Report

Recent scientific literature on PFAS in context of the PFAS restriction proposal

KWR 2023.053

Date
29 June 2023

Client
Vewin, Harrie Timmer

More information
Stefan Kools, PhD
T +31 (0)30 60 69 511
E [redacted]@kwrwater.nl

Author(s)
Milo L. de Baat, PhD
Youssef Boudguiyer, MSc
Stefan A.E. Kools, PhD

Project number
404545

Quality Assurance
Milou M.L. Dingemans, PhD, ERT

Project manager
Astrid Reus, MSc

Page
1/26

Summary

The ECHA restriction proposal on per- and polyfluoroalkyl substances (PFAS) seeks to ban both the use and production of all PFAS to reduce any risks these substances pose to humans and the environment. Considering this proposal, the scientific literature on per- and polyfluoroalkyl substances since 2021 was systematically reviewed by means of a scoping review in the Scopus and PubMed databases. The most important (recent) findings on risks to humans and the environment were summarized. In short, PFAS constitute a wide class of chemicals that can pose risks to both human health and the environment. PFAS have been detected in a variety of media and pathways of PFAS toxicity have been described in recent literature. Treatment options to remove PFAS from water exist but are not applied at sufficiently large scales to mitigate risks of PFAS in water. Restrictions of chemicals show promise in reducing the risks of PFAS to humans and the environment.

Fluoropolymers, such as polytetrafluoroethylene (PTFE), are a specific type of PFAS that are high-molecular-weight solid plastics and are considered, by some authors, as chemically inert materials. A key article by Henry et al. (2018) argues that fluoropolymers should be separated from other polymeric and nonpolymeric PFAS because they constitute a harmless class of compounds. In response, others have argued that all PFAS, including fluoropolymers, give rise to emissions of harmful PFAS at some stage of their life cycle. Therefore, these authors support the broad definition of PFAS used in the restriction proposal and the resulting ban on fluoropolymers and other PFAS alike.

In this report, we illustrate both abovementioned lines of reasoning underlying the two different positions, supported by substantial research efforts and data. Multiple publications have argued for either of the rationales, often coming from the same authors. It was noted that the authors supporting the exemption of fluoropolymers from a ban represent or are affiliated with PFAS-producing companies. This is a conflict of interest. For fluoropolymers, substantial data gaps on the full life cycle still exist, and it can be argued that there is currently insufficient (public) data to definitively qualify their life cycle as safe for human and environmental health.

Contents

1 Context

1.1 Context

A proposal for a European restriction on per- and polyfluoroalkyl substances (PFAS) was published by the European Chemicals Agency (ECHA) on 7 February 2023. The details of the proposed restriction of around 10 000 PFAS are available on ECHA's website1. In this, the Dutch government worked on this proposal together with Denmark, Germany, Norway and Sweden. The proposal is currently under public consultation (see Figure 1).

***Figure 1** Timeline of the PFAS restriction proposal by ECHA (as taken from ECHA website).*

In short, the restriction proposal consists of these findings:

- All PFAS are either highly persistent themselves or degrade to other persistent PFAS
- Persistence is due to the strength of the carbon-fluorine bond
- PFAS are used in high tonnages in a variety of applications
- Emissions occur in all life cycle stages
- Monitoring data show ubiquitous presence of PFAS in the environment and in humans
- PFAS have adverse effects on environment and human health
- PFAS are difficult to remove once released into the environment

PFAS are regarded as "forever chemicals", as they remain in the environment for decades. Furthermore, it states that if releases are not minimised, adverse effects are inevitable. Hence, the proposal has the aim to reduce emissions with 95% and has several elements:

- It targets a broad group of PFAS
- (Time-limited) derogations for certain uses, and industry effort is needed to switch to alternatives
- Stakeholders are invited to provide input during consultation

Vewin, the Association of Dutch drinking water companies, is responding to this public consultation and has commissioned KWR to provide an overview of recent scientific literature on risks of PFAS to the environment and drinking water.

[1] https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal

2 Research questions and Approach

2.1 Research Questions

For this review, KWR has taken into consideration the following research questions when evaluating new scientific literature in a systematic review:

1. What are the implications of the findings for the risks of PFAS for human- and environmental health, in addition to the restriction proposal?

2. What are the implications of the findings for the whole life cycle of PFAS, including production and end of use?

3. Do any (potential) conflicts of interest arise from authorship by researchers employed either directly or indirectly by the fluorochemical industry?

2.2 Approach

The scientific literature on PFAS from 2021 was systematically reviewed by means of a scoping review in both Scopus and PubMed databases. The search strategy is outlined in Table 1. It was tailored to obtain the available scientific literature on the topic of PFAS in general and risks to humans and the environment. Keywords with relevance to the ECHA proposal for the restriction of PFAS were added to the search query in a stepwise manner (‘water’, ‘health’, ‘harmless’ and ‘harmful’) and only publications published since 2021 were selected, as this was the moment the restriction proposal was finalized. The final query (No. 9) was applied as it provides a sufficient number of papers as well as representing the most important keywords.

Subsequently, the papers were included in the systematic review only if they support in answering the research questions outlined in paragraph 2.1. To do so, the following inclusion criteria were applied:
- The paper provides new insights compared to the restriction proposal
- The paper provides information on PFAS regulation or the restriction proposal
- The paper describes specific human health aspects of PFAS exposure
- The paper describes life cycle aspects of PFAS including removal

Papers that met these criteria were marked as “relevant” (Appendix I). The outcomes of the systematic literature review are reported in Section 3.1.

Considering a potential total ban on PFAS, scientific debate has arisen on whether a particular subclass of PFAS, the fluoropolymers, are harmless and should be excluded from a restriction. Therefore, alongside the *systematic literature review*, a *focused investigation* was done into the rationales provided in the scientific literature for the in- or exclusion of the subclass of fluoropolymers in the restriction. The starting point for this is a paper by Henry et al. (2018) that argues for the exclusion of fluoropolymers from restrictions on production and use. For the focused investigation, this paper and the papers that were written in response to this or closely related to the topic are summarized and their relevance to the restriction proposal is discussed. The outcomes of the focused investigation are reported in Section 3.2.

Potential conflicts of interest for authors of the reviewed papers were evaluated by i) screening the "Conflict of Interest" statements provided in the publications, ii) asserting whether the authors are either directly or indirectly (e.g. as external consultants) employed by the fluorochemical industry, and iii) confirming whether the funding source of the paper includes fluorochemical producers.

Table 1 *Systematic review strategy for recent literature on PFAS risks to humans and the environment from Scopus and PubMed.*

No.	**Search string (SCOPUS, Search within title, abstract, keywords)**	**Number of documents**
1	TITLE-ABS-KEY (pfas)	4759
2	TITLE-ABS-KEY (pfas OR perfluor* OR polyfluor*)	59910
3	TITLE-ABS-KEY ((pfas OR perfluor* OR polyfluor*) AND water*)	13435
4	TITLE-ABS-KEY ((pfas OR perfluor* OR polyfluor*) AND water* AND health)	1529
5	TITLE-ABS-KEY ((pfas OR perfluor* OR polyfluor*) AND water* AND health AND harmful)	58
6	TITLE-ABS-KEY ((pfas OR perfluor* OR polyfluor*) AND water* AND health AND harmless)	1
7	TITLE-ABS-KEY (((pfas OR perfluor* OR polyfluor*) AND health AND (harmless OR harmful)))	138
8	TITLE-ABS-KEY ((pfas OR perfluor* OR polyfluor*) AND water* AND health AND (harmless OR harmful))	59
9	TITLE-ABS-KEY (((pfas OR perfluor* OR polyfluor*) AND water* AND health AND (harmless OR harmful))) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021))	34
No.	**Search string (PubMed)**	**Number of documents**
1	(pfas OR perfluor* OR polyfluor*) AND water* AND health AND (harmless OR harmful) *[Filters applied: from 2021/1/1 - 2023/6/20]*	30

3 Outcome of the literature review

The literature search resulted in 34 papers within Scopus, which were then manually scrutinized based on their abstracts considering their relevance to PFAS risks to human- and environmental health in the context of water. The same search string was applied to the PubMed database, which resulted in 30 papers. From this, 19 papers overlapped with the search results from Scopus, and 11 papers were unique. When combining both the Scopus and PubMed search results, 45 unique papers were found in total.

Of these 45 papers, 28 were identified that met the inclusion criteria (i.e., they support in answering the research questions outlined in paragraph 2.1). Of these 28 papers, several provide novel scientific findings, while some of the review papers provide general information regarding PFAS. The total list of publications with their relevance to the present literature review, a short summary (when relevant), and an evaluation of a potential conflict of interest are provided in Appendix I. These 28 selected papers are summarized below.

