

Primary and Secondary Microplastic and Nanoplastic Regulations: Perspectives on Water Industry Impacts

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Abstract

Plastic pollution, both primary and secondary, is an environmental challenge, prompting regulatory actions at global and regional levels. With increasing research about the impacts of micro- and nanoplastics on ecosystems and human health, governments worldwide have undertaken efforts to address this issue. The global community has advanced regulatory efforts that have led to the implementation of national laws or regulations in numerous countries. These measures ban or restrict the use of primary and secondary microplastics and nanoplastics. An overview of global and European regulatory frameworks is presented to provide context for the United States (US). In the endeavor to document plastics regulation development in the US, a description of regulatory agencies and their roles in advancing policy and rules as well as future direction and areas for improvement in regulating plastics are introduced. A discussion of what emerging regulations mean to utilities and industries is also provided along with a comparison of regulatory frameworks.

Keywords

Microplastic Regulation, Environmental Governance, Plastic Pollution Mitigation, Regulatory Framework

1. Introduction

Plastic pollution, both primary and secondary, has emerged as an environmental

challenge, prompting regulatory actions at global as well as regional levels. Primary plastics encompass a spectrum of manufactured materials, ranging from macro to micro and nano sizes, whereas secondary micro/macro/nano plastics refer to the disintegration of larger plastic items into smaller particulate forms [1]. With increasing documentation of the impacts of plastics on ecosystems and human health, governments worldwide have undertaken efforts to address this issue [2]. Globally, regulations encompass all sizes of plastics, including macro-, micro-, and nanoplastics; however, a great deal of emphasis is placed on microplastics due to their significant role as a contaminant and greater ease of analysis compared to nanoplastics. In this context, the European Union (EU) and the United States (US) have taken steps to regulate both primary and secondary plastics, each with their own legislative frameworks and approaches.

The EU has adopted measures, such as bans on specific single-use plastic products, signaling a commitment to reducing plastic pollution and fostering sustainability [3]. Additionally, regulatory initiatives have been spearheaded by the European Commission and the European Chemicals Agency (ECHA). These efforts have culminated in proposals for restrictions on microplastics in various products, aiming to prevent or minimize their release into the environment [3] [4].

Similarly, the US has responded to the challenge of plastic pollution through federal and state-level regulations. Federal legislation such as the “Save Our Seas Act” and state-level bills like California’s “Ban on Plastic Microbeads” reflect concerted efforts to address microplastic contamination in coastal and inland environments. Notably, the California ban, effective from January 1, 2020, extends beyond cosmetic products, specifically targeting items designed for “rinse off” use [5] [6]. Despite variations in regulatory approaches, both the EU and the US acknowledge the urgency of addressing microplastic pollution and are actively pursuing regulatory solutions.

Plastic pollution, including micro- and nanoplastics, is a complex issue with multiple roadblocks in addressing the issue. A major obstacle is the absence of standardized methods for environmental sample collection [7]. This makes it difficult to compare and interpret data accurately, impeding efforts to grasp the full extent of microplastic contamination. Moreover, the lack of universally recognized analytical techniques for identifying and characterizing micro- and nanoplastics further complicates the problem. The variety of methodologies employed by researchers and regulatory bodies poses a challenge in evaluating and contrasting data effectively [8].

Despite increasing concerns, the complete scope of the ecological and human health impacts of micro- and nanoplastic pollution remains uncertain [9]. While research is emerging, there is yet limited scientific knowledge on the environmental effects and health risks of micro- and nanoplastics, which restricts the development of regulatory frameworks for minimizing their impacts [9]. Without thorough scientific data on possible risks linked to plastics, policymakers encounter difficulties in crafting precise and efficient regulations. Further, on-

going regulatory endeavors may struggle due to a lack of solid scientific evidence to inform their implementation [10].

The presence of plastic in the environment has sparked discussions among scientists, regulators, and the public [11]. Plastics' extensive presence seriously threatens ecosystems and human health, necessitating global and local governance strategies to mitigate pollution [12]. Additionally, microplastics' pervasive nature and potential health impacts underscore the need for enhanced regulatory measures and waste management practices [13]. This review summarizes current plastic regulations, with a focus on understanding regulatory approaches globally and in the US, delineating the complexities inherent in regulating plastic pollution. Through comprehensive analysis, this manuscript highlights the role of regulatory efforts in combating plastic pollution and identifies potential areas for future policy development. Additionally, this review employs BillTrack50 to track US legislation broadly related to plastics, providing a perspective on the evolving regulatory landscape. This approach enables an analysis of how legislation intersects with efforts to reduce sources of microplastic pollution, underlining the necessity of such tools in legislative tracking [14].

2. Global Plastics Regulations

As part of global efforts to address plastic pollution, by July 2018, 127 countries had implemented legislation aimed at reducing the use of plastic bags, while twenty-seven countries had either banned or placed restrictions on the production of specific items like straws and polystyrene. This historic progress reflects a growing recognition of the urgent need for action. The United Nations Environmental Program (UNEP) published a report in December 2018 titled "Legal Limits on Single-Use Plastics and Microplastics" [15]. Additionally, forty-three countries have incorporated the concept of extended producer responsibility (EPR) in regulations, with sixty-three countries mandating EPR specifically for single-use plastics [15]. Recognizing the need to address plastic pollution, the United Nations Environmental Assembly (UNEA) adopted a resolution titled "End of plastic pollution: Towards an international legally binding instrument" in March 2022. This milestone signifies a global consensus on the necessity of an international framework to combat plastic pollution. Consistent with this resolution, an intergovernmental negotiating committee (INC) was established to deliberate specifics of a treaty, anticipated to be developed and finalized by the end of 2024 [16]. As depicted in **Figure 1**, countries have initiated plastic source reduction by establishing rules and regulations regarding plastic bags [17]. These regulations aim to reduce the use and disposal of plastic bags, minimizing the introduction of primary plastics into the environment. By implementing such measures, countries proactively address secondary plastic contamination, including microplastics, and mitigate impacts on ecosystems and human health.

Efforts to address microplastic contamination have led to the implementation of national laws or regulations in numerous countries. These measures ban or restrict the use of microbeads, a common type of microplastic found in cosmetic

products. These countries include Canada, France, Argentina, China, Thailand, India, Italy, the Republic of Korea, New Zealand, Sweden, the United Kingdom, and the US (Figure 2). Such bans and regulations contribute to the objective of reducing microplastic pollution [18]-[27]. Further, the United Nations' #Clean Seas campaign has played a significant role in raising public awareness and garnering support for tackling marine plastic pollution [28].

