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Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Biosolids and Wastewater Treatment Plants through Stakeholder-Engaged Regulatory Frameworks

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Abstract

Per- and polyfluoroalkyl substances (PFAS) represent a pervasive group of over 15,000 chemicals characterized by their water and stain repellency, heat resistance, and chemical stability. Despite their microscopic size, many PFAS persist extensively in the environment, bioaccumulating within organisms and leading to serious health complications, including various forms of cancer and developmental problems in young children. Among the paramount threats to human health posed by PFAS, indirect contamination through food and water through biosolids emerges as a critical policy concern, as this type of exposure necessitates governmental intervention.[1] Wastewater treatment plants (WWTPs) stand out as prime examples of passive exposure nodes, as their byproducts contain PFAS and are reused as alternatives to fertilizer, thereby contaminating the food and water of unsuspecting populations. To address this pressing issue, this paper proposes a stakeholder-centered assessment group process modeled after the Ozone Transport Assessment Group (OTAG) to address passive PFAS exposure through biosolids. This collaborative body will include diverse PFAS stakeholders, including state and federal EPA, industry representatives, environmental advocacy groups, and community leaders, to make up smaller subgroups dedicated to PFAS research. These groups will curate credible knowledge about PFAS that can be directly funneled to policymakers through transparent and open meetings, ensuring effective regulation implementation. This paper will also recommend immediate policy and regulatory measures, informed by domestic environmental legislation and innovative international pollution-regulation precedents, to minimize the risk of passive exposure from PFAS while the assessment group works on further solutions.

[1] Indirect contamination by a pollutant through food and water will hereby be referred to as 'passive exposure.'

Introduction

In the 21st century, consumers have grown accustomed to handling a wide range of chemicals in their daily lives, from the acetone used to remove nail polish to the bleach applied for household cleaning. As such, we often implicitly place our trust in government regulations, assuming that if a substance is available for use, the government has determined its safety within the specified quantities. This trust relieves the general public from the burden of regulating potentially harmful products themselves through conscious shopping habits or personal research. Despite this perception, the federal government still needs to implement up-to-date regulations to protect citizens from a pervasive group of chemicals known as per- and polyfluoroalkyl substances (PFAS) that is currently challenging this confidence in government oversight.

Jason Grostic, a third-generation cow farmer in Michigan, recently was the victim of this lapse in federal regulation. Michigan regulators shut down Grostic's 100-year-old farm due to the "high levels of PFAS […] in both his beef and soil" (NPR Illinois). PFAS are a group of non-traditional and widespread chemicals that do not break down in the environment. As a result, Grostic's farm is now no longer operational due to the elevated levels of these chemicals, and he is at risk of bankruptcy, all because he used PFAS-contaminated biosolids as fertilizer, which he maintains was "recommended and was EPA-approved" (NPR Illinois). Michigan is leading the charge in PFAS-biosolid regulation and is equipped with state-of-the-art detection and screening technology. However, the lack of corresponding federal biosolid regulations creates gaps that adversely affect farmers. The federal EPA's hesitation in establishing stringent PFAS regulations is starkly evident in the agency's delayed response to biosolid-related risks, a stance that not only threatens public health but also endangers farms that use federally sanctioned biosolids for fertilization.

Jason Grostic's experience emphasizes the stark discrepancies between state and federal protocols regarding PFAS in biosolids. His situation highlights the significant repercussions for farmers who, in their efforts to comply with EPA standards, later discover that their state has more stringent regulations. While it is easy to villainize Michigan's more stringent regulations, Michigan is proactively taking steps ahead of the federal government to safeguard its citizens from chemical pollutants in their state's farms. Addressing this issue requires a cohesive and thorough strategy from the EPA, transcending beyond the traditional, fragmented methods to establish a more sophisticated trajectory from scientific research to regulatory action. The EPA needs to break free from its solitary operations and bring together a coalition of stakeholders – not just federal EPA scientists and regulators, but state policymakers and regulators, non-EPA academic researchers, industry experts, environmental groups, and community leaders – to facilitate the knowledge needed to regulate PFAS-biosolids correctly and efficiently. Given the duality of biosolids – their critical role as alternatives to synthetic fertilizer and their potential threat to compromise food sources – this issue presents a compelling case for the EPA to pioneer a collaborative and cutting-edge approach to regulatory innovation.

Background and Context

Per- and polyfluoroalkyl substances (PFAS), a group of non-traditional and widespread pollutants, have stealthily pervaded our lives and environment. To date, around 14,375 PFAS analytes have been identified, being manufactured in consumer, military, industrial, and scientific products, with uses ranging from the non-stick coating on pans to fire-fighting foams to artificial lung membranes (Glüge et al.).[2] These applications have demonstrated their indispensability to human health and society-dependent technologies. Due to their extensive use and

[2]An analyte is a substance or chemical constituent of interest.

bioaccumulative characteristics, PFAS pervade virtually every corner of the world, exposing humans to low levels through water, air, fish, and soil (OA US EPA, *Our Current Understanding of the Human Health and Environmental Risks of PFAS*). In recent years, there has been a substantial increase in research on PFAS and its health effects (Abunada et al.). At the same time, various animal and epidemiological studies suggest that heightened PFAS exposure may result in elevated cholesterol levels, weakened antibody responses to certain vaccines, disturbances in liver enzymes, and an augmented risk of specific cancers, such as kidney and testicular cancers (ATSDR).

The first of many PFAS was initially developed by accident in the 1930s (Teflon). Marketed under the brand name ‘Teflon,’ this chemical, polytetrafluoroethylene (PTFE), revolutionized the culinary experience for many due to its non-stick properties and resistance to high temperatures (Renfrew and Pearson). Its creation also signified a transformation in society as its application extended into virtually every sector of industry – clothing, homeware, medical technology, fire-fighting technology, and more. Chemical giants like Dupont and 3M have capitalized on PFAS’ extreme durability and resistance to degradation to create a billion-dollar market that is threatening both the environment and human health (Glüge et al.).

A chemical is considered under the umbrella term ‘PFAS’ if it contains a fluorocarbon backbone. This backbone is one of the strongest bonds in organic chemistry and is largely responsible for why PFAS do not break down in the environment (Buck et al.). When substances do not break down, they can bioaccumulate in living organisms, meaning they gradually build up in the tissues of plants and animals over time (George et al.). This accumulation can lead to elevated concentrations of the substance in individual organisms if they continue to consume contaminated food or water, posing significant health risks and potentially impacting other organisms higher up the food chain (George et al.). So far, the EPA has issued a health advisory for less than 10 PFAS analytes, warning that increased PFAS exposure can lead to developmental and reproductive effects, increased risk of some cancers, and interference with the body's immune system and hormones (OA US EPA, *Our Current Understanding of the Human Health and Environmental Risks of PFAS*). While there have been preliminary steps taken to address certain PFAS chemicals, like PFOS and PFOA, in drinking water, due to the long-established linkage between them and increased risk of certain cancers and reproductive effects, the extensive array of chemicals falling under the PFAS umbrella remains inadequately understood (Ojo et al.). Health agencies and the EPA have been exercising caution, recognizing that health effects observed in one PFAS analyte may not necessarily mirror those of others. Consequently, the EPA has focused on regulating PFAS in drinking water through a piecemeal strategy that poses ongoing risks to the public as they are exposed to many different PFAS analytes through other media in the environment.

At present, the EPA needs more comprehensive information regarding all of the existing PFAS analytes in the environment and is currently developing detection methods to identify and track PFAS that were not previously in their database (ORD US EPA, *PFAS Analytical Methods Development and Sampling Research*). The EPA acknowledges the significant gaps in its database, admitting that "thousands of chemicals in commerce and the environment for which there is little to no readily available exposure data" (ORD US EPA, *Non-Targeted Analysis Research*). To address unknown PFAS analytes, the EPA employs various detection methods to identify all PFAS accumulating in the environment (ORD US EPA, *PFAS Analytical Methods Development and Sampling Research*). To identify and characterize previously unknown PFAS analytes, a 'non-targeted analysis' method is used, which requires mass spectrometry, a technique that can only be done inside laboratories. This technique finds and uses the mass-to-charge ratio of a chemical to determine the structure of an unknown chemical compound (Garg and Zubair).[3] Another technique is 'targeted analysis,' which consists of detection methods that can only quantify around 50 or so pre-defined analytes (ORD US EPA, *PFAS Analytical Methods Development and Sampling Research*). Both of these methods play a crucial role in identifying areas of PFAS contamination and the specific PFAS compounds affecting these particular sites. However, there are no on-site methods that would enable testing for PFAS without the need for a laboratory. This on-site technology would be a significant advancement in addressing PFAS contamination, and numerous institutions are actively working toward its development (Wu and He).

The EPA's current strategy can be characterized as 'traditional' because it attempts to regulate PFAS as if it were a normal pollutant, such as lead, benzene, or arsenic, to name a few. Traditional pollutants like these are typically well-understood substances with stable chemical structures and predictable environmental behaviors. In contrast, PFAS pose unique challenges due to their complex and diverse chemical structures, variable properties, and persistence in the environment, which complicates regulatory efforts. The current estimation of known PFAS analytes, numbering around 14,735, indicates that each PFAS analyte was manufactured and tailored for particular applications, and health effects may vary from analyte to analyte (*CompTox Chemicals Dashboard*). The EPA, adhering to a conventional regulatory process, is narrowly focusing on the most well-studied PFAS compounds, PFOA and PFOS, which they had identified as contaminants of concern in 2009 (Pontius)and only in 2022 had the EPA proposed PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response,

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[3] The EPA utilizes the following types of mass spectrometry in their PFAS analysis: high-resolution mass spectrometry (HRMS) and liquid chromatography/tandem mass spectrometry (LC/MS/MS) (ORD US EPA, *PFAS Analytical Methods Development and Sampling Research*).

Compensation, and Liability Act, 20 years after PFOS had been phased out of production and seven years after manufacturers had phased out PFOA (National Toxicology Program). While these steps are necessary and overdue, there are still thousands of other PFAS that are in commerce, polluting our environment and posing health risks to everyday citizens. The EPA has not fully addressed the environmental contamination by PFAS, as its regulatory efforts have been limited to managing only a few specific analytes – PFOA, PFOS, PFNA, PFHxS, PFBS, and GenX chemicals – in drinking water. At the same time, other media avenues of pollution remain unregulated (OW US EPA, *Per- and Polyfluoroalkyl Substances (PFAS)*). Particularly, concerted efforts are needed to address PFAS in biosolids that inadvertently expose unsuspecting populations to higher concentrated levels of these pervasive substances through their use as fertilizer in agriculture.

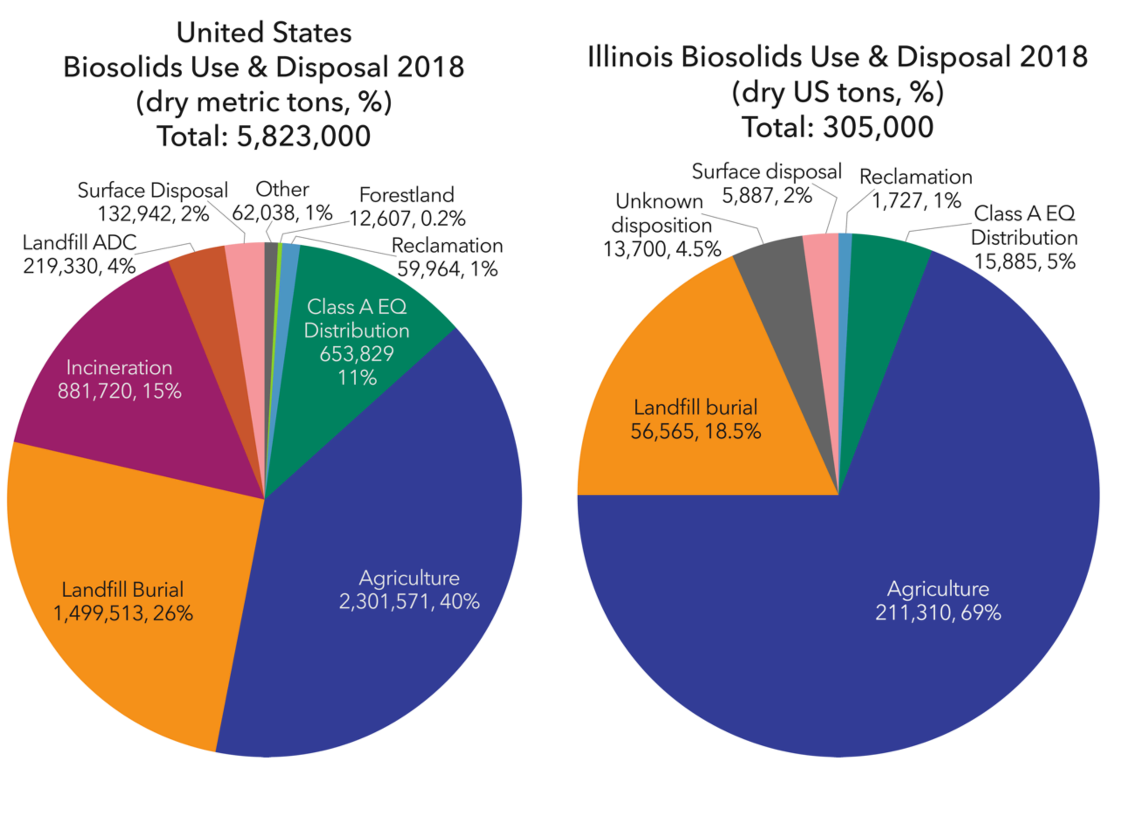

Fig. 1. Biosolid Use in the United States and Illinois. Source: National Biosolids Data Project.

