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Communities at Risk: PFAS Contamination Near Industrial Sites and Separation Strategies

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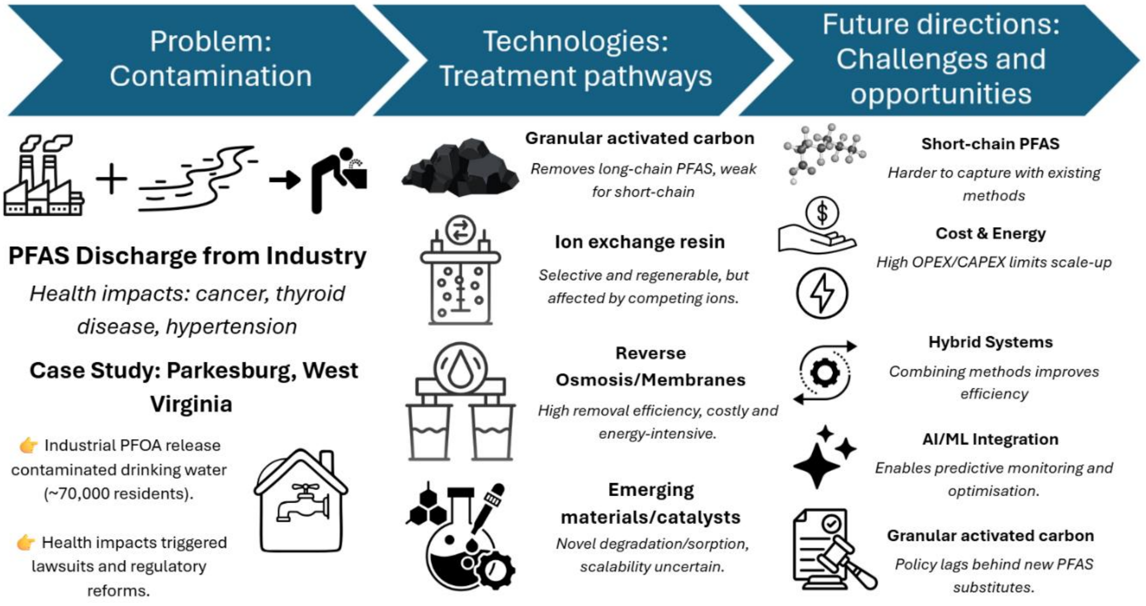
Graphical Abstract



Abstract

This review examines the growing challenge of per- and polyfluoroalkyl substances (PFAS) contamination in small communities located near chemical production facilities, with particular attention to perfluorooctanoic acid (PFOA). The case of Parkersburg, West Virginia highlights the scale of the problem, where adverse health outcomes and community exposure culminated in over USD $670 million in remediation and legal settlements.[1] To mitigate these risks, multiple separation technologies have been evaluated, including granular activated carbon (GAC), ion exchange resins, and high-pressure membrane processes such as reverse osmosis and nanofiltration. Emerging nanomaterials are also being investigated for their high selectivity and adsorption capacity.[2] However, significant challenges remain in addressing short-chain PFAS, scaling up pilot processes, managing energy and cost demands, and preventing harmful treatment by-products. Integrating artificial intelligence and machine learning (AI/ML) into monitoring and optimisation frameworks offers opportunities to improve system efficiency and predictive maintenance.[3] Beyond technical considerations, PFAS remediation has far-reaching environmental, societal and economic implications, from reducing long-term health burdens to preventing the continued degradation of local water systems. Additionally, effective PFAS remediation advances progress toward several United

Nations Sustainable Development Goals, particularly SDG 3 (Good Health and Well-Being), SDG 6 (Clean Water and Sanitation), and SDG 12 (Responsible Consumption and Production).[4]

Keywords: PFAS, Separation, GAC, Ion Exchange Resin, Reverse Osmosis

1. Introduction

1.1 Context and relevance

Per- and polyfluoroalkyl substances, including compounds such as PFOA, are a class of synthetic chemicals with strong carbon-fluorine bonds that make them extremely stable, persistent and non-biodegradable. Since the 1950s, they have been widely used in non-stick cookware, waterproof fabrics, food packaging, firefighting foams, and industrial coatings, earning the term “forever chemicals”.[3] Figure 1 illustrates the chemical structure of common PFAS molecules.