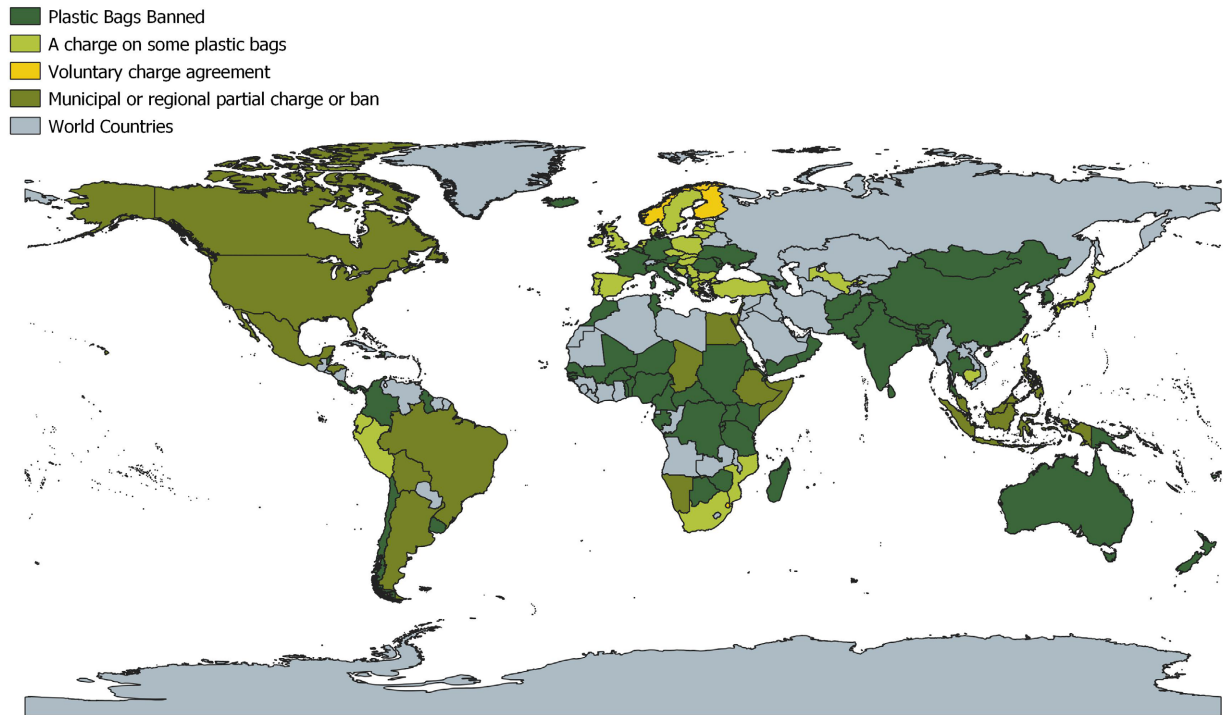


Figure 1. Global plastic bag regulation. Adapted from [17].

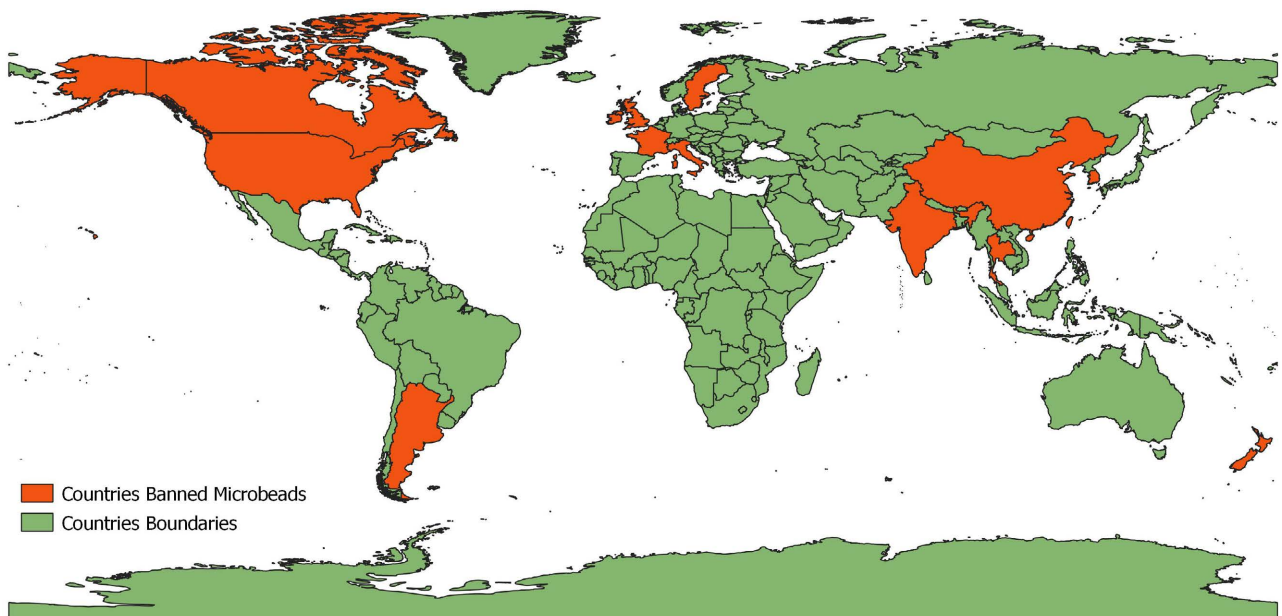


Figure 2. Global Microbead regulation by 2022. Adapted from [18]-[27].

3. Plastics Regulations in Europe

The European Union (EU) has been a leader in plastics regulations and took action by banning ten specific single-use plastic products, demonstrating its commitment to reducing plastic pollution and promoting sustainability [29]. The EU also initiated an effort to regulate microplastics in 2017 when the European Commission tasked the European Chemicals Agency (ECHA) to evaluate measures against microplastic pollution. By 2019, ECHA proposed restrictions on microplastics in various products to prevent or reduce their release into the environment [4]. These proposals covered a range of products, including cleansers, cosmetics, and fertilizers, potentially avoiding the release of about 500,000 tons of microplastics over two decades [30]. The EU consulted with stakeholders and the public on microplastic pollution with regulations under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) framework [30]. Regulations target products with added microplastics above specified concentrations, imposing restrictions on products, such as cosmetics, detergents, and medical devices, aiming to mitigate environmental contamination [29]. Further, the EU Ecolabel Regulation prohibits inclusion of microplastics and microbeads in animal care and cosmetic products, reinforcing efforts to protect the environment. Suppliers and manufacturers must ensure compliance with these regulations to maintain environmental standards and promote sustainable practices.