3.1 Summary of selected papers

3.1.1 Exposure, hazards and risks of PFAS

Some of the papers included in the systematic review only summarized the information already included in the restriction proposal rather than presenting new findings. For example, multiple papers highlighted that PFAS are anthropogenic chemicals commonly known for their strong persistence (Kang et al., 2023; Verma et al., 2023; Zarębska & Bajkacz, 2023). It was also reconfirmed that PFAS accumulate in both the environment and aquatic organisms (Koban & Pfluger, 2023; D. Liu et al., 2023; Zarębska & Bajkacz, 2023).

The estimation of industrial PFOA and its salts (PFO) showed that China released about 38.19 tons PFOA/PFO into the atmosphere through industrial activities in 2019, 97 % of which originated from the production of fluoropolymers (Du et al., 2023). This is of relevance to the discussion in section 3.2, in which the life cycle impact of fluoropolymers is discussed further.

Exposure routes of consumers to PFAS through the use of cosmetics were described (Whitehead et al., 2021) and the consumption of freshwater fish (Barbo et al., 2023). The adsorption to micro- and nanoplastics was also described as a potential exposure route of PFAS to organisms (Zhang et al., 2022). Adverse effects of PFAS exposure on human health were also found, in line with the restriction proposal. One review paper highlighted that PFAS toxicity data for humans remain highly variable, and that the extrapolation from animal to human studies is complex and inconclusive because adverse outcome pathways to PFAS differ among species, sexes, and life stages (Espartero et al., 2022). Furthermore, the review showed that emerging PFAS can induce toxicity like legacy PFAS like PFOS and PFOA. A review of omics based PFAS exposure studies revealed that the “pentose phosphate shunt” is a common biochemical response pathway to PFAS, which partly contradicts the findings by Espartero et al. that response pathways to PFAS are strongly divergent (Beale et al., 2022). Another review paper demonstrated that PFAS such as perfluorooctanoic acid (PFOA) have been shown to accumulate in kidneys and can cause nephrotoxicity and other negative effects on kidneys in humans (D. Liu et al., 2023). An in-silico study showed a novel finding, that 14 PFAS are predicted to have a strong competitive binding affinity to the human vitamin D receptor (Azhagiya Singam et al., 2023). This receptor is important for immune and endocrine homeostasis, which may explain some of the adverse health effects observed for PFAS in humans. Indeed, epidemiological studies indicate that exposure to PFAS appears to have infrequent but statistically significant associations with cancer and reproductive hazards (Naz et al., 2022).

3.1.2 PFAS lifecycle and mitigation options

In the systematic review, a substantial number of papers was identified that describe removal options to reduce PFAS concentrations in water, even though the search query was not directly targeted towards this. However, removal is of relevance to the research questions considering the whole life cycle of PFAS, and it highlights that a lot of research effort is being put towards the mitigation of the growing impact of PFAS on humans and the environment. Since the removal of PFAS from water is challenging owing to their mobility, attempts have been made which can potentially drastically reduce the presence of PFAS in drinking- and surface water (Kavusi et al., 2023). Multiple papers describe the use of novel materials or chemical processes to aid in the removal of PFAS from water. A recent study showed that MOF-808 (Metal–Organic Framework) is effective in adsorbing PFOS from water (Chang et al., 2022). Another study showed that perfluorohexanesulfonic acid (PFHxS) can be removed from water using membrane filtration (Liu et al., 2023). Next, a paper discusses a technique that can remove PFAS from tap water by implementing a household point-of-use water purifier that uses coconut shell-derived activated carbon (He et al., 2022). Mantripragada et al. (2022) reviewed and demonstrated the efficient adsorption of the short-chained PFAS GenX (hexafluoropropylene oxide dimer) from water using nanofibrous filter material obtained by electrospinning. Another paper describes the peroxymonosulfate activation by iron self-doped sludge-derived biochar for degradation of PFOA (Fu et al., 2022). Mulabagal et al. (2022) describe that biochar derived from biomass can be effective in sequestering PFAS from the environment. Another study demonstrated that the use of a multifunctional magnetic adsorbent, cerium-incorporated ferrite decorated polyaniline hybrid composite can efficiently and selectively sequester PFOS and PFOA (Elanchezhiyan et al., 2021). Besides sequestration, the degradation and mineralization of PFAS has been described. This has a preference over mere removal, as these ‘forever chemicals’ are notoriously difficult to degrade, and their persistence is one of the major concerns also highlighted in the restriction proposal. In a paper that received substantial attention in the media, Trang et al. (2022) describe the low-temperature mineralization of perfluorocarboxylic acids. A review paper summarized the currently known degradation mechanisms of PFOS and PFOA by different chemical methods (Deng et al., 2021). Two other papers discuss various PFAS removal or degradation processes such as electrocoagulation, bioremediation, foam fractionation and photocatalysis (Leung et al., 2022; Meegoda et al., 2022). Many of the reported methods have the potential to efficiently remove PFAS from water. Nevertheless, it should be noted that these findings are novel and sometimes promising, but it remains yet unclear if their implementation on a large scale is feasible.

Besides the removal of PFAS, mitigation can also come from the prevention of emissions of PFAS. A recent paper describes how the implementation of the Stockholm Convention on persistent organic pollutants in China has resulted in the decrease of PFOS and perfluorooctane sulfonyl fluoride (PFOSF) concentrations in water bodies (Zhang et al., 2022). This illustrates that the restriction of PFAS can indeed result in lower exposure and thus risks to humans and the environment. Similarly, the inclusion of PFAS sum parameters in the revised European Union Drinking Water Directive may serve as an impetus to reduce emissions of PFAS in order to reduce the concentrations in drinking water sources (Dettori et al., 2022).

3.2 Scientific positions on the in- or exclusion of fluoropolymers from a PFAS restriction

3.2.1 Definition of PFAS

The restriction proposal calls for a ban on “all” PFAS. This has become a point of debate, and, therefore, it is relevant to consider the definition of PFAS that is used generally and in the restriction proposal specifically. Scientific deliberation on the appropriate definition of PFAS has been ongoing (Wang et al., 2021), with the first clear structural definition of PFAS provided by Buck et al. (2011). Since then, the definition of PFAS has been expanded to include newly identified PFAS and the most recent report on the terminology of PFAS was published in 2021 under the framework of the Global PFC Group (OECD, 2021). The ECHA restriction proposal seeks a ban on both the use and production of PFAS to reduce the risks these substances pose to humans and the environment.

The proposal defines PFAS as "any substance that contains at least one fully fluorinated methyl (–CF3) or methylene (–CF2–) carbon atom (without any H/Cl/Br/I attached to it)", in line with the most recent Global PFC Group definition. A total ban on PFAS would include all chemicals that fit this definition, presently approximately 10,000 substances, with the rationale that restricting the entire class of PFAS "is the most appropriate and effective option to adequately control such a large and complex group of substances which are used in numerous applications". Interestingly, recent research has highlighted that this new OECD definition includes up to 7 million chemicals in the open chemical database PubChem, posing an even larger challenge to researchers and computational workflows alike in the risk assessment of these chemicals (Schymanski et al., 2023).

3.2.2 PFAS as a single chemical class

The justification for managing PFAS as a single chemical class to reduce PFAS-related risks is provided in the scientific literature (Kwiatkowski et al., 2020). Therein, it is argued that a class-based approach can be implemented to eliminate non-essential uses of PFAS more effectively, develop safer alternatives, and clean up highly contaminated areas. Ultimately, this should reduce and prevent further accumulation of these hazardous chemicals in people and the environment and avoid replacing them with other related and harmful substances. However, members of the chemical industry appear to be pushing back against the broad definition of PFAS used in the restriction proposal because they fundamentally disagree with the inclusion of all PFAS within a single broad chemical class with common properties. In multiple scientific publications, scientists working for or in collaboration with the fluorochemical industry argue that this definition is too broad to allow effective, science-based assessment and regulation of chemical compounds as an entire group and that certain subclasses of PFAS with chemical, physical, thermal and biological properties pose little to no harm to human and environmental health. Indeed, based on the available scientific literature, many PFAS have serious health and environmental concerns (Panieri et al., 2022; and systematic literature review above), but substances in the PFAS family have very different properties and risks. Some subgroups, such as fluoropolymers, appear to pose minimal direct risk to human health, while other substances, such as PFOS and PFOA, have well-understood negative impacts on health. Fluoropolymers, such as polytetrafluoroethylene (PTFE; commonly known under the brand name Teflon), are high-molecular-weight solid plastics and are considered by some authors as chemically inert materials (Ameduri, 2023).