Ordinary citizens unwittingly face exposure to PFAS through the ingestion of their food, a consequence of the use of wastewater byproducts, known as biosolids, as alternatives to fertilizer on farms and in agriculture (Blaine et al.). Wastewater treatment plants (WWTPs) receive wastewater from homes, businesses, and industrial sites, with the ultimate goal of cleaning and reusing wastewater for discharge into streams or other receiving waters (OW US EPA, *Municipal Wastewater*). Influent wastewater is received by the plant and treated to remove solids through physical and biological processes. [4] Besides effluent water, WWTPs often produce biosolids, the separated solids from the initial influent, which are physically and chemically treated to make a "semisolid, nutrient-rich product" (US EPA). [5] While it is ultimately up to the wastewater treatment plant to dictate where these byproducts go, they will almost always be introduced to a water source like groundwater or surface water (OW US EPA, *Municipal Wastewater*).

Studies have found that concentrations of PFAS in WWTPs' effluents are often higher than the initial influent due to "existing PFAS precursors in wastewater and their biodegradation after the activated sludge process" (Barisci and Suri 3446). Essentially, these studies have found that PFAS are being broken down through the wastewater treatment process, but only into smaller components of PFAS, which are then discharged as effluent or made into biosolids and contaminating food sources. According to the National Biosolids Data Project, around 2.3 million dry metric tons of biosolids are being used for agriculture in the United States (Fig. 1, National Biosolids Data Project). Over the past few decades, biosolids have become popular with farmers and the agriculture industry as more eco-friendly alternatives to synthetic fertilizers (National Biosolids Data Project). However, this practice has become scrutinized as studies show

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[4] Influent wastewater is raw, untreated wastewater flowing into a treatment plant or process.
[5] Effluent wastewater is partially or fully treated wastewater flowing out of a treatment plant or process.

that biosolids contain more concentrated levels of PFAS than the initial influent, and this byproduct is being used to fertilize and, therefore, contaminate food and water sources.

While the EPA has acknowledged the need for more research into PFAS-contaminated biosolids and the uptake of PFAS into agriculture, they still need to produce a concrete framework for organizing and streamlining these studies. As of 2024, the EPA has only acknowledged that they are “working to address PFAS in biosolids” for PFOA and PFOA. However, they have not shared a concrete plan with the public or stakeholders like Jason Grostic that could be negatively affected by biosolid regulation (OA US EPA, 8, *Second PFAS Strategic Roadmap*). A noteworthy example of collaborative efforts that could be applied to the EPA’s regulation of PFAS-biosolids is the Ozone Transport Assessment Group (OTAG). Tasked with recommending strategies to reduce ozone transport, this endeavor, led by state environmental protection agencies and the Environmental Council of the States, hinged on a transparent coalition of diverse stakeholders from the federal EPA, state governments, environmental groups, and industry that worked together to develop impactful air quality control measures (Koerber). Over the course of two years, this diverse array of participants was able to produce ‘credible knowledge’ of the issue at hand, which was subsequently channeled upward to inform policy groups (Farrell and Keating). These groups engaged in concerted negotiation to reach a consensus on strategies to reduce ozone transport and attain the required National Ambient Air Quality Standards (NAAQS), culminating in well-supported decisions that could be adeptly put into action by EPA regulators. This is a model process that should be used by the EPA when attempting to regulate such a complicated and far-reaching chemical pollutant as PFAS.

Conceptual Framework

There needs to be more scientific organization and communication between third-party researchers and the EPA, leading to a bottleneck within the regulatory process and preventing the agency from effectively regulating the thousands of PFAS accumulating within agriculture from biosolids. This is mainly because the EPA is operating as if PFAS are traditional pollutants when they are anything but. As such, this project will recommend and outline a non-traditional and collaborative assessment process for researching and regulating PFAS in biosolids and WWTPs based on a previous assessment process coordinated by the Environmental Council of the States, state EPAs, and the federal EPA called the Ozone Transport Assessment Group (OTAG). The goal of this recommendation is to provide an example of a novel framework for the EPA to organize and utilize the vast amount of information needed to regulate these pollutants that can be adapted to fit any non-traditional pollutant now or in the future.

Through this recommendation, this project will seek to answer two questions: First, how can a collaborative, OTAG-like process be used to bridge the gap between current scientific knowledge of PFAS in biosolids and PFAS regulation? Second, what are some effective regulatory measures that can be implemented during the process to control and remediate PFAS in biosolids?

In response to these inquiries, my paper asserts that the establishment of an assessment group comprising state and federal regulators, industry representatives, and environmental groups is imperative to develop ‘credible knowledge’ of PFAS science, laying the groundwork for a practical regulatory framework to address PFAS. If assessment groups are recognized as “forums for interaction and negotiation between experts and policymakers” (Farrell and Keating, 2538), the creation of widely accepted knowledge from small, expert working groups to higher-up policy decision-makers is indispensable for addressing an issue as complex as PFAS. While this collaborative process can be used to address various PFAS-related challenges, this paper will specifically focus on building a framework for PFAS-biosolid regulation.

Therefore, this paper argues that a collaborative approach involving states, the EPA, federal decision-makers, industry, and scientific experts is essential for finding solutions to the heightened concentrations of PFAS in biosolids. A collaborative process is indispensable to ensure that regulation efforts effectively reduce the presence of PFAS in biosolids and, therefore, food sources, the environment, and humans.

Literature Review

This project seeks to propose a stakeholder-driven regulatory framework to mitigate downstream PFAS contamination in wastewater treatment plants (WWTPs), aiming to minimize passive PFAS exposure through biosolids application. Drawing on peer-reviewed scientific research, official EPA reports, and law review articles, this project establishes the contemporary landscape of PFAS research and regulation. Scientific studies illustrate the potential threat of biosolids to human health, the relevance of PFAS in agriculture, and possible technologies for PFAS-biosolids remediation solutions. EPA documents provide insights into actions taken so far by the federal government to address PFAS in biosolids and areas requiring further attention. Law review articles identify gaps in current PFAS policy recommendations, and the project addresses these by proposing pragmatic, actionable measures tailored for effective implementation by the EPA.

Overview of Current EPA Strategies

The Environmental Protection Agency has been aware of the possibility of PFAS' detrimental health effects since the late 1990s. While federal response and scientific literature surrounding this topic have increased dramatically in the past few years, the EPA has been slow to respond with concrete actions to address this widespread contaminant and its disposal.

In 2002, manufacturers agreed to voluntarily phase out the toxic PFAS known as PFOS (US EPA) amid a CDC investigation revealing PFOS in the blood of 98% of Americans in 2000 (Lewis et al.). Almost a decade later, PFOA, a similar long-chain PFAS, was associated with immunotoxic effects (National Toxicology Program), and its voluntary phase-out concluded in 2015. Despite these chemicals no longer being produced or sold in the United States, PFOS and PFOA blood serum levels in Americans persist, marked by studies referencing the accumulation of 'legacy' PFAS like PFOS and PFOA in wastewater effluents today (Spyrakis and Dragani). The EPA and other federal agencies like the CDC have understood PFOS and PFOA's persistent environmental and health-related impacts for decades. However, the EPA only set "non-enforceable" drinking water advisory levels for PFOS and PFOA in 2016 (Brennan et al. 9). Over two decades after these PFAS were understood to be toxic, the EPA stated in December of 2023 that they are "in the final stages of developing a regulation to list perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) as hazardous substances under CERCLA" (US EPA 3). As the EPA focuses its efforts on regulating two out of 15,000 known PFAS, the fate of thousands of less-understood PFAS passing through public WWTPs remains unclear, with recent EPA publications lacking guidance on addressing them.

As of December 2023, the EPA issued its second 'PFAS Strategic Roadmap,' which provides a summary of the EPA's goals and key actions taken to address this pollutant since

Michael S. Regan, the 16th EPA Administrator, was appointed by the Biden Administration. It is clear from the roadmap that Regan and the EPA's main priority is researching the extent to which PFAS are present in water sources, and there is minimal reference to biosolids or the threats biosolids pose to agriculture. While contaminated water sources are quantitatively a much bigger problem than biosolid contamination, biosolids are used as fertilizers for farmland in almost every state (US EPA). The EPA states that they are "working to further engage with a wide range of partners in managing biosolids" (US EPA 8) and that they "recognize the unique challenges and uncertainties presented […] and they highlight the importance of partnership across all levels of government" (US EPA 11) to address PFAS. The lack of acknowledgment of the threat of PFAS contamination to agriculture and groundwater or mention of any plans for remediation justifies my recommendation for an assessment process similar to the Ozone Transport Assessment Group (OTAG) in addressing PFAS accumulation in biosolids produced from WWTPs. These recommendations also align with the EPA's expressed intent to engage in partnerships and stakeholder-based procedures.

PFAS Uptake in Agriculture and Groundwater Contamination

PFAS, characterized by their resistance to degradation and bioaccumulative properties, are pervasive in numerous consumer products. Their ubiquitous use in daily life results in their presence in wastewater through industrial discharges, stormwater runoff, household wastewater, and improper disposal of PFAS-containing products (The Environmental Council of the States (ECOS)). While upstream regulation, which involves preventing industrial discharges into water sources and halting the production of new PFAS, represents a critical step in addressing PFAS pollution (US EPA), it is equally imperative to remediate the PFAS already released into the environment to prevent their bioaccumulation in humans.

Studies have revealed that PFAS-contaminated soils lead to the uptake of PFAS by diverse vegetative plants like carrots, cucumbers, potatoes, corn, wheat, and oats, meaning that the use of biosolids as fertilizer for agriculture represents an alarming route of exposure in humans (Blaine et al.). Multiple studies by Weber et al. and Johnson et al. also indicate that agricultural soils exposed to repeated biosolid applications serve not only as reservoirs for PFAS but also as contributors to below-soil groundwater pollution. The current scientific literature shows that biosolid application poses a worrisome route of exposure to humans that the EPA should be addressing. As such, given the troubling PFAS levels that Americans are exposed to through food and water, PFAS remediation technologies could be a viable way to mitigate downstream PFAS contamination in biosolids.

PFAS Remediation Technologies for Wastewater Treatment Plants

Because WWTPs stand in between PFAS and human exposure, implementing remediation technology has been described as a possible solution to PFAS contamination in biosolids. Consequently, WWTPs stand as pivotal targets for increased PFAS regulation. They actively contribute to heightened human exposure through the contamination of biosolids and, subsequently, human food sources (Ghisi et al.). Extensive research has focused on the efficacy of treatments aimed at eliminating PFAS from biosolids, with the primary objective being to ensure that biosolids can remain a viable resource for agriculture without risking the potential uptake of PFAS by plants. A study by Kim Lazcano et al. tested the effectiveness of current wastewater treatment processes in filtering out PFAS from biosolids. The researchers found that four treatments used by WWTPs – heat treatment, composting, blending, and thermal hydrolysis – "either increased the [PFAS] concentrations [...] or had no significant effect on the level of [PFAS]" (1676). They have characterized existing wastewater treatment processes as inadequate, emphasizing the need for the introduction of remediation technologies in WWTPs.