Looking ahead, the regulation of nanoplastics poses a challenge for policy-makers and regulatory agencies in the EU. Nanoplastics, plastic particles with the range size between 1 nm to 1000 nm, have increased bioavailability and toxicity compared to their larger counterparts, requiring their inclusion in existing regulatory frameworks. The EU is considering proposals to restrict intentionally added microplastics and redefine polymers under REACH to also address nanoplastics. Moreover, revisions to the definition of nanomaterials are ongoing, highlighting the EU's commitment to keeping pace with scientific advancements and evolving regulatory needs. By integrating nanoplastics, the EU will strengthen its regulatory framework, enhance environmental protection, and promote sustainable practices [10].

4. Plastics Regulations in the United States

During the last two decades, plastics detection in the environment has been documented in several studies, forcing US regulators to engage in discussions. The "Save Our Seas Act," signed by President Trump in December 2020, was the most recent federal regulation on plastics to address coastal debris [6]. Other federal regulations include the H.R. 1321 bill by the House Committee on Energy and Commerce, signed by President Obama in July 2017. Following reports on the presence of microbeads in aquatic environments, the "Microbead-Free Waters Act of 2015" prohibited the use of microbeads in personal care products [5].

Soon after, the “Ban on Plastic Microbeads (AB 888)” was signed by the governor of California, Jerry Brown, in October 2015, banning plastic microbeads in personal care products by 2020 [31]. Even before these bans, the “Plastic Pellet Litter Prevention (AB 258)” bill was signed by California Governor Schwarzenegger in October 2007, when the US Environmental Protection Agency (EPA) Total Maximum Daily Load required local governments to clean up microplastics with one incentive of the bill being a reduction in clean-up costs [32].

In September 2014, the State of California Governor, Jerry Brown, signed the “Solid waste: Single-use Carryout bags (SB 270)” bill into law to reduce the total cost of managing plastic bag litter in streets, waterways, recycling facilities, and landfills [33]. In 2018, the “Solid Waste: Foodservice Packaging: State Agencies, facilities, and Property (SB 1335)” bill required California food service facilities to use the CalRecycle List of Approved Food Service Packaging, requiring sustainable packaging in the State of California [34]. During the same period, California passed “Assembly Bill 1884” to require sit-down restaurants to forgo automatic distribution of single-use straws, and instead offer straws only upon customer request [35]. More recently, California passed “Solid Waste: reporting, packaging, and plastic food service ware (SB 54)” on June 30, 2022, to reduce plastic waste by requiring all packaging to be recyclable or compostable by 2032. This legislation also raised \$5 million from industry to shift the plastic pollution burden from consumers to plastic manufacturers [36].

After several peer-reviewed journals and scientific reports reported the presence of microplastics in drinking water, the State of California passed the “Testing Drinking Water for Microplastics (State Bill (SB) 1422)” law in July 2018, to generate data on the presence of microplastics in drinking water [37]. The objective of the bill was to bring awareness to the public about the sources and fate of microplastics. California also passed SB 1263 to reduce the ecological impacts of microplastics in the marine environment by establishing a framework to address microplastic contamination, mandating the Ocean Council to formulate a State-wide Microplastics Strategy [38]. State bills SB 1422 and SB 1263 were the first regulations that addressed microplastics through research and strategic plans. Before SB 1422 and SB 1263 were passed, California addressed microplastics only through source reduction. **Figure 3** presents a chronology of microplastic regulations in the US, with a focus on California.

4.1. ITRC Microplastics Outreach Toolkit

In response to concerns around microplastics, in 2021 the Interstate Technology Regulatory Council (ITRC) surveyed US states to gather insights into the efforts to regulate microplastics. With a total of forty-three responses from twenty-six states and one territory, the survey revealed that most of the states did not conduct sampling for microplastics, while four states indicated that they had sampling plans. Eight states have developed or planned to adopt criteria or standards for microplastics sampling and analysis in different media (**Figure 4**). Several

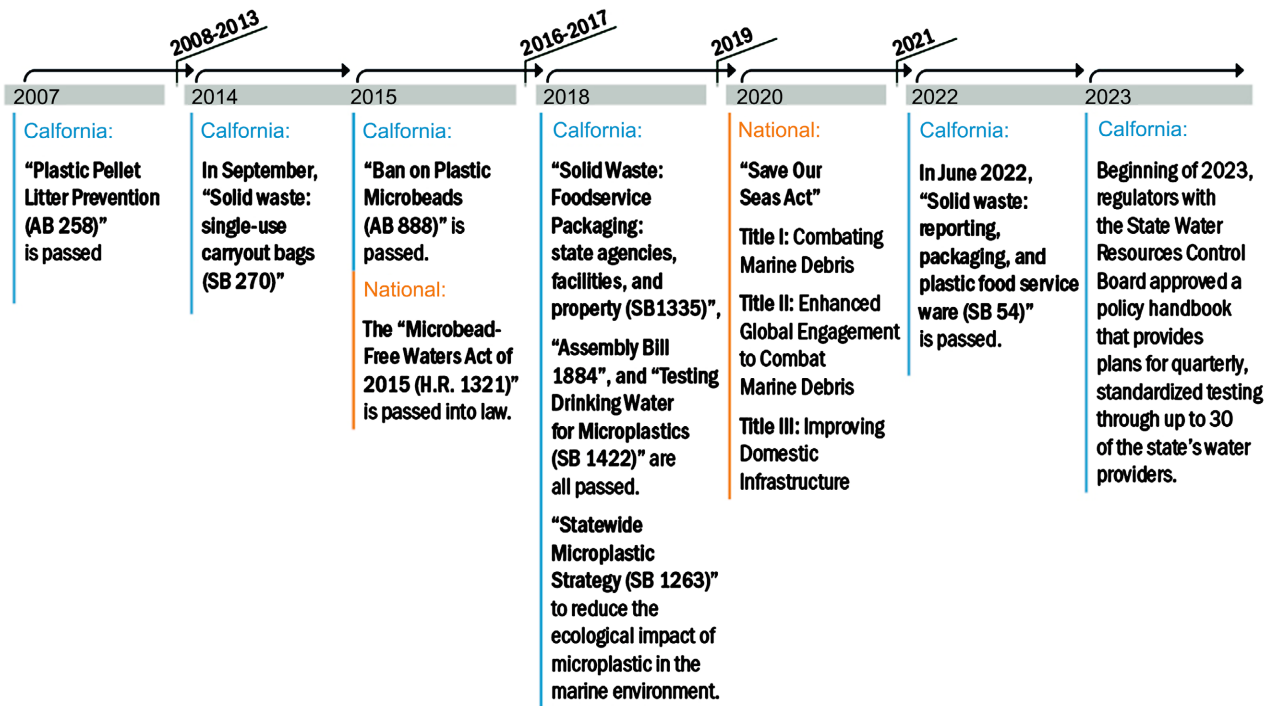


Figure 3. Federal and California state regulations on Microplastics.

