

TAKING CONTROL OF PERSISTENT SOLID WASTE POLLUTION

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Abstract

The complexity and scale of the sources, types and environmental impacts of persistent solid waste pollution (PSWP) continue to overwhelm the capabilities of government and private efforts to control it. Global cumulative production of virgin plastics is expected to quadruple by 2050 with a concomitant doubling of plastic waste. All nations must take significant steps to realize eventual mitigation of PSWP. These will include adopting a long-term PSWP elimination policy, creating an overarching authority to lead and coordinate a comprehensive national solid waste management program, and creating an International Convention for the Prevention of PSWP to enable global solutions for this global pollution. Initiating these changes will necessitate major, coordinated efforts on the part of environmental organizations, their supporting foundations and concerned citizens.

Key Words: persistent solid waste, marine debris, marine litter, plastic pollution, waste management

Introduction

While it is difficult to characterize the rise of the petrochemical revolution in a few sentences, the salient features of this industrial-economic phenomenon certainly include cycles of innovation, acceptance and widespread realization of the associated benefits followed by eventual recognition of the environmental consequences with efforts to mitigate them. Examples of these impacts include smog, ozone depletion, climate change, acid rain, ocean acidification, toxic substance pollution, and persistent solid waste pollution (PSWP), to name a few (McLusky, 1982; Mehlman, 2006; Schreck, 1998; Yin et al., 2017). The overall effectiveness of responses to these pollutants depends on the timing of the identification of the types, sources and the assessments of their impacts. The more complex and varied the polluting materials, their sources and types of environmental threats and the longer the period over which they are identified, the more piecemeal and less efficient the collective mitigation response is likely to be. This pattern may be obvious, but it seems to be at the heart of the on-going marine debris issue, 90% of which is plastics (Kaza et al., 2018). The proportion of persistent solid waste in the waste stream varies globally based on economy, consumption patterns and product availability.

Further, the amount of PSWP generated from any waste stream depends significantly on the effectiveness of local waste management processes (Jambeck et al., 2015; Zhang et al., 2010). Plastics specifically constitute over 12% of all municipal solid waste (Kaza et al., 2018) and ‘leakage’ occurs at all phases of the production-disposal life cycle due to inadequate management (Kershaw, 2016). PSWP includes a staggering number of types and formulations of plastic products with varying characteristics as pollutants (Derraik, 2002; Jepson et al., 2016; Murphy et al., 2015; Vasseur and Cossu-Leguille, 2006). Add to this the range of sizes and shapes of individual pollutant particles from meters to nanometers (they are constantly fragmenting at varying rates; Cole et al., 2011), and one begins to appreciate the complexity inherent in measuring the problem and conceiving strategies for its mitigation.

In general, global solid waste is composed of persistent (plastics, glass, metal, other) and naturally degradable components (food and green, wood, paper and cardboard, rubber/leather, other). While any of these components may be classified as pollutants depending on circumstances, the persistent materials require specific collection and processing to prevent their becoming long-term pollutants. Among the persistent wastes, glass and metals are relatively inert and have, or can have, high rates of recycling because of their value as feedstock, their general purity, and ease of identification and separation in the waste stream. Plastics and other materials make up 26% of global solid waste, an estimated ratio of 12% plastics and 14% other (Kaza et al., 2018). The proportion of that “other” category that is a persistent material like plastic is, as of now, unknown and a topic for future study. While virtually all the following treatise is based on plastics data, we have chosen the term persistent solid waste pollution (PSWP) as our subject in recognition of this potentially significant “other” category of persistent solid wastes. This choice emphasizes the necessary recognition that mitigating the deleterious impacts of marine debris (marine litter) is, in fact, a global solid waste management challenge.