Parallel to this study, Kumar and Ravinder et al. reviewed the different degradation pathways for PFAS-biosolids and gave advantages and disadvantages for each.[6] Among the pathways are biological degradation (biodegradation), hydrothermal liquefaction treatment (HTL), thermal degradation (smoldering combustion), incineration, and pyrolysis. Although biodegradation and HTL did not achieve complete PFAS destruction, biodegradation emerged as the most cost-effective and environmentally friendly approach because it relies on microbes to consume PFAS and slowly remove them from biosolids. On the other hand, HTL offers the advantage of not requiring biosolid pre-drying or exposure to high temperatures. These factors typically lead to substantial upfront costs and prolonged treatment processes. Smoldering combustion, incineration, gasification, and pyrolysis were found to be >99% effective for PFAS destruction. However, they are energy-intensive and expensive, and some, like incineration and gasification, could result in hazardous emissions. More research is needed to understand the intermediate steps in these processes and what forms PFAS take after they are destroyed. Factors like cost and carbon emissions associated with these technologies will be further evaluated to determine the most suitable option for my proposal. This literature reveals that despite many researchers studying biosolids and the best technologies for their effective removal, only some of these scientists are able to propose pragmatic regulatory frameworks to institute them. This project acknowledges the scientific discoveries made by researchers in this field while

[6] A degradation pathway is defined as a chain of chemical reactions that results in the breaking down of a complex molecule.

concurrently proposing a regulatory framework tailored to effectively implement these technologies in wastewater treatment plants (WWTPs) where they are most crucial.

Legal Reviews and Current Policy Recommendations for the Regulation of PFAS

Given the EPA's limited focus on regulating PFAS, numerous policy recommendations and law review papers have surfaced, offering insights into how the EPA can enhance its oversight of this non-traditional pollutant. Notably, Molly Carey from the Vermont Law School has presented federal policy recommendations, advocating for financial assistance, medical monitoring, and mental health services to farmers affected by PFAS contamination from land-applied biosolids (Carey). Although Carey's review delves into the regulatory aspects under various environmental laws, such as the Clean Water Act, Toxic Substances Control Act, and Resource Conservation and Recovery Act, it falls short of providing a novel and practical regulatory framework for the EPA to implement these regulations effectively.

With PFAS contamination reaching a massive scale nationwide, the EPA has grappled with treating PFAS as a conventional pollutant, overlooking the diverse categories and sources of contamination that defy traditional approaches. Carey's recommendations suggest regulating PFAS as a class. While this strategy would prove very effective at reducing PFAS exposure by implementing stringent control measures, it neglects the complexity of PFAS essential for societal functions and, therefore, will have widespread ramifications on the economy and medical practices and could result in a chain reaction of supply chain issues (Spyrakis and Dragani). It is not a pragmatic solution in terms of U.S. policy, as there is no precedent for regulating a chemical with as many analytes and insufficient evidence of acute and low-dose toxicity as a class. In order to understand strategies that the EPA would consider for regulation, this paper will conduct case studies to explore the United States' historical role in regulating widespread pollutants and the legislation that affords this responsibility. An examination of pollutants such as CFCs and synthetic fertilizers can provide valuable insights.

Dean et al. suggested a comparable strategy to regulate PFAS as a class in their 2020 framework, drawing on the Montreal Protocol's principle of determining essentiality based on application. However, this paper falls short of providing specific policy recommendations for remediating existing PFAS already circulating in our environment and wastewater, and it is somewhat outdated in the context of contemporary PFAS knowledge. Ongoing research, such as Spyrakis and Dragani's paper, challenges the notion that all PFAS are uniformly toxic. Their findings indicate that larger PFAS, like fluoropolymers, are too large to bioaccumulate in humans, ultimately being eliminated from the body. This highlights the evolving understanding of PFAS toxicity, emphasizing the need for up-to-date considerations and communication between third-party scientists and decision-makers within the EPA.

<u>The Ozone Transport Assessment Group (OTAG) and its Applicability to PFAS</u>

The Ozone Transport Assessment Group (OTAG) was a two-year initiative "led by the heads of the environmental regulatory agencies of 37 eastern states to develop strategies" to decrease the issue of transboundary pollution, specifically the transport of tropospheric ozone (Farrell and Keating 2537). Ozone transport transcends political jurisdictions and cannot be confined to the state that is sourcing the pollution; as such, OTAG emerged against a backdrop of conflict between upwind sources of ozone precursors and downwind receptors. Upwind states hesitated to implement regulations controlling their NOx emissions as downwind states felt the consequences. These downwind states faced a dilemma: their regions were technically non-compliant with the federal EPA's air quality regulations, but they could not rectify the situation since they were not the ones contributing to the emissions. In response to this conflict, the Environmental Council of the States and the U.S. EPA established OTAG with the aim of "[identifying] and [recommending] a strategy to reduce transported ozone and its precursors" (Koerber 2169) to achieve compliant National Ambient Air Quality Standards.

Essentially, the conflicting states were tasked with collaboration and compromise through a "social process by which expert knowledge related to an environmental policy problem is organized, evaluated, integrated, and delivered to decision-makers" (Farrell and Keating 2537). While the OTAG process did not result in a miraculous compromise where all upwind sources ceased pollution and downwind sources achieved their air quality standards, it allowed for the establishment of 'credible knowledge.' This term, coined by Farrell and Keating, refers to "knowledge that scientific and engineering experts hold [being] transferred or translated into information that is widely acknowledged to be true by policymakers and other nonexperts" (Farrell and Keating 2538).

Establishing credible knowledge is crucial for regulating PFAS, given the thousands of peer-reviewed scientific articles addressing various aspects of PFAS, proposing policy recommendations, and providing evidence of their correlation with health effects and pervasive presence. Despite this extensive body of knowledge dating back to the early 2000s when PFOS and PFOA began to be phased out, there has been a need for concrete regulatory action.

The scientific consensus maintains several vital points: 1) PFAS contamination has reached almost every corner of the environment (Buck et al.), 2) certain PFAS pose risks to human health and child development (Betts, Inoue et al., Pierozan et al., Barry et al.), 3) insufficient wastewater treatment processes are causing increased PFAS concentration, contaminating food and water sources (Barisci and Suri), and 4) PFAS are inherently transboundary pollutants. Introducing an OTAG-like process for PFAS would foster meaningful dialogue between scientists and policymakers, facilitating consensus among both state and federal decision-makers on established scientific knowledge. This shared foundation of assumptions could then serve as a springboard for informed policy development. Given the diverse range of chemicals falling under the PFAS umbrella, with varying uses, essentiality, health impacts, size, and properties, a multitude of stakeholders are necessary to regulate these pollutants effectively.

While Farrell, Keating, and Koerber's papers provide a comprehensive overview of the OTAG process, they fall short of adequately highlighting OTAG's landmark significance in securing state compromise and advancing our understanding of ozone transport. This project aims to address this gap in the literature by emphasizing these achievements and demonstrating their continued relevance in addressing nontraditional pollutants like PFAS.

As of 2024, research on the health effects of PFAS and their widespread contamination of the environment has increased exponentially. The EPA's efforts to address PFAS have also sped up. However, their most recently published work fails to have a plan for biosolid research or regulation avenues, providing a space in which this project can provide recommendations for the EPA's next steps in addressing biosolids. These recommendations will be based on the OTAG process – a framework based on OTAG will be outlined to show how adaptable this collaborative and scientific assessment process can be to any complicated and far-reaching environmental problem. Research on PFAS remediation technologies, their costs and benefits, and their feasibility will be included in this recommendation, as well as historical pollutant regulation precedent that can be used to recommend a pragmatic way for the EPA to regulate PFAS.

Data & Methods

Qualitative analyses of existing legislation and regulation precedent and historical case studies of pollutant regulation inform the policy recommendations proposed in this paper. Visualizations drawing on data collected by environmental thinktanks like the Environmental Council of the States, the Natural Biosolids Data Project, and the SUNY Rockefeller Institute of Government are utilized to provide additional context and legibility to densely informative sections and as evidential statistics within the recommendation.

Legislative Exploration

This project's legislative exploration encompasses primary legal sources, focusing on regulations derived from the Clean Water Act and the Toxic Substances Control Act to determine their applicability to the regulation of biosolids. The regulatory interpretation of these laws is published on the EPA website, with citations and direct links to their origins in the United States Code. The EPA commonly uses these laws to regulate traditional pollutants, yet not all of them have been used for regulating or remediating PFAS in WWTPs. Understanding why these environmental protection laws have not been utilized is crucial, as it allows for a comprehensive examination of existing gaps in regulating PFAS in biosolids. The identification of these regulatory gaps will serve as gateways for this project to recommend the establishment of a PFAS-centered assessment group to advance scientific understanding of PFAS in biosolids and facilitate the seamless transmission of credible knowledge to decision-makers.

Case Studies

Examining case studies of pollutant regulation with comparable novelty to PFAS is a crucial approach for informing practical policy recommendations because they can provide historical insights that help distinguish successful regulation strategies from unsuccessful ones. This is especially important when proposing policies to address environmental pollutants, as 'regrettable substitution' is a potential pitfall of chemical regulation that must be carefully navigated.[7] To understand historical efforts of regulating novel pollutants, this project will conduct case studies on the Montreal Protocol and nutrient pollution regulation in the United States. Details of these case studies are often published in credible academic policy forums or reviews. In the case of the Montreal Protocol, information was sourced from K. Chatterjee's *Ozone Depletion and Montreal Protocol on Substances Depleting Ozone Layer*.

While these case studies do not detail a perfect regulatory 'fit' for PFAS, they represent unique and non-traditional approaches to addressing an environmental pollutant. Given that the EPA has been regulating this group of over 15,000 analytes in an individual, piecemeal fashion as they would any regular pollutant, understanding novel pollutant approaches is critical to proposing a regulatory framework that embraces the complexity inherent in addressing such a multifaceted collection of contaminants.

The premise of this project and the policy recommendations within are reliant on the organizational framework behind the Ozone Transport Assessment Group (OTAG), which provides the basis for the collaborative, stakeholder-centric regulatory framework that this paper will argue for. The success of OTAG is attributed to its adept engagement of stakeholders, including the EPA, the Environmental Council of the States, scientists, industry, and

[7] Regrettable substitution is defined as "when a chemical with an unknown or unforeseen hazard is used to replace a chemical identified as problematic" (Maertens et al.).

environmental groups. By consulting their diverse perspectives and leveraging their collective knowledge on ozone, OTAG fostered collaboration among previously disagreeing states, leading to consensus on ozone transport policy. OTAG's process is not only applicable to PFAS regulation due to its efficacy in reaching consensus but also because the transparent assessment process facilitated scientific research, consultation, and understanding of a previously unknown variable—ozone transport. This advancement enabled government bodies to accurately regulate pollutants and achieve tangible and positive effects without imposing burdensome and unattainable limits. Given the pervasive presence of PFAS in consumer products, industrial, medical, and military processes, as well as the environment, a substantial gap exists in scientific knowledge regarding toxicity and health effects of PFAS, analytical detection methods for different analytes, treatment technologies, and monitoring and surveillance of concentrations within environmental mediums like water, soil, and even air. This knowledge deficit hampers the EPA's capacity to regulate PFAS effectively; therefore, a regulatory process modeled after the Ozone Transport Assessment Group would not only offer a framework for advancing scientific understanding but also facilitate the dissemination of 'credible knowledge' directly to policy decision-makers (Farrell and Keating).

Quantitative Data

Quantitative data and statistics from multiple environmental think tanks on PFAS-contaminated WWTPs, biosolid use by state, introduced and passed legislation on PFAS by state, and suspected industrial users of PFAS. More will be the basis of visualizations throughout this project in order to convey the massive scale in which PFAS are contaminating the WWTPs in almost every community, town, and city in the United States, further emphasizing the need for a collaborative, transparent, and science-forward approach to regulate PFAS in biosolids.

Qualitative data from legal sources and historical case studies will be used to form recommendations for a non-traditional regulatory approach to PFAS contamination in biosolids and WWTPs. In contrast, quantitative data will be used to supplement these recommendations and offer a clear representation of trends, patterns, and the magnitude of PFAS contamination. By examining legislative and regulatory precedents and leveraging case studies to identify parallels between historical pollutants and PFAS, this project aims to integrate the most effective elements of environmental policy to address the unique challenges posed by a non-traditional and pervasive pollutant.