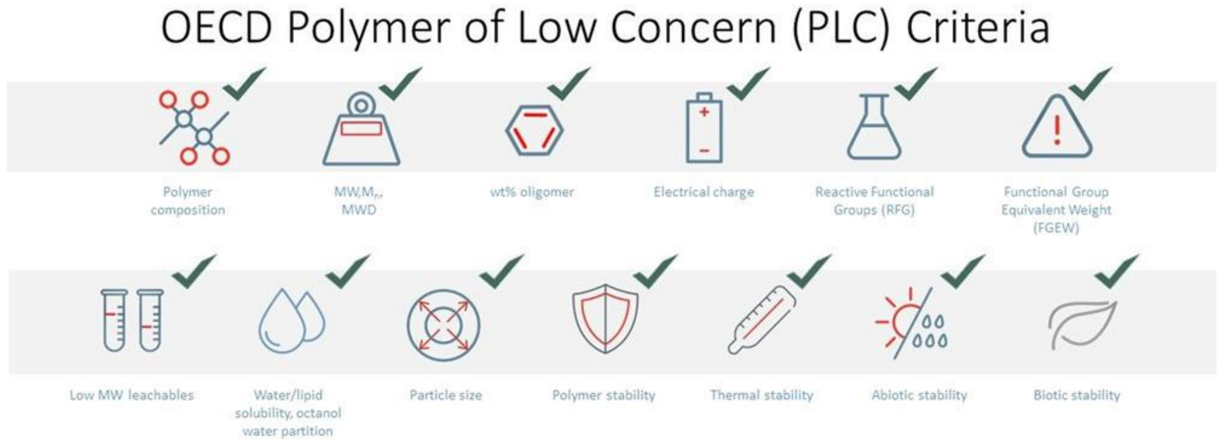

Figure 2 *OECD polymer of low concern (PLC) criteria (copied from Korzeniowski et al. 2022). Checkmarks indicate that the fluoropolymers discussed in the paper by Korzeniowski et al. fulfil the PLC criteria according to the authors.*

3.2.3 Fluoropolymers as a distinct class of PFAS

A starting point of the scientific debate with relevance to the present restriction proposal seems to be the article by Henry et al. (2018) who argued that fluoropolymers have limited water solubility, these compounds do not undergo thermal, (photo)chemical, hydrolytic, oxidative, or biological degradation, are not subject to long-range transport and have limited bioavailability. Based on these properties, they concluded that these compounds constitute a separate and harmless class of PFAS. By bringing together fluoropolymer toxicity data, human clinical data, and physical, chemical, thermal, and biological data for review and assessment, the authors demonstrated that fluoropolymers satisfy assessment criteria to be considered to have insignificant environmental and human health impacts and, as such satisfy the OECD definition of "polymers of low concern" (PLC; figure 2). Based on those data the authors conclude that fluoropolymers are distinctly different from other polymeric and nonpolymeric PFAS and should be separated from them for hazard assessment or regulatory purposes. The paper by Henry et al. (2018) was published in the reputable journal Integrated Environmental Assessment and Management (IEAM), published by the Society of Environmental Toxicology and Chemistry (SETAC), which publishes scientific articles that have been subjected to external peer review. Nonetheless, it is of interest that all the authors on the paper are either directly or indirectly employed by fluoroproduct manufacturers, giving rise to a conflict of interest which is clearly mentioned at the end of the paper.

It is important to note here that conflicts or funding by bodies with vested interests may result in (un-)conscious biases during the entire study, from planning to publication (Samuel et al., 2016). In a critical review like the paper by Henry et al. (2018), this, for example, could lead to selective outcome reporting (i.e., the reporting of only selected results, not all results). Whether this or other forms of bias arising from conflicts of interest have occurred in the papers discussed here is outside the scope of the current review. For the present review, we have only recorded whether any conflicts of interest are present (see Appendix I & II).

3.2.4 In response to the paper by Henry et al.

In response to the argument made in the paper by Henry et al. (2018), Lohmann et al. (2020) provided a policy analysis in which they rebuke the low concern for human- and environmental health of fluoropolymers by taking a life-cycle perspective. This paper argues that although fluoropolymers intrinsically may pose low risks to humans and the environment owing to their particular properties, the production of some fluoropolymers is intimately linked to the use and emissions of legacy and novel PFAS as polymer processing aids. There are serious concerns regarding the toxicity and adverse effects of such fluorinated processing aids on humans and the environment. Moreover, they demonstrate that a variety of other PFAS, including monomers and oligomers, are emitted during the production, processing, use, and end-of-life treatment of fluoropolymers. There are further concerns regarding the safe disposal of fluoropolymers and their associated products and articles at the end of their life cycle. While recycling and reuse of fluoropolymers are performed on some industrial waste, there are yet only limited options for their recycling from consumer articles. Lohmann et al. thus argue that there is no scientifically supported rationale for concluding that fluoropolymers are of low concern for environmental and human health. They conclude that due to fluoropolymers' extreme persistence; emissions associated with their production, use, and disposal; and a high likelihood of human exposure to PFAS, their production and uses should be curtailed except in cases of essential uses.

3.2.5 Reported scientific rationales

Since then, multiple publications have argued for either rationale, often coming from the same (groups of) authors and/or representing the same companies. In summary, these publications collectively make up the following two positions:

A) Fluoropolymers constitute a separate class of PFAS with distinct properties and are essential for multiple uses in daily life (Ameduri, 2023). There are 14 commercially available fluoropolymers that meet the criteria to be considered PLC, which represent approximately 96% of the global fluoropolymer market (Korzeniowski et al., 2023). Fluoropolymer manufacturers recently committed voluntarily to responsible manufacturing principles by continuously improving and/or developing the best available techniques in line with the objectives of the circular economy (Améduri & Hori, 2023; Korzeniowski et al., 2023). Fluoropolymers that are manufactured without the use of PFAS polymerization aids should be exempted from any regulatory initiative, and their uses should be allowed without any restriction (Ameduri et al., 2023).

B) PFAS are a group of problematic chemicals owing to their physicochemical, environmental, and toxicological properties (Kwiatkowski et al., 2020). Environmental contamination by PFAS defines a separate planetary boundary and this boundary has been exceeded, and it is, therefore, vitally important that PFAS uses and emissions are rapidly restricted (Cousins et al., 2022). The only answer is a switch to fluorine-free alternatives for all applications in which PFAS are not essential (Brunn et al., 2023). Industries consider most fluoropolymers as being PLC, although there is already a considerable environmental burden and widespread contamination resulting from their production, manufacturing, and use (Lohmann & Letcher, 2023). There is insufficient public data available on the compositions, and hence the potential environmental hazards and risks of fluoropolymers remain uncertain, which precludes treating them as a harmless subclass of PFAS (Lohmann & Letcher, 2023).

In general, position A is represented by scientists working for or in collaboration with the fluorochemical industry, while position B is represented by academics supporting a total ban of PFAS.

4 Conclusions

The general trend emerging from the literature based on the systematic review is that PFAS have documented adverse effects on human health and the environment, and that (drinking) water is an important exposure route for humans to PFAS. Both long- and short-chain PFAS cause adverse effects. The newly published papers hence support the literature used in the restriction proposal but add little new information to either support or rebuke such a proposal. Recent papers describing the removal of PFAS from water discuss new technologies with high potential that could mitigate the negative impact on humans and the environment, but they are yet to be implemented on a large scale and in an efficient manner.

In our focused review of scientific literature on whether the restriction proposal for PFAS should be as broad as possible (or not) resulted in an overview on different positions. It seems that the diverging scientific debate mainly focusses on the group of fluoropolymers that, according to one position, should be excluded from the PFAS restriction, while authors supporting the other position state they should not. Both lines of reasoning seem to be supported by substantial research efforts and data. Nonetheless, it is important to consider the conflict of interest of the authors employed by the chemical industry. It is in the interest of their employers for the commercially important fluoropolymers to be PLCs and, as a result, exempt from a ban on PFAS. This makes it of vital importance to critically assess the safety of these products, considering their full life cycle.

It was more challenging to answer the implications of the findings for the whole life cycle of PFAS, including production and end of use. The systematic review elucidated new and promising removal options for PFAS from water, although their capacities are limited, including those applied in drinking water production. Moreover, drinking water consumption constitutes only a part of the total PFAS exposure of humans, and there are many pathways for environmental emissions of PFAS that are not mitigated by water treatment. For fluoropolymers, substantial data gaps on the full life cycle still exist, and it can be argued that there is currently insufficient (public) data to definitively qualify their life cycle as safe for human- and environmental health.

A voluntary commitment to responsible manufacturing principles by manufacturers is meaningful. However, it is not a guarantee that the manufacturing process will not lead to any more emissions of harmful PFAS, and it does not include other phases of the life cycle. For example, a study that was highlighted in the systematic review illustrated that 97 % of China’s PFOA/PFO emissions originated from the production of fluoropolymers. Moreover, in this era of increasing environmental awareness, such a commitment may also be considered a requirement rather than an asset (Extended Producer Responsibility, 2016). Even with a total ban on PFAS, a phase-out period is expected, and many products would be phased-out over the course of a considerable period (up to 12 years). In this period, safe fluorine-free alternatives can be developed. Essential uses could be exempt from the ban, answering an argument for the essentiality of several products, but also requiring clear criteria for the assessment of essentiality (Cousins et al., 2019).