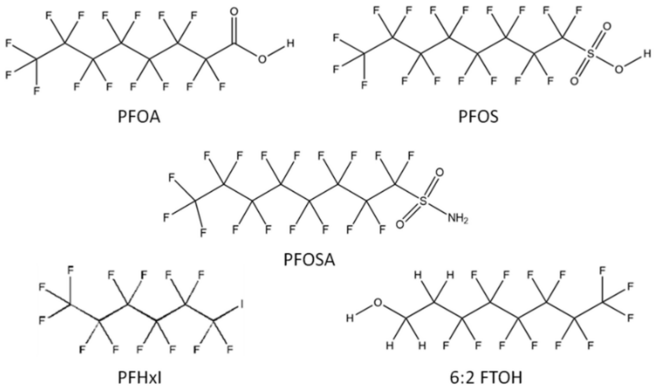


Figure 1 – PFAS structure of common molecules[5]

PFAS enter the environment through multiple pathways, including industrial discharges and wastewater from manufacturing. Conventional wastewater treatment processes redistribute rather than remove PFAS, and PFAS from land-applied biosolids, landfills, and fire-fighting foam sites can leach into the surface and groundwater.[3] Contaminated water supplies have become the primary route of human exposure, with PFAS accumulating in drinking water, and subsequently, in human bodies over time.[3]

1.2 Parkersburg, West Virgina case study

The Parkersburg, West Virginia case involved decades of PFOA (C8) discharges from DuPont’s Washington Works Teflon facility into the Ohio River and connected aquifers, contaminating municipal water, soils, and resident’s blood. The C8 health project linked this exposure to increased risks of thyroid disease, high cholesterol, pregnancy-induced hypertension, and kidney and testicular cancers, affecting approximately 300,000 residents and downstream communities.[1] Substantial social and economic impacts were experienced, including USD $670 million in settlements and ongoing costs for monitoring, remediation, and healthcare.

1.3 Size of the problem

While this review will focus on high concentration PFAS exposure, it must be acknowledged that low level PFAS exposure is a widespread and global problem. A recent study by the Australian Bureau of Statistics found PFOA at detectable levels in 99.1% of males and 98.3% of females. While Australia has relatively high PFAS concentrations, average levels of PFOA were lower than in the US, Canada and Europe.[6] If these levels are extrapolated to the world population, they indicate that PFAS such as PFOA are a potential threat to almost every human. High concentrations of PFAS can also be found in groundwater worldwide as can be seen in Figure 2. The health impact of these high concentration sites is difficult to estimate as both the number of people affected, and the magnitude of exposure vary from site to site and studies have not been conducted for every location. As a substitute for health data, an estimate based on number of exposure sites must be used. In Europe alone, the forever pollution project estimates more than 23000 contaminated sites and more than 2100 ‘hotspots’ where contamination levels exceed 100 ng/L. As these hotspot sites exceed safe limits significantly, they are far more dangerous and are likely responsible for the majority of PFAS related harm, both social and economic. A portion of this cost, specifically the price to remove all PFAS from the environment, was estimated by the same project as €95 billion over 20 years if only long chain PFAS were removed and production ceased immediately, or €2 trillion over the next 20 years if short and ultra-short chain PFAS were included in the removal and emissions continued (SDG12).[7] As this cost is currently not viable for most countries to bear, efforts should be focused on high concentration sites where removal efforts are more effective and have a higher impact.