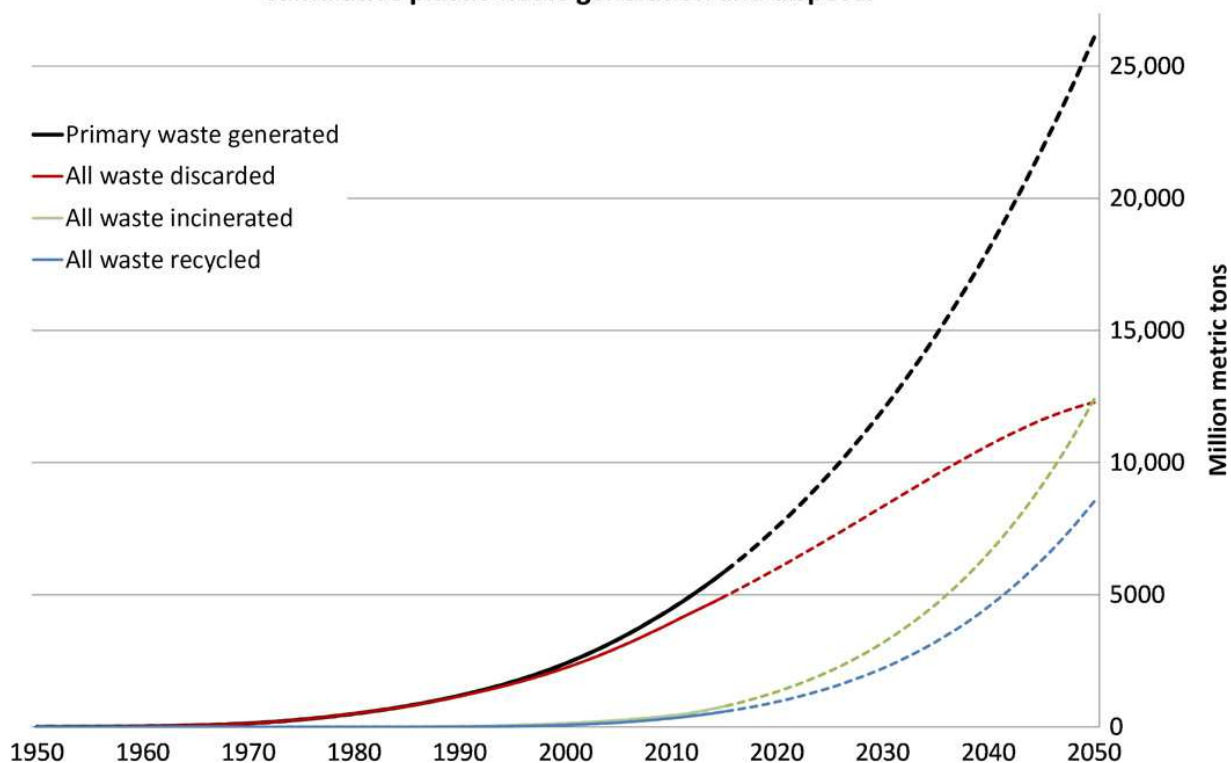
The Status Quo

PSWP is now recognized to be ubiquitous in all terrestrial and aquatic ecosystems and in the atmosphere (Derraik, 2002; Dris et al., 2016). A recent assessment of global plastics production and waste management practices concludes that, as of 2015, the world has produced a total of 8300 million metric tons (Mt) of virgin plastics, out of which 6300 Mt is plastic waste (13.86 trillion lbs.; Geyer et al., 2017). The study predicts that if present production growth rates continue, cumulative production of virgin plastics is expected to rise to 34000 Mt by 2050, 12000 Mt of which will end up in landfills or extant in the environment (Fig. 1; 2017).

Figure 1. Cumulative plastic waste generation and disposal (in million metric tons).

Solid lines show historical data from 1950 to 2015; dashed lines show projections of historical trends to 2050. From Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. *Science Advances* 3, e1700782. <https://doi.org/10.1126/sciadv.1700782>. Reprinted with permission from AAAS.