4.1 Current limitations and future recommendations

The present systematic and focused literature reviews, although thorough, may have missed recent key publications. For example, we noted the difference between the systematic literature search and the focused investigation in which we specifically searched for papers that were part of a scientific debate on whether PFAS should be regarded as one group of (to be banned) chemicals. To maintain an up-to-date overview of literature with relevance to a potential ban on PFAS, given the high pace with which new publications appear, it is recommended to systematically collect and document publications on a (semi-)continuous basis. This ensures that no relevant papers are overlooked and facilitates the provision of a contemporary literature overview whenever the need arises. A list of publications with relevance to a potential ban on PFAS that were encountered during the targeted investigation of literature is provided in Appendix II. Additionally, it would be valuable to critically assess the impact of the different definitions for PFAS that are used, gain a better understanding of PLC criteria, develop a framework to analyse the quality of scientific papers in a structured manner, and to gain insight into what constitutes essential use of chemicals.

5 References

Ameduri, B. (2023). Fluoropolymers: A special class of per- and polyfluoroalkyl substances (PFASs) essential for our daily life. *Journal of Fluorine Chemistry*, *267*, 110117. https://doi.org/10.1016/J.JFLUCHEM.2023.110117

Améduri, B., & Hori, H. (2023). Recycling and the end of life assessment of fluoropolymers: recent developments, challenges and future trends. *Chemical Society Reviews*. https://doi.org/10.1039/D2CS00763K

Ameduri, B., Sales, J., & Schlipf, M. (2023). Developments in Fluoropolymer Manufacturing Technology to Remove Intentional Use of PFAS as Polymerization Aids. *International Chemical Regulatory and Law Review*, *6*(1), 18–28. https://icrl.lexxion.eu/article/ICRL/2023/1/5

Azhagiya Singam, E. R., Durkin, K. A., La Merrill, M. A., Furlow, J. D., Wang, J. C., & Smith, M. T. (2023). The vitamin D receptor as a potential target for the toxic effects of per- and polyfluoroalkyl substances (PFASs): An in-silico study. *Environmental Research*, *217*, 114832. https://doi.org/10.1016/J.ENVRES.2022.114832

Barbo, N., Stoiber, T., Naidenko, O. V., & Andrews, D. Q. (2023). Locally caught freshwater fish across the United States are likely a significant source of exposure to PFOS and other perfluorinated compounds. *Environmental Research*, *220*, 115165. https://doi.org/10.1016/J.ENVRES.2022.115165

Beale, D. J., Sinclair, G. M., Shah, R., Paten, A. M., Kumar, A., Long, S. M., Vardy, S., & Jones, O. A. H. (2022). A review of omics-based PFAS exposure studies reveals common biochemical response pathways. *Science of The Total Environment*, *845*, 157255. https://doi.org/10.1016/J.SCITOTENV.2022.157255

Brunn, H., Arnold, G., Körner, W., Rippen, G., Steinhäuser, K. G., & Valentin, I. (2023). PFAS: forever chemicals—persistent, bioaccumulative and mobile. Reviewing the status and the need for their phase out and remediation of contaminated sites. *Environmental Sciences Europe 2023 35:1*, *35*(1), 1–50. https://doi.org/10.1186/S12302-023-00721-8

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., Voogt, P. De, Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. J. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*(4), 513–541. https://doi.org/10.1002/IEAM.258

Chang, P. H., Chen, C. Y., Mukhopadhyay, R., Chen, W., Tzou, Y. M., & Sarkar, B. (2022). Novel MOF-808 metal–organic framework as highly efficient adsorbent of perfluorooctane sulfonate in water. *Journal of Colloid and Interface Science*, *623*, 627–636. https://doi.org/10.1016/J.JCIS.2022.05.050

Cousins, I. T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., Patton, S., Scheringer, M., Trier, X., Vierke, L., Wang, Z., & Dewitt, J. C. (2019). The concept of essential use for determining when uses of PFASs can be phased out. *Environmental Science: Processes & Impacts*, *21*(11), 1803–1815. https://doi.org/10.1039/C9EM00163H

Cousins, I. T., Johansson, J. H., Salter, M. E., Sha, B., & Scheringer, M. (2022). Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS). *Environmental Science and Technology*, *56*(16), 11172–11179. https://doi.org/10.1021/ACS.EST.2C02765/ASSET/IMAGES/LARGE/ES2C02765_0001.JPEG

Deng, Y., Liang, Z., Lu, X., Chen, D., Li, Z., & Wang, F. (2021). The degradation mechanisms of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) by different chemical methods: A critical review. *Chemosphere*, *283*, 131168. https://doi.org/10.1016/J.CHEMOSPHERE.2021.131168

Dettori, M., Arghittu, A., Deiana, G., Castiglia, P., & Azara, A. (2022). The revised European Directive 2020/2184 on the quality of water intended for human consumption. A step forward in risk assessment, consumer safety and informative communication. *Environmental Research*, *209*, 112773. https://doi.org/10.1016/J.ENVRES.2022.112773

Du, D., Lu, Y., Li, Q., Zhou, Y., Cao, T., Cui, H., & Han, G. (2023). Estimating industrial process emission and assessing carbon dioxide equivalent of perfluorooctanoic acid (PFOA) and its salts in China. *Science of The Total Environment*, *867*, 161507. https://doi.org/10.1016/J.SCITOTENV.2023.161507

Elanchezhiyan, S. S., Muthu Prabhu, S., Karthikeyan, P., & Park, C. M. (2021). Efficient and selective sequestration of perfluorinated compounds and hexavalent chromium ions using a multifunctional spinel matrix decorated carbon backbone N-rich polymer and their mechanistic investigations. *Journal of Molecular Liquids*, *326*, 115336. https://doi.org/10.1016/J.MOLLIQ.2021.115336

Extended Producer Responsibility. (2016). OECD. https://doi.org/10.1787/9789264256385-en

Fu, S., Zhang, Y., Xu, X., Dai, X., & Zhu, L. (2022). Peroxymonosulfate activation by iron self-doped sludge-derived biochar for degradation of perfluorooctanoic acid: A singlet oxygen-dominated nonradical pathway. *Chemical Engineering Journal*, *450*, 137953. https://doi.org/10.1016/J.CEJ.2022.137953

He, A., Lu, Y., Chen, F., Li, F., Lv, K., Cao, H., Sun, Y., Liang, Y., Li, J., Zhao, L., Zhang, X., Li, L., Wang, Y., & Jiang, G. (2022). Exploring the origin of efficient adsorption of poly- and perfluoroalkyl substances in household point-of-use water purifiers: Deep insights from a joint experimental and computational study. *Science of The Total Environment*, *831*, 154988. https://doi.org/10.1016/J.SCITOTENV.2022.154988

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, *14*(3), 316–334. https://doi.org/10.1002/IEAM.4035

Jane L Espartero, L., Yamada, M., Ford, J., Owens, G., Prow, T., & Juhasz, A. (2022). Health-related toxicity of emerging per- and polyfluoroalkyl substances: Comparison to legacy PFOS and PFOA. *Environmental Research*, *212*, 113431. https://doi.org/10.1016/J.ENVRES.2022.113431

Kang, Y.-G., Birch, Q., Nadagouda, M. N., & Dionysiou, D. D. (2023). Advanced destruction technologies for PFAS in soils: Progress and challenges. *Current Opinion in Environmental Science & Health*, *33*, 100459. https://doi.org/10.1016/J.COESH.2023.100459

Kavusi, E., Shahi Khalaf Ansar, B., Ebrahimi, S., Sharma, R., Ghoreishi, S. S., Nobaharan, K., Abdoli, S., Dehghanian, Z., Asgari Lajayer, B., Senapathi, V., Price, G. W., & Astatkie, T. (2023). Critical review on phytoremediation of polyfluoroalkyl substances from environmental matrices: Need for global concern. *Environmental Research*, *217*, 114844. https://doi.org/10.1016/J.ENVRES.2022.114844

Koban, L. A., & Pfluger, A. R. (2023). Per- and polyfluoroalkyl substances (PFAS) exposure through munitions in the Russia–Ukraine conflict. *Integrated Environmental Assessment and Management*, *19*(2), 376–381. https://doi.org/10.1002/IEAM.4672

Korzeniowski, S. H., Buck, R. C., Newkold, R. M., kassmi, A. El, Laganis, E., Matsuoka, Y., Dinelli, B., Beauchet, S., Adamsky, F., Weilandt, K., Soni, V. K., Kapoor, D., Gunasekar, P., Malvasi, M., Brinati, G., & Musio, S. (2023). A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. *Integrated Environmental Assessment and Management*, *19*(2), 326–354. https://doi.org/10.1002/IEAM.4646