1.4 Scope and Objectives

This review focuses on separation techniques used to remove PFAS, including PFOA, from drinking water in small communities located near chemical manufacturing facilities, where ingestion via water is the dominant exposure pathway. Grounded in the Parkersburg, West Virginia case study, the scope encompasses established and emerging technologies, including Granular Activated Carbon (GAC), anion exchange

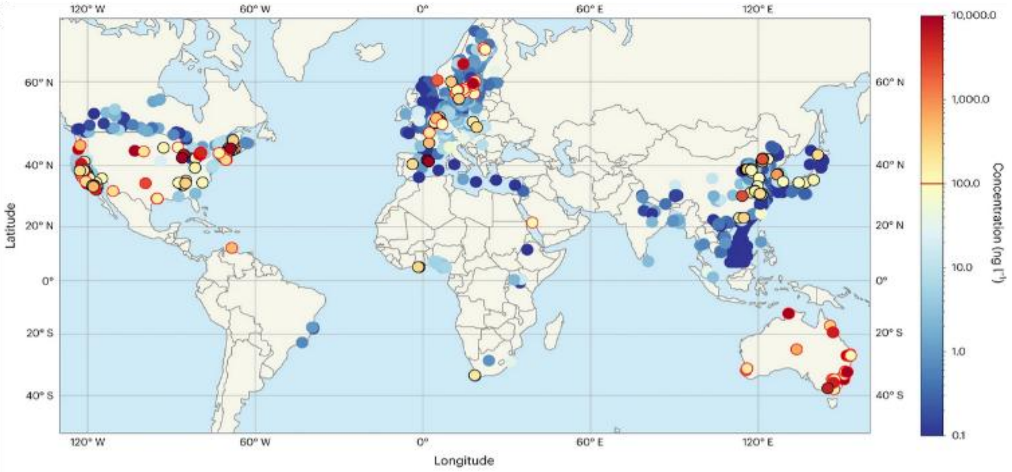


Figure 2: Groundwater PFAS levels globally, sites with PFAS levels above the EU limit for drinking water are circled in red for known contamination sources and black for unknown.[8]

resins, reverse osmosis, and novel sorbents or catalytic materials, with attention to relevant limitations and benefits, whilst examining real world case studies of these technologies. Topics beyond the scope of this review include destructive PFAS degradation processes such as electrochemical oxidation and plasma treatment, which, while promising fall outside the focus of separation-based techniques.[2]

Objectives:

1. Comparing current and emerging PFAS separation technologies assessing their effectiveness across long and short chain species, cost, energy requirements, and sustainability.
2. Evaluating the role of AI/ML in optimising treatment processes, including predictive modelling, monitoring, and hybrid system design.
3. Identifying key challenges and research gaps, including the removal of short term PFAS, scalability limitations, costs, and treatment by-products.
4. Quantifying the social and economic impacts of PFAS contamination in high-risk communities, including potential healthcare savings, remediation costs, and long-term benefits of early intervention.

1.5 Literature Overview

- Key findings from studies:
    - GAC (2.1.1): Effective for long-chain PFAS removal, but diminishing efficacy for short-chain variants
    - Ion Exchange Resins (2.1.2): Targeted removal, regenerable, but may be less effective for short-chain
    - RO (2.1.3): broad removal capabilities but expensive/energy intensive
    - Emerging materials/techniques
- Gaps in current research
    - Limited methods for short chain PFAS
    - Challenges in scale-up
    - Need for integration of predictive technologies to optimise treatment processes (AI)
- Major research questions:
    - How can short chained PFAS effectively be addressed?
    - How can hybrid systems (two or more PFAS removal techniques) be used to capitaliase on their strengths and compensate for limitations.
    - In what ways can AI/ML improve monitoring and optimisation of separation processes?
    - How can sustainability considerations (energy consumption, cost, waste management) be incorporated into treatment design?
    - Where should PFAS removal systems be implemented? (Point of production, general water treatment or point of use)

2. State of the Art in Advanced Separation Strategies

2.1 Current Methodologies

2.1.1 Granular Activated Carbon

Granular Activated Carbon (GAC) is a common resource used to separate PFAS from water and soil. It is carbon filtration made from raw organic materials that are carbon rich. Heat is used to activate the surface area of the carbon and remove chemicals that are dissolved in water.[9] It is a porous nonselective, hydrophobic adsorbent and is extremely effective due to its high surface area and microporous structure enabling it to trap and hold harmful compounds.

