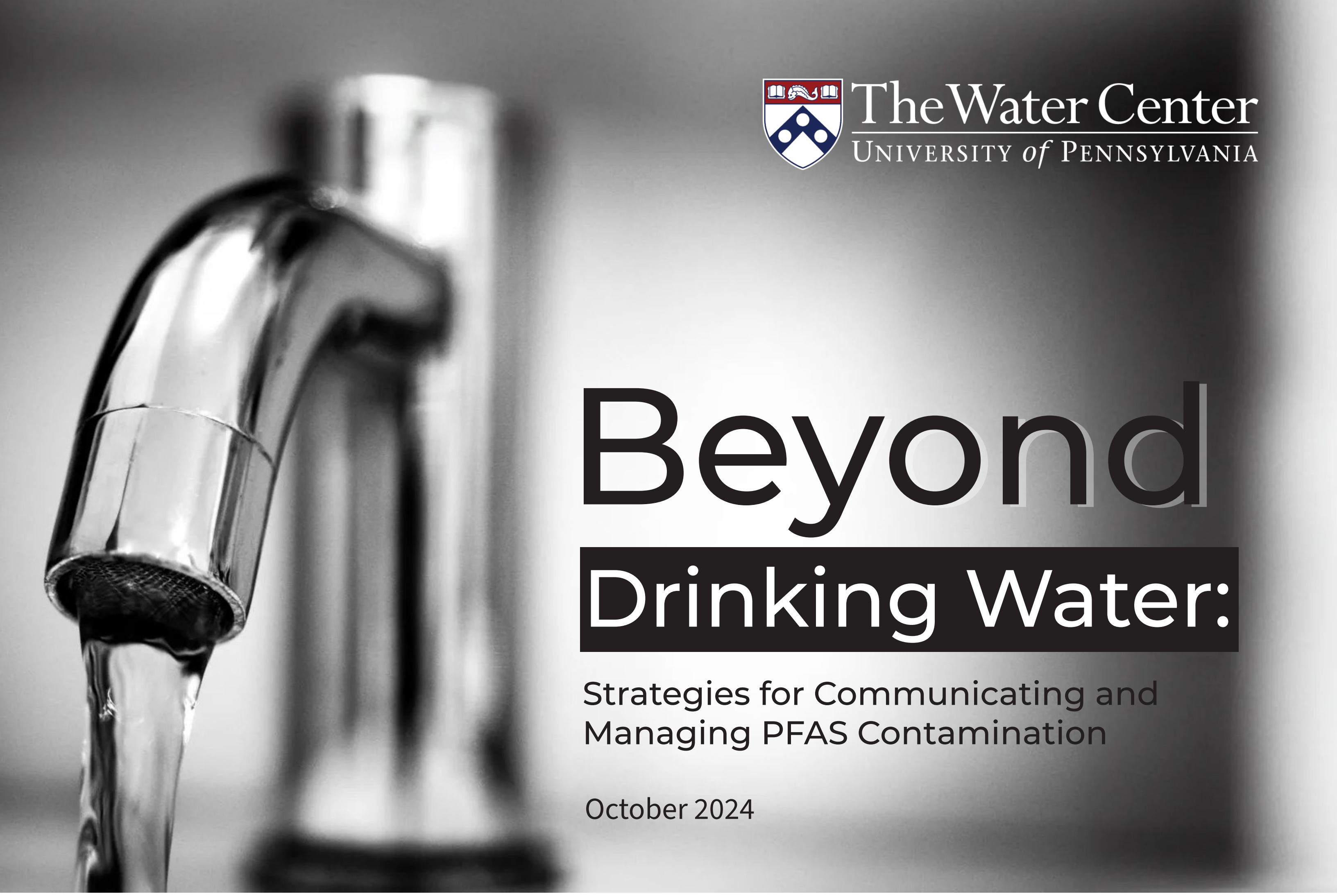

The Water Center
University of Pennsylvania

Beyond Drinking Water:

Strategies for Communicating and Managing PFAS Contamination

October 2024

Summary

In April 2024, the EPA finalized a new National Primary Drinking Water Regulation (NPDWR), setting limits – well below existing state standards – on PFAS[1] concentrations in drinking water. While research into PFAS health risks is ongoing, exposure to some PFAS has been linked to certain cancers and other negative health outcomes. Because of these potentially adverse effects on human health, and because certain PFAS are known to occur in drinking water,[2] the EPA determined that it was obligated to regulate these PFAS under the Safe Drinking Water Act (SDWA). This new rule will require many water systems to adopt new technologies into their existing treatment processes. When PFAS contamination is discovered in drinking water, water systems also become responsible for educating their communities about PFAS exposure risks, sources, and solutions.

Through interviews with water industry stakeholders, we investigated how the water industry has been impacted by recent PFAS regulations. Interviewees described the challenges of addressing PFAS in drinking water, especially funding treatment facility upgrades and mitigating increasing consumer distrust of public water. Water systems will continue to bear these burdens as we wrestle with the challenge of PFAS contamination. To address this challenge, interviewees advocate for a holistic approach that

1. Addresses the sources of PFAS contamination, and
2. Manages PFAS contaminated waste to prevent reentry into the environment.

Stakeholders such as regulatory bodies, water systems, private industry, and academic institutions are exploring opportunities to collaborate on the development of these integrated solutions, as each group has a role to play in solving this complex problem.

Acknowledgements

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Contents

Glossary of Acronyms

AEA – Association of Environmental Authorities

AFFF – Aqueous film-forming foam

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

EPA – Environmental Protection Agency

EPCRA – Emergency Planning and Community Right-to-Know Act

DRBC – Delaware River Basin Commission

GAC – Granular activated carbon

HFPO-DA – Ammonium perfluoro-2-methyl-3-oxahexanoate, Perfluoro(2-methyl-3-oxahexanoic) acid