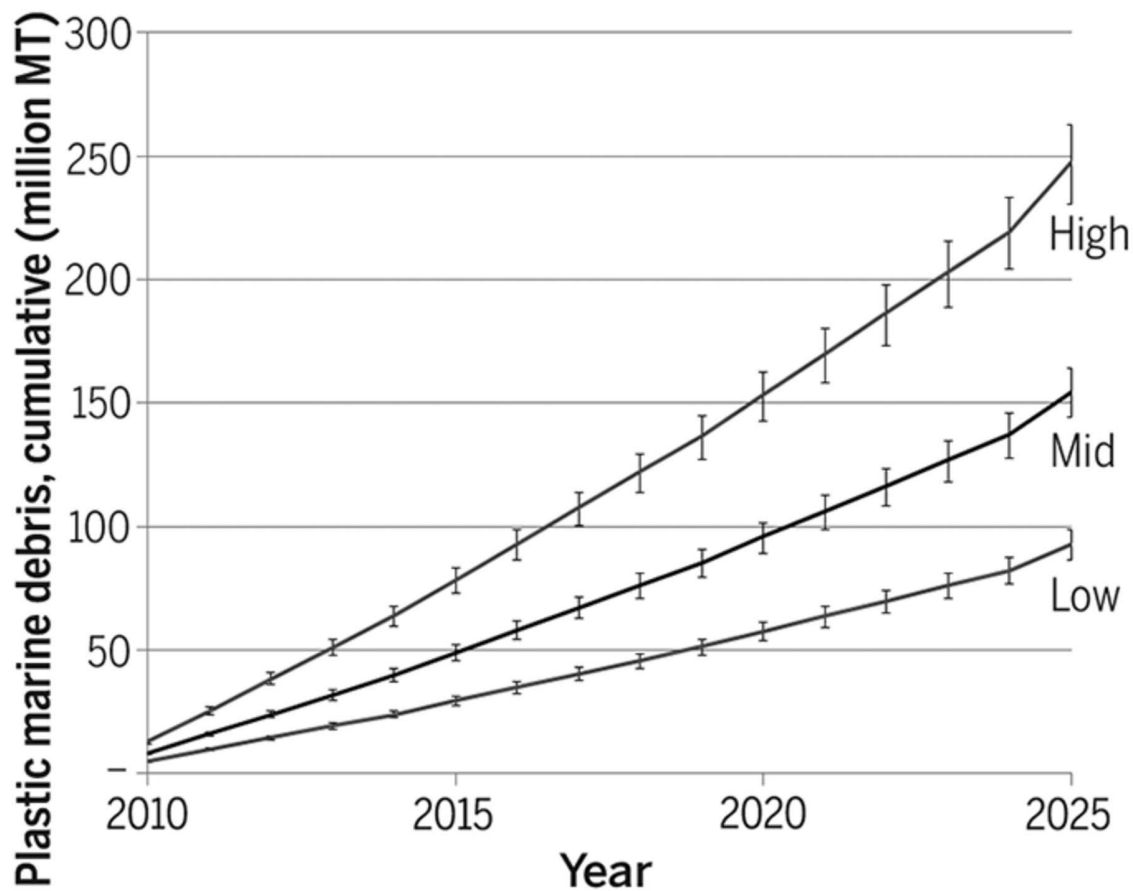
Cumulative plastic waste generation and disposal



The fate of persistent solid waste depends on the existence and effectiveness of waste management systems on the local level. Jambeck et al. (2015) estimated that in 2010 alone 275 Mt of plastic waste was generated in 192 coastal countries (representing approximately 93% of the global population) of which 99.5 Mt was generated within 50 km of the coast. Using information on the types of waste management systems in use in each of the coastal regions, the authors classified 31.9 Mt as mismanaged, of which between 4.8 to 12.7 Mt of plastic waste entered the ocean in that year. Presumably, the residual 19.2 to 27.1 Mt of mismanaged plastic waste remained on land as potential future ocean pollution. Assuming no improvements in current waste management infrastructure, the cumulative amount of mismanaged plastic waste (available to reach the ocean from land) is estimated to grow by an order of magnitude by 2025 (Fig. 2) (Jambeck et al., 2015). While these estimates do not include maritime sources or input resulting from natural disasters (floods, tsunamis, etc.), Kefela et al., 2018 estimate tsunamis to contribute up to 2.4 Mt and textile fibers add another 0.4 Mt to the annual flow of PSWP into the oceans. There have been no recent estimates of total maritime sources of PSWP.

Figure 2. Estimated mass of mismanaged plastic waste (millions of metric tons) input to the ocean by populations living within 50 km of a coast in 192 countries, plotted as a cumulative sum from 2010 to 2025.