In South Australia a company called Bygen has deployed this method of PFAS removal by integrating GAC into a wetland system as part of a pilot project targeting PFAS contamination.[10] Over the 8-month trial, Bygen's GAC showed a significant increase in PFAS adsorption, from initially undetectable levels to over 1000 ng/g. In comparison, biochar, which is a carbon-rich material also used in soil purification, was used in the same trial only to capture around 100-200 ng/g of PFAS.

Bygen's GAC is made from organic waste materials like nut shells (almond, walnut, hazelnut) and sustainably sourced wood.[10] Through a controlled thermal activation process, these materials are converted into a microporous carbon that efficiently captures long-chain PFAS compounds like PFOA and PFOS, preventing their spread in the environment.

The total amount of water that passes through GAC filters significantly impacts both the filter's lifespan and the likelihood of PFAS breakthrough. As more water flows through the filter which is measured in bed volumes BVs, PFAS are adsorbed at different depths depending on how strongly they bind to the carbon.

At low bed volumes (2,600 BVs), most pollutants are captured in the top layer of the GAC filter. As the number of treated bed volumes increases to around 7,300 BVs and beyond , the adsorption continues at varying rates, with certain PFAS compounds moving faster and reaching the bottom of the filter bed earlier than others. This uneven movement means that weaker-binding PFAS compounds may break through the filter earlier, reducing overall filtration process effectiveness over time. Monitoring and frequently replacing the GAC is crucial in order to maintaining effective PFAS removal**.**

2.1.2 Ion Exchange Resins

Ion exchange resins are a practical and innovative technology for removing PFAS from contaminated water. Ion exchange resins are porous, polymer-based beads that swap charged ions from water with ions attached to the resin's surface. In anion exchange, negatively charged ions on the resin are replaced by other negatively charged contaminants in the water: such as PFAS.[11] Ion exchange resins have proven highly effective at capturing PFAS, which are also negatively charged.

These ion exchange resins work through a combination of hydrophobic and electrostatic interactions, making them particularly effective at targeting both short- and long-chain PFAS compounds. Because most PFAS molecules are anionic with low pKa values, strong-base anion exchange resins are especially well-suited for this task.

As opposed to other treatment technologies like (GAC), ion exchange offers both operational and financial advantages. Many systems use single-use resins, which securely binds PFAS and allows the used material to be safely disposed of in a landfill.

A case study, titled '*PFAS removal The forever chemical now has an expiration date* (published in the AWA Water e-Journal), tracked the performance of a regenerable ion exchange system between 2019 and 2023.[12] The treated water, taken from a site with significant PFAS contamination, showed incoming concentrations averaging around 16 µg/L, with occasional peaks surpassing 60 µg/L. The treatment train included a pre-treatment stage designed to remove competing ions such as nitrate, sulfate, and bicarbonate, as well as natural organic matter (NOM), which can reduce the resin's PFAS adsorption capacity. While not designed specifically for PFAS removal, this pre-treatment step did help lower total PFAS concentrations from roughly 10 µg/L to 4 µg/L before the water even reached the resin beds.

Throughout the operational period, the RIEX resin system performed well. Water passing through the lead and lag resin vessels showed marked reductions in PFAS concentration. This case study demonstrates that ion exchange resins, when properly supported by a tailored pre-treatment process and regeneration strategy, can provide a reliable and cost-effective solution for PFAS removal.

2.1.3 Membrane Processes (RO/NF)

High-pressure membrane processes, such as nanofiltration (NF) and reverse osmosis (RO), are among the most effective technologies available for removing long chain PFAS from water. This removal system works by forcing water through a semi-permeable membrane under high pressure and physically separating PFAS molecules based on size and charge. They have shown a strong performance in eliminating long-chain PFAS, such as PFOA and PFOS, which are among the most studied.