IX – Ion exchange

MCL – Maximum contaminant level

MRRSA – Manasquan River Regional Sewerage Authority

MUA – Municipal Utilities Authority

NJDEP – New Jersey Department of Environmental Protection

NPDES – National Pollutant Discharge Elimination System

NPDWR – National Primary Drinking Water Regulation

PFAS – Per and Polyfluoroalkyl substances

PFBS – Perfluorobutyl sulfonic acid

PFHxS – Perfluorohexyl sulfonic acid

PFNA – Perfluorononanoic acid

PFOA – Perfluorooctanoic acid

PFOS – Perfluorooctane sulfonic acid

PN – Premanufacture notice

PPA – Pollution Prevention Act

PPT – Parts per trillion

PWS – Public water system

SNUR – Significant new use rules

TRI – Toxic Release Inventory

TSCA – Toxic Substances Control Act

Introduction

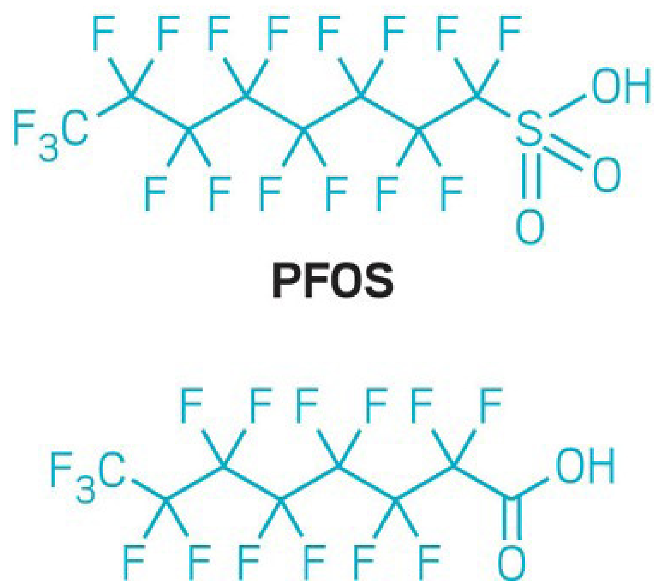
Per- and polyfluoroalkyl substances (PFAS) are a category of synthetic chemicals that have become pervasive environmental pollutants since their discovery in the 1930s. The special physicochemical properties arising from strength of their carbon-fluorine bonds led to the widespread use of PFAS in manufacturing just a few years later. Because of these special properties, PFAS are still used as a flame retardant, insulator, and water repellent, among other applications.[3]

However, the same properties that make PFAS so valuable in industry also make them persist in the environment. PFAS are present in many everyday household items including non-stick cookware, water resistant clothing, plastic containers, and personal hygiene products such as some shampoos and cosmetics, and more. In addition to contact with consumer products containing PFAS, humans are exposed to these substances by consuming contaminated food and water. Some food becomes contaminated through build up in the food chain, contact with food packaging that contains PFAS, and the application of bio solids to agricultural lands, while some sources of drinking water become contaminated through the release of PFAS-containing wastewater from municipal and industrial sources, the use of aqueous film-forming foam (AFFF), and leachate from landfills.[4] As a result, PFAS have been detected in the bloodstreams of 97% of the US population.[5]

Because thousands of chemicals fall within the PFAS category, researchers are still studying their impacts. Distinct PFAS chemicals differ in their impacts on human health, the degree to which they have been studied,[6] and their prevalence in local communities.[7] Exposure to certain PFAS has been linked to:

- Reproductive and developmental effects,
- Increased risk of certain cancers,
- Lowered immune system function,
- Endocrine impacts,
- And elevated cholesterol levels (among other health outcomes).[8]

PFOA and PFOS are the most extensively studied of these chemicals and have been voluntarily phased out of manufacturing in the United States. PFOA and PFOS were replaced with other, less-extensively studied PFAS.[9]



PFOS and PFOA Molecular Structure[11]

To protect the public from these health impacts, the EPA is regulating PFAS concentrations in drinking water more intensely than any existing state regulations.[10] The EPA's National Primary Drinking Water Regulation (NPDWR) sets maximum contaminant levels (MCLs) of 4 parts per trillion (ppt) each for PFOA and PFOS and 10 ppt each for PFHxS, PFNA, and HFPO-DA. It also sets a hazard index of 1 for mixtures containing two or more PFHxS, PFNA, HFPO-DA, and PFBS. A hazard index considers the combined levels of these PFAS to determine if they pose potential risks to human health. Public water systems (PWS) have until 2027 to complete initial monitoring and until 2029 to take action to reduce PFAS concentrations in their water if they violate these regulations. The recent regulation of PFAS in drinking water has broad reaching implications for water systems across the United States because of the rule's stringency.

Considering the evolving regulatory landscape, the goal of this white paper is to assess the current state of PFAS response across different water industry stakeholders and to investigate solutions to limit the pressure on water systems while protecting public health.

Methodology

To accomplish this goal, the Water Center at Penn conducted 30-to-45-minute interviews with large water systems and other water industry stakeholders. We contacted organizations based on our existing industry relationships, starting with members of the Corporate Round table at the Water Center at Penn. Once a representative from the identified organization agreed to an interview, we asked them a series of questions pertaining to water treatment and destruction technologies, communications about PFAS health impacts and regulations, and what next steps should be taken to resolve identified challenges. We then analyzed transcripts of these interviews to identify emerging themes.

Name of Organization	Description	Involvement with PFAS
AECOM	Infrastructure consulting firm	Has been focused on the impacts of PFAS in the Environment and Human Health for the last two decades across the world, including investigation, monitoring, risk assessment and remediation of PFAS impacts on over 500 sites. Treatment provides for the separation and destruction of PFAS.
Aqua	Private water and wastewater system owner/operator	Treats their water systems for PFAS when necessary.
Aquatech	Industrial water treatment solutions provider	Designs, manufactures, installs, rents, and operates integrated PFAS treatment systems for industrial and municipal water and wastewater treatment facilities when necessary. Treatment includes the separation and destruction of PFAS.
Delaware River Basin Commission (DRBC)	Regulatory commission	Works to identify where PFAS is present in surface waters to locate and prevent PFAS discharges.
GHD	Engineering consulting firm	Works with industrial clients and water systems to design PFAS treatment solutions for industrial effluent, drinking water, and wastewater.
Manasquan River Regional Sewerage Authority (MRRSA)[12] - NJ	Public wastewater conveyor	Preparing for potential PFAS wastewater regulations.
McBride Lab, University of Pennsylvania	Fluid physics and interfacial engineering research lab	Working to identify sustainable, renewable alternatives to PFAS compounds.
Ridgewood Water – NJ	Public water system (52 groundwater wells serving Glen Rock, Midland Park, Wyckoff, and Ridgewood)	Treats their water for PFAS contamination.
Veolia	Private water and wastewater system owner/operator	Treats their water and wastewater systems for PFAS when necessary and provides PFAS waste management services – including AFFF site remediation.
Willingboro Municipal Utilities Authority (MUA) – NJ	Public water system (6 wells serving Willingboro and selling to Mt. Laurel)	Treats for PFAS contamination at one of their treatment facilities.