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., Dewitt, J. C., Knappe, D. R. U., Maffini, M. V., Miller, M. F., Pelch, K. E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C. C., Wang, Z., & Blum, A. (2020). Scientific Basis for Managing PFAS as a Chemical Class. *Environmental Science and Technology Letters*, *7*(8), 532–543. https://doi.org/10.1021/ACS.ESTLETT.0C00255/ASSET/IMAGES/LARGE/EZ0C00255_0001.JPEG

Leung, S. C. E., Shukla, P., Chen, D., Eftekhari, E., An, H., Zare, F., Ghasemi, N., Zhang, D., Nguyen, N. T., & Li, Q. (2022). Emerging technologies for PFOS/PFOA degradation and removal: A review. *Science of The Total Environment*, *827*, 153669. https://doi.org/10.1016/J.SCITOTENV.2022.153669

Liu, D., Yan, S., Wang, P., Chen, Q., Liu, Y., Cui, J., Liang, Y., Ren, S., & Gao, Y. (2023). Perfluorooctanoic acid (PFOA) exposure in relation to the kidneys: A review of current available literature. *Frontiers in Physiology*, *14*, 1103141. https://doi.org/10.3389/FPHYS.2023.1103141/BIBTEX

Liu, M., Zhang, L., Han, L., Zhang, Y., Gu, C., & Huang, J. (2023). Mechanism Analysis of PFHxS Purification in Water Using Nanofiltration under the Coexistence of Sodium Alginate and Ca2+ Based on DFT. *Water (Switzerland)*, *15*(4), 792. https://doi.org/10.3390/W15040792/S1

Lohmann, R., Cousins, I. T., Dewitt, J. C., Glüge, J., Goldenman, G., Herzke, D., Lindstrom, A. B., Miller, M. F., Ng, C. A., Patton, S., Scheringer, M., Trier, X., & Wang, Z. (2020). Are Fluoropolymers Really of Low Concern for

Human and Environmental Health and Separate from Other PFAS? *Environmental Science and Technology*, *54*(20), 12820–12828. https://doi.org/10.1021/ACS.EST.0C03244/ASSET/IMAGES/LARGE/ES0C03244_0002.JPEG

Lohmann, R., & Letcher, R. J. (2023). The universe of fluorinated polymers and polymeric substances and potential environmental impacts and concerns. *Current Opinion in Green and Sustainable Chemistry*, *41*, 100795. https://doi.org/10.1016/J.COGSC.2023.100795

Meegoda, J. N., Bezerra de Souza, B., Casarini, M. M., & Kewalramani, J. A. (2022). A Review of PFAS Destruction Technologies. In *International Journal of Environmental Research and Public Health* (Vol. 19, Issue 24). https://doi.org/10.3390/ijerph192416397

Mulabagal, V., Baah, D. A., Egiebor, N. O., Sajjadi, B., Chen, W.-Y., Viticoski, R. L., & Hayworth, J. S. (2022). Biochar from Biomass: A Strategy for Carbon Dioxide Sequestration, Soil Amendment, Power Generation, CO2 Utilization, and Removal of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) in the Environment. *Handbook of Climate Change Mitigation and Adaptation*, 1023–1085. https://doi.org/10.1007/978-3-030-72579-2_80/FIGURES/9

Naz, M., Raza, M. A., Tariq, M., Shackira, A. M., & Fan, X. (2022). Unraveling a correlation between environmental contaminants and human health. *Microbial Consortium and Biotransformation for Pollution Decontamination*, 27–40. https://doi.org/10.1016/B978-0-323-91893-0.00005-5

OECD. (2021). Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. *OECD Series on Risk Management - No.61*, *61*.

Panieri, E., Baralic, K., Djukic-Cosic, D., Djordjevic, A. B., & Saso, L. (2022). PFAS Molecules: A Major Concern for the Human Health and the Environment. *Toxics 2022, Vol. 10, Page 44*, *10*(2), 44. https://doi.org/10.3390/TOXICS10020044

Samuel, G. O., Hoffmann, S., Wright, R. A., Lalu, M. M., Patlewicz, G., Becker, R. A., DeGeorge, G. L., Fergusson, D., Hartung, T., Lewis, R. J., & Stephens, M. L. (2016). Guidance on assessing the methodological and reporting quality of toxicologically relevant studies: A scoping review. *Environment International*, *92–93*, 630–646. https://doi.org/10.1016/J.ENVINT.2016.03.010

Schymanski, E. L., Zhang, J., Thiessen, P. A., Chirsir, P., Kondic, T., & Bolton, E. E. (2023). *Per- and polyfluoroalkyl substances (PFAS) in PubChem: 7 million and growing*. https://doi.org/10.26434/CHEMRXIV-2023-J823Z

Trang, B., Li, Y., Xue, X. S., Ateia, M., Houk, K. N., & Dichtel, W. R. (2022). Low-temperature mineralization of perfluorocarboxylic acids. *Science*, *377*(6608), 839–845. https://doi.org/10.1126/SCIENCE.ABM8868/SUPPL_FILE/SCIENCE.ABM8868_SM.PDF

Verma, S., Lee, T., Sahle-Demessie, E., Ateia, M., & Nadagouda, M. N. (2023). Recent advances on PFAS degradation via thermal and nonthermal methods. *Chemical Engineering Journal Advances*, *13*, 100421. https://doi.org/10.1016/J.CEJA.2022.100421

Wang, Z., Buser, A. M., Cousins, I. T., Demattio, S., Drost, W., Johansson, O., Ohno, K., Patlewicz, G., Richard, A. M., Walker, G. W., White, G. S., & Leinala, E. (2021). A New OECD Definition for Per- And Polyfluoroalkyl Substances. *Environmental Science and Technology*, *55*(23), 15575–15578. https://doi.org/10.1021/ACS.EST.1C06896/ASSET/IMAGES/LARGE/ES1C06896_0002.JPEG

Whitehead, H. D., Venier, M., Wu, Y., Eastman, E., Urbanik, S., Diamond, M. L., Shalin, A., Schwartz-Narbonne, H., Bruton, T. A., Blum, A., Wang, Z., Green, M., Tighe, M., Wilkinson, J. T., McGuinness, S., & Peaslee, G. F. (2021). Fluorinated Compounds in North American Cosmetics. *Environmental Science and Technology Letters*, *8*(7), 538–544. https://doi.org/10.1021/ACS.ESTLETT.1C00240/ASSET/IMAGES/LARGE/EZ1C00240_0001.JPEG

Zarębska, M., & Bajkacz, S. (2023). Poly– and perfluoroalkyl substances (PFAS) - recent advances in the aquatic environment analysis. *TrAC Trends in Analytical Chemistry*, *163*, 117062. https://doi.org/10.1016/J.TRAC.2023.117062

Zhang, Q., He, Y., Cheng, R., Li, Q., Qian, Z., & Lin, X. (2022). Recent advances in toxicological research and potential health impact of microplastics and nanoplastics in vivo. *Environmental Science and Pollution Research 2022 29:27*, *29*(27), 40415–40448. https://doi.org/10.1007/S11356-022-19745-3

Zhang, Y., Peng, Z., Dong, Z., Wang, M., & Jiang, C. (2022). Twenty years of achievements in China’s implementation of the Stockholm Convention. *Frontiers of Environmental Science and Engineering*, *16*(12), 1–11. https://doi.org/10.1007/S11783-022-1587-7/METRICS

Appendix I

***Table 2** Overview of papers with relevance, based on inclusion criteria (see text), with a summary and an evaluation of conflict of interest. Full references of the relevant papers can be found in the reference list of the review.*

Paper reference (SCOPUS)	Relevance	Summary of reason for in-/exclusion	Potential conflict of interest	DOI
Liu, D., Yan, S., Wang, P., Chen, Q., Liu, Y., Cui, J., ... & Gao, Y. (2023). Perfluorooctanoic acid (PFOA) exposure in relation to the kidneys: A review of current available literature. Frontiers in Physiology, 14, 1103141.	Relevant	Shows that PFOA expose leads to nephrotoxicity	No	10.3389/fphys.2023.1103141
Azhagiya Singam, E. R., Durkin, K. A., La Merrill, M. A., Furlow, J. D., Wang, J.-C., & Smith, M. T. (2023). The vitamin D receptor as a potential target for the toxic effects of per- and polyfluoroalkyl substances (PFASs): An in-silico study. Environmental Research, 217.	Relevant	Shows that PFOA has a strong affinity to Vitamin D receptor, potentially causing adverse health related effects	No	10.1016/j.envres.2022.114832
Mantripragada, S., Obare, S. O., & Zhang, L. (2022). Addressing Short-Chain PFAS Contamination in Water with Nanofibrous Adsorbent/Filter Material from Electrospinning. Accounts of Chemical Research.	Relevant	Shows that short-chain-PFAS are toxic	No	10.1021/acs.accounts.2c00591
Liu, M., Zhang, L., Han, L., Zhang, Y., Gu, C., & Huang, J. (2023). Mechanism Analysis of PFHxS Purification in Water Using Nanofiltration under the Coexistence of Sodium Alginate and Ca2+ Based on DFT. Water (Switzerland), 15(4)	Relevant	Explains that PFHxS is a harmful substance and shows novel technique to remove it from water matrices	No	10.3390/w15040792
Zarębska, M., & Bajkacz, S. (2023). Poly– and perfluoroalkyl substances (PFAS)—Recent advances in the aquatic environment analysis. TrAC - Trends in Analytical Chemistry, 163.	Relevant	Explains negative impact on (aquatic) environment, water, accumulation PFAS in environment and organisms.	No	10.1016/j.trac.2023.117062
Kavusi, E., Shahi Khalaf Ansar, B., Ebrahimi, S., Sharma, R., Ghoreishi, S. S., Nobaharan, K., Abdoli, S., Dehghanian, Z., Asgari Lajayer, B., Senapathi, V., Price, G. W., & Astatkie, T. (2023). Critical review on phytoremediation of polyfluoroalkyl substances from environmental matrices: Need for global concern. Environmental Research, 217	Relevant	Highlights the need to remove PFAS out of our environment due to its harmful effects	No	10.1016/j.envres.2022.114844