Estimates reflect assumed conversion rates of mismanaged plastic waste to marine debris (high, 40%; mid, 25%; low, 15%). Error bars were generated using mean and standard error from the predictive models for mismanaged waste fraction and percent plastic in the waste stream. From Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science* 347, 768–771. <https://doi.org/10.1126/science.1260352>. Reprinted with permission from AAAS.



By another estimation, approximately 60% of all plastics ever produced were discarded and are accumulating in landfills or in the natural environment (Geyer et al., 2017). Sequestration of persistent waste in landfills is only a temporary measure for the prevention of pollution. Landfilling may delay the release into the environment for periods of weeks to millennia, depending on the product and the design of the landfill, but it is by no means an endpoint disposal option. Perhaps mankind will be mining these landfills for valuable resources in some distant future. Recycling may delay some future primary plastics production but this effect is extremely difficult to verify (Geyer et al., 2015). Done properly, incineration or other thermal

destruction methods including waste-to-energy programs are potential endpoint disposal strategies for most plastics. The potential large-scale use of thermal destruction, however, will require development and incorporation of significant emission control technology to avoid environmental and public health impacts. Open burning is a common method for reducing trash heaps, but it is a dangerous, potentially toxic and incomplete disposal method (U.S. Environmental Protection Agency, 2016). To date, biodegradable or other enhanced fragmentation formulations for single-use materials may reduce litter and potential rates of physical interactions with megafauna, for example, but are not endpoint solutions as they merely accelerate the dispersion of the polymer materials into the environment as micro- and nano-plastic bits. Ultimately, the long-term sustainable solution to PSWP will result from global movement towards an economy in which persistent solid waste pollutants are designed out of the production and use cycle (Kershaw, 2016; ISWA, 2017).

One must contemplate the fate of plastics that are not or cannot be recovered from the environment. We know that PSWP is created and distributed world-wide. Some proportion of macro-, or mega-plastics are recovered through waste stream collection systems and by clean-up programs, most to be sequestered in landfills of varying quality. Once plastic waste materials are fragmented into particles less than a five mm in diameter, the likelihood of their being removed from the environment becomes vanishingly small (da Costa, 2018; Gallo et al., 2018). While rates of degradation and fragmentation vary based generally on polymer type, additives, and exposure, the process is inexorable (Andrady, 2011). Scientific attention to this micro-plastic phenomenon is accelerating and some mechanisms for biological impacts have been described (Rocha-Santos, 2018; Gallo et al., 2018). The standards and techniques for quantification of micro- and nano-plastics in the environment require further development (Ogonowski et al., 2018) before the extent and character of their potential ecosystem impacts can be realistically evaluated. However, the physics of this degradation suggest that the chemical additives employed in polymer formulations are eventually released into the environment, including colorants, plasticizers and other known toxic materials (Gallo et al., 2018; Murphy et al., 2015; Ng, 2017).

After nearly 40 years we know a great deal about PSWP but struggle to implement mitigating and preventive solutions. While a welter of projects and plans exist to tackle various sources or types of concentrations of PSWP, the obvious fact is that no large-scale progress has been or is being made against the rising tide of marine (and terrestrial) debris. It appears that some combination of vastly improved waste collection, sequestration and destruction technologies will be required to change the course of PSWP growth. Reduction in the demand for virgin plastic production through increasing recycling rates, reusing and creating reusable alternates for disposable materials, adopting minimal packaging strategies, eliminating incentives to discard, and many other innovations in chemical and materials engineering must be pursued (United Nations Environment Programme, 2016; Kershaw, 2016). None of this is new, it just hasn't come to fruition at a scale that will reduce the growing pollution of the entire planet. The

concepts are simple and have been voiced for decades, however, under current efforts best estimates suggest cumulative plastic waste will double by 2050 (Geyer et al., 2017) and the amount available to become ocean pollution will grow by an order of magnitude by 2025 (Jambeck et al., 2015). The organizations, resources, leadership and commitment to tackle this problem, with all due respect to the millions of people concerned and involved, are inadequate.