Fig. 2. Case Study Synthesis

Data Analysis

This section contains comprehensive analyses of legislative explorations and critical case studies that have significant implications for shaping the regulatory framework for PFAS. These case studies on the Toxic Substances Control Act (TSCA), the Montreal Protocol, and nutrient pollution regulation play a vital role in illuminating historical precedents, regulatory achievements, and the intricate challenges inherent in regulating pollutants deeply intertwined with the social, economic, and health contexts of our world. They offer invaluable lessons essential for crafting robust and adaptable regulations governing PFAS.

Figure 2 depicts the key insights gleaned from each case study that will be applied to the policy recommendations within this paper. By integrating these historical milestones and precedents of pollutant control, the proposed regulatory framework is designed to encompass a comprehensive understanding of pollution management, a necessity given the non-traditional and pervasive nature of PFAS. This innovative approach is crucial for addressing the unique challenges posed by PFAS, ensuring that regulations are not only informed by past successes and obstacles but are also tailored to confront the novel complexities of these persistent pollutants.

The first case study scrutinizes a particular legislative measure, the Toxic Substances Control Act (TSCA), which underwent an amendment in 2016 to bolster the Environmental Protection Agency's (EPA) authority over the manufacturing and production of chemicals. Before this amendment, the EPA had scant ability to regulate the production of novel chemicals without providing proof of harm. This pivotal amendment, the Lautenberg Act, empowered the EPA to halt the manufacture of any new PFAS and furnish broader powers to prevent industry from manufacturing chemicals with health and environmental repercussions, akin to their past actions with CFCs and PFAS.

The second case study revolves around the Montreal Protocol, a pioneering and collaborative endeavor that unified over 197 nations in the cessation of 'nonessential' production, usage, and distribution of chlorofluorocarbons (CFCs), chemicals notorious for their role in ozone layer depletion (US EPA). The crux of this investigation lies in the essentiality clause, highlighting its role as a guiding precedent for pollutant regulation. This clause holds the potential to delineate essential versus nonessential applications of PFAS, thereby curbing their production, utilization, and market proliferation.

The third case study will delve into the ways that nutrient pollution is controlled in the United States, specifically focusing on the regulation of fertilizers containing nitrogen and phosphorus, which contribute significantly to the phenomenon of eutrophication in both freshwater and marine ecosystems (Ngatia et al.). This investigation is crucial for creating innovative PFAS regulation, as nutrients like Nitrogen and Phosphorus, while naturally occurring compared to PFAS, are equally as pervasive and can cause harmful effects to ecosystems if not stringently controlled. These nutrients and PFAS contamination share similar pathways of dispersion and environmental impact. By examining the strategies employed to mitigate nutrient pollution and their efficacy, valuable insights can be gained that may inform the development of effective regulatory measures for addressing PFAS contamination.

Utilizing the information gathered from these case studies, significant regulatory precedents can be extracted and applied to a regulatory framework for controlling PFAS biosolids in WWTPs. These findings will be combined with an assessment process based on the Ozone Transport Assessment Group. While the entire process will follow the assessment group's methodology, the most critical aspects of these case studies will be utilized to create an innovative and non-traditional pollutant control recommendation.

The Toxic Substances Control Act (TSCA)

The Original Framework 1978-2015

The Toxic Substances Control Act (TSCA) is an essential instrument for the Environmental Protection Agency (EPA) in its mandate to regulate the use of chemicals within a range of sectors, including industry, commerce, and consumer products. Enacted in 1976, TSCA's original framework granted broad regulatory authority over any chemical posing an unreasonable risk to human health or the environment (Denison) while simultaneously requiring that the agency's authority "should be exercised in such a manner as not to impede unduly or create unnecessary economic barriers to technological innovation" (TSCA §2(b)). The EPA had to weigh the advantages of regulatory measures against their economic implications, often necessitating proof that regulatory benefits surpass financial costs and do not stifle innovation (Denison). This effectively meant that the EPA had to establish the harmfulness of a chemical before its market release—a near-impossible task exacerbated by the original TSCA's Confidential Business Information clause, which allowed companies to withhold chemical information as proprietary or confidential, thus concealing it from both the government and the public.

In a bizarre contradiction, for the regulation of drugs and pesticides, which falls under the jurisdiction of the Food and Drug Administration, "producers have the burden of providing to the government information sufficient to demonstrate their safety." In contrast, for the TSCA, the EPA has the burden of proving that the substance is unsafe (Denison, 3). From 1978 until 2015, all chemicals manufactured under the TSCA were presumed safe until proven otherwise after their release to the public, with the onus on the EPA to provide irrefutable evidence of risk to compel producers to conduct tests (Denison). The EPA later identified several chemicals introduced as harmful – Bisphenol A (BPA), asbestos, and lead as notable examples (US EPA). Now, we are seeing history repeat itself with PFAS.

The Lautenberg Amendment of 2016

The original framework of the TSCA was only suitable for actually regulating chemicals after they came onto the market or ensuring that they were safe for humans or the environment. The consensus that the TSCA needed to be more adequate for providing the EPA tangible powers to regulate chemicals came to a head in 2016 when the Frank R. Lautenberg Chemical Safety for the 21st Century Act was passed, acting as an amendment to the original TSCA. The amendment also followed global chemical safety concerns, notably that Canada and the European Union were passing much more stringent laws on chemical safety, which made it difficult for the U.S. chemical industry to compete globally (Denison). For this reason, even the chemical industry supported TSCA reform.

The revision of the Toxic Substances Control Act through the Lautenberg Act brought about substantial changes to the EPA's regulatory powers. Notably, the Act divorced risk evaluation from cost-benefit analysis (Denison). Now, the EPA's risk determination focuses exclusively on the potential health and environmental impacts of a chemical without intertwining economic considerations into this phase (TSCA §4(f)(2)). This ensures that safety is the paramount concern during the risk assessment process. It also obligates the EPA to assess the safety of all new chemicals before they enter the market, identifying any unreasonable risks they might pose (Denison) and empowering the EPA to require chemical testing without demonstrating potential risk. Transparency is also significantly enhanced under the Lautenberg

Act, particularly regarding confidential business information (Denison). Now, general details about the usage and function of chemicals cannot be concealed under CBI, and access to CBI is granted to state and local authorities, environmental and health professionals, and others as appropriate, fostering a more open regulatory environment (Denison).

The Lautenberg Act enhances the EPA's authority to regulate the introduction of new chemicals and manage existing substances like PFAS. The EPA has used the Lautenberg Act's provisions to finalize Significant New Use Rules for PFAS, preventing any company from "starting or resuming the manufacture or processing of 329 PFAS" without EPA review (US EPA). They have also created a comprehensive framework for the scrutiny of new PFAS, obligating the EPA to conduct thorough risk assessments concerning human health and environmental impacts (OCSPP US EPA, *Framework for Addressing New PFAS and New Uses of PFAS*).

While the Lautenberg amendment empowers the EPA to oversee chemicals more stringently before they reach the market, challenges persist for those currently in production. The ongoing production of goods using PFAS continues to contribute to environmental contamination and health risks for those exposed. It is critical to recognize that preventing the release of PFAS into the environment requires more than just preventing new PFAS from being manufactured; it necessitates robust attention to the legacy PFAS that have already polluted the environment and will continue to exist since they do not break down. This includes special attention to the pollution of passive exposure nodes, such as biosolids from wastewater treatment plants, which risk contaminating food and water supplies with PFAS. Therefore, the EPA must address not only the regulatory oversight of PFAS use but also actively pursue strategies to remediate and mitigate the effects of PFAS that have already entered our ecosystems. This integrated approach aligns with the agency's broader mandate to safeguard public health and preserve environmental integrity in the face of PFAS-related challenges.

The Montreal Protocol

Background

In the early 1970s, groundbreaking studies conducted by chemists Mario Molina and Frank Sherwood Rowland brought attention to the environmental repercussions of chlorofluorocarbons (CFCs), commonly utilized in aerosol sprays, packaging materials, and refrigerants. They had detected CFCs throughout the atmosphere "in amounts roughly corresponding to the integrated world industrial production to date" (Molina and Rowland, 810). While these chemicals are not considered reactive nor volatile in certain parts of the atmosphere, when they reach the stratosphere, CFCs are broken down by ultraviolet radiation, releasing highly reactive chlorine atoms known as chlorine radicals. A single chlorine radical can react with thousands of ozone molecules through catalytic reactions, essentially acting as an intermediate molecule to turn ozone (O_3) into oxygen (O_2). This chemical reaction depleted ozone, which is an essential molecule in the atmosphere that protects the Earth from harmful levels of ultraviolet radiation (California Air Resources Board). This hypothesis was only confirmed in 1985 when researchers stationed in Antarctica, Joe Farman and his colleagues, discovered a hole in the ozone layer (Farman et al., 207).

With almost ten years between the initial hypothesis and confirmation of CFC's detrimental effects on the ozone, this situation mirrors the developments within the scientific community's research on PFAS. It is clear from a research standpoint that research on PFAS has exploded in the past few years. For example, searching for the terms 'PFAS' or 'per- and polyfluoroalkyl substances' in the database ProQuest for the years 2000-2015 yields only 3,281 results, while a search from 2016-2024 returns 70,564 results for the same terms. This stark contrast not only highlights the growing body of research on PFAS but also reflects an increased awareness and concern over these pollutants. Despite this escalation, there has yet to be comprehensive action taken by the federal government to address the many ways in which PFAS are contaminating our environment.

Fortunately for the ozone layer, after ten years, the harmful effects of CFCs identified by Farman and colleagues acted as a pivotal impetus for global action, bringing together twenty nations to endorse the Vienna Convention for the Protection of the Ozone Layer under the guidance of the United Nations Environment Programme (UNEP). Although this agreement was non-binding, the participating nations acknowledged the urgency of the issue (Chatterjee, 6). The initial negotiations resulted in two opposing viewpoints: one advocating for a complete ban on CFCs and the other proposing limitations on CFC production (Chatterjee). This dichotomy mirrors the current discourse on per- and polyfluoroalkyl substances (PFAS), with a segment of the scientific community advocating for a total prohibition, countered by voices cautioning against the potential repercussions such a ban could have on the global supply (American Chemistry Council).

The extensive use of PFAS across a multitude of sectors – consumer goods, military applications, industrial processes, medical fields, and scientific research – presents a complex challenge in realizing a blanket ban. Simultaneously, the accumulating evidence about the risks associated with PFAS and the degree to which they infiltrate the environment demands urgent and decisive action. The quandary thus lies in balancing the immediate need to mitigate environmental and health hazards with the practical considerations of a world heavily reliant on these substances. This is a similar juncture encountered by the Vienna Convention almost three decades ago, which was reconciled by introducing ‘Essential Use’ criteria within the final Montreal Protocol treaty that was ultimately signed and ratified by over 197 countries. This solution provided a balanced approach to phasing out CFCs that were known to deplete the ozone layer while still permitting their use when absolutely necessary for health or safety reasons.

Rules of Essentiality within the Montreal Protocol

The Montreal Protocol sets forth specific criteria for determining whether a substance is essential. Based on this framework, uses are categorized into three types: essential, non-essential, and substitutable. To qualify as essential, the substance must be “necessary for the health, safety or is critical for the functioning of society” (Decision IV/25, Montreal Protocol). A substance can also be considered essential if “there are no available technically and economically feasible alternatives or substitutes that are acceptable from the standpoint of environment and health” (Decision IV/25, Montreal Protocol). In the case of CFCs, these would be products like inhalers that are medically necessary to a large global population and rely on CFCs for their function. PFAS, when employed in the production of medical devices such as stents or implants, represents an analogous essential use to CFCs in inhalers, underscoring the possible repercussions of a blanket ban on PFAS (Corcoran).

A use deemed essential becomes substitutable when viable alternatives exist that render the original use non-essential (Cousins et al.). A notable example of substitutability is the use of PFAS in food packaging. Food packaging is essential to public health, but the use of PFAS to make this packaging is not necessarily essential. Fast food wrappers, microwave popcorn bags, and single-use plates have all been found to contain PFAS, likely because of their water and grease-resistant properties. These applications are feasible to be phased out with viable alternatives such as wax, plant-based films, or compostable paper with little technological innovation or industry turnaround to realize the substitution (Phelps et al.). Alternatively, uses deemed as non-essential are those that are "driven by convenience […] rather than having a function that is critical to health and safety" (Cousins et al.). Many PFAS are used in clothing for their water and grease resistance or in carpets for the same reasons (Phelps et al.). While these uses are convenient, they do not justify the continued production of PFAS when considering the environmental and health risks associated with these substances. Therefore, such applications should be deemed non-essential and phased out of production.