Meegoda, J. N., Bezerra de Souza, B., Casarini, M. M., & Kewalramani, J. A. (2022). A Review of PFAS Destruction Technologies. International Journal of Environmental Research and Public Health, 19(24).	Relevant	Explains that destructive PFAS technologies can remediate the harmful effects. Examines PFAS destruction technologies	No	10.3390/ijerph192416397
Chang, P.-H., Chen, C.-Y., Mukhopadhyay, R., Chen, W., Tzou, Y.-M., & Sarkar, B. (2022). Novel MOF-808 metal–organic framework as highly efficient adsorbent of perfluorooctane sulfonate in water. Journal of Colloid and Interface Science, 623, 627–636.	Relevant	Shows that MOM-808 is an efficient adsorbent for PFOS in water matrices.	No	10.1016/j.jcis.2022.05.050
He, A., Lu, Y., Chen, F., Li, F., Lv, K., Cao, H., Sun, Y., Liang, Y., Li, J., Zhao, L., Zhang, X., Li, L., Wang, Y., & Jiang, G. (2022). Exploring the origin of efficient adsorption of poly- and perfluoroalkyl substances in household point-of-use water purifiers: Deep insights from a joint experimental and computational study. Science of the Total Environment, 831.	Relevant	Explains that full-scale PFAS removal is inefficient and that household water purifiers can filter out PFAS in tap water	No	10.1016/j.scitotenv.2022.154988
Kang, Y.-G., Birch, Q. T., Nadagouda, M. N., & Dionysiou, D. D. (2023). Advanced destruction technologies for PFAS in soils: Progress and challenges. Current Opinion in Environmental Science and Health, 33.	Relevant	Explains strong persistence in environment. Examines recent potential destructive PFAS treatments to mitigate health and environmental impact.	No	10.1016/j.coesh.2023.100459
Verma, S., Lee, T., Sahle-Demessie, E., Ateia, M., & Nadagouda, M. N. (2023). Recent advances on PFAS degradation via thermal and nonthermal methods. Chemical Engineering Journal Advances, 13.	Relevant	Explains strong persistence in environment. Examines various PFAS destruction methods.	No	10.1016/j.ceja.2022.100421
Koban, L. A., & Pfluger, A. R. (2023). Per- and polyfluoroalkyl substances (PFAS) exposure through munitions in the Russia–Ukraine conflict. Integrated Environmental Assessment and Management, 19(2), 376–381.	Relevant	Explains PFAS bioaccumulation in living organisms and PFAS being able to be released into the environment as aerosols.	No	10.1002/ieam.4672
Suran, M. (2022). EPA Takes Action Against Harmful "forever Chemicals" in the US Water Supply. JAMA, 328(18), 1795–1797.	Not relevant	appears to be a news article instead of a peer reviewed article		doi:10.1001/jama.2022.12678
Lei, S.-N., & Cong, H. (2022). Fluorescence detection of perfluorooctane sulfonate in water employing a tetraphenylethylene-derived dual macrocycle	Not relevant	only discusses a new fluorescent PFOS detector.		10.1016/j.cclet.2021.08.068

BowtieCyclophane. Chinese Chemical Letters, 33(3), 1493–1496.				
Whitehead, H. D., Venier, M., Wu, Y., Eastman, E., Urbanik, S., Diamond, M. L., Shalin, A., Schwartz-Narbonne, H., Bruton, T. A., Blum, A., Wang, Z., Green, M., Tighe, M., Wilkinson, J. T., McGuinness, S., & Peaslee, G. F. (2021). Fluorinated Compounds in North American Cosmetics. Environmental Science and Technology Letters, 8(7), 538–544.	Relevant	foundations, mascaras, and lip products had the highest proportion of products with high total fluorine 6:2 and 8:2 fluorotelomer compounds, including alcohols, methacrylates, and phosphate esters, were most detected. These compounds are precursors to PFCAs that are known to be harmful.	No	10.1021/acs.estlett.1c00240
Phung, T. V., Nguyen, T. N., Phan Thi, L. A., Pham, H. V., & Duong, H. A. (2021). Determination of per-and polyfluoroalkyl substances in craft villages and industrial environments of Vietnam. Journal of Analytical Methods in Chemistry, 2021, 1-9.	Not relevant	Only measured wastewater samples obtained from metal-plating and textile-dyeing companies, as well as surface water samples surrounding these companies		10.1155/2021/5564994
Jane L Espartero, L., Yamada, M., Ford, J., Owens, G., Prow, T., & Juhasz, A. (2022). Health-related toxicity of emerging per- and polyfluoroalkyl substances: Comparison to legacy PFOS and PFOA. Environmental Research, 212.	Relevant	Relevant: Shows that recent reviews showed that exposure to PFAS causes several adverse health impacts, including pancreatic dysfunction, vitamin D deficiency, neurological function and Type 2 diabetes, among others. It highlights that other lesser known PFAS (besides PFOA and PFOS) can cause such effects.	No	10.1016/j.envres.2022.113431
Lukač Reberski, J., Selak, A., Lapworth, D. J., Maurice, L. D., Terzić, J., Civil, W., & Stroj, A. (2023). Emerging organic contaminants in springs of the highly karstified Dinaric region. Journal of Hydrology, 621.	Not relevant	only mentions that PFBS exceeded EU standards and occurred at concentrations that are likely to be harmful to ecosystems. Does not provide any additional information.		10.1016/j.jhydrol.2023.129583
Baralić, K., Živančević, K., Bozic, D., & Đukić-Ćosić, D. (2023). Probiotic cultures as a potential protective strategy against the toxicity of environmentally relevant chemicals: State-of-the-art knowledge. Food and Chemical Toxicology, 172.	Not relevant	only discusses potential protective effects of different probiotic strains against PFAS, among others. This is outside the scope of this review.		10.1016/j.fct.2022.113582
Moro, G., Chiavaioli, F., Zubiate, P., Del Villar, I., Baldini, F., De Wael, K., Moretto, L. M., & Giannetti, A. (2023). Albumin-Based Optical and Electrochemical Biosensors for PFAS Detection: A Comparison. Lecture Notes in Electrical Engineering, 999, 1–15.	Not relevant	discusses a novel albumin protein biosensing strategy to monitor perfluoroalkyl carboxylic acids, as they are fatty acid mimics		10.1007/978-3-031-25706-3_1
Landrigan, P. J., Raps, H., Cropper, M., Bald, C., Brunner, M.,	Not relevant	this paper focuses on plastics		doi.org/10.5334/aogh.4056