Judging from the rising frequency of relevant keywords in the scientific literature (Google, 2018), the trend in topics presented at International Marine Debris Conferences in 2011 and 2018, and in the growing national participation in the United Nations Environment Programme (UNEP) Clean Seas Program (UNEP, 2017) among others, the time appears ripe for taking control of persistent solid waste pollution. A recent systematic review of the literature on the impacts of plastics in the ocean concluded that irreversible harm may be unavoidable should governments fail to begin mitigating plastic debris (Rochman et al., 2016). The way forward depends on the concerted actions of national governments with the concomitant leadership and support of civil society.

A National PSWP Policy

Because the oceans are a global system, PSWP in the oceans is a global problem. The primary sources of PSWP in the oceans are land-based, and all power and most resources to enact, sustain and enforce solutions to national and international pollution problems are held by national governments. Therefore, the first step toward marshalling forces for solving the PSWP problem begins with national governments. Despite widespread commitment in many international fora, such as UNEP, the G-7, UNSDG-14, etc., governments around the world have not yet implemented the steps necessary to reverse the growth of PSWP. The steps taken, while laudable and necessary, are typically non-binding and involve single product bans (bags, straws, utensils, microbeads, etc.) aimed primarily at litter control and recycling rates. Absent the full commitment by national governments to research, funding, implementation and enforcement, these steps will not materially change the plastic pollution trajectory. In this paper we propose three major actions for PSWP mitigation using the United States government example to illustrate the problems and types of changes that are necessary to meet the PSWP challenge. With some imagination, the steps described here are likely to be generally adaptable for most other governments.

Persistent solid waste is a major ocean, terrestrial and atmospheric pollutant (fibers) that is rapidly increasing without signs of slowing. The enormity of the PSWP problem will not be adequately addressed in the short-term no matter what actions governments choose to take. Massive amounts are already extant in the environment, inputs are global in scale and effective waste management system capacity is limited, particularly in low income countries, despite the fact that 187 out of 217 (86%) countries and economies reported they had laws or guidelines regarding solid waste management (Kaza et al., 2018). The escalation of this pollution to unimaginable levels and impacts is inevitable without the adoption of a long-term commitment to comprehensive efforts to control it. This begins with national governments adopting and

communicating a permanent policy to eliminate PSWP. This does not presume there will be no persistent solid waste. It presumes that a drastic reduction in persistent solid waste pollution over time is in the best interests of all nations and the world. The IUCN listed an improved governance framework as critical to addressing marine plastic pollution (Kershaw, 2016). Adoption of such a national policy tells civil society, the legislature, the courts, agencies and industries and other nations that the most effective way to rise above the status quo must involve a significant level of government leadership and intervention. This in turn enables commitment, stimulates ideas, fosters innovation and elevates attention to potential solutions strategies, all of which lead toward more effective implementation.

Very recently, some nations recognized this need; they articulated broad policy pledges addressing systematic attention to plastic pollution. The UK, is applying the concept of a circular economy (Pearce, D. W. and Turner, R. K., 1991) to plastic waste elimination (Neufeld et al., 2016). Indonesia's Plan of Action on Marine Plastic Debris (Government of the Republic of Indonesia, 2017) is credible model for PSWP mitigation policy. At an international scale, five of the seven members of the G-7 endorsed the Charlevoix Blueprint for Health Oceans, Seas and Resilient Coastal Communities, including the Ocean Plastics Charter Annex to incorporate "a lifecycle approach to plastics stewardship on land and at sea." While these international pledges remain nonbinding, they are essential steps toward national policy commitments for effective action on PSWP.

Reorganizing to meet the PSWP Challenge

The revelation of, and governments' responses to plastic pollution began in the 1970's and '80s and have continued to evolve over the decades. For example, by 2005 a review of US laws relating to elements of the marine debris problem revealed no less than twenty-one statutes involving seven Federal Departments and at least eleven agencies within them (National Oceanic and Atmospheric Administration, 2008). Also, US commitments in eight international agreements involve at least five Federal Departments (NOAA Marine Debris Program, 2005). Departments, and their respective agencies are in competition with each other for limited resources as well as for executive and legislative attention and public approval. The dynamics of this competition across these agencies and various responsibilities under the marine debris laws and agreements guarantees a severe compartmentalization (turf) of activities responding to the PSWP challenge. The principal point is that none of the charged agencies has, or will likely ever have sufficient authority, resources or expertise to lead or direct a coherent national effort to mitigate PSWP. Absent this leadership, the current piecemeal, bottom-up approaches are doomed to collective inadequacy. This problem was clearly identified by the US National Research Council's Committee on Shipborne Wastes during its assessment of the US implementation of Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) (International Maritime Organization, 1983) in 1995 (National Research Council, 1995).