Many states have already taken the initiative to combat these forms of substitutable or non-essential uses—Washington has banned the use of PFAS in food packaging beginning in 2023, California has banned the use of PFAS in carpets and textiles in 2021, and many more have taken to addressing single issues concerning PFAS through legislation (Washington State Department of Ecology) Department of Toxic Substances Control, State of California). Figures 3 and 4 elucidate the variance in legislative fervor among states and the breadth of PFAS-related issues that have been legislatively addressed, respectively.

The initiative taken by individual states to mitigate non-essential PFAS applications in consumer goods is commendable. However, such a fragmented, state-centric approach can result in regulatory disparities across the country. This inconsistency, described as regulatory asymmetry, poses challenges in the collective effort to phase out PFAS. For example, one state's ban on PFAS in carpets does little to prevent the demand for the same (most likely water and grease-repellent) carpets in states without such bans. It also does not deter consumers from ordering a water-repellent carpet from a different state over those sold in their state without added PFAS. While demand may decrease in states enforcing bans, PFAS contamination is not confined by state lines due to their pervasive nature, allowing them to spread through waterways, waste, and bioaccumulation far beyond their initial use site.

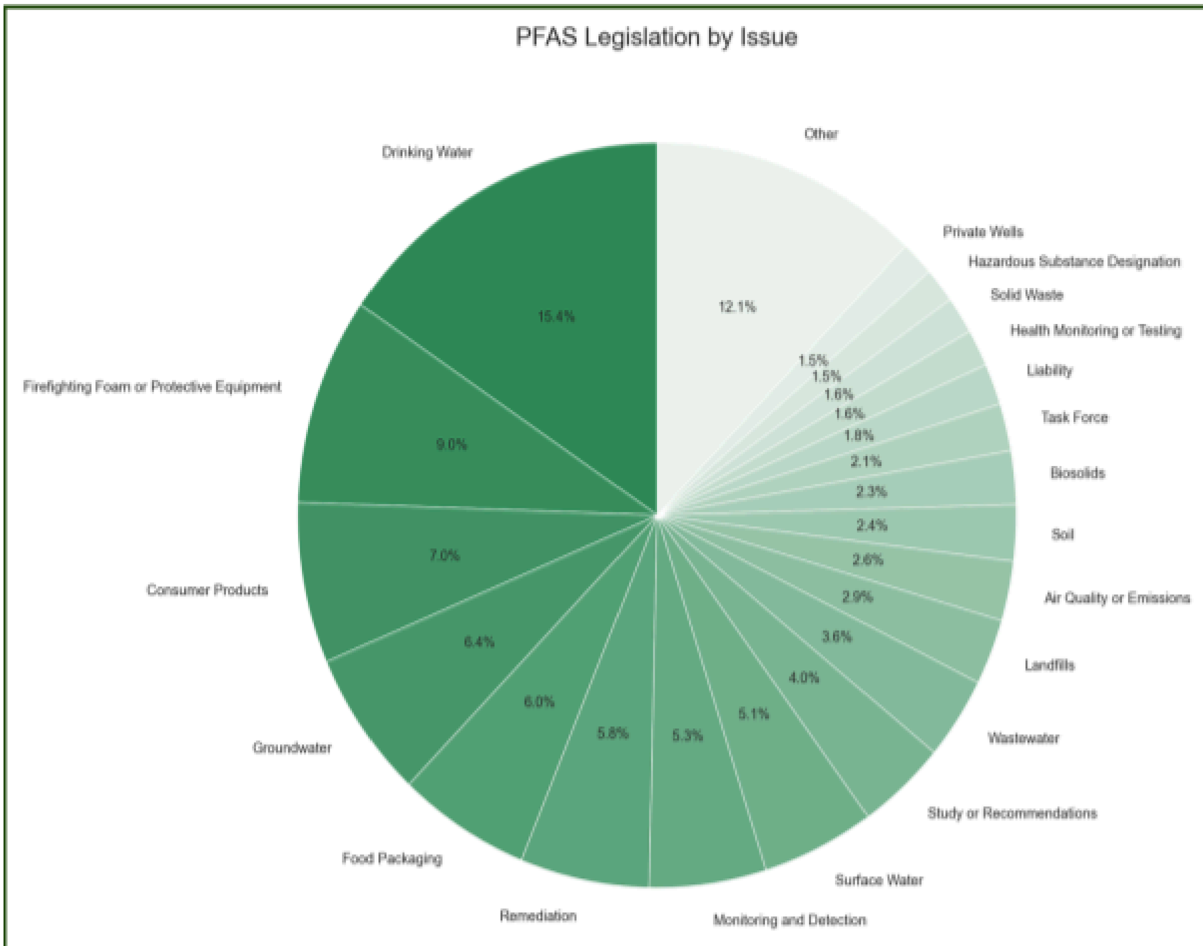

Fig. 3. PFAS Legislation by Issue. Source: SUNY Rockefeller Institute of Government

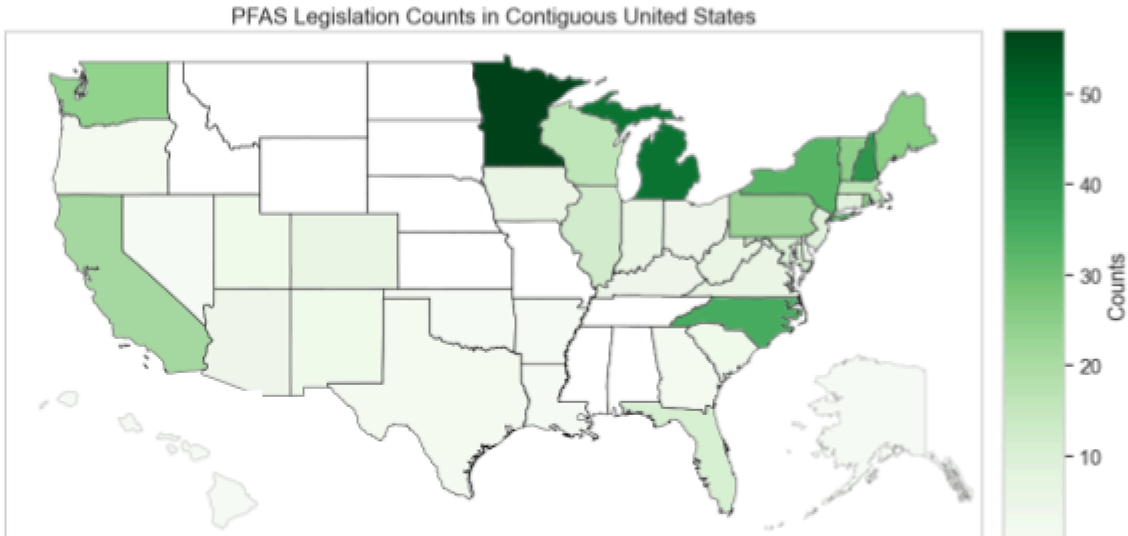

Fig. 4. Amount of PFAS legislation per state. Source: SUNY Rockefeller Institute of Government

Essentiality evaluations play a crucial role in systematically phasing out environmental pollutants like PFAS. An essential consideration in these assessments is the avoidance of 'regrettable substitution.' This term describes the unintended consequences of adopting a replacement chemical without a thorough evaluation of its broader environmental and health implications. A notable instance of regrettable substitution occurred after the ratification of the Montreal Protocol, with industries adopting hydrofluorocarbons (HFCs) as an alternative to ozone-depleting substances (Chatterjee). While HFCs are ozone-friendly, they are potent greenhouse gases, with their emissions projected to contribute to 7-19% of global CO2 emissions by 2050 (Environment). In order to avoid regrettable substitution, PFAS uses in the substitutable category must only be considered within this category if there are viable and safer alternatives to PFAS so as to avoid unintended and possibly even worse risks from the alternative than the original chemical.

In the context of the successful implementation of the Montreal Protocol, the concept of essentiality can be pivotal in curbing the proliferation of PFAS within commerce and industry, thereby decreasing their presence in biosolids. The EPA should work together with industry, states, and economists to strategically identify products where PFAS use is not critical and can be replaced. This will involve a thorough assessment to ascertain the availability and effectiveness of safer alternatives. A systematic approach to essentiality could serve as a cornerstone in the regulation of PFAS in biosolids, emulating the Montreal Protocol's legacy of impactful environmental policy.

Comparative Analysis: Nutrient Pollution Regulation and its Relevance to PFAS Control

The regulation of nutrient pollution and PFAS in the United States share everyday complexities, notably the difficulty of managing non-point source pollution. Drawing parallels between the two, one can observe that approaches used in nutrient pollution regulation—such as stringent reporting requirements, monitoring protocols, and detailed labeling requirements—may offer valuable strategies for the regulation of PFAS.

Fertilizers, which are crucial for providing essential nutrients to plants, often contain high levels of nitrogen and phosphorus. While the Haber-Bosch process is well-known for synthesizing ammonia from atmospheric nitrogen to create nitrogen-based fertilizers, the production of phosphorus in fertilizers follows a different route (Chemistry LibreTexts). Phosphorus fertilizers are typically derived from phosphate rock, which is mined and then treated with sulfuric acid to produce phosphoric acid – a precursor for various fertilizer products (OW US EPA, *EPA's Ongoing Efforts to Reduce Nutrient Pollution*). Excessive use of such fertilizers can lead to eutrophication. This process over-enriches water bodies with nutrients and harms aquatic ecosystems by causing harmful algal blooms and depleting oxygen levels (OW US EPA, *EPA's Ongoing Efforts to Reduce Nutrient Pollution*). This situation underscores the intricate challenge of managing nutrient inputs in the environment, which is analogous to the difficulty of controlling PFAS pollution. The EPA has initiated efforts such as the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force to target the hypoxic zone in the Gulf of Mexico, largely a result of nutrient runoff. This concerted effort includes an integrated approach involving multiple states and stakeholders, aiming to reduce the inflow of nutrients into water bodies and thus mitigate the impacts of eutrophication (US EPA). By leveraging the regulatory experiences from fertilizer management, it is conceivable to adopt and adapt specific regulatory tactics to tackle the widespread and intricate issue of PFAS contamination. Such a cross-application of regulatory techniques underscores the importance of interdisciplinary learning and the need for a multi-faceted approach to environmental regulation.

Regulatory Efforts

To combat nutrient pollution, the EPA uses tools like the Clean Water Act and the National Water Quality Initiative (OW US EPA, *EPA's Ongoing Efforts to Reduce Nutrient Pollution*). Numeric nutrient water quality criteria have been developed for nitrogen and phosphorus to facilitate effective monitoring, permit formulation, and the development of Total Maximum Daily Loads (TMDLs) for impaired waters. However, challenges arise due to the lack of numeric criteria for these nutrients adopted into state water quality standards and the difficulty in pinpointing the exact sources of nitrogen and phosphorus. The EPA uses Effluent Guidelines to set national regulatory standards for wastewater discharged into surface waters and sewage treatment plants (OW US EPA, *EPA's Ongoing Efforts to Reduce Nutrient Pollution*). These guidelines also cover nutrient pollution, aiming to reduce the amount of nitrogen and phosphorus entering water bodies. The Emergency Planning and Community Right-to-Know Act (EPCRA) mandates reporting by the fertilizer industry regarding the storage, use, and release of chemicals (US EPA). Retailers are required to report chemicals stored on-site unless exempt under specific conditions outlined by EPCRA sections 311 and 312 (US EPA). These reporting requirements allow the EPA to know how much fertilizer is being used at any particular time, akin to the inventory requirements under the Toxic Substances Control Act. At the federal level, regulations that may affect fertilizer management include the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA), which mandate reporting in cases such as discharges that may reach navigable waters (US EPA). Additionally, the Resource Conservation & Recovery Act (RCRA) dictates the proper disposal of pesticide waste, which can be related to fertilizers, especially those that may contain pesticide residues (US EPA). There are also regulations regarding underground storage tanks, which could be pertinent to the storage of liquid fertilizers, and requirements related to the handling of used oil, which could be relevant for farms using machinery for fertilizer application.