Removing PFAS From Drinking Water

Technologies

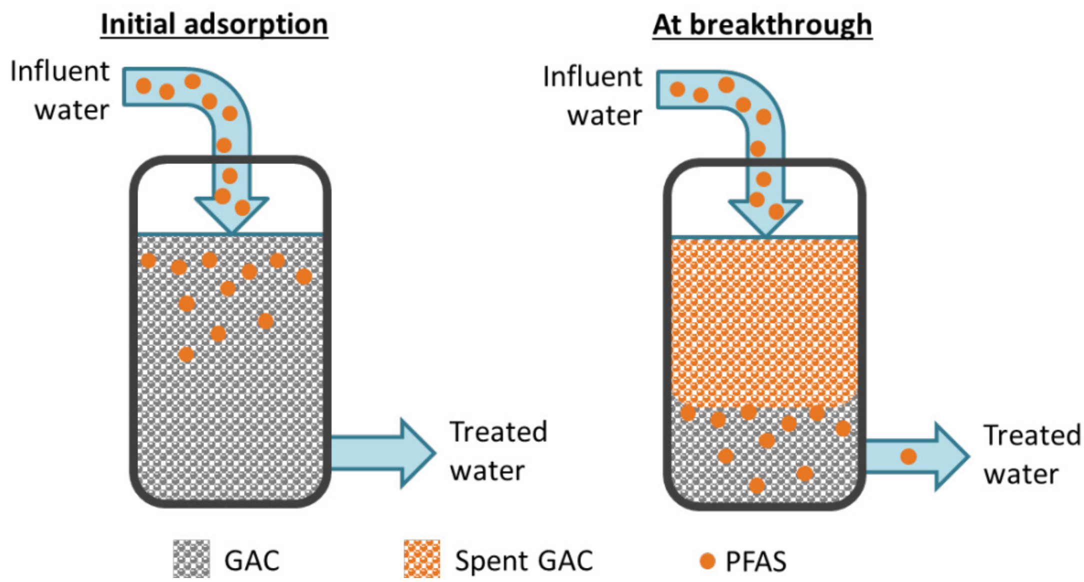
The EPA's NPDWR requires water systems to treat drinking water for PFOA, PFOS, PFHxS, PFNA, and HFPO-DA if water concentrations exceed their MCLs, and to treat for PFHxS, PFNA, HFPO-DA, and/or PFBS if the hazard index of 1 is exceeded. Some water systems have already been treating certain PFAS because their concentrations exceeded state regulations. However, the new federal regulations are more stringent than any previous state rules. Many systems had not yet been driven to adopt treatment technologies because of state regulations, and are now needing to investigate solutions for the first time.[13] Our interviewees report that water systems are likely to stick to the EPA's best available treatment technologies for PFAS removal: granular activated carbon (GAC), ion exchange (IX), and high-pressure membrane technologies, although some representatives mentioned interest in foam fractionation.[14] Overall, water treatment technologies are chosen for their low operating costs while achieving the best removal outcomes.[15]

New GAC Treatment Equipment at Willingboro

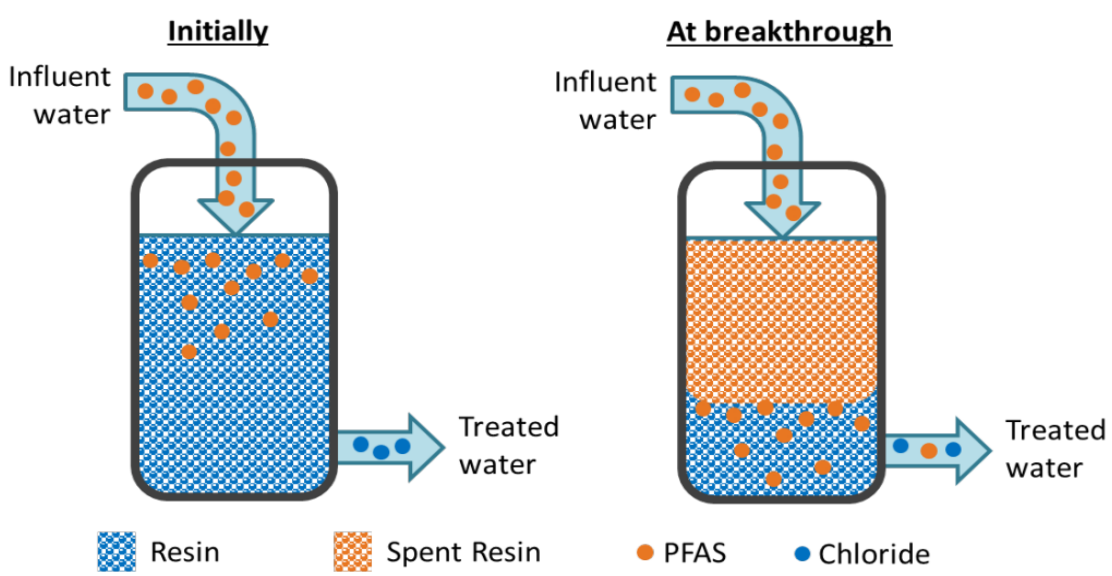
Granular Activated Carbon (GAC)[16]	
Description	Coal, peat, wood, coconut and other carbon-based materials are treated with chemical and physical processes to create and/or enlarge interior pores. Water passes through the GAC and dissolved contaminants are adsorbed into it, filtering PFAS and other contaminants out.
Removal Efficiency	GAC treatment has a high removal efficiency at 90-99% for the PFAS regulated under the new NPDWR.
Co-Removal	GAC removes contaminants without discrimination, removing additional contaminants but also shortening the time until "breakthrough" – when the GAC beds need to be replaced.
Reactivation	GAC can be reactivated through incineration, in which enough heat is applied to GAC residuals to destroy PFAS contamination. Potential PFAS combustion byproducts are not yet well understood.[17]
Compatibility with Other Treatment Processes	GAC integrates easily into existing treatment trains, although interviewees note recently increasing costs.
History of Full-Scale Operation	GAC is already used by large and medium water systems.