The NRC Committee's recommendations for the consolidation of leadership to guide the full implementation of MARPOL Annex V were never enacted.

The remedy for this dilemma which may be common among national governments, incorporates the creation of an overarching authority (a permanent national commission or new agency/ministry) to either direct the existing agencies activities with respect to PSWP policy, programs and law or to extract those elements from the agencies and assemble them as a new, independent entity within the national government. Some form of hybridization of these might be workable if based on reasonably independent elements of the overall challenge (e.g., maritime vs. land-based, impacts research vs. waste management R&D, enforcement, etc.). A national policy commitment to the eventual elimination of PSWP coupled with broad public mandate for legislation to create the lead Commission or agency will be necessary to make this happen. A related US example might be the US Marine Mammal Protection Act of 1972 and its creation of the Marine Mammal Commission to oversee and advise multiple US agencies with marine mammal related authority.

Mandates for the new authority should include the development and direction of coordinated strategies to address the technological, economic, legal and bureaucratic features of the PSWP challenge. This effort should begin with the commissioning of a program of studies by competent national (e.g., the US National Research Council) and/or international (e.g., UNEP, ISWA) technical bodies to provide carefully considered strategic guidance for the effective prioritization and accomplishment of the Commission/Agency's objectives.

Broadly, these strategies and the implicated US agencies should include:

1. The analysis and consolidation of existing laws, regulations and policies to establish a coherent, coordinated legal foundation and regulatory authority for actions required to address PSWP (Department of Justice (DOJ), Office of Management and Budget (OMB)).
2. The development of the capacity to conceive, set priorities for, fund and coordinate chemical engineering and waste management technology research to develop non-polluting (or less polluting) materials and disposal alternatives (Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), Department of the Interior (DOI), Department of Energy (DOE), Department of Agriculture (DOA)).
3. The development, coordination and funding of public awareness and education programs to foster voluntary acceptance of behaviors supporting PSWP reduction (Department of Education (ED), EPA, NOAA, DOI).
4. The research, design and implementation of appropriate incentive systems to foster behavior and business decisions favoring PSWP reduction (Department of Commerce (DOC), Internal Revenue Service (IRS)),
5. The evaluation, implementation and funding of long-term, internationally applicable indices for monitoring changes in key types and sources of PSWP (NOAA, EPA, DOI).

6. The creation and funding of suitable government, industry, university, and NGO grants programs and partnerships to augment the work of the Commission/Agency (OMB, DOJ, IRS).
7. The development and funding of adequate enforcement capacity for both land-based, sea-based and fiscal regulatory regimes as they evolve under national and international programs (US Coast Guard (USCG), US Navy (USN), DOJ, EPA, Department of Defense (DOD)).

Ideally, the entity(s) created to carry out these mandates for mitigating PSWP, whatever form it may take, should be permanently chartered and funded as full success is surely many decades in the future.

A Global Framework is Essential

Part XII, Section 5, article 207 of the United Nations Convention on the Law of the Sea (United Nations, 1983) delineates States' obligations to prevent, reduce and control pollution of the marine environment from land-based sources. States shall adopt laws and regulations and other measures as necessary for these purposes "taking into account internationally agreed rules, standards and recommended practices and procedures." This Article explicitly recognizes the importance of "taking into account the characteristics of regional features, the economic capacity of developing states and their need for economic development."

While Article 207 was written prior to the recognition of persistent solid waste as significant pollutant and particularly as it originates from land-based sources, these obligations clearly include PSWP in the ocean and on land. The Article suggests that "states acting through international organizations or diplomatic conferences endeavor to establish global and regional rules, standards and recommended practices and procedures to meet these obligations." Because the potential economic and environmental consequences of PSWP are not confined to national boundaries and exhibit multi-scalar and temporal mechanisms (da Costa, 2018), international cooperation is of paramount importance for the effective mitigation of land-based sources of PSWP.