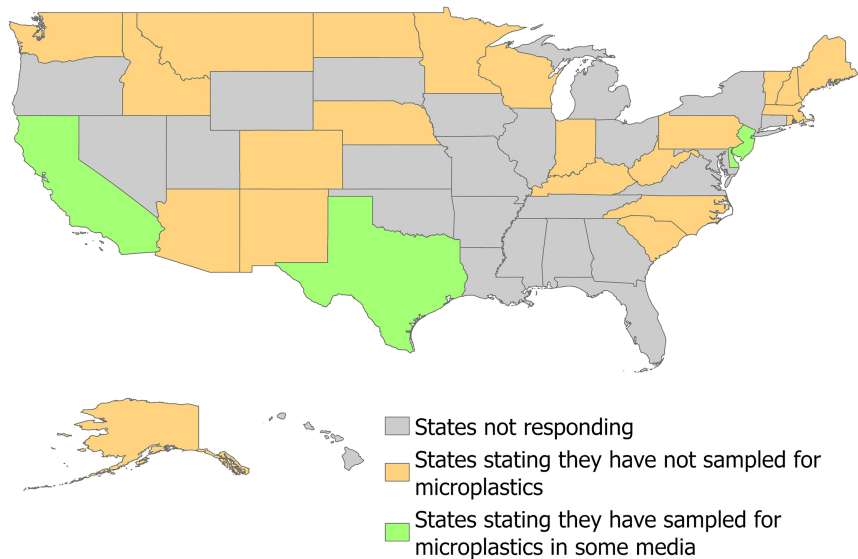


Figure 4. Responses of different states to the ITRC Microplastics team survey. Adapted from [39].

states have enacted regulations or legislations targeting primary microplastic or single-use plastics, including their presence in water and wastewater (Figure 5). The survey revealed a lack of regulations for addressing atmospheric emissions of microplastics, highlighting a gap in current regulatory frameworks. Further, findings from the survey underscore the varying degrees of progress and challenges faced by states in regulating microplastic pollution.

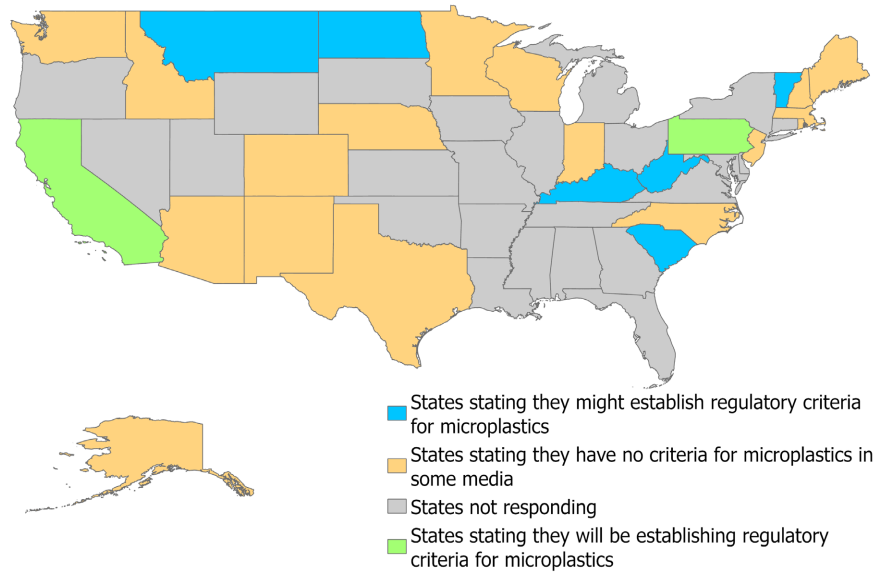


Figure 5. State of Microplastic regulations across different states based on ITRC data. Adapted from [39].

4.2. EPA's Trash Free Waters Program and Microplastic Pollution Prevention Efforts

The EPA initiated the Trash Free Waters (TFW) program in 2013 to combat aquatic trash pollution across the US. The program aims at understanding the sources, pathways, and impacts of aquatic trash with a specific emphasis on microplastics. While initially focusing on preventing trash infiltration from inland water bodies into oceans, the program expanded its scope to address the multi-faceted problem of microplastic pollution through collaborative educational initiatives, technical support, and community-based projects.

The TFW program encompasses various projects aimed at addressing plastic pollution, categorized into six overarching themes: 1) Trash Capture, 2) Source Reduction, 3) Food Service-Related Source Reduction Programs, 4) Community Engagement, 5) Research, and 6) Trash Free Waters Stakeholder Engagement Strategies. Within these project categories, three initiatives specifically target plastic and microplastic pollution. One project under the Food Service-Related Source Reduction Programs focuses on reducing plastic contamination, titled "Reducing Food Service Plastics on University of California Campuses." Additionally, two projects fall under the Research umbrella, focusing on microplastics: "Salish Sea Hydrodynamic Modeling of Microplastic Hotspots" and "Supporting the Development of a National Approach to Extracting Microplastics from Sediment." These targeted efforts demonstrate the program's commitment to addressing the pervasive issue of microplastic pollution through multifaceted approaches, ranging from source reduction to advanced research methodologies [40].

The TFW program has achieved significant milestones since its inception in 2013 (Figure 6), with notable progress made in addressing the issue of plastic

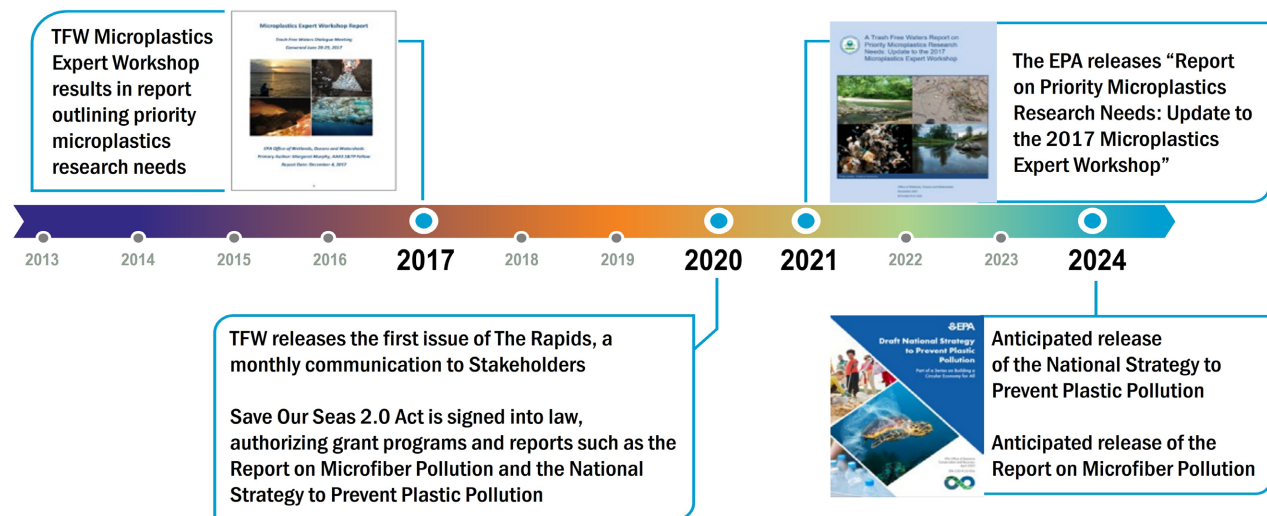


Figure 6. Key milestones related to plastic in the implementation of the EPA's trash-free waters program. Adapted from [42].