Ion exchange (IX)[18]	
Description	Water passes through a bed of PFAS-selective resin, which exchanges PFAS for another ion, typically chloride.
Removal Efficiency	IX treatment has high removal efficiency at >99% for the PFAS regulated under the new NPDWR.
Co-Removal	While PFAS-selective resins have a higher affinity for PFAS, other ions in the water can compete with PFAS for exchange sites, shortening the time until breakthrough.
Reactivation	PFAS selective resins are either single-use or regenerable. Single-use resins are incinerated or landfilled after breakthrough, while regenerable resins can be returned to reduced capacity using a regenerant solution.[19] The EPA notes that these are only cost effective on a very large scale.
Compatibility with Other Treatment Processes	IX can increase corrosivity, potentially necessitating changes to the water distribution system to correct. Using buffered resin can help reduce corrosivity resulting from chloride discharge.[20]
History of Full-Scale Operation	GAC is more widely used by water systems, as full-scale use of PFAS specific resins is only demonstrated by 2 medium systems, though many additional facilities use IX for other contaminants. Sometimes IX is chosen because it better treats the PFAS contaminant in question.[21]

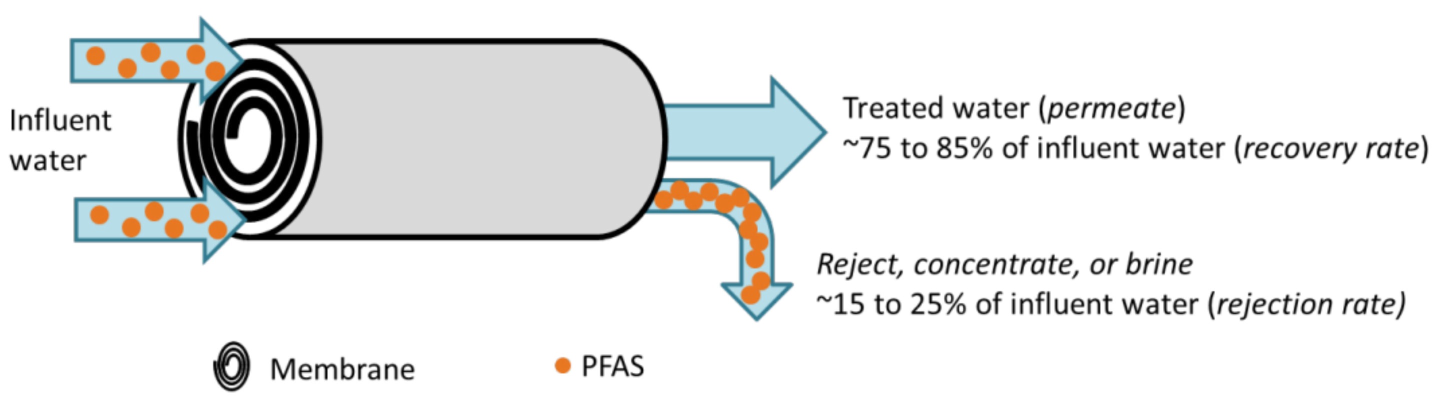
High-Pressure Membrane Technologies[22]	
Description	High-pressure membrane technologies such as nanofiltration and reverse osmosis force contaminated water through membranes at pressures higher than osmotic pressures. Clean water will pass through the membranes and higher molecular weight solutes – including PFAS – will not.
Removal Efficiency	Removal efficiencies are >99% for PFOA, PFOS, and PFHxS and are >98% for PFNA and PFBS, but are much lower or unreported for HFPO-DA.
Co-Removal	Membrane technologies remove a wide variety of contaminants and require low doses of disinfectant.
Compatibility with Other Treatment Processes	Membrane technologies produce large volumes of residuals and can produce corrosive permeate, potentially necessitating changes to the water distribution system to correct.
History of Full-Scale Operation	While full scale use of membrane technologies is demonstrated by 2 large systems in the United States (North Carolina and Alabama), none of our interviewees reported the use of membrane technologies for PFAS removal. GHD reasons that membranes are more costly and more complex to operate because you need to add additional energy to overcome the osmotic pressure of the solute. These challenges make GAC and IX simpler. However, membrane systems are often used when they are required for the removal of additional contaminants.[23]



Conceptual Diagram of the GAC Treatment Process[24]



Conceptual Diagram of the IX Treatment Process[25]



Conceptual Diagram of the Membrane Treatment Process[26]

Foam fractionation is another PFAS separation process. Foam fractionation technologies introduce gaseous bubbles to a PFAS-containing liquid, causing amphiphilic PFAS to separate from the bulk liquid. These technologies have been studied at the bench scale and implemented to remove PFAS from groundwater, leachate, and industrial water.[27] While foam fractionation is effective at removing longer chain PFAS – including PFOA and PFOS[28] – it is not included in the EPA's list of best available technologies.

Willingboro PFAS treatment Installation

Treatment Costs

The cost to water systems to install these treatment technologies is immense, with federal funding likely insufficient to cover all costs. The treatment technologies themselves are expensive and, furthermore, many water systems do not have space to install new treatment technologies within existing facilities, leading to major capital expenses in the form of new buildings.[29]

For example, Ridgewood Water detected PFAS contamination in all its wells in 2020. Because the water system is made up of 31 different treatment plants, it would have been prohibitively expensive to treat PFAS at all its plants. Consequently, Ridgewood Water made the decision to consolidate their 31 plants down to just 12 new, larger facilities. After the capital investment, interest, fees, notification costs, and testing costs, treatment at the 12 plants ultimately cost at least $140 million. The water system received a $2.8 million congressional appropriation for one of its plants while the rest were funded through 0% interest loans from the NJ Infrastructure Bank. The Bank also provides Ridgewood $2 million principal forgiveness each year.[30]

Willingboro MUA also had to construct a new building, with improvements costs totaling $6.5 million. Willingboro funded these improvements with a $3.45 million federal grant, a one time, $1 million principal forgiveness loan from the NJDEP, and a $2.04 million low-interest rate loan from the New Jersey Infrastructure Bank. [31]

Litigation has also emerged as an avenue for recouping the costs of treating drinking water for PFAS contamination. In addition to many citizens and 30 State Attorney Generals,[32] some water systems have also filed suits against industrial PFAS manufacturers and users to recover the costs necessary to treat their drinking water for PFAS. However, the costs are estimated to exceed settlements and can take years to be resolved, during which the federal compliance deadline will have already passed. Ridgewood Water has been involved in active multi jurisdictional litigation against PFAS manufacturers for the past 4 years and has yet to receive any compensation.[33] Meanwhile, they have increased residential water bills to pay for these investments. Our interviewees note that, in general, federal/state funding and funding from litigation will not be sufficient to cover costs. Water systems will likely need to raise rates, especially public water systems that are unable to distribute the cost burden across a wider portfolio of water systems and business units.[34]

Water systems will be hard pressed to meet these cost challenges, likely needing the full 5 years that the EPA allotted to achieve compliance.[35] During this time, costs are likely to rise further due to demand pressure on vendors.[36] Representatives report increased costs for engineering consultants, building expenses, treatment media, and electrical components.[37] Other water systems have only recently started treating for PFAS and have not had to change their treatment media yet. Veolia notes that media vendors are scaling up to meet demand, but costs are still high in the short run. Presently there is also a bottleneck in water testing capacity due to a shortage of laboratories testing with approved methods, which will also increase costs.[38] Water systems also face the burden of simultaneous compliance with other new water regulations.[39]

Additional Challenges

Water systems also face the threat of litigation from the EPA’s designation of PFOA and PFOS as “hazardous substances” under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This designation increases reporting, remediation, and monitoring requirements for entities that release PFOA and PFOS. CERCLA also allows parties to assert a claim for recovery of costs for remediation. While CERCLA designation permits claims against water systems, the EPA’s PFAS Enforcement Discretion Document states that the agency does not intend on using this designation to pursue public water systems and wastewater systems.[40] However, because the discretion document is non binding, CERCLA still poses a legal threat to water systems[41] and may make the disposal of PFAS-contaminated residuals more challenging.[42] Private water systems are even more concerned, as they generally have less protection from liability compared to public water systems.