The need for an international convention explicitly for the prevention of persistent solid waste pollution is obvious. Between states' obligations to mitigate land-based sources, current conflicting standards and practices, and the potential benefits of technical, financial and enforcement collaboration, it is unquestionable that constructive actions would result from international consensus on PSWP. While a plethora of international agreements exist addressing various forms of pollution, none was conceived explicitly to address the scope and complexity of PSWP. However, proposals to include PSWP under some existing treaties are under consideration, including the Basel, Rotterdam and Stockholm Conventions that address forms of hazardous wastes, toxic chemicals and POPs. While forming a new convention is time consuming and costly, the notion that adding responsibilities as complex as the mitigation of PSWP to existing, more narrowly conceived treaty structures, is counterintuitive. Adding PSWP

mitigation commitments calls for vast increases in new expertise, creates unnecessary conflicts in priority setting and funding, leads inherently to sub-divisions of participants and functions, and creates additional levels of decision making rendering the entire effort less effective. We believe the global, technical and economic scope of this issue demands a PSWP Convention that would provide the foundation for future concerted action.

In contemplating the form of a PSWP Convention, the MARPOL (73/78) Convention may be an appropriate general model. Specifically, within MARPOL (73/78), a Marine Environment Protection Committee (MEPC) was established as a forum for consistent review, clarification and refinement of the various provisions of the Treaty. This mechanism has proven indispensable to the relevance and efficiency of evolving Treaty requirements. The MEPC also provides a forum within which national, industry, and NGO experts work to develop and refine practical guidelines for the implementation of the many technically complex Treaty requirements. With the possible exceptions of the uniquely difficult maritime (and sovereignty) issues of flag state vs. port state enforcement and the provision of adequate port waste reception facilities, MARPOL and especially its MEPC exemplify the kind of international leadership and coordination needed for PSWP mitigation.

Why Bother?

So, why should we expend the effort to control the future pollution of all ecosystems by billions of tons of persistent solid waste? There can be no doubt that plastics production will continue to increase, and that waste MIS-management rates will decrease slowly if at all, thus adding substantially to the backlog of disintegrating persistent waste materials already in the environment. At present, actions to mitigate PSWP may be categorized as source reduction or prevention, recovery, reuse, sequestration and destruction. In a mass/balance sense, the global data clearly show current efforts addressing PSWP are fighting a losing battle. This is further exacerbated by rising instability in the international trade and infrastructure systems in place to facilitate high volume plastics recycling (Brooks et al, 2018). It is reasonable to conclude that these activities, while vigorously pursued at some local, and a few national scales are thoroughly inadequate at regional and global scales.

With respect to persistent solid waste pollution of the planet, we are already careening down a one-way street with only partial appreciation of the ultimate environmental costs. Of course, this problem is one of many that we have unwittingly perpetrated on ourselves as we have reaped the myriad benefits of the golden age of petrochemistry. Since it is quite certain that most of us and our progeny will not be in on the emigration to Mars or other exoplanets, it would be prudent to take the big steps needed now to protect natal biosystems from certain incremental degradation. Absent major reorganizations, renewed policy commitments, and significant long-term funding from national governments we will certainly continue down this path.

Despite the increasingly compelling case for the implementation of these recommendations, there does not seem to be a mechanism to bring them to fruition. Arguably, the most powerful

engines of change in environmental protection, aside from the scientific community, have been the large environmental NGOs and their supporting foundations. Their ability to marshal public opinion, to disseminate scientific findings, and to create and assure the exercise of existing law is unequalled. Unfortunately, the same compartmentalization and competitive circumstances that plague government agencies also exist in the NGO community. While there is no possibility of mandating coordination among major environmental NGOs, the unifying environmental theme and the inevitable direction of the global PSWP problem indicate the need for this coordination to promote national and global PSWP objectives. We recommend coordinated NGO campaigns include the continuing global lead for civil society for PSWP mitigation and the administration of a global petition to demonstrate to national leaders and legislators the overwhelming public support for long-term measures to address PSWP. Further, high priority must be given to the drafting and promotion of national PSWP policies, of national legislation for PSWP oversight agencies/commissions; and, of an International Convention for the Prevention of PSWP.

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