Canonizado, E. M., Charles, D., Chiles, T. C., Donohue, M. J., Enck, J., Fenichel, P., Fleming, L. E., Ferrier-Pages, C., Fordham, R., Gozt, A., Griffin, C., Hahn, M. E., Haryanto, B., Hixson, R., … Dunlop, S. (2023). The Minderoo-Monaco Commission on Plastics and Human Health. Annals of Global Health, 89(1).				
Fu, S., Zhang, Y., Xu, X., Dai, X., & Zhu, L. (2022). Peroxymonosulfate activation by iron self-doped sludge-derived biochar for degradation of perfluorooctanoic acid: A singlet oxygen-dominated nonradical pathway. Chemical Engineering Journal, 450.	Relevant	discusses the use of iron species self-doped biochar (ISBC) as an efficient activation method of peroxymonosulfate (PMS) to degrade PFOA.	No	10.1016/j.cej.2022.137953
Zhang, Y., Peng, Z., Dong, Z., Wang, M., & Jiang, C. (2022). Twenty years of achievements in China's implementation of the Stockholm Convention. Frontiers of Environmental Science and Engineering, 16(12).	Relevant	Mentions how after 20 years since the implementation of the Stockholm Convention, PFOS/PFOSF (Perfluorooctane sulfonic acid/Perfluorooctane sulfonyl fluoride) concentrations have lowered in water bodies in China.	No	10.1007/s11783-022-1587-7
Trang, B., Li, Y., Xue, X.-S., Ateia, M., Houk, K. N., & Dichtel, W. R. (2022). Low-temperature mineralization of perfluorocarboxylic acids. Science, 377(6608), 839–845.	Relevant	reports that PFCAs can be mineralized using a sodium hydroxide–mediated defluorination pathway as a destruction method.	No	10.1126/science.abm8868
Wenmin, Z., Guancheng, L., Wende, M., Min, F., & Lan, Z. (2022). Application progress of covalent organic framework materials in extraction of toxic and harmful substances. Chinese Journal of Chromatography (Se Pu), 40(7), 600–609.	Not relevant	this papers focus is on covalent organic frameworks (COFs)		10.3724/SP.J.1123.2021.12004
Dettori, M., Arghittu, A., Deiana, G., Castiglia, P., & Azara, A. (2022). The revised European Directive 2020/2184 on the quality of water intended for human consumption. A step forward in risk assessment, consumer safety and informative communication. Environmental Research, 209.	Relevant	EU regulation wants the sum concentration of PFAS to be kept under a certain level	No	https://doi.org/10.1016/j.envres.2022.112773
Mulhern, R., Grubbs, B., Gray, K., & MacDonald Gibson, J. (2022). User experience of point-of-use water treatment for private wells in North Carolina: Implications for outreach and well stewardship. Science of the Total Environment, 806.	Not relevant	discusses a household pilot-scale point-of-use (POU) water treatment system using an activated carbon filter designed to filter out two long-chain PFAS, but the paper only focuses on participants'		10.1016/j.scitotenv.2021.150448

		perceived vulnerability to well water contamination.		
Mulabagal, V., Baah, D. A., Egiebor, N. O., Sajjadi, B., Chen, W.-Y., Viticoski, R. L., & Hayworth, J. S. (2022). Biochar from Biomass: A Strategy for Carbon Dioxide Sequestration, Soil Amendment, Power Generation, CO2 Utilization, and Removal of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) in the Environment. In Handbook of Climate Change Mitigation and Adaptation: Third Edition (Vol. 2, pp. 1023–1086).	Relevant	explains that biochars derived from biomaterials are effective in the removal of a variety of pollutants, such as PFAS.	No	10.1007/978-3-030-72579-2_80
Naz, M., Raza, M. A., Tariq, M., Shackira, A. M., & Fan, X. (2022). Unraveling a correlation between environmental contaminants and human health. In Microbial Consortium and Biotransformation for Pollution Decontamination (pp. 27–40).	Relevant	This book chapter describes the complete epidemiological literature and representative case reports connected to emerging contaminants and humans such as perfluorinated chemicals. It has been found that they have infrequent but statistically significant associations with cancer and reproductive hazards.	No	10.1016/B978-0-323-91893-0.00005-5
Gooty, J. M., Srinivasulu, M., Mosquera, J. A. N., & Llaguno, S. N. S. (2022). Occurrence and fate of micropollutants in surface waters. In Environmental Micropollutants: A Volume in Advances in Pollution Research (pp. 233–269).	Not relevant	Not relevant: explains that emerging contaminants such as PFAS can behave as endocrine disruptors due to their bioaccumulation. Does not provide any additional information.		10.1016/B978-0-323-90555-8.00023-4
Clark, R. B., & Dick, J. E. (2021). Towards deployable electrochemical sensors for per-And polyfluoroalkyl substances (PFAS). Chemical Communications, 57(66), 8121–8130.	Not relevant	only discusses the use of molecularly imprinted polymers (MIPs) as a sensor to detect PFAS.		doi.org/10.1039/d1cc02641k
Khan, F. S. A., Mubarak, N. M., Tan, Y. H., Khalid, M., Karri, R. R., Walvekar, R., Abdullah, E. C., Nizamuddin, S., & Mazari, S. A. (2021). A comprehensive review on magnetic carbon nanotubes and carbon nanotube-based buckypaper for removal of heavy metals and dyes. Journal of Hazardous Materials, 413.	Not relevant	does not discuss PFAS at all		doi.org/10.1016/j.jhazmat.2021.125375
Elanchezhiyan, S. S., Prabhu, S. M., Karthikeyan, P., & Park, C. M. (2021). Efficient and selective sequestration of perfluorinated compounds and hexavalent chromium ions using a	Relevant	This study proposes a multifunctional magnetic adsorbent – a cerium-incorporated ferrite (CMF) decorated polyaniline (PANI) – to adsorb PFAS out of mixtures	No	10.1016/j.molliq.2021.115336

multifunctional spinel matrix decorated carbon backbone N-rich polymer and their mechanistic investigations. Journal of Molecular Liquids, 326, 115336.		of perfluorinated chemicals with heavy metals. It showed higher adsorption capacities toward the perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), and hexavalent chromium (Cr(VI)) ions than the individual forms.		
Köck-Schulmeyer, M., Ginebreda, A., Petrovic, M., Giulivo, M., Aznar-Alemany, Ò., Eljarrat, E., ... & Barceló, D. (2021). Priority and emerging organic microcontaminants in three Mediterranean river basins: Occurrence, spatial distribution, and identification of river basin specific pollutants. Science of the Total Environment, 754, 142344.	Not relevant	This work provides raw chemical data from different families of microcontaminants found in three selected Mediterranean rivers. It only shows that perfluoronated compounds (PFCs) are present in the Sava Mediterranean River. Does not provide any additional information.		10.1016/j.scitotenv.2020.142344

Paper title (PubMed)	**Relevance**	**Summary**	**Potential conflict of interest**	**DOI**
Leung, S. C. E., Shukla, P., Chen, D., Eftekhari, E., An, H., Zare, F., ... & Li, Q. (2022). Emerging technologies for PFOS/PFOA degradation: A review. Science of The Total Environment, 153669.	Relevant	Discusses various PFAS degradation processes	No	10.1016/j.scitotenv.2022.153669
Zhang, Q., He, Y., Cheng, R., Li, Q., Qian, Z., & Lin, X. (2022). Recent advances in toxicological research and potential health impact of microplastics and nanoplastics in vivo. Environmental Science and Pollution Research, 29(27), 40415-40448.	Relevant	highlights a potential interaction of micro/nano plastics (MP/NPs) with pollutants such as perfluorinated compounds.	No	10.1007/s11356-022-19745-3
National Academies of Sciences, Engineering, and Medicine. (2022). Guidance on PFAS exposure, testing, and clinical follow-up.	Not relevant	It recommends the CDC to update its clinical guidance to recommend that clinicians offer PFAS blood testing to patients who are likely to have a history of elevated exposure. This is outside the scope of this review.		10.17226/26156
Beale, D. J., Sinclair, G. M., Shah, R., Paten, A. M., Kumar, A., Long, S. M., ... & Jones, O. A. (2022). A review of omics-based PFAS exposure studies reveals common biochemical response pathways. Science of The Total Environment, 845, 157255.	Relevant	reviews omics-based PFAS exposure studies using environmentally relevant exposure levels. It shows common biochemical response pathways. A major one is the pentose phosphate shunt pathway	No	10.1016/j.scitotenv.2022.157255

Sun, Q., Wang, T., Zhan, X., Hong, S., Lin, L., Tan, P., ... & Khim, J. S. (2023). Legacy and novel perfluoroalkyl substances in raw and cooked squids: Perspective from health risks and nutrient benefits. Environment International, 108024.	Not relevant	Relative higher concentrations of PFAS in squid were found in the subtropical zone of southern China compared to those of the temperate zone of northern China. Cooking methods have a significant contribution to eliminating PFAS (in squids). Does not provide any additional information.		10.1016/j.envint.2023.108024
Deng, Y., Liang, Z., Lu, X., Chen, D., Li, Z., & Wang, F. (2021). The degradation mechanisms of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) by different chemical methods: A critical review. Chemosphere, 283, 131168.	Relevant	provides a comprehensive review on the degradation mechanisms of PFOA and PFOS. Overall, the degradation pathways of PFAS are associated closely with their head groups and chain lengths, and H/F exchange and chain shortening were found to be predominant degradation mechanisms.	No	10.1016/j.chemosphere.2021.131168
Barbo, N., Stoiber, T., Naidenko, O. V., & Andrews, D. Q. (2023). Locally caught freshwater fish across the United States are likely a significant source of exposure to PFOS and other perfluorinated compounds. Environmental Research, 220, 115165.	Relevant	Relevant: The two datasets indicate that an individual's consumption of freshwater fish is potentially a significant source of exposure to perfluorinated compounds. PFOS was the largest contributor to total PFAS levels.	No	10.1016/j.envres.2022.115165
Sun, J., Zhang, L., Zhou, F., Shaw, S., Roos, A., Berger, M., ... & Chen, D. (2022). Hepatic fatty acid profiles associated with exposure to emerging and legacy halogenated contaminants in two harbor seal populations across the North Atlantic. Environmental Science & Technology, 56(3), 1830-1840.	Not relevant	shows that PFAS were present in seals by investigating fatty acid profiles. Does not provide any additional information.		10.1021/acs.est.1c06512
Ciccarelli, D., Braddock, D. C., Surman, A. J., Arenas, B. I. V., Salal, T., Marczylo, T., ... & Barron, L. P. (2023). Enhanced selectivity for acidic contaminants in drinking water: From suspect screening to toxicity prediction. Journal of Hazardous Materials, 448, 130906.	Not relevant	does not mention PFAS at all		10.1016/j.jhazmat.2023.130906
Guo, M., Wu, F., Geng, Q., Wu, H., Song, Z., Zheng, G., ... & Tan, Z. (2023). Perfluoroalkyl	Not relevant	PFOA, PFOS, PFNA, PFOSA, and PFUdA were more predominantly and frequently		10.1016/j.envpol.2023.121514