However, the effectiveness of these membranes in removing shorter-chain or lesser-known PFAS compounds is uncertain. Removal efficiency can vary depending on several factors, including membrane type, water chemistry (such as pH and the presence of salts or organic matter), and operating conditions.[13] Despite the high removal rates, these systems come with significant challenges, especially high energy costs and expensive structures. These factors limit their use in large-scale industry as a viable separation method.

Some newer research explores hybrid approaches, combining RO or NF with either destructive treatments (like advanced oxidation) or non-destructive treatments (such as activated carbon or ion exchange), aiming to enhance PFAS removal while reducing costs and membrane fouling.[14]

Reverse osmosis (RO) is an extremely effective method for PFAS removal. However, the management of the concentrate and brine waste remains a significant challenge. The brine and wastewater generated by this process can have detrimental environmental impacts. This by-product contains high concentrations of contaminants and salts that can negatively affect biodiversity when improperly disposed of. To reduce the environmental impact of this waste, several technologies have been explored. One of these advances is known as Zero Liquid Discharge (ZLD). This approach aims to eliminate liquid waste by recovering water and reducing the brine volume, while solidifying the dissolved contaminants. The process recovers clean water and leaves behind only solid waste, which can then be disposed of in a more sustainable manner.

2.1.4 Emerging Materials

In the search for more effective and sustainable ways to separate PFAS from water, researchers in South Australia have been developing new materials that go beyond just capturing and removing PFAS but aim to break the compound down entirely.[15] A team at the University of Adelaide has created a promising method involving a metal sulfide powder activated by UV light. When mixed with a PFAS-contaminated solution and exposed to UV, the photocatalyst becomes energised, triggering a reaction that begins to break apart the extremely strong carbon-fluorine bonds in PFAS molecules. Early trials have shown this process is particularly effective at degrading long-chain PFAS like PFOS and PFOA, which are known for their high toxicity and persistence. The team is now working on shifting from UV to natural sunlight as the energy source, with the aim of making the process more cost-effective and scalable for real-world use.

Alongside this, Australian company OLEOLOGY has introduced a new filtration and polishing technology using MyCelx media, which has been approved through in-field use across the country. This system captures PFAS to below detectable limits, all within a compact, lower-cost setup. Unlike traditional granular activated carbon or high-pressure membranes, which often require large infrastructure and higher operating costs, MyCelx offers a smaller footprint and proven performance across a wider spectrum of contaminants.[12]

There is growing interest in integrating emerging technologies with existing systems, such as using covalent organic frameworks (COFs) to enhance membrane-based separation, or exploring resin regeneration methods to reduce waste and improve sustainability in ion exchange processes.[16]

2.2 Integration of Emerging Technologies

According to the European Journal of Sustainable research*,* AI has already been seen as an effective tool for environmental sustainability management, tracking pollution and modelling the climate among many other applications yet its uses within the scope of PFAS mitigation remains relatively unexplored.[17] The implementation of AI contains the potential to be a pivotal tool in terms of mapping PFAS hotspots and predicting migration patterns in real-time as well as optimising remediation. Further AI driven sensing technologies and spectral analysis could significantly improve early detection of PFAS within agricultural soils, already showing valuable applications to reduce bioaccumulation of PFAS within food sources.