pollution. In 2017, the program organized the Microplastic Expert Workshop, which helped identify and prioritize research needs for microplastics [41]. In 2020, the Save Our Seas 2.0 Act was signed, authorizing grants for programs and studies aimed at addressing plastic pollution. The Report on Microfiber Pollution and the National Strategy to Prevent Plastic Pollution was developed through one of the programs supported through this grant. Building upon the findings of the 2017 Microplastics Expert Workshop, the TFW program released the Report on Priority Microplastics Research Needs in 2021, consolidating the emerging research priorities [42]. Furthermore, in 2024, the publication of the Draft National Strategy to Prevent Plastic Pollution outlined measures to prevent plastic pollution [43]. These milestones highlight the TFW program's focus on microplastic pollution and its commitment to driving impactful change through strategic initiatives and collaborative efforts.

4.3. Overview of the US Congress 118th Session, January 2023-January 2025, Legislation on Plastics

While some states have taken proactive measures to address microplastic contamination through legislation and regulations, others are still in the preliminary stages of developing comprehensive frameworks. There is a pressing need for increased collaboration and knowledge sharing among states to develop effective and uniform regulatory approaches to mitigate microplastic pollution. While tracking regulatory provisions and efforts to control microplastic pollution using BillTrack50, we found one thousand bills in the 118th Session of the US Congress, which directly or indirectly addressed plastic regulations (Figure 7). Among these bills, approximately 60 percent are currently in committee, indicating ongoing deliberation and review by the relevant legislative bodies (Figure 8). Fourteen percent of the bills are already signed, enacted, or adopted, demonstrating the realization of urgency in addressing the pollution issue and rapid progress made at the state level.

Count by State

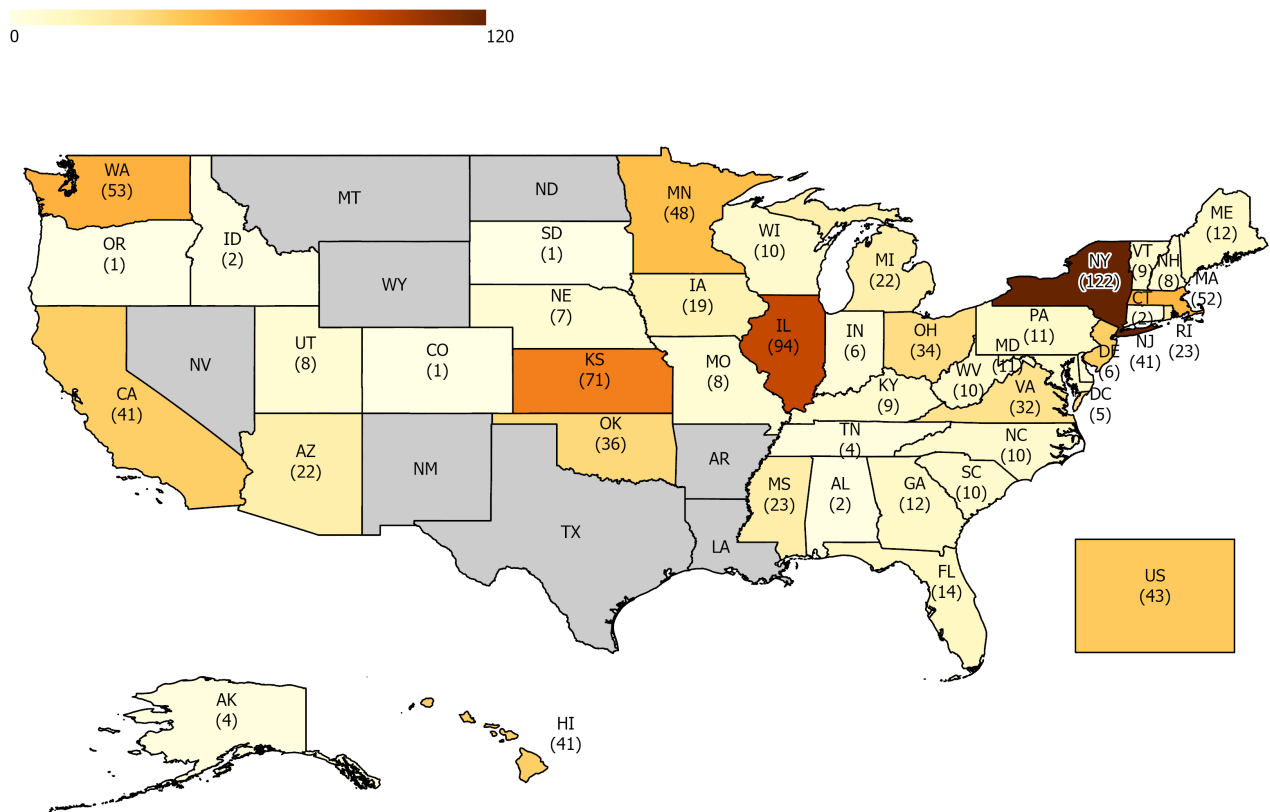


Figure 7. The US map with the number of plastic-related bills in each state. Adapted from [14].