In addition to the threat of litigation, many water systems are concerned that the current federal rules will open the door for additional regulation. The EPA may further lower MCLs for currently regulated PFAS or introduce regulations for more PFAS. The landscape of effective treatment technologies may also change. Given the uncertain regulatory future, our Ridgewood representative emphasized the importance of proactive planning. They have been anticipating additional regulations since their discovery of PFAS contamination and completed test runs and pilots to identify the right technologies for each plant while also making sure that the new technologies did not have any negative side effects – especially lead and copper corrosion. Similarly, Veolia’s representative recommends increasing flexibility through facility design. Veolia has been looking at vessel designs that can support either GAC or ion exchange. A more flexible design would allow PWS to switch between treatment technologies depending on future regulations.

Communicating PFAS Issues to Our Communities

Water utilities and local governments are primarily responsible for communicating to the public about water quality. Water systems are required to issue public communications when their water exceeds any EPA NPDWR, burdening them with the task of educating the public in addition to the task of treating water.[43] Public notifications are the avenue that inform most water consumers about PFAS in their drinking water. The language specifically used in these notifications varies depending on state interpretations of the Safe Drinking Water Act's requirements.[44] These communications often instill fear and cause communities to mistrust water systems.

Effective PFAS communication has proven to be a momentous challenge due to: [45]

1. **PFAS Complexity**

   PFAS is a large category of chemicals that, while they share chemical characteristics, are used in a wide range of applications and have differing impacts on public health. Furthermore, the language surrounding regulatory efforts is often technical and difficult to communicate.

2. **Scientific uncertainty**

   While PFAS have been manufactured for many years, their impacts on public health were not explored until relatively recently. Furthermore, only the most prevalent PFAS have been studied – the wide variety of PFAS make it impossible for researchers to produce comprehensive reports on every chemical. Because of this uncertainty, regulators and water systems have difficulty communicating about the health impacts of PFAS exposure.

3. **Risk perception**

   People have varying risk tolerances and may react differently to information about PFAS contamination in drinking water. Some are highly concerned and may react with anger towards water systems even though these facilities are not the source of PFAS pollution. These individuals may prefer higher water bills to PFAS in their drinking water. Other individuals downplay the risks of PFAS contamination and may prefer the potential of having PFAS in their drinking water to having higher water bills.

   A representative from the Willingboro MUA recalls the outrage that ensued after Willingboro issued its first public notification in 2021. Many residents assumed that the water system had knowingly delivered contaminated water to consumers because the MUA's exceedance was calculated using a running annual average.[49] Even when water systems shut off contaminated wells or take other swift actions to lower PFAS concentrations, public communications can still frighten residents.

4. **Conflicting messaging**

   Many sources release information on PFAS – including state and federal regulators, scientific journals, industrial actors, environmental and public health organizations, and water systems. These stakeholders have differing agendas and present the issue of PFAS contamination in different ways.

Public notifications surrounding PFAS should be carefully crafted to notify the public about the contamination without causing undue panic. To prevent widespread fear and mistrust, interviewees recommend that water systems communicate PFAS risk relative to exposure and reassure the public regarding action taken to mitigate the contamination.[46] Interviewees also note that educating the public on sources of PFAS contamination can also help combat declining trust in water systems.[47]

Some water systems are better prepared to develop responsible communications than others. While private water systems often have public relations teams that can draft public communications in such a way as to minimize public fear, public water systems usually do not. Public water systems usually have the least capacity for risk communications due to lack of capital, staffing shortages and lack of training in this area. A representative from MRRSA considers the possibility of water systems contracting with marketing firms and collaborating amongst themselves to share knowledge about communication best practices.

As public awareness of PFAS contamination grows, so does the need for careful and effective communication from water systems. Interviewees recommend that regulators serve as a central information source that not only explains PFAS health risks, but also centers what utilities are doing to keep people safe and how drinking water treatment works.[48] However, due to their proximity to the public, water systems will continue to serve as PFAS educators and bear public frustration. Careful consideration of PFAS communication and the sharing of best practices between water systems can help alleviate concerns and ultimately build a more informed and trusting relationship between water systems and the customers they serve.

A Holistic Approach to Addressing PFAS Contamination

Addressing these challenges will require a more holistic approach to the problem of PFAS contamination, including addressing sources of contamination and developing safer waste disposal options. [50]

1. Addressing sources of contamination

While water industry stakeholders – including many of our interviewees – support the EPA's motivation to protect public health, many object to the agency's regulatory approach.[51] Released in 2021, the EPA's PFAS Strategic Road map established the agency's intention to regulate industrial PFAS users as well as water systems. However, the EPA has not moved as swiftly to regulate industrial users as it has to regulate water systems. Critics argue that:

Regulating drinking water does not hold polluters accountable. PFAS contamination occurs around aqueous film-forming foam (AFFF) discharge sites, certain industrial facilities in industries that are known to use PFAS in their operations, and facilities handling PFAS-contaminated wastewater and solid wastes.[52] However, the new NPDWR places the cost burden for limiting human PFAS exposure on water systems – and not on the industries that manufacture and use these chemicals. Because federal funding and legal settlements are unlikely to cover the full cost of NPDWR compliance, the remaining costs will fall upon water consumers in the form of higher water rates.

Regulating drinking water does not eliminate human PFAS exposure. Treating drinking water does not protect the public from other sources of PFAS exposure such as consumer products and other PFAS-contaminated environmental media. For the regulated PFAS, the EPA attributes 20% of our exposure to drinking water, attributing the remaining 80% of our exposure to other sources. [53]

Although human exposure to PFAS is highest surrounding PFAS-contaminated sites,[54] the EPA has taken the swiftest action regulating drinking water. Interviewees point out that preventing PFAS from entering the environment through the regulation of these sites can lower PFAS concentrations in public water supplies without necessitating expensive water treatment.