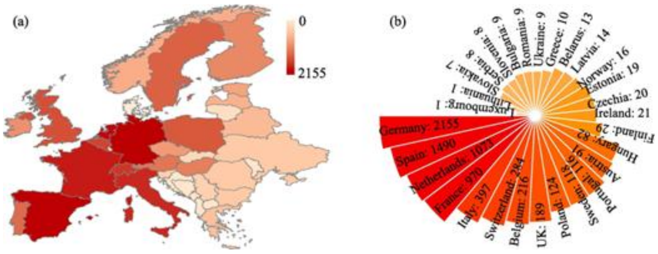


Figure 3: Heat map showing ML predicted PFAS

Machine learning (ML) based technologies that utilise AI have been identified as powerful tools for enhancing PFAS monitoring, source identification and remediation.[18] These technologies offer accuracies of up to 96% when classifying PFAS sources and show great promise in areas specifically using large data sets to identify relationships between physical, chemical and biological factors that otherwise require extensive experimentation to quantify. For this reason, artificial neural networks (ANN) and random forest (RF) technologies are useful to minimise reliance on experimental procedures and directly make predictions and observations about a wide array of PFAS characteristics such as source types, LD50 values, ionisation efficiency and many more. However, despite the vast applications of these technologies they rely on high quality datasets to be trained on, one of the largest challenges for the applications of these techniques moving forwards is having large amounts of high-quality data to further train them on to yield more optimal results.[19] Despite this technology still being developed and emerging there are case studies available for interpretation. One study focussing on Europe used machine learning models to interpret and predict high risk PFAS contaminated water sources and the people who would be affected by them at high-risk levels exceeding the 100ng/L safety limit guideline for European drinking water.[20] Conducted in May 2025 this case study is on the breaking edge of applying machine learning to predict and scope the challenging problem of PFAS contaminated water sources and their movements. Using this model they estimated nearly 8,000 individuals within Europe are affected by higher than acceptable PFAS contaminant levels and also importantly found a threshold distance of 4.1-4.9km from contaminated water sources that within which the water sources pose risk for elevated PFAS levels. Using data of 20 different PFAS contaminants and 9,985 sites across Europe this case study sets an exemplary model of how machine learning can be used to great advantage in analysing large data sets and finding trends in contributing factors to get results in a field that is historically poorly understood. The heat map of elevated PFAS concentrations predicted by this study can be found in Figure 3 and shows which countries have the most individuals above the acceptable risk threshold. Further ways to strengthen or ensure this technology develops in the right direction would be to implement some validation methods for the ML models. This could include human oversight of the models and also cross-testing predicted sites values with actually measured values. That is using a validation set of data that the machine has not been trained on. By utilising these methods to ensure the models develop accurately under the guidance of human oversight and validation they show potential to be a valuable resource in PFAS contamination movement and tracking

2.3 Comparative Analysis

RO and NF membranes are both highly viable solutions for PFAS removal. In a pilot-scale closed-circuit membrane filtration system, tap water spiked with PFAS was treated, achieving a recovery rate of up to 97%. The study compared the performance of NF and RO membranes, with PFAS removal by NF corresponding to a log removal value (LRV) of approximately 1.8, while RO achieved a higher LRV of 2.3.[21] For NF membranes with larger pore sizes, removal rates dropped significantly under high recovery conditions or in more challenging water matrices. Generally, NF removal of PFAS compounds falls within the 1–2 LRV range, whereas RO often achieves 2 log or higher LRV under favourable conditions. Because of its higher LRV, RO is more suitable when regulatory limits for PFAS are extremely stringent. However, NF may be acceptable in situations where PFAS concentrations are higher or when used as part of a multi-step treatment process.[22]

The adsorption capacity of ion exchange (IX) resins compared to granular activated carbon (GAC) showed that IX resins have a higher initial removal efficiency at lower pH and with dosages up to 6.0 g/L of water. Removal effectiveness decreased at higher IX dosages due to the desorption of previously adsorbed compounds. In contrast, GAC exhibited a consistent increase in removal efficiency with increased dosage, suggesting a more stable and predictable capacity range. Both treatment methods performed better at lower temperatures and after 12 hours of contact time.[23] While IX offers higher selectivity and capacity for certain compounds, it is highly sensitive to water chemistry. GAC provides more scalable and reliable performance across a range of conditions. Overall, IX may be preferable for targeted PFAS removal, while GAC is a more versatile option with broader operational usage for full-scale drinking water application.[24]