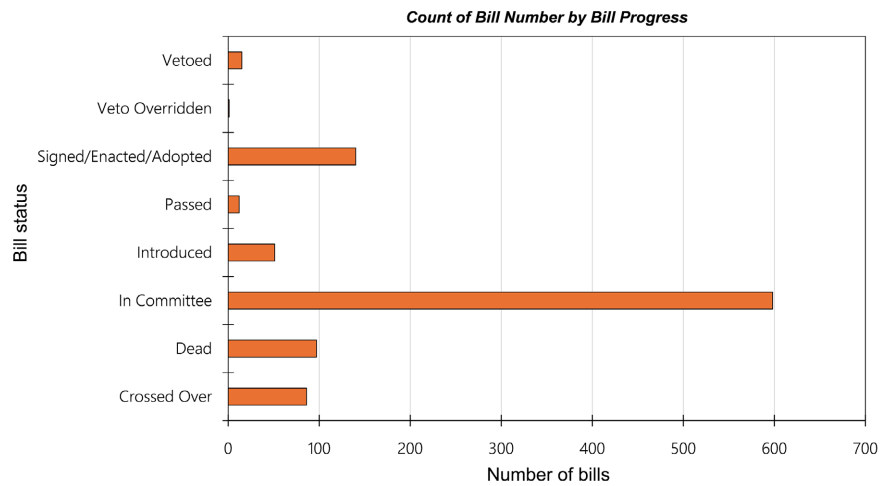


Figure 8. Number of plastic-related Bills in the 118th US Congress. Adapted from [14].

Notably, New York State leads the nation with 122 bills focused on plastic-related issues, followed by Illinois with ninety-four bills (Figure 7).

Despite the considerable attention given to primary plastic regulations, microplastic-specific regulations are just recently emerging across the US. Surprisingly, among the 122 bills addressing plastics in New York state (Figure 9),

Count by State

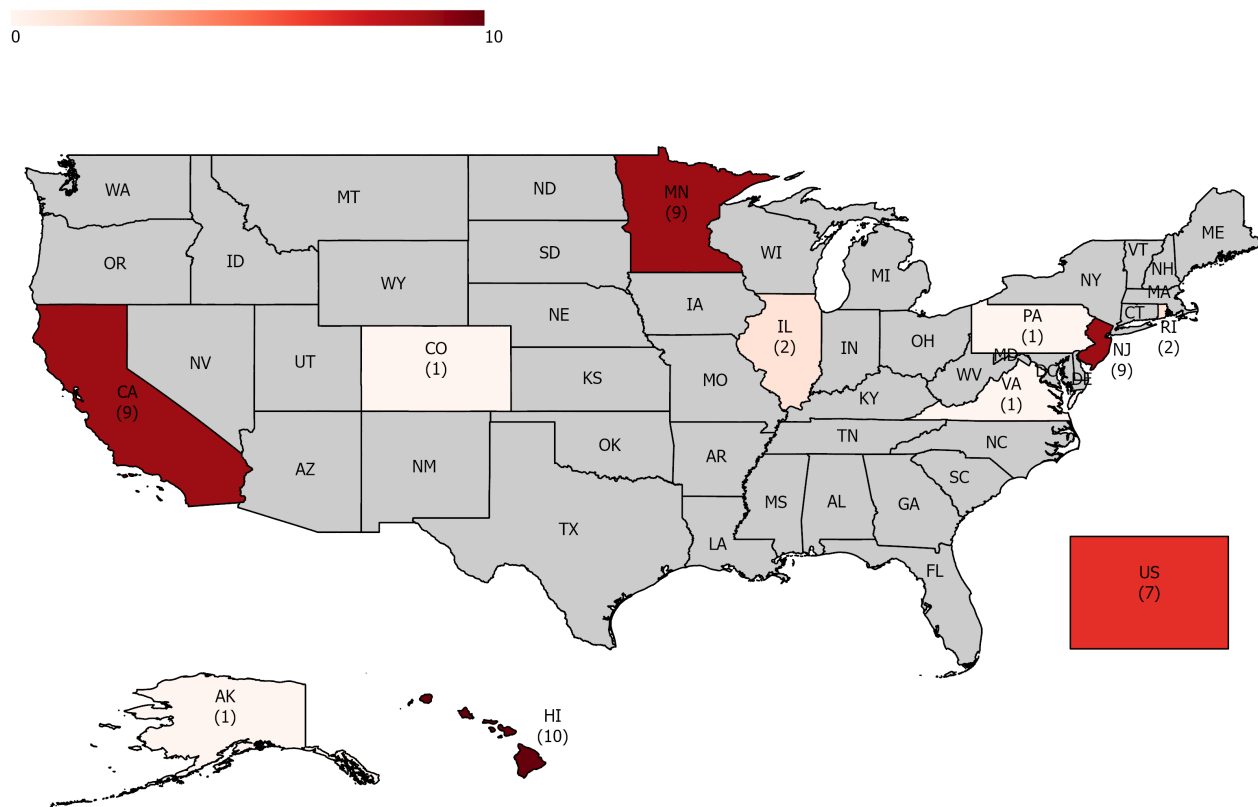


Figure 9. Map of the US with the Number of Microplastic-related Bills in each State. Adapted from [14].

none were specifically focused on microplastics. However, despite the high importance given to regulating plastics more broadly (*i.e.*, one thousand bills), regulatory activity for directly addressing microplastics is limited (fifty-two bills), underscoring the emphasis on source reduction strategies by states [14].

Among states with microplastics legislation, Hawaii emerges as the leader with ten bills. Out of the total microplastic-related bills, a majority (63%) are currently in committee, whereas approximately 15% of the bills have already been signed, enacted, or adopted (Figure 10).

In alignment with the European approach, Minnesota and California have recognized nanoplastics as an emerging contaminant [14]. Currently, there are five bills specific to nanoplastics in Minnesota and one bill in California (Figure 10). Among these, only one from Minnesota has been passed, while the rest are in committee (Figure 11 and Figure 12).

4.4. Focus of Legislative Activity

In review of these bills, it is notable that regulatory efforts have approached microplastic regulations in six diverse ways: 1) Source Reduction, 2) Collaborative Integration, 3) Recycling, 4) Research Funding, 5) Data Collection, and 6) Incentives. Source Reduction minimizes production and use of single-use plastics,

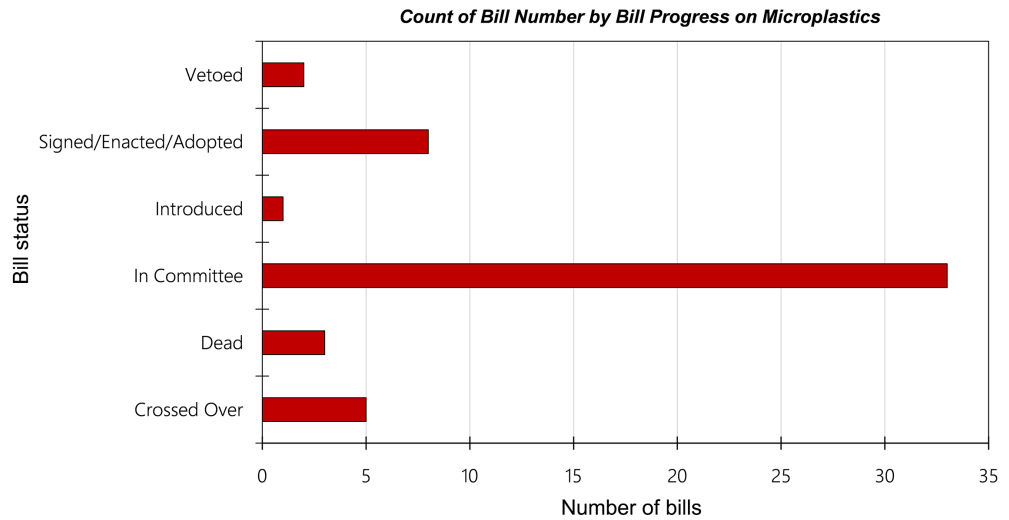


Figure 10. Number of Microplastic-specific bills in the 118th US Congress. Adapted from [14].