substances (PFASs) in aquatic products from the Yellow-Bohai Sea coasts, China: Concentrations and profiles across species and regions. Environmental Pollution, 327, 121514.		detected than other PFAS in aquatic products from the coasts of the Yellow-Bohai Sea in China. Does not provide any additional information.		
Du, D., Lu, Y., Li, Q., Zhou, Y., Cao, T., Cui, H., & Han, G. (2023). Estimating industrial process emission and assessing carbon dioxide equivalent of perfluorooctanoic acid (PFOA) and its salts in China. The Science of the Total Environment, 867, 161507.	Relevant	China released about 38.19 tons PFOA/PFO (perfluorooctanoic acid and its salts) into the atmosphere through industrial activities in 2019, 97 % of which originated from the production of fluoropolymers.	No	10.1016/j.scitotenv.2023.161507

Appendix II

Recent scientific literature on PFAS definitions, exposure, hazards and risks

Ankley, G. T., Cureton, P., Hoke, R. A., Houde, M., Kumar, A., Kurias, J., ... & Valsecchi, S. (2021). Assessing the ecological risks of per-and polyfluoroalkyl substances: Current state-of-the science and a proposed path forward. Environmental toxicology and chemistry, 40(3), 564-605.
https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4869

Panieri, E., Baralic, K., Djukic-Cosic, D., Buha Djordjevic, A., & Saso, L. (2022). PFAS molecules: a major concern for the human health and the environment. Toxics, 10(2), 44. https://www.mdpi.com/2305-6304/10/2/44

Wang, Z., Buser, A. M., Cousins, I. T., Demattio, S., Drost, W., Johansson, O., ... & Leinala, E. (2021). A new OECD definition for per-and polyfluoroalkyl substances. Environmental science & technology, 55(23), 15575-15578.
https://pubs.acs.org/doi/full/10.1021/acs.est.1c06896

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., De Voogt, P., ... & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins. Integrated environmental assessment and management, 7(4), 513-541.
https://setac.onlinelibrary.wiley.com/doi/full/10.1002/ieam.258

Recent scientific literature supporting position A (“Fluoropolymers that are manufactured without the use of PFAS polymerization aids should be exempted from any regulatory initiative, and their uses should be allowed without any restriction”). *Authorships in these papers give rise to a conflict of interest, as described in section 3.2.3 of the report.*

Améduri, B., & Hori, H. (2023). Recycling and the end of life assessment of fluoropolymers: recent developments, challenges and future trends. Chemical Society Reviews.
https://pubs.rsc.org/en/content/articlelanding/2023/cs/d2cs00763k/unauth

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., ... & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. Integrated Environmental Assessment and Management, 14(3), 316-334.
https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035

Korzeniowski, S. H., Buck, R. C., Newkold, R. M., kassmi, A. E., Laganis, E., Matsuoka, Y., ... & Musio, S. (2023). A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management, 19(2), 326-354.
https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4646

Ameduri, B. (2023). Fluoropolymers: A special class of per-and polyfluoroalkyl substances (PFASs) essential for our daily life. Journal of Fluorine Chemistry, 267, 110117.
https://www.sciencedirect.com/science/article/pii/S0022113923000325?via%3Dihub

Buck, R. C., Korzeniowski, S. H., Laganis, E., & Adamsky, F. (2021). Identification and classification of commercially relevant per-and poly-fluoroalkyl substances (PFAS). Integrated environmental assessment and management, 17(5), 1045-1055. https://setac.onlinelibrary.wiley.com/doi/full/10.1002/ieam.4450

Ameduri, B., Sales, J., & Schlipf, M. (2023). Developments in fluoropolymer manufacturing technology to remove intentional use of PFAS as polymerization aids. Journal of Fluorine Chemistry, 267, 110117. https://icrl.lexxion.eu/article/ICRL/2023/1/5

Recent scientific literature supporting position B ("There is insufficient public data available on the compositions, and hence the potential environmental hazards and risks of fluoropolymers remains uncertain, which precludes to treat them as a harmless subclass of PFAS").

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A never-ending story of per-and polyfluoroalkyl substances (PFASs)?. https://pubs.acs.org/doi/full/10.1021/acs.est.6b04806

Cousins, I. T., DeWitt, J. C., Glüge, J., Goldenman, G., Herzke, D., Lohmann, R., ... & Wang, Z. (2020). Strategies for grouping per-and polyfluoroalkyl substances (PFAS) to protect human and environmental health. Environmental Science: Processes & Impacts, 22(7), 1444-1460. https://pubs.rsc.org/en/content/articlehtml/2020/em/d0em00147c

Lohmann, R., & Letcher, R. J. (2023). The universe of fluorinated polymers and polymeric substances and potential environmental impacts and concerns. Current Opinion in Green and Sustainable Chemistry, 100795. https://www.sciencedirect.com/science/article/pii/S2452223623000445?via%3Dihub

Brunn, H., Arnold, G., Körner, W., Rippen, G., Steinhäuser, K. G., & Valentin, I. (2023). PFAS: forever chemicals—persistent, bioaccumulative and mobile. Reviewing the status and the need for their phase out and remediation of contaminated sites. Environmental Sciences Europe, 35(1), 1-50. https://enveurope.springeropen.com/articles/10.1186/s12302-023-00721-8

Cousins, I. T., Johansson, J. H., Salter, M. E., Sha, B., & Scheringer, M. (2022). Outside the safe operating space of a new planetary boundary for per-and polyfluoroalkyl substances (PFAS). Environmental Science & Technology, 56(16), 11172-11179. https://pubs.acs.org/doi/full/10.1021/acs.est.2c02765

Lohmann, R., Cousins, I. T., DeWitt, J. C., Gluge, J., Goldenman, G., Herzke, D., ... & Wang, Z. (2020). Are fluoropolymers really of low concern for human and environmental health and separate from other PFAS? Environmental science & technology, 54(20), 12820-12828. https://pubs.acs.org/doi/full/10.1021/acs.est.0c03244

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., DeWitt, J. C., Knappe, D. R., ... & Blum, A. (2020). Scientific basis for managing PFAS as a chemical class. Environmental Science & Technology Letters, 7(8), 532-543. https://pubs.acs.org/doi/full/10.1021/acs.estlett.0c00255

Recent scientific literature on essential use

Cousins, I. T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., ... & DeWitt, J. C. (2019). The concept of essential use for determining when uses of PFASs can be phased out. Environmental Science: Processes & Impacts, 21(11), 1803-1815. https://pubs.rsc.org/en/content/articlehtml/2019/em/c9em00163h

Cousins, I. T., De Witt, J. C., Glüge, J., Goldenman, G., Herzke, D., Lohmann, R., ... & Wang, Z. (2021). Finding essentiality feasible: common questions and misinterpretations concerning the "essential-use" concept. Environmental Science: Processes & Impacts, 23(8), 1079-1087. https://pubs.rsc.org/en/content/articlelanding/2021/EM/D1EM00180A#cit1

Glüge, J., London, R., Cousins, I. T., DeWitt, J., Goldenman, G., Herzke, D., ... & Scheringer, M. (2021). Information requirements under the essential-use concept: PFAS case studies. Environmental science & technology, 56(10), 6232-6242. https://pubs.acs.org/doi/pdf/10.1021/acs.est.1c03732

Year of publishing
2023

More information
Dr. Stefan Kools
T +31 (0)30 60 69 511
E [redacted]@kwrwater.nl

Keywords
PFAS; systematic review, restriction

Groningenhaven 7
Postbus 1072
3430 BB Nieuwegein
The Netherlands

T +31 (0)30 60 69 511
E [redacted]@kwrwater.nl
I www.kwrwater.nl

2023.053 | 29 June 2023 ©KWR

All rights reserved by KWR. No part of this publication may be reproduced, stored in an automatic database, or transmitted in any form or by any means, be it electronic, mechanical, by photocopying, recording, or otherwise, without the prior written permission of KWR.