At the state level, regulation is more directly focused on the fertilizers themselves. Fertilizers and amending materials are regulated by individual states rather than at the federal level, with some degree of uniformity achieved through guidelines developed by the Association of American Plant Food Control Officials (AAPFCO). This includes aspects such as product registration, label language and format, and compliance with state-specific regulatory changes. These fertilizers are not exempt from the Toxic Substances Control Act (TSCA), meaning all chemicals found in these products must be listed in the TSCA Inventory (US EPA). This includes not only the primary nutrients like nitrogen, potassium, and phosphorus but also any heavy metals and chemical compounds that may be present.

Nutrient pollution, while distinct in its regulatory approach, offers valuable insights into how the government monitors and manages the use of fertilizers, providing a template for the heightened regulatory needs of PFAS. Regulations such as the Effluent Guidelines, the Emergency Planning and Community Right-to-Know Act (EPCRA), the Clean Water Act (CWA), and the Safe Drinking Water Act (SDWA) demonstrate robust systems for tracking and reporting chemical usage. Similarly, state-level product registration frameworks reveal a structured method to account for substances disseminated in commerce. These mechanisms, although designed for nutrients, can inform and shape the strategies for a more vigilant tracking of PFAS, tailoring oversight to their extensive environmental and health implications.

Results

The historical and regulatory insights from past successes in managing widespread and harmful chemicals, as highlighted by case studies, demonstrate that effective regulation is achievable. For example, the Montreal Protocol and controls on fertilizer in the U.S. have laid the groundwork for contemporary challenges. With the enactment of the Lautenberg Act, which mandates the pre-market vetting of new chemicals by the EPA, our country is positioned at a new juncture. However, it is crucial to establish processes that not only regulate but also remediate legacy pollutants like PFAS, which continue to infiltrate our water and food supplies. These case studies underscore the importance of collaborative and engaged regulatory processes and stringent controls. They advocate for a comprehensive approach, including identifying hotspots of PFAS contamination in biosolids, enhancing remediation efforts at wastewater treatment facilities, and fostering an assessment group process that empowers decision-makers with the necessary scientific insights to implement effective regulations.

Despite this groundwork, the challenge extends beyond simply formulating recommendations; it involves grappling with the pervasive legacy of PFAS contamination. Legacy PFAS compounds have insidiously permeated diverse ecological niches, notably in biosolids, a medium that unwittingly exposes large populations to concentrated levels of these chemicals in their food and water. While the EPA has made some progress, such as setting advisory limits for PFOS and PFOA in drinking water, the vast multitude of almost 15,000 PFAS compounds necessitates a more expansive regulatory scope than the current targeted approach allows. A comprehensive strategy is required—one that avoids piecemeal regulation and fosters an all-encompassing understanding and management of the entire spectrum of PFAS substances. Regulation must be as dynamic and expansive as the contaminants it seeks to govern; as such, transparency and concerted efforts are paramount in regulating the transmission of PFAS from biosolids into agricultural systems. The EPA's 2024 PFAS roadmap, while a step forward, alludes vaguely to "addressing PFAS in biosolids," which signifies a gap in the agency's current disclosure of its full range of endeavors. This lack of detailed planning underscores the need for an integrated approach that bridges historical regulatory successes with innovative strategies to tackle current challenges.

To enact dynamic and comprehensive regulation, I recommend the establishment of an assessment group tasked with conducting scientific research and funneling findings directly to a policy group. This collaborative, science-based framework is designed specifically to regulate PFAS contamination in biosolids and wastewater treatment plants. By ensuring state representation at every stage, this framework facilitates the convergence of industry, policy, and scientific expertise to develop effective regulatory measures for PFAS. While comprehensive state representation cannot be guaranteed, the Environmental Council of the States has been diligent in monitoring PFAS legislation and regulation, discovering that 29 states have already developed, proposed, or finalized health-based regulatory values for PFAS ("ECOS Paper"). This level of engagement with PFAS-related issues is promising for a collaborative initiative as extensive as this assessment process. Additionally, securing participation from a majority of states could encourage even greater involvement. The success of the Ozone Transport Assessment Group in securing state engagement, despite varied regional interests, highlights the potential effectiveness of such a collaborative approach. Although only the downwind states initially faced non-adherence to the NAAQS, the collaborative framework helped to bridge the gap between different state interests. Even upwind states, which did not directly suffer from the pollution they contributed to, were persuaded to participate in the OTAG process. This was largely due to the facilitation by the Environmental Council of the States, which played a pivotal role in encouraging states to see the broader benefits of regional air quality management.

This approach will address my first research question: how can a collaborative, OTAG-like process be used to bridge the gap between current scientific knowledge of PFAS and PFAS regulation? Figure 5 below illustrates this process, emphasizing continuous information dissemination through a bottom-up approach. In this model, scientific research and new understandings of PFAS contamination flow upwards from the assessment group to the policy group. This ongoing exchange ensures that the policy group remains informed of the latest scientific developments, enabling informed decision-making and the formulation of new policies to address PFAS contamination in biosolids and wastewater treatment plants effectively.

Additionally, this section will tackle the second research question: How can effective regulatory measures be implemented to control and remediate PFAS in wastewater treatment plants? By leveraging environmental regulatory precedents gleaned from the case studies in the data analysis section, this framework will draw from the regulatory facets outlined in the Montreal Protocol, the Toxic Substances Control Act (TSCA), and nutrient pollution regulations. These precedents will inform the development of relevant measures to control and remediate PFAS contamination, ultimately aiming to decrease the amount of PFAS entering wastewater treatment plants and biosolids. By integrating these proven regulatory approaches into the framework, we can develop comprehensive strategies to effectively mitigate PFAS contamination in wastewater treatment facilities.

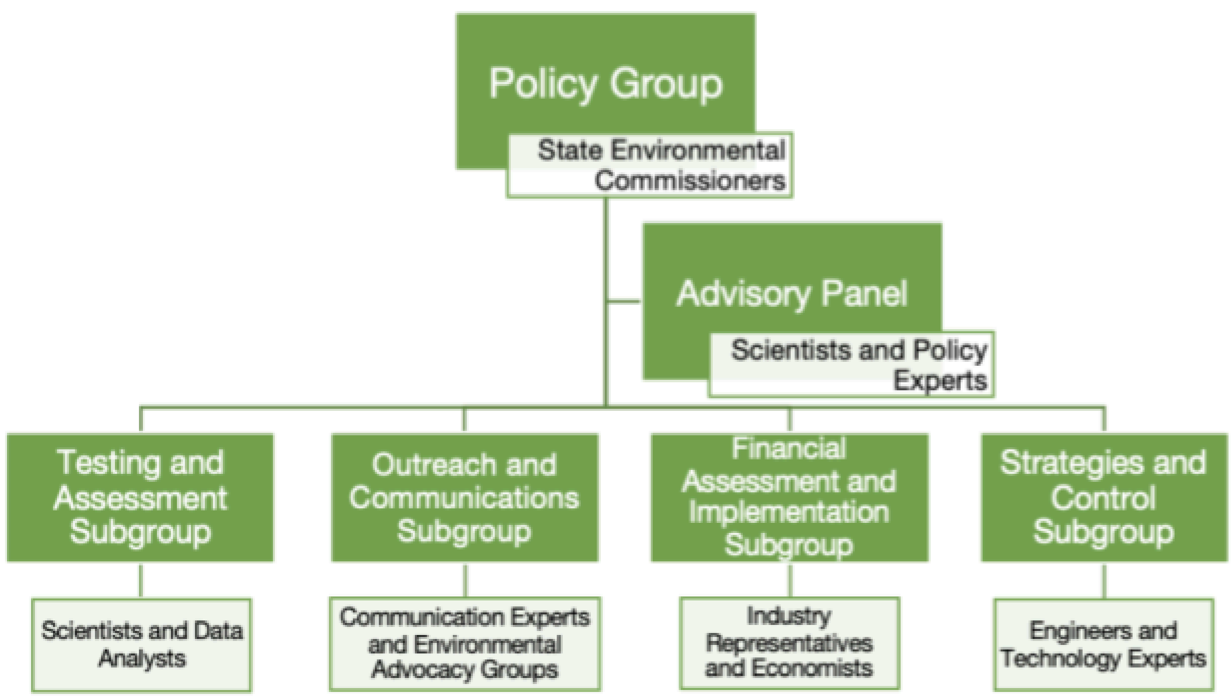

Fig. 5. Organizational Framework for a PFAS-Biosolids Assessment Group.

PFAS-Biosolids Assessment Group Organization and Duties

The following framework for addressing PFAS contamination in biosolids encompasses a systematic and collaborative approach, integrating insights from a broad range of expertise across several specialized groups.

The Policy Group

The Policy Group serves as the regulatory helm of the framework, ideally composed of state environmental commissioners from participating states who bring a wealth of experience and regulatory acumen to the table. Their primary duty lies in setting broad policy goals and priorities to address PFAS contamination in biosolids based on the research that is being funneled up from lower subgroups. This involves a dual approach of crafting state-specific strategies while also ensuring these are aligned with the overarching national objectives. The synergy between federal and state policies is pivotal, as uniformity in regulations facilitates coherent and efficient implementation.

The Policy Group is responsible for identifying issues that require further investigation to inform sound policy-making or regulatory decisions. Take, for instance, the imperative need for comprehensive research into wastewater treatment facilities that are particularly burdened by PFAS, resulting in concentrated PFAS biosolids. It is essential to pinpoint the source of agriculturally applied biosolids to effectively implement remediation technologies within the most impacted WWTPs while also identifying the agricultural lands most affected by these biosolids. This is especially important given the high cost of remediation technologies, resulting in a need for a more targeted approach to implement them.

The findings from such targeted research are instrumental for the policy group to determine where remediation technologies and regulatory efforts toward PFAS-biosolids are most critically needed. Given that the group comprises environmental commissioners from every state, there is ample capacity and expertise to guide the necessary research efforts undertaken by lower subgroups. Ultimately, the Policy Group should be directing the lower subgroups toward researching questions that need to be answered in order to establish credible policy recommendations. If done correctly, the questions posed by this group will be answered through scientific research conducted by subgroups, and the information gathered from this research will serve as valuable evidence for policy recommendations. This evidence can be used to support discussions on policy development and revisions among commissioners and state representatives within the policy group, ensuring that decisions are based on solid data.

The meetings of the Policy Group are public and transparent, open to all stakeholders involved in the process, allowing for the vetting of information to ensure credibility, like peer review. These meetings should be live-streamed, published, and easily accessible to any stakeholder who is curious about the process of regulating PFAS. The notes from these meetings should also be published and easily accessible, with recommendations from previous meetings continually being updated. Here, the group should be presented with the issues from lower subgroups and, using the research provided by these subgroups, deliberate on crafting recommendations for policy and regulation implementation. The information presented would have undergone rigorous review at preceding stages and has been vetted by the Technical Advisory Panel.

Unlike the federal EPA's process, which tends to implement uniform regulations across all states, the Policy Group adopts a more localized approach that recognizes and addresses the unique environmental challenges and economic activities of each state. This state-centric, collaborative method ensures that policies are not only equitable but also finely tuned to the specific needs and conditions of different regions. For example, Iowa, with its heavy reliance on agriculture, might advocate for federal assistance to help clean up PFAS contamination without financially burdening farmers. In contrast, a more industrialized state like New Jersey, where agriculture plays a minor economic role, might push for stringent regulations on industrial emissions of PFAS, which could differ substantially from agricultural concerns. The diversity in state needs requires careful negotiation within the Policy Group. One potential compromise could involve ensuring that Iowa's farmers use biosolids only from treatment facilities that have implemented effective PFAS remediation technologies. Meanwhile, a state like New Jersey might focus on tightening discharge regulations for industrial plants, ensuring that new sources of PFAS are curtailed.

This approach contrasts sharply with the EPA's method, which, while comprehensive, might not fully adjust for such localized nuances. The state-driven process facilitated by the Policy Group allows for a more nuanced and responsive policy environment, where decisions are made not only based on a national standard but also on regional specifics that respect and protect local industries and ecosystems. This ensures more tailored and effective environmental governance, with states playing a proactive role in shaping policies that directly impact their communities.