Count by State

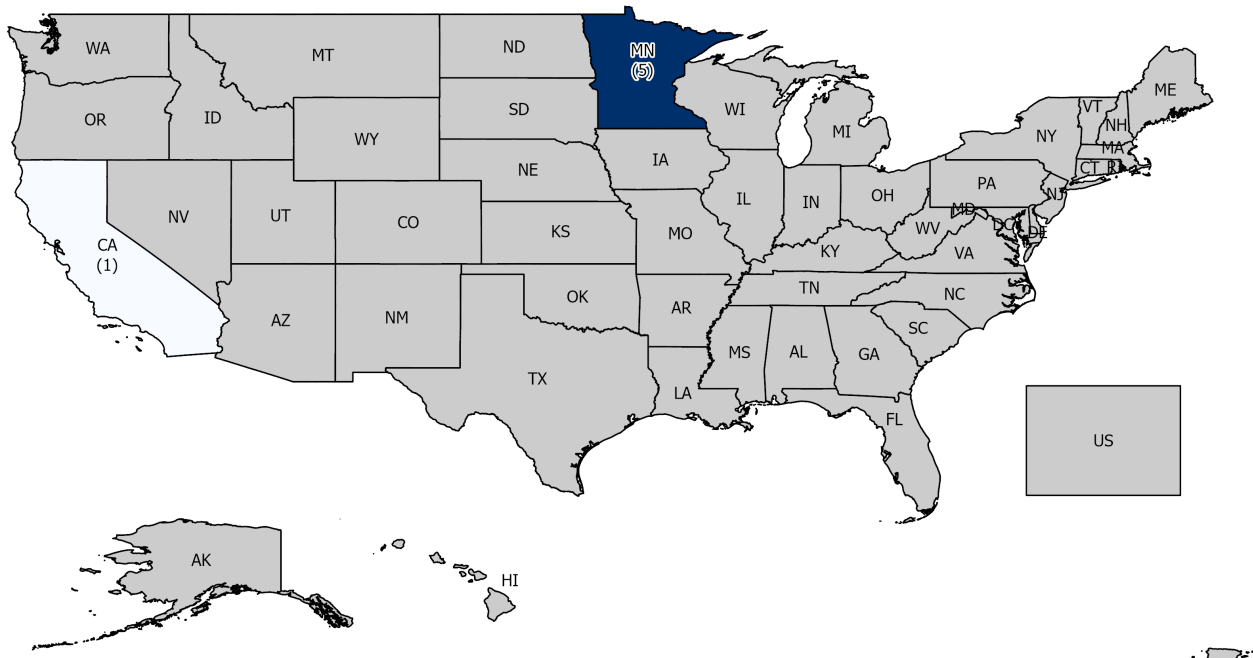


Figure 11. Map of the US with the number of Nanoplastics-related Bills in each State. Adapted from [14].

whereas Collaborative Integration encourages stakeholders, including regulatory bodies, to collaborate in enacting and enforcing microplastic regulations. Recycling initiatives focus on enhancing recycling infrastructure and promoting reuse of plastic materials to minimize environmental impact. Research Funding

directs resources toward scientific studies and technological innovations to better understand and address microplastic pollution. Data Collection involves collection, management, analysis, and interpretation of data on microplastic presence and its potential effects on the environment and human health, providing valuable insights for policymaking. Finally, Incentives aim to encourage individuals and businesses to adopt environmentally friendly practices and technologies, promoting a culture of sustainability. Some bills target more than one aspect, reflecting the multifaceted nature of the microplastics problem. While there are six key focus areas, **Figure 13** provides an overview of all approaches distributed among states actively addressing microplastic regulations [14].

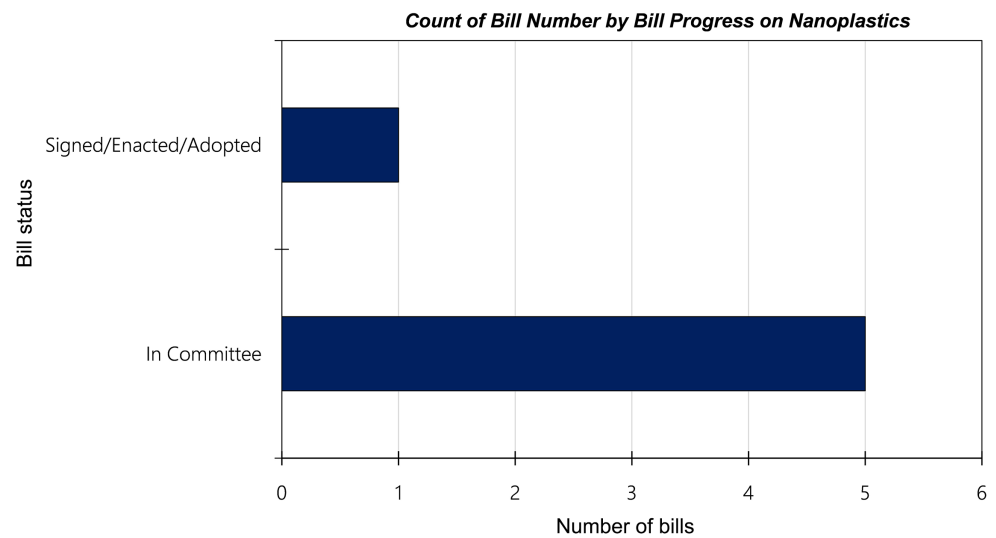


Figure 12. Number of Nanoplastics-specific Bills in the 118th US Congress. Adapted from [14].