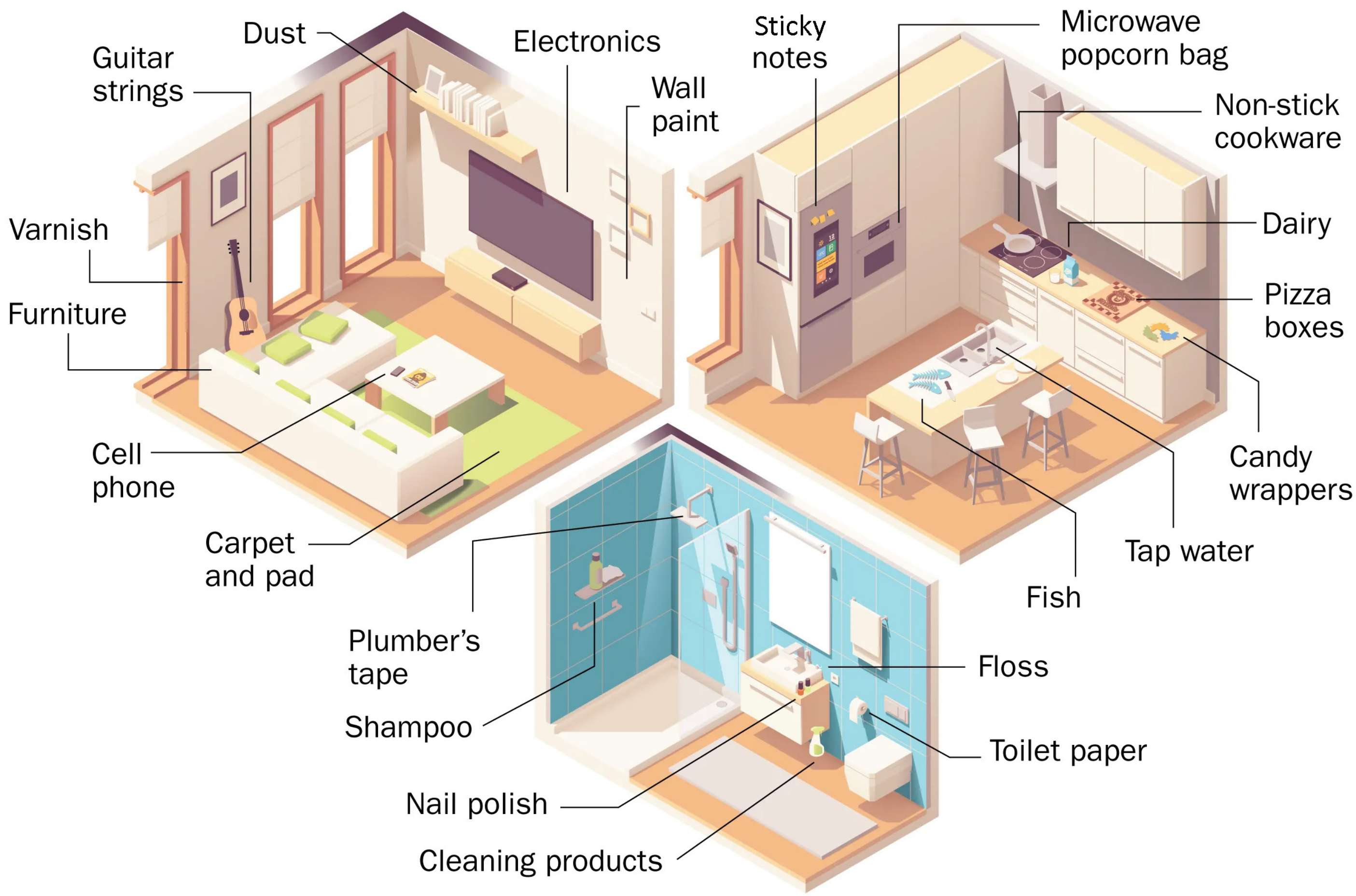
Regulating Wastewater

Wastewater from municipal and industrial sources are major points of PFAS entry into the environment. The Clean Water Act grants the EPA the ability to regulate wastewater through the National Pollutant Discharge Elimination System (NPDES). The NPDES requires point source dischargers of pollutants to waters of the United States ("direct dischargers") and industrial users that release pollutants to wastewater treatment facilities ("indirect dischargers") to meet certain effluent guidelines as a condition of obtaining permits to do so. Many water systems emphasize the importance of regulating PFAS in industrial wastewater in particular.[55] While the EPA is currently studying industrial PFAS discharges,[56] it has yet to release effluent guidelines for PFAS.

Treating wastewater for PFAS contamination utilizes similar technologies as treating drinking water, though wastewater is complicated by larger amounts of contaminants. Wastewater treatment saturates media faster[57] and produces bio solids in addition to other residuals from treatment, which complicates disposal options. Current options include agricultural land application, incineration, and landfilling, but all of these may be severely restricted due to state regulations and the CERCLA hazardous substance designation, leaving wastewater treatment facilities with nowhere to take their residuals. Without these options, some wastewater plants may be forced to ship their bio solids to other jurisdictions for disposal.[58] To overcome the challenges presented by the production of PFAS-contaminated bio solids, a representative from Veolia emphasizes the importance of partnerships between treatment plants, vendors receiving solids, and commercial entities sending discharge to wastewater treatment plants.

Regulating PFAS-Containing Products

The EPA has finalized a collection of federal rules requiring industrial users to report on PFAS use and release, among other metrics. While these regulatory actions have put pressure on industrial PFAS users to develop alternative chemistries to replace PFAS, most alternatives are inferior to their fluorinated counterparts.



PFAS-containing products in the home[59]

Current federal rules on industrial PFAS users include:

Rule	Authority	Description
Significant new use rules (SNURs)	Toxic Substances Control Act (TSCA)	The EPA has been progressively adding more contaminants to the PFAS SNURs since 2002, requiring manufacturers and importers of these chemicals to notify the EPA at least 90 days before commencing the manufacture or import of these chemical substances for the significant new uses.[60]
Premanufacture notices (PNs)	TSCS	Premanufacture notices must be submitted to the EPA when a new chemical is manufactured or imported that the TSCA requires persons to notify EPA at least 90 days before they manufacture or import a new chemical substance for commercial purposes. Polymers are generally exempt from premanufacture notices, so the EPA removed this exemption for certain PFAS.[61]
Toxic Release Inventory (TRI)	Emergency Planning and Community Right-to-Know Act (EPCRA); Pollution Prevention Act (PPA)	Since 2020, the EPA has also added many PFAS to the TRI, which requires companies to report annually how much of each chemical on the list is released to the environment and how much of each chemical is managed through recycling, energy recovery and treatment.[62]
Reporting and record keeping requirements	TSCA	Today, companies must report on PFAS as a group of chemicals under the TSCA, meaning that companies must report uses, production volumes, byproducts, disposal, exposures, and existing information on environmental or health effects for all PFAS, not just those on the TRI.[63]
"Hazardous substance" designation	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)	Finally, producers of PFAS-containing products are especially threatened by the designation of PFOA and PFOS as hazardous substances under CERCLA.[64]

While federal regulation is notoriously sluggish, some states (NY, NJ, CA, NV, WA, MD, NH, MI, CO, HI, RI, MN)[65] have taken swifter and more stringent action to reduce PFAS use. These states have adopted bills prohibiting the use of PFAS in certain categories of products, or outright banning all non-essential uses. Pressure from states has especially encouraged industrial users to seek alternative chemistries for PFAS applications.[66] Additional federal regulation could expedite this process.

However, PFAS substitutes are extremely difficult to develop. PFAS derive their properties from their carbon-fluorine bonds, while substitutes are made from naturally derived fatty acids with carbon-carbon bonds. Carbon-carbon bonds degrade naturally in the environment, which makes them shorter lasting than PFAS but also less versatile for industrial applications. It is especially difficult to find one replacement chemistry that works well for every single PFAS application, so researchers are targeting one application – such as nonstick cookware or AFFF – at a time.[67] Given the shortcomings of current PFAS substitutes, customers are unlikely to eschew PFAS-containing products altogether and companies will continue to use PFAS in products as long as there is a market for them.[68]

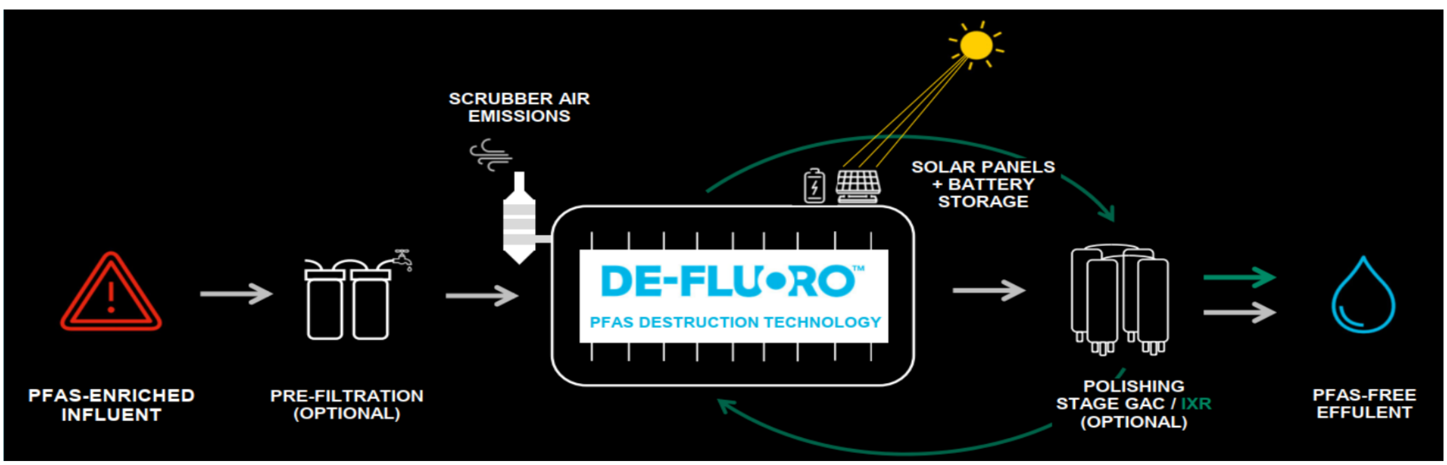
PFAS also have many extremely useful applications, making the elimination of these chemicals challenging. Due to their important uses, PFAS are unlikely to be eliminated from production.[69] Even the most stringent state standards have banned PFAS manufacture in all nonessential uses, continuing to allow the use of PFAS in essential applications. These exceptions make adopting a holistic approach even more important. For example, a significant source of groundwater contamination is the release of AFFF, a PFAS-containing foam that is used for fire suppression and flammable vapor suppression at fire departments, military installations, airports, and some manufacturing plants.[70] The use of AFFF also pollutes nearby groundwater where it is applied. Researchers are working to develop comparable non-fluorinated foams to replace present formulations. In the meantime, many AFFF users have stopped releasing AFFF for training purposes – a practice now banned in some states. Regulators should also undertake extensive efforts to remediate these sites to prevent PFAS contamination in drinking water without necessitating expensive drinking water treatment.[71]

2. Managing PFAS-contaminated waste

Treating wastewater and remediating contaminated sites are both strategies that address human PFAS exposure by preventing the pollution of drinking water altogether, while removing PFAS from drinking water is another pathway. All three of these approaches produce PFAS contaminated residuals that may reenter the environment. Furthermore, the CERCLA hazardous substance designation makes the disposal of these residuals more complex.

One solution to the challenges of preventing PFAS reentry into the environment and avoiding CERCLA liability is the deployment of PFAS destruction technologies. These technologies have attracted more attention since the hazardous substance designation, although researchers have been investigating them for years. High temperature destruction/incineration is widely used to remove PFAS from treatment media. However, incineration produces air pollution, potentially including PFAS air emissions.[73] An interviewee from the MRRSA remarks that New Jersey is seemingly considering restricting the use of incineration in general, further restricting disposal options.

Electrochemical oxidation, non thermal plasma, hydrothermal alkaline treatment, and supercritical water oxidation are not as widely applied, but have all demonstrated effectiveness for PFAS destruction.[74] These technologies have been shown to be effective for the treatment of high concentration, low volume liquids, and less suitable for high volume, low concentration liquids.[75] Therefore, PFAS needs to be concentrated through one of the treatment processes described above before any of these destruction processes are applied. Samantha McBride, from McBride labs, points out that continued research is needed to find the most efficient, cost-effective, and sustainable solutions for PFAS treatment. It is very important that these technologies are given the opportunity to be demonstrated and developed to allow a transition from traditional approaches such as incineration.



DE-FLUORO® PFAS destruction process[72]

Aquatech and AECOM recently partnered to accelerate the deployment of AECOM's onsite DE-FLUORO® PFAS destruction technology. DE-FLUORO® uses electrochemical oxidation – passing electrical currents through a solution to break the carbon and fluorine bonds that form PFAS and mineralize the contamination. This destroys PFAS, eliminating the need for off site landfilling or incinerating PFAS-contaminated residuals. When asked why they chose to focus on electrochemical oxidation instead of other emerging destruction technologies a representative said that electrochemical oxidation:

- Is scalable and mobile, able to be brought directly to the consumer,
- Is sustainable and significantly less energy intensive than traditional off site destruction (including incineration),
- Operates at low pressure with low risk of air emissions and without creating hazardous by-products,
- Can be customized to meet specific project and site needs
- Can be incorporated with multiple treatment stages for efficient PFAS removal and destruction,
- And is very fast, with a deployment cycle of between two and three days.

The DE-FLUORO® technology's portability allows it to be used on site, removing the need to transport hazardous materials and avoiding hazardous levies.[76] Additionally, permitting requirements are low because DE-FLUORO® systems are modular and usually temporary.

DE-FLUORO® has been undergoing development over the past 6 years. During that time, it has completed a series of large on site demonstrations and commercial programs across a variety of industry sectors and PFAS impacted waste streams.[77] This experience has allowed AECOM to improve and develop the technology. Representatives from AECOM and Aquatech point out that these improvements are not reflected in the current academic literature surrounding the use of electrochemical oxidation for PFAS destruction, and that they were encouraged by how much less energy DE-FLUORO® uses and how fast reduction times are compared to bench scale studies.

Aquatech was a perfect partner for AECOM in the deployment of this technology due to their experience providing integrated treatment processes for industrial water clients. Aquatech provides "water as a service" by renting out a fleet of assets to industrial clients and servicing and maintaining those assets.[78] In the same vein, they wanted to provide PFAS destruction as a service, which led to their partnership with AECOM. Through this partnership, the two companies hope to cut off PFAS reentry points into the environment, utilizing DE-FLUORO® and coupling with complementary treatment technologies when needed to remediate industrial wastewater, AFFF sites, landfill leachate, and concentrates from drinking water treatment.[79]

GHD also comments on increasing interest in destruction technologies. Some of GHD's clients have expressed interest in adding an incineration or other destruction step to their treatment process, and government agencies are putting in a lot of funding into their research. A representative notes that facilities utilizing destruction technologies need to be sure that they are not converting some of the less toxic PFAS precursors into more toxic terminal species or converting longer chain PFAS into shorter chain PFAS instead of destroying them. GHD remarks that treatment processes may need to include multiple different types of destruction technologies to destroy PFAS completely. Residuals produced by destruction technologies must be carefully monitored to ensure that destruction is complete.

Ultimately, no single strategy will be sufficient to address the challenge of PFAS contamination. A combination of regulatory measures, technological innovation, and proactive management at both the source and downstream will be necessary to protect public health and the environment from the harmful effects of PFAS. The success of these efforts will depend on continued collaboration among regulators, water systems, the research community, and the public to develop and implement effective and sustainable solutions.

Next Steps and Research Opportunities

Industrial and Academic Research

Although PFAS have been manufactured since the mid-20th century, research identifying them as a potentially harmful contaminant is relatively recent. Consequently, there is much research to still be done.

1. Researchers are working to develop better models to understand the **health impacts of PFAS compounds.**[80] Complicating the study of PFAS health impacts is the variety present within this category of compounds. There are thousands of unique PFAS chemistries, which means that not every single compound can undergo comprehensive study. Therefore, toxicologists are trying to identify ways that PFAS can be reasonably grouped to draw general conclusions about health risks. [81]
2. Researchers and regulators alike are also concerned about the **potential health risks of PFAS inhalation.**[82] The EPA has two test methods for measuring PFAS in air emissions and has considered the inclusion of PFAS in its proposed revisions to the air emissions reporting requirements.[83]
3. Another emerging research area is the study of **PFAS precursors**. Precursors are compounds that can be transformed into terminal PFAS as they undergo environmental or treatment processes.[84] These terminal PFAS include the compounds currently regulated under the NPDWR. Researchers want to understand the fate and transport of precursors to prevent them from turning into more harmful terminal PFAS.[85]
4. Advancing **PFAS analytical methods**[86] is also necessary to better understand the fate and transport of these chemicals – especially for small PFAS concentrations, air emissions, and PFAS precursors.
5. Advancing **treatment technologies** is another important research objective, both for concentrating PFAS and ultimately destroying PFAS.[87] Several alternative concentration and destruction technologies have been proposed, although many have yet to be studied at a large scale. In the same vein, researchers are still investigating the relationship of proposed treatment technologies to the co removal of other, non-fluorinated contaminants.[88]
6. Finally, given the origination of PFAS contamination from PFAS use in consumer products, developing **alternative chemistries** for their current applications remains an important area of research.[89]

In addition to their role as research centers, academic institutions also play a role in providing unbiased communications about PFAS.[90] By bridging the gap between research and public understanding, these institutions help foster informed decision-making and support efforts to address the complex challenges posed by PFAS contamination.

Partnership Across Stakeholder Groups

Interviewees mentioned the importance of collaboration between regulatory bodies, water systems, private industry, and academic institutions.[91] Each of these stakeholder groups has a role to play in limiting the public's exposure to harmful PFAS compounds.

One interviewee provides the NJDEP's collaboration with the Association of Environmental Authorities (AEA) as a great example of collaborative regulation. The NJDEP is considering establishing wastewater effluent limits for PFAS – particularly for facilities that discharge to surface water. AEA and has been working with the NJDEP for more than a year on a voluntary sampling program to assist in guiding the design of any potential regulation. Interviewees want to continue to see collaboration between water and wastewater systems and regulators to strike a balance between health protection and affordability.[92]

Interviewees noted that the Water Center and the University of Pennsylvania particularly foster an atmosphere of collaboration that can help craft reasonable policies and facilitate policy making to help solve this issue.[93] The Water Center's Corporate Round table, which provided the impetus for this white paper, serves as an excellent example of how corporate water sector organizations can engage with academic research to identify solutions to the PFAS issue.

Conclusion

The challenge of managing pervasive PFAS contamination requires a multifaceted approach that addresses not only contamination of drinking water but also the sources of contamination. While the EPA's new National Primary Drinking Water Regulation will reduce PFAS exposure, it places a disproportionate burden on water systems that are not responsible for the initial contamination. Water systems are feeling the pressure of this rule already.

Furthermore, removing PFAS from drinking water often does not permanently remove PFAS from the environment. Air emissions from PFAS incineration and leachate from landfills can reintroduce these compounds back into the environment, requiring further drinking water treatment. Considering these challenges, it is impactive to regulate sources of PFAS contamination and invest in safer PFAS disposal options.

While these regulations and technologies are in development, regulators and water systems must take care in releasing clear and solution-oriented communications. Providing accurate messaging about the risks and sources of PFAS - alongside transparent communication about regulatory actions and water quality efforts - can help mitigate public fear and build confidence in the measures that authorities are taking to protect health.

Overall, solving the PFAS challenge will require a coordinated, comprehensive strategy that combines regulatory action, scientific research, technological innovation, and public engagement. Now that the issue of PFAS contamination has entered public consciousness, stakeholders involved in all stages – from production to disposal – can contribute to the effective management of these "forever chemicals" and protect public health.

Endnotes

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