Table 1: Comparison of PFAS Treatment Technologies by Cost, Effectiveness, and Sustainability

Separation Method	**Cost**	**Effectiveness**	**Sustainability**
Granular Activated Carbon (GAC)	Relatively low cost depending on source material of carbon	High for long-chain PFAS	Uses organic waste- low emissions, 1 to 80 kg of CO_2 eq./g PFAS removed. Disposal and replacement required.[25]
Ion Exchange Resins	Lower than GAC in operational costs. [26]	Very effective for both short- and long-chain PFAS More selective and longer bed life than GAC[27]	Regenerable options available but some single-use resins go to landfill.
Nanofiltration / Reverse Osmosis (NF/RO)	High cost: energy-intensive operations and expensive infrastructure.	Excellent for long-chain PFAS; effectiveness for short-chain PFAS is less certain.	Membrane requires frequent maintenance. Energy use limits sustainability[28]
Metal sulphide powder	Estimated US $50-200/g[29]	Promising for PFAS degradation, especially long-chain types	Sustainable if shifted from UV to natural sunlight as the energy source

3. Challenges and Future Perspectives

3.1 Identified challenges

The vast diversity of PFAS and PFAS related compounds introduces significant challenges for detection, separation, and regulation. With nearly 15000 varieties identified,[20] individually crafted solutions are not viable, and datasets of sufficient size and quality are not currently available for ML solutions. As such, detection and separation systems must be generalised to be effective against many variations of PFAS.

Regulatory challenges are also presented by the variety of PFAS, as more countries implement bans or limits on the use of common varieties such as PFOA, PFOS and PFHxS, other compounds such as HFPO-DA (commonly GenX), ADONA, F–53B and 6:2 FTAB are becoming more prevalent as replacements.[30] As these are relatively recent developments, there is far less research on their health or environmental impacts (SDG3, SDG6). Despite this, they have all been found at significant levels globally,[31–34] and both GenX and ADONA have been found to affect gene expression in thyroid cells.[35] Current regulations are unable to keep up with development of these chemicals, and individualised bans only lead to the use of less researched alternatives, many of which have similar impact.[30]

Despite this potential harm from PFAS replacement options, it is essential to find replacements that are able to effectively fill the roles of PFAS in industrial and consumer applications. This presents another significant challenge, as the properties of PFAS that make them industrially relevant are the same that cause their bioaccumulation and harmful effects. One study found potentially suitable alternatives for PFAS for 40 applications, but identified 83 uses for which no alternative could be found.[36] If PFAS are to be phased out completely, this challenge must be addressed by further research into safer alternatives.

3.2 Roles of separation techniques in addressing challenges

Advanced separation techniques are paramount in overcoming the challenges presented by PFAS contamination, as varied techniques enable effective detection and removal of the persistent pollutants. Conventional analytical methods, that were popular in the past, such as gas chromatography, struggled to capture both structural diversity and the scarce concentrations that PFAS occur at environmentally. A notable 2024 study highlighted that the singular method, liquid chromatography-mass spectrometry (LC-MS), had proven successful for rapid separation and identification of all chain lengths (including ultra short) of PFAS.[37] This technology provides comprehensive monitoring at environmentally plausible concentrations (≈1 μg/L), however the limitation of small scale injection volume (20 μL) largely limits the technique to detection.[37]

Considering treatment, nanofiltration has shown remarkable performance, achieving a 99.61% targeted rejection rates of short-chain PFAS at 100 μg/L levels, with efficiency varying in accordance with applied pressures. This elucidates the promise of a membrane-based approach; to address the harder separation of smaller, agile PFAS that often bypass conventional treatment. However, scalability and energy requirements remain significant challenges.

Beyond separation, secure storage and disposal of concentrated PFAS waste are essential, as inadequate management risks environmental re-entry.[38] Hence, separation must be integrated with sustainable downstream strategies – to promote the ESG requirements and SDGs. It serves two functions: minimising risk through PFAS removal and enabling precise monitoring to support regulation and treatment evaluation.

