposure assessment. This assessment evaluted four exposure routes across six PROMISCES CSs. Each exposure route leads to a consumable product - drinking water or crops. For example, treated wastewater in CS#3 could be used to irrigate crops for human consumption.

PROMISCES developed and published the probabilistic human health exposure assessment model (D2.5) and the SimpleBox model for improved environmental risk assessment and life cycle assessment (D2.6).

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Health-related indicator values are used to evaluate micropollutants in drinking water that have not been assessed at all or only in part to date and closes the time, data and legal gap between the analytical detection of a micropollutant in drinking water above 0.1 $\mu g/I$ and the existence of a guideline or threshold value.

Developing Safer and More Sustainable Solutions



Provide remediation technologies to protect the water cycle.

PROMISCES developed and tested cost-effective and sustainable remediation technologies laboratory and pilot scales, demonstrating strong potential for future large-scale applications.

Remediating soil and groundwater

To clean contaminated soil and groundwater, multiple techniques and combinations of technologies were explored.

- One method involved injecting chemicals like persulfate and ferrate into groundwater, where the removal rates for PFAS varied beteen 34% and 95% and toxicity removal between 50% to 89%. This approach was successfully tested at a real contaminated site (CS#7).
- Another technique investigated the mobilisation of PFAS from soil and groundwater by injecting a flushing solution, which is then pumped to the surface for on-site treatment. In laboratory experiments, more than 93% of the tested PFAS were recovered after flushing (CS#6).
- For on-site groundwater treatment **ultrasonic cavitation** was evaluated (CS#6) and showed **high potential to break down the 97% PFAS tested** regardless of their carbon chain length.
- **Biological treatment** was tasted at laboratory scale and it reduced toxicity but requires weeks to achieve results.



Recycling materials

Contaminated sediments, such as those dredged from a harbour, are washed during remediation processes. In PROMISCES, this washing process was optimised (D3.3) and the washed sediments were mixed with lime or lime-cement to bind any remaining PFAS, enabling their reuse in construction materials. Tests confirmed that the treated materials did not leach PFAS, making them safe for use (CS#5; D3.4).





Removing PM(T)s from water matrices

To remove PFAS from drinking water resources, even those with high background concentrations of organic matter, new **adsorptive media** were tested. Surface modified clays and ion exchange resins were validated in a pilot plant at a legacy contaminated site and showed higher selectivity for PFAS than granular activated carbon (CS#1).

To minimise the transfer of PM(T)s and PFAS during water reuse for agricultural irrigation, PROMISCES further treated municipal wastewater containing a high proportion of industrial wastewater using an advanced oxidation process (AOP) based on electro-peroxone.

The process was tested on-site in combination with a nature-based post-treatment. The treated water was then used to irrigate lettuce, which was analysed for PM(T) uptake. The treatment train worked quite well for PM(T)s, but did not show consistent removal of PFAS, requiring further research.

Quarternary wastewater treatment technologies for micropollutant removal at municipal wastewater treatment plants may fail to effectively remove PFAS. Whereas ozonation did not provide adequate PFAS removal, granular or powdered activated carbon (GAC/PAC) systems showed better removal, but may require changing the PAC dosing conditions or GAC runtimes.

The AOP based on electroperoxone combines ozone with powerful in situ generated oxidants, such as hydroxyl radicals, to break down pollutants.

The results provide methods for and technologies to remove chemical pollutans from matrices. This information is particularly important for companies specialized in remediation techniques.



Adsorptive media accumulate substances in water on their surface and remove them from the water. High selectivity is achieved when such substance as more PFAS accumulate on the adsorptive surface in comparison to other substances.

Conventional landfill leachate treatments, including physical-chemical and biological methods, are ineffective at removing PFAS. To address this, PROMISCES tested additional approaches. Nanofiltration and reverse osmosis, which use membranes with different pore sizes, were applied to concentrate PFAS while reducing the overall leachate volume, effectively separating PFAS from the treated water. The resulting concentrate was then treated using two advanced techniques: **pyrolysis**, where the concentrate was mixed with sludge for thermal contaminant removal, and plasma, which destroys pollutants. These treatment options were evaluated and compared to determine the most effective method for PFAS removal.

PROMISCES technologies were tested at both laboratory and pilot scale and offer practical solutions for tackling PFAS and iPM(T)s, with recommendations for further scaling and refinement.

Pyrolysis is a non-oxidative thermo-chemical treatment that involves the thermal decomposition of materials at elevated temperatures (300-700°C) in the absence of oxvaen.

Preventing Pollution in a Circular Economy



Provide innovative approaches to prevent and manage iPM(T)s in circular economy routes.

PROMISCES created a Decision Support Framework to assist risk managers in understanding, assessing and managing PM(T)s.

The PROMISCES project developed a Decision Support Framework (DSF) designed to help decision-makers in managing PM(T)s. This framework provides solutions focused on **prevention**, **monitoring**, **risk assessment**, **and treatment**. These solutions are incorporated into the DSF as five distinct modules, each aiming to enhance the effectiveness of existing regulations and tackle implementation challenges.

In line with the <u>Safe and Sustainable by Design</u> (SSbD) approach, the most effective way to limit the spreading of iPM(T), including PFAS, is to identify at early stage the intrinsic properties of the PM(T) compund. The diagnosis module of the **Decision Support Framework** (DSF) is a fit-for-purpose tool as it allows to identify substances meeting PM(T) criterion.

According to SSbD, these compounds should be prioritized for substitution, re-designed to reduce their adverse effects, or allowed only in uses proven essential to society. The PROMISCES project investigated two sectors of use as case studies, highlighting both successful substitution examples and potential challenges.



The results support regulatory frameworks and contribute to support the pathway to circular economy.



PM(T) Assessment

Verify if a substance is persistent, mobile, and/or toxic according to multiple data sources.

Search Substances

Explore PM(T)
chemicals across
various chemical
classes and sectors of
use.

Diagnosis

Get a personalized diagnosis for a PM(T) case to support solution assessment.

Solution Assessment

Solutions for preventing, assessing, monitoring and treating PM(T) substances.

Strategy Creation

Guidance and examples for developing strategies for PMT substances across sectors.



By translating science into policy, PROMISCES provides policymakers with actionable recommendations to improve the management of PM(T)substances in the soil-sedimentwater system, addressing policy gaps, enhancing regulatory alignment, and supporting the EU's circular economy and zero pollution goals (D5.8). These recommendations are based on key EU directives, such as the Water Directive, ensuring Framework alignment with existing regulatory frameworks.



PROMISCES Impact on Society



1300 followers on social media



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More than 130 events attended



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More than 15 scientific papers





































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In Extenso



