The Advisory Panel

The Advisory Panel functions as a technical core in the PFAS regulatory framework, uniting a diverse array of experts, including scientists, engineers, and policy specialists from federal, state, and local environmental agencies. This assembly of minds is critical for distilling a wide range of scientific and technical data into coherent, actionable advice for the Policy Group. The panel is structured to ensure equitable representation, with each participating state and even large municipalities contributing their own cadre of technical experts. Each expert arrives with an intimate knowledge of their state's specific environmental intricacies, challenges, and priorities related to PFAS in biosolids. In collaboration with the Policy Group, they serve as critical liaisons, adept in both the scientific discourse and the intricacies of regulatory policymaking. Tasked with interpreting the research conducted by subsidiary groups, they are responsible for distilling it into accessible insights. This synthesis is essential, enabling the Policy Group to leverage the extensive data effectively in shaping their recommendations.

The Testing and Assessment Subgroup

The Testing and Assessment Subgroup stands as the scientific brains of the organization, made up of environmental scientists, researchers, and data analysts drawn not only from state and federal agencies but also from third-party institutions such as universities, think tanks, and industry. This diversified team is charged with any issue that the Policy Group believes needs more scientific evidence to support regulation or policy. By expanding its membership beyond government scientists, the subgroup enriches its investigative scope, ensuring that its findings and recommendations encompass the breadth of knowledge and perspectives required to address PFAS in biosolids.

There are many possible issues that the subgroup can be tasked with. Most notable would be an assessment of how agricultural systems absorb PFAS through biosolids, an investigation that has far-reaching implications for food safety and environmental health. This subgroup also could quantify the magnitude of PFAS contamination within agricultural landscapes, a task that underpins the development of targeted remediation strategies. Another important topic would be research into remediation technologies, identifying those best suited to the unique conditions of each wastewater treatment plant.

The collaboration with industry experts plays a dual role. On the one hand, it deepens the understanding of the different PFAS analytes, which is vital given that the industry is responsible for the genesis of these compounds. On the other, it fosters the exploration of PFAS alternatives in conjunction with representatives from entities like the American Chemistry Council. The subgroup's responsibility also extends to the standardization of testing protocols, a task that ensures consistency and reliability in the data gathered across jurisdictions.

A unique aspect of the subgroup's work is the harmonization of independent third-party research with policy development needs. By offering a structured platform for researchers to share their findings, the subgroup not only bridges the gap between science and policy but also enhances the transparency of the regulatory process. The Testing and Assessment Subgroup is an evolving body that adapts to emerging PFAS-related challenges. Regular meetings that update research findings not only aid transparency but also inform the Advisory Panel on potential gaps in knowledge, which may lead to the establishment of new focused subgroups. This fluid, adaptive dialogue is what makes the Testing and Assessment Subgroup a cornerstone in establishing credible knowledge for the Policy Group.

The Financial Assessment and Implementation Subgroup

The Financial Assessment and Implementation Subgroup is an essential cog in the machinery of PFAS regulation, tasked with analyzing and articulating the economic ramifications of PFAS-related policies. Staffed by financial analysts, economists, and industry representatives, this subgroup is pivotal in ensuring that the economic impacts of PFAS regulations are fully understood and addressed. State-centered economists bring a localized perspective to the assessment, ensuring that the unique economic fabric of each state is considered when evaluating the feasibility and impact of regulations. Additionally, the involvement of industry representatives provides critical insights into sector-specific challenges, enabling the development of regulation that supports environmental goals without stifling economic growth.

The subgroup's responsibilities extend to the determination of financial implications resulting from the implementation of PFAS regulations in biosolids and wastewater treatment operations. They endeavor to develop strategies that balance fiscal responsibility with environmental efficacy, facilitating the removal, treatment, and disposal of PFAS in a manner that is both cost-effective and sustainable. Their collaboration with the Outreach and Communications Subgroup is critical in translating complex financial concepts into digestible information for stakeholders, thereby fostering an informed and engaged community. This integrated approach ensures that economic considerations are woven into the fabric of PFAS management strategies, aligning ecological imperatives with economic realities.

The Outreach and Communications Subgroup

The Outreach and Communications Subgroup is an essential component within the assessment group, composed of skilled communication specialists, community outreach coordinators, and environmental advocates. This subgroup is dedicated to disseminating critical information regarding the research done by subgroups, targeting the general public and those within the process. By utilizing internet software like Zoom, the Communications Subgroup is responsible for organizing the meeting schedule between groups and ensuring that the meetings are transparent and open for anyone interested in engaging with the issues. They act as administrative support, recording meetings, publishing newsletters, and ensuring the flow of information within groups but also between the groups and external entities, such as the federal EPA, state agencies, legislators, and other key actors. This includes broadcasting significant research breakthroughs and pivotal policy decisions and ensuring all communications are as impactful as they are informative.

The Strategies and Controls Subgroup

The Strategies and Controls Subgroup is an essential component of the framework. It comprises engineers, technology specialists, and professionals from wastewater treatment and biosolids management facilities. Their crucial role is to bring a hands-on, practical perspective to the PFAS management discourse. With representatives from large municipalities, this subgroup benefits from a wealth of in-field experience, ensuring that the Testing and Assessment Group's strategies are not only theoretically sound but also practically viable.

The subgroup's duties center around the identification and appraisal of cutting-edge and established best practices and technologies for the containment, removal, and control of PFAS in both biosolids and wastewater treatment processes. They analyze various stages of wastewater treatment, aiming to integrate effective PFAS control measures that are both efficient and scalable. A significant aspect of their responsibility is to develop comprehensive strategies that can be recommended for widespread implementation across the country.

Working in tandem with the Testing and Assessment Subgroup, the Strategies and Controls Subgroup ensures that rigorous scientific assessments and current research findings underpin any recommended practices. This symbiotic relationship guarantees that the subgroup's strategies are not only informed by empirical data but are also adaptable to an evolving scientific understanding of PFAS behavior and impact.

Additional Considerations

Regular meetings and collaborative efforts among the subgroups and the advisory panel are crucial. This regular interaction fosters a culture of constant communication and adjustment, which is vital for a responsive and flexible regulatory approach. Data sharing and standardization across states are pivotal for maintaining consistency in monitoring and assessment practices. At the same time, transparency in decision-making processes is a cornerstone for building trust with the public and other stakeholders. By regularly updating practices and policies, the framework stays relevant and practical, continuing to mitigate PFAS risks based on the latest knowledge and tools available. This iterative process ensures that the regulatory measures are not static but dynamic, evolving to meet the challenges presented by PFAS as new information comes to light.

Integrating Regulatory Precedents to Address PFAS Contamination as a Whole

Addressing the second question regarding the implementation of effective regulatory measures for controlling and remediating PFAS in wastewater treatment plants, this section will provide recommendations based on regulatory precedents outlined in the case studies.

1. **Establish a 'Comprehensive Product Registry' to catalog all PFAS-containing products currently available in the commercial marketplace.** Under the Toxic Substances Control Act (TSCA), the EPA has the authority to require reporting,

record-keeping, testing requirements, and restrictions related to chemical substances (OP US EPA). The final rule under Section 8(a)(7) by the EPA, as required by the 2020 National Defense Authorization Act, "requires all manufacturers and importers of PFAS and PFAS-containing articles in any year since 2011 to report information related to chemical identity, uses, volumes made and processed, byproducts, environmental and health effects, worker exposure, and disposal" (P. Bergeson & Campbell, P.C.) to the EPA. Compiling the information on PFAS will allow for a comprehensive list of products or categories of products that contain PFAS that should be evaluated for essentiality.

2. **Expand the criteria for essentiality to include considerations of whether the PFAS are utilized within closed systems.** For instance, the use of PFAS in semiconductor manufacturing or other electronic components, where the potential for environmental release and human exposure is minimal, could be considered a more justifiable use.
3. **Require manufacturers and producers of PFAS-containing products to clearly label their products as containing PFAS to increase consumer awareness.** Establish fines for noncompliance and utilize the money generated from these fines to establish a Farmer's Relief Fund for Farms Impacted by PFAS-biosolids.
4. **Incentivize companies with substitutable uses of PFAS to transition to alternatives based on the essential use criteria.** Use financial incentives such as grants, subsidies, tax breaks, and low-interest loans to offset initial costs. Market advantages, like preferred supplier status and public procurement preferences, alongside certification programs, can further motivate businesses. Regulatory measures, such as gradual phase-outs and standards, combined with R&D support through tax credits and innovation grants, provide a structured pathway for change. Consumer demand, fueled by education

campaigns and clear product labeling, can drive market preferences, incentivizing companies to adopt safer or more sustainable alternatives.

5. **Provide financial incentives such as grants, low-interest loans, or tax incentives to encourage WWTPs to adopt PFAS remediation technologies and manufacturers to transition to safer alternatives.**
6. **Establish performance-based incentives for wastewater treatment plants that achieve measurable reductions in PFAS levels.** A certification program akin to Energy Star recognizing plants that meet environmental standards would motivate others to follow suit. Supporting pilot programs and demonstration projects to test PFAS remediation technologies can offer insights into best practices and showcase the benefits of transitioning to safer biosolid management strategies.
7. **Enhance risk determination processes to include complete lifecycle analyses.** This should evaluate the entire journey of PFAS from production through to their eventual end of life, with particular scrutiny on their accumulation in biosolids used as fertilizers, which can lead to the contamination of groundwater and broader ecosystems.
8. **Collaborate with the National Biosolids Data Project to systematically monitor the use of biosolids on agricultural lands.** Farmers should be required to report the quantity of biosolids used and their sources, while wastewater treatment plants should maintain records of their biosolids distribution. This information should be maintained in a centralized database, enabling policymakers to identify where biosolids are being applied easily. This database would facilitate targeted PFAS remediation by allowing for the prioritization of wastewater treatment plants that supply the most biosolids to agricultural

lands. Given the high cost of implementing remediation technologies, this approach would allow for allocation of resources toward farms most at risk of contamination.

Conclusion

The current regulatory landscape surrounding PFAS contamination in biosolids is woefully inadequate, given the potential for these pollutants to pervade our agriculture, food, and water systems. Although several states have pioneered PFAS legislation, the issue of PFAS contamination, much like ozone transport, is not confined by state borders. Actions in one state can have direct consequences on the citizens of another, particularly where there is a disparity in the seriousness with which the problem is addressed. This issue is exacerbated in the context of interstate distribution of food products, where the absence of stringent PFAS regulations in one state could impact the food supply in others. Hence, it is crucial for states to engage in dialogue and not merely adhere to the minimum standards set by the EPA, which often fall short of addressing the magnitude of the problem.

Historical distrust in the EPA's effectiveness, stemming from its inception, underscores this point. Critics argue that the EPA, as a top-down regulatory body, must navigate the dual challenges of environmental regulation and political appeasement, often prioritizing industrial interests over public health and environmental integrity (Lazarus). The EPA's sluggish approach to regulating PFOS and PFOA—compounds suspected to be hazardous for decades and phased out of production—illustrates the pitfalls of relying solely on federal oversight for resolving multifaceted environmental issues. The complex nature of PFAS contamination, especially concerning biosolids and the costly infrastructure required for remediation, calls for innovative approaches that transcend traditional regulatory frameworks.

This paper argues for a collaborative, state-led process modeled after the Ozone Transport Assessment Group (OTAG) framework, where state decision-makers work alongside stakeholders to grasp the full extent of PFAS challenges. Such collaboration could incentivize states that are lagging in their legislative efforts to recognize the broader implications of inaction. Comprehensive state cooperation is crucial for effective federal rulemaking and for addressing the transboundary nature of PFAS pollution.

The establishment of a multi-stakeholder assessment group that includes state and federal regulators, industry representatives, and environmental groups would be instrumental in generating credible knowledge about PFAS, facilitating expert interaction, and shaping informed policy decisions. Through such collaborative efforts, not only can we develop practical solutions for reducing PFAS concentrations in biosolids, but we can also ensure that these solutions are uniformly implemented across jurisdictions. As PFAS contamination knows no boundaries, our regulatory strategies must also be boundless, harmonizing efforts across all states and sectors to mitigate this pervasive threat.

This paper set out to delve into the regulatory landscape of PFAS, aiming to identify gaps in current practices and propose a robust framework for the management of these persistent and pervasive contaminants. Addressing the complexity of PFAS regulation demands an innovative solution. This study has advocated for the formation of an assessment group that brings together state and federal regulators, industry representatives, and environmental groups – all pivotal in fostering ‘credible knowledge’ of PFAS. Such collaborative groups serve as vital platforms for expert interaction and policy negotiation, ensuring that decisions are informed by comprehensive scientific understanding and practical industry insights. The collaborative effort is not merely beneficial but essential in developing practical solutions limiting concentrations of PFAS in biosolids and beyond. The transboundary nature of PFAS pollution requires a unified response, ensuring that efforts in one area are not undermined by inaction in another. As we recognize that PFAS contamination transcends geographic and jurisdictional boundaries, regulatory strategies must be harmonized across states and sectors.