3.3 – Current and Prospective Regulatory Solutions

Currently, the manufacture, import, and export of PFOA, PFOS, and PFHxS is prohibited in Australia due to their status as schedule 7 chemicals[39] under the industrial chemicals environmental management instrument. Guidelines for drinking water have also been updated for various PFAS and are summarised in table *2* below.

Table 2: Summary of Australian and US drinking water guidelines for PFAS concentration*[40,41]*

PFAS Derivative	Australian Guideline (ng/L)	US Guideline (ng/L)
PFOS	8	4
PFOA	200	4
PFHxS	30	10
PFBS	1000	No value set
GenX	No value set	10

While these are significant steps towards reducing the public health risk from PFAS, they are heavily focused on only a few specific varieties. This limited approach could cause significant harm if emerging PFAS are found to have similar or worse health effects. While new PFAS in Australia are automatically categorised as medium to high risk to human health[42] and must obtain an assessment certificate, the test data for the assessment is provided by the chemical manufacturer, introducing a significant opportunity for biased or incorrect data to be submitted, as was the case with DuPont's manufacture of PFAS in the 1970s[43] which led to the case of Parkersburg, West Virginia. Unfortunately, there is no apparent solution for this, new chemicals must be manufactured both to replace hazardous or banned materials and to allow for scientific advancement, and the government lacks the resources to perform independent health studies for every new chemical to be manufactured.

3.4 Future directions

Incremental advances in separation methodologies hold potential to significantly enhance PFAS management. One priority lies in developing accessible on-site detection techniques. Optical and electrochemical sensors have potential for rapid and cost-conscious monitoring of PFAS in environmental matrices. Nevertheless, current systems lack sufficient selectivity across PFAS subclasses and the sensitivity required to detect trace concentrations.[44]

Improving these capabilities enables more responsive field-based monitoring and support regulatory enforcement. Considering this, high-temperature incineration remains the only proven large-scale option for highly contaminated media such as aqueous film-forming foams (AFFF), polluted soils, and biosolids. This approach is costly and environmentally burdensome, underscoring the need for alternatives.[45] Emerging combinant strategies such as ion-exchange with electrochemical, hydrothermal, sonolysis, or plasma-based processes warrant further investigation to establish viable, scalable routes for PFAS destruction. Collectively, these incremental refinements could improve both detection and treatment, offering more sustainable and effective management frameworks.

4. Conclusions and recommendations

The persistence and toxicity of PFAS present one of the most pressing global water contamination challenges. The case of Parkersburg, West Virginia, where unregulated industrial discharges contaminated drinking water supplies, illustrates the severe local health and economic consequences that arise in the absence of effective separation strategies.

This review has assessed the performance of established and emerging approaches. Granular activated carbon methods remain reliable for long-chain PFAS but are limited by regeneration issues and poor removal of shorter-chain analogues, ion exchange lacks this weakness to short chain PFAS but faces the same issues with regeneration and waste generation. Membrane processes such as reverse osmosis and nanofiltration provide broad removal albeit more uncertain with short-chain species but require high energy and infrastructure inputs. Novel hybrid and photocatalytic systems show promise, though questions of scalability and by-product management remain unresolved.

In the Australian context, several research teams are advancing PFAS treatment through photocatalysis and advanced membranes, reflecting both recognition of the issue and commitment to innovation. Internationally, the integration of AI and machine learning is emerging as a tool for optimising treatment processes and supporting predictive monitoring.

Addressing PFAS contamination demands a combined strategy: advancing technological performance, integrating digital tools, and aligning regulatory frameworks. Continued investment in translational research will be critical to move these laboratory advances into scalable, real-world solutions that safeguard public health and environmental resilience. The cost of inaction is continued community-level harm and

escalating national and global health burdens, whereas decisive investment in these solutions offers the opportunity to break the cycle of persistent contamination.

Acknowledgements

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