WRITTEN TESTIMONY OF:

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HEARING: "Marine Debris and Wildlife: Impacts, Sources and Solutions"

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Key Points:

- With few exceptions, global plastic production has increased annually for 65 years and is anticipated to continue this rapid growth. 311 million metric tons of plastic were produced globally in 2014 and an estimated 8 million metric tons enter the ocean every year.
- Plastic waste continues to be an important environmental contamination issue, with implications for freshwater and soils as well as oceans and wildlife. Individual animals ingest and become entangled in plastic, and microplastic is ubiquitous and persistent in the environment. Economic impacts in contaminated areas are evident.
- Interventions and mitigation strategies can occur along the plastic value chain. They must be informed by science and be culturally appropriate. Investment in science and innovation may also spur economic growth in new industries.

Introduction

I would like to thank Chairman Sullivan, Ranking Member Whitehouse and the rest of the Fisheries, Water and Wildlife Subcommittee for the opportunity to testify at this hearing to examine marine debris and wildlife, focusing on impacts, sources, and solutions. It is an honor and privilege to be with you today. My name is Jenna Jambeck and I am an Associate Professor of Environmental Engineering at the University of Georgia. I have been conducting research on solid waste issues for 20 years with related projects on marine debris since 2001, especially projects regarding location and spatial analysis of debris, debris quantification and characterization, global plastic waste mismanagement and technology/mobile device usage (mapping, etc.). I have also sampled open ocean plastic sailing across the Atlantic and co-developed the mobile app, Marine Debris Tracker, funded by the NOAA Marine Debris Program. I have presented at three Capitol Hill staffer briefings, a Global Ocean Commission meeting, the 2015 Our Ocean Conference, a 2015 G7 workshop, and at the White House Office of Science Technology and Policy (OSTP). I also serve as the U.S. representative on an Advisory Panel for the United Nations Environment Program Global Partnership on Marine Litter. My testimony today is my opinion, based upon my background and experience in studying marine debris.

Context

I grew up in the 1970s outside a small town (fewer than 3,000 people) in Minnesota. Like many people at the time, we managed our trash by taking it to the landfill and putting it in ourselves. I always found it fascinating to see what people throw away – and I have seen bowling balls to bologna in landfills. In graduate school, my fascination turned into a passion for studying solid waste management as an environmental engineer. Environmental engineers can also design urban drinking water and wastewater facilities, but to me, solid waste management felt like it most closely involved people. Unlike the small effort required to turn off a faucet or flush a toilet (even a sensor can do this with no human effort), we all have to decide daily what to consume, what materials to use, what *is* and *is not* "solid waste" in our own home, and then whether to give away, discard, compost or recycle unwanted materials. The human component of solid waste management, and the direct interaction with people, is an aspect of my work that continues to be important to me.

In 1976 Congress passed the Resource Conservation and Recovery Act (RCRA) that required the U.S. EPA (typically through the states) to regulate solid and hazardous waste. [