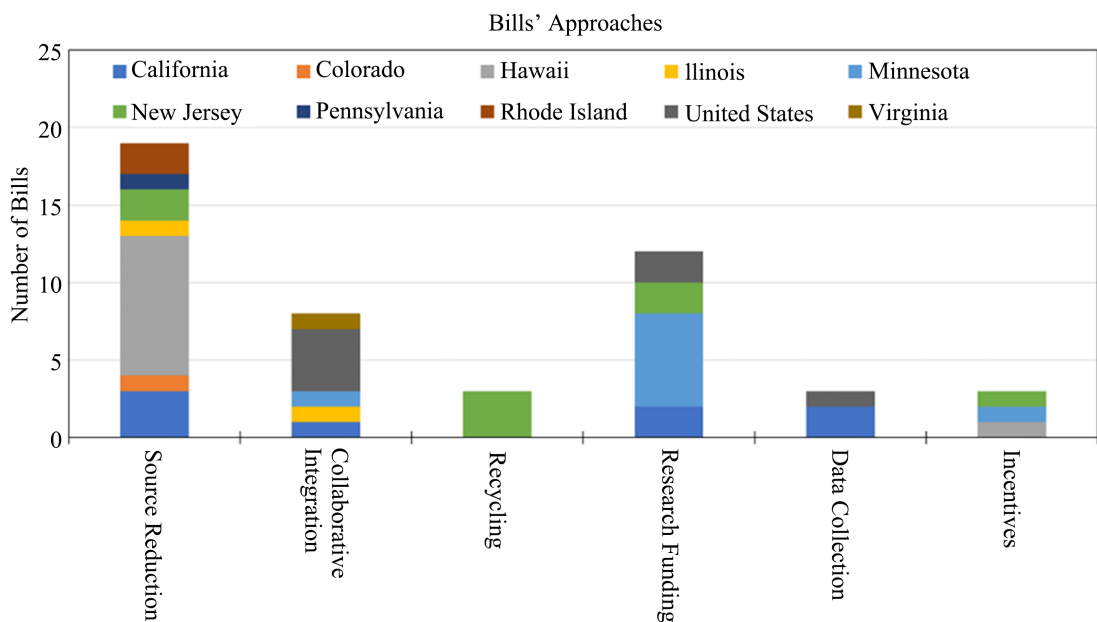


Figure 13. Snapshot of Microplastics Bills Across the U.S. Adapted from [14].

4.5. Regulatory Agencies and Their Roles

Regulatory agencies have a critical role in pollution prevention through the development and implementation of policies and regulations, and monitoring compliance with the enacted regulations. Their responsibilities also include supporting research, providing funding, collaborating with stakeholders and other regulatory agencies, informing and educating the public, promoting technological innovation, and facilitating international cooperation. Through their various efforts, regulatory agencies contribute to protecting the environment and human health.

Looking toward the future and considering avenues for improvement, it is crucial to encourage collaboration among various stakeholders. Policymakers, scientists, industry leaders, and the public must unite their efforts to effectively address the diverse challenges posed by microplastics. Enhancing the comprehensiveness and efficacy of regulatory frameworks stands out as a crucial objective. This involves leveraging emerging technologies and innovative scientific insights to refine legislative measures. Moreover, intensified research efforts are essential to enhance our understanding of the long-term environmental and human health implications of micro- and nanoplastics. Further, there is a pressing need to enhance public awareness and education regarding hazards associated with micro- and nanoplastics and the need for sustainable practices. By prioritizing these initiatives, regulatory frameworks can be strengthened, informed decision-making can be promoted, and the environment can be collectively protected while enhancing public health.

5. What Do These Regulations Mean to the Water Industry?

Regulations surrounding plastics carry significant implications for utilities and industries. First, compliance with these regulations demands rigorous monitoring and management practices from utilities responsible for water treatment and supply. As regulations aim to reduce plastic contamination in water sources, utilities must invest in advanced monitoring tools and methods, and treatment technologies to meet potentially stringent standards. This may require substantial financial investments to upgrade infrastructure and implement specialized equipment capable of effectively monitoring, characterizing, and removing microplastics from water supplies. Additionally, utilities may face heightened public scrutiny and accountability, necessitating transparent reporting mechanisms to demonstrate compliance with regulatory requirements. Failure to adhere to new regulations could result in reputational damage and legal consequences, highlighting the importance of prioritizing compliance efforts and upholding public trust.

Industries reliant on plastic manufacturing and production processes are also subject to the impacts of microplastic regulations. These regulations compel industries to reassess their product design, manufacturing practices, and waste management strategies to minimize the generation and release of plastics into

the environment. Implementing source reduction measures and transitioning toward sustainable alternatives can help industries align with regulatory objectives, while reducing their ecological footprint. However, compliance with microplastic regulations may entail substantial operational changes and investments in research and development to innovate eco-friendly materials and production methods. Further, utilities may face heightened regulatory oversight and enforcement measures, necessitating proactive engagement with regulatory authorities and industry stakeholders to navigate evolving compliance requirements effectively. Overall, plastics regulations present both challenges and opportunities for the water industry, underscoring the need for proactive adaptation and sustainable practices to mitigate environmental risks and ensure long-term compliance.

6. Conclusions

Despite regional disparities, globally, regulatory agencies face common challenges in regulating microplastics, such as ensuring effective enforcement and promoting public awareness. International collaboration and information sharing are essential to harmonize regulatory frameworks and address cross-border issues. Moreover, investments in research and innovation are crucial to develop sustainable alternatives to plastic and advance understanding the impacts of microplastics on ecosystems and human health. By fostering cooperation and adopting evidence-based policies, the environmental and health risks posed by plastic pollution can be mitigated, contributing to a cleaner and healthier future for all.

Given the recent focus on microplastics, ITRC convened a Microplastics Team that initiated a project in January 2023 aimed at developing a toolkit to equip environmental professionals with resources for communicating plastic issues to the public. ITRC published the Online Guidance Document in February 2023, highlighting its commitment to addressing plastic pollution [39].

To develop robust and effective regulatory frameworks, there is a critical need for continued and focused research into the pervasive effects of microplastics. Recent studies highlighting the contamination of microplastics in the Indian Ocean and their biological effects, such as the impact on enzymatic activities and soil microbes, underscore the urgency of these efforts [44] [45]. These findings should prompt increased scientific investigations to provide an understanding of microplastic pollution's environmental and biological impacts. These types of research will deepen the scientific community's understanding and provide regulators with the important evidence needed to develop impactful policies. By strengthening the scientific foundation of regulations, policymakers can ensure that measures are both practical and impactful, leading to more sustainable environmental outcomes.

In conclusion, the examination of plastics regulations globally and in the US reveals progress in addressing this environmental challenge. International and

regional efforts highlight the importance of mitigating plastic pollution to protect ecosystems and human health. While progress has been made in implementing regulatory measures, there is a need for ongoing collaboration and coordination among stakeholders. By fostering dialogue and sharing best practices, nations can collectively strengthen their regulatory frameworks and advance toward more effective solutions for managing plastics. Further research and cooperation are essential to this end.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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