The policy recommendations outlined within indeed face the universal constraints of time and financial resources, common hurdles in the realm of policy development and implementation. However, the reformed Toxic Substances Control Act (TSCA) serves as a beacon of progressive policy, offering frameworks that aim to prevent environmental issues akin to those presented by PFAS. Investing time and resources into this domain is not merely a regulatory necessity but a commitment to the public's well-being, a pursuit that promises a healthier environment. While acknowledging these constraints, the recommendations offered are designed with feasibility in mind, seeking to optimize the EPA's efficacy in tackling PFAS without necessitating excessive political capital. This pragmatic approach, centering on the establishment of an assessment group, echoes the successful collaboration and compromise achieved by the Ozone Transport Assessment Group (OTAG). It underscores a pathway for progress that can be realized even within our current climate of polarization and the tendency to prioritize economic growth over environmental stewardship.

The proposed assessment group is relevant to biosolids and wastewater treatment and presents a versatile model that can address an array of complex environmental challenges. Its foundation on multidisciplinary collaboration and compromise allows for its application to diverse issues requiring integrated, multifaceted solutions. In acknowledging the necessity for an assessment group, we lay a solid foundation for a regulatory framework capable of not only navigating the intricacies of PFAS science but also catalyzing proactive policy development and implementation. This collaborative model echoes the success of previous joint initiatives and stands as a testament to the power of federal and state collaboration in the face of environmental adversity.

Bibliography

Abunada, Ziyad, et al. “An Overview of Per- and Polyfluoroalkyl Substances (PFAS) in the Environment: Source, Fate, Risk and Regulations.” *Water*, vol. 12, no. 12, 12, Dec. 2020, p. 3590. *www.mdpi.com*, https://doi.org/10.3390/w12123590.

ATSDR. *Potential Health Effects of PFAS Chemicals*. 17 Jan. 2024, https://www.atsdr.cdc.gov/pfas/health-effects/index.html.

Barisci, Sibel, and Rominder Suri. “Occurrence and Removal of Poly/Perfluoroalkyl Substances (PFAS) in Municipal and Industrial Wastewater Treatment Plants.” *Water Science and Technology*, vol. 84, no. 12, Nov. 2021, pp. 3442–68. *Silverchair*, https://doi.org/10.2166/wst.2021.484.

Blaine, Andrea C., et al. “Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies.” *Environmental Science & Technology*, vol. 47, no. 24, Dec. 2013, pp. 14062–69. *DOI.org (Crossref)*, https://doi.org/10.1021/es403094q.

Buck, Robert C., et al. “Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins.” *Integrated Environmental Assessment and Management*, vol. 7, no. 4, 2011, pp. 513–41. *Wiley Online Library*, https://doi.org/10.1002/ieam.258.

California Air Resources Board. *Ozone & Health | California Air Resources Board*. https://ww2.arb.ca.gov/resources/ozone-and-health. Accessed 5 Apr. 2024.

Carey, Molly. “Fatal Fertilizer: PFAS Contamination of Farmland from Biosolids and Potential Federal Solutions.” *Pace Environmental Law Review*, vol. 40, no. 2, Mar. 2023, p. 282. *DOI.org (Crossref)*, https://doi.org/10.58948/0738-6206.1870.

Chemistry LibreTexts. “The Haber Process.” *Chemistry LibreTexts*, 2 Oct. 2013, https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Equilibria/Le_Chateliers_Principle/The_Haber_Process.

CompTox Chemicals Dashboard. https://comptox.epa.gov/dashboard/chemical-lists/PFASSTRUCTV5. Accessed 5 Apr. 2024.

Corcoran, Brooke. “Navigating the Complex World of PFAS Regulation for Medical Devices.” *MED Institute*, 20 Oct. 2023, https://medinstitute.com/blog/navigating-the-complex-world-of-pfas-regulation-for-medical-devices/.

Cousins, Ian T., et al. “The Concept of Essential Use for Determining When Uses of PFASs Can Be Phased Out.” *Environmental Science: Processes & Impacts*, vol. 21, no. 11, Nov. 2019, pp. 1803–15. *pubs.rsc.org*, https://doi.org/10.1039/C9EM00163H.

Denison, Richard A. “A Primer on the New Toxic Substances Control Act (TSCA) and What Led to It.” *Environmental Defense Fund Healh*, Apr. 2017, https://www.edf.org/sites/default/files/denison-primer-on-lautenberg-act.pdf.

Department of Toxic Substances Control, State of California. “Effective July 1, 2021: Carpets and Rugs with Perfluoroalkyl or Polyfluoroalkyl Substances (PFASs).” *Department of Toxic Substances Control*, https://dtsc.ca.gov/scp/carpets-and-rugs-with-perfluoroalkyl-and-polyfluoroalkyl-substances-pfass/. Accessed 5 Mar. 2024.

Environment, U. N. "About Montreal Protocol." *Ozonaction*, 29 Oct. 2018, http://www.unep.org/ozonaction/who-we-are/about-montreal-protocol.

Farman, J. C., et al. "Large Losses of Total Ozone in Antarctica Reveal Seasonal ClOx/NOx Interaction." *Nature*, vol. 315, no. 6016, 6016, May 1985, pp. 207–10. *www.nature.com*, https://doi.org/10.1038/315207a0.

Farrell, Alexander E., and Terry J. Keating. "Transboundary Environmental Assessment: Lessons from OTAG." *Environmental Science & Technology*, vol. 36, no. 12, June 2002, pp. 2537–44. *ACS Publications*, https://doi.org/10.1021/es0106725.

Garg, Eshita, and Muhammad Zubair. "Mass Spectrometer." *StatPearls*, StatPearls Publishing, 2024. *PubMed*, http://www.ncbi.nlm.nih.gov/books/NBK589702/.

George, Serena E., et al. "Nonlethal Detection of PFAS Bioaccumulation and Biomagnification within Fishes in an Urban- and Wastewater-Dominant Great Lakes Watershed." *Environmental Pollution (Barking, Essex: 1987)*, vol. 321, Mar. 2023, p. 121123. *PubMed*, https://doi.org/10.1016/j.envpol.2023.121123.

Glüge, Juliane, et al. "An Overview of the Uses of Per- and Polyfluoroalkyl Substances (PFAS)." *Environmental Science: Processes & Impacts*, vol. 22, no. 12, 2020, pp. 2345–73. *pubs.rsc.org*, https://doi.org/10.1039/D0EM00291G.

Koerber, M. "Ozone Transport Assessment Group: Ozone Modeling." *IECEC 96. Proceedings of the 31st Intersociety Energy Conversion Engineering Conference*, vol. 3, IEEE, 1996, pp. 2169–73. *DOI.org (Crossref)*, https://doi.org/10.1109/IECEC.1996.553563.

"National Biosolids Data Project." *National Biosolids Data Project*, https://www.biosolidsdata.org. Accessed 5 Apr. 2024.

National Toxicology Program. "Immunotoxicity Associated with Exposure to Perfluorooctanoic Acid (PFOA) or Perfluorooctane Sulfonate (PFOS)." *National Toxicology Program*, https://ntp.niehs.nih.gov/whatwestudy/assessments/noncancer/completed/pfoa. Accessed 10 Jan. 2024.

Ngatia, Lucy, et al. "Nitrogen and Phosphorus Eutrophication in Marine Ecosystems." *Monitoring of Marine Pollution*, IntechOpen, 2019. *www.intechopen.com*, https://doi.org/10.5772/intechopen.81869.

NPR Illinois. "This Farmer's Livelihood Was Ruined by PFAS-Contaminated Fertilizer That Few Midwest States Test For." *NPR Illinois*, 11 Mar. 2024, https://www.nprillinois.org/2024-03-11/pfas-contaminated-biosolids-state-testing.

Ojo, Atinuke F., et al. "Assessing the Human Health Risks of Per- and Polyfluoroalkyl Substances: A Need for Greater Focus on Their Interactions as Mixtures." *Journal of Hazardous Materials*, vol. 407, Apr. 2021, p. 124863. *ScienceDirect*, https://doi.org/10.1016/j.jhazmat.2020.124863.

"PFAS: Essential to America's Supply Chains." *American Chemistry Council*, https://www.americanchemistry.com/chemistry-in-america/chemistries/fluorotechnology-per-and-polyfluoroalkyl-substances-pfas/pfas-essential-to-america-s-supply-chains. Accessed 5 Mar. 2024.

Phelps, Drake W., et al. "Per- and Polyfluoroalkyl Substances in Food Packaging: Migration, Toxicity, and Management Strategies." *Environmental Science & Technology*, vol. 58, no. 13, Apr. 2024, pp. 5670–84. *ACS Publications*, https://doi.org/10.1021/acs.est.3c03702.

Pontius, Frederick. "Regulation of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonic Acid (PFOS) in Drinking Water: A Comprehensive Review." *Water*, vol. 11, no. 10, 10, Oct. 2019, p. 2003. *www.mdpi.com*, https://doi.org/10.3390/w11102003.

Renfrew, Daniel, and Thomas W. Pearson. "The Social Life of the 'Forever Chemical': PFAS Pollution Legacies and Toxic Events." *Environment and Society*, vol. 12, no. 1, Sept. 2021, pp. 146–63. *www.berghahnjournals.com*, https://doi.org/10.3167/ares.2021.120109.

Spyrakis, Francesca, and Tommaso A. Dragani. "The EU's Per- and Polyfluoroalkyl Substances (PFAS) Ban: A Case of Policy over Science." *Toxics*, vol. 11, no. 9, 9, Sept. 2023, p. 721. *www.mdpi.com*, https://doi.org/10.3390/toxics11090721.

Teflon. *The History of Teflon™ Fluoropolymers*. https://www.teflon.com/en/news-events/history. Accessed 4 Apr. 2024.

The Environmental Council of the States (ECOS). "Joint Principles for Preventing and Managing PFAS in Biosolids." *The Environmental Council of the States (ECOS)*, https://www.ecos.org/documents/joint-principles-for-preventing-and-managing-pfas-in-biosolids/. Accessed 8 Jan. 2024.

US EPA, OA. *EPA's PFAS Strategic Roadmap: Second Annual Progress Report*. 14 Oct. 2021, https://www.epa.gov/pfas/pfas-strategic-roadmap-epas-commitments-action-2021-2024.

US EPA. *Key EPA Actions to Address PFAS*. 13 Mar. 2018, https://www.epa.gov/pfas/key-epa-actions-address-pfas.

US EPA. *Our Current Understanding of the Human Health and Environmental Risks of PFAS*. 14 Oct. 2021, https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas.

US EPA. *PFAS Explained*. 30 Mar. 2016, https://www.epa.gov/pfas/pfas-explained.

US EPA, OCSPP. *Framework for Addressing New PFAS and New Uses of PFAS*. 12 June 2023, https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/framework-addressing-new-pfas-and.

US EPA, ORD. *Non-Targeted Analysis Research*. 17 Jan. 2024, https://www.epa.gov/chemical-research/non-targeted-analysis-research.

US EPA. *PFAS Analytical Methods Development and Sampling Research*. 21 Apr. 2020, https://www.epa.gov/water-research/pfas-analytical-methods-development-and-sampling-research.

US EPA, OW. *EPA's Ongoing Efforts to Reduce Nutrient Pollution*. 21 Feb. 2013, https://www.epa.gov/nutrientpollution/epas-ongoing-efforts-reduce-nutrient-pollution.

US EPA. *Municipal Wastewater*. 22 Oct. 2015, https://www.epa.gov/npdes/municipal-wastewater.

US EPA. *Per- and Polyfluoroalkyl Substances (PFAS)*. 16 Nov. 2021, https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas.

Wu, Jayne, and Qiang He. *Developing a Sensor Platform for Rapid On-Site Detection of PFAS in the Environment | Institute for a Secure & Sustainable Environment*. https://isse.utk.edu/news/developing-a-sensor-platform-for-rapid-on-site-detection-of-pfas-in-the-environment/. Accessed 4 Apr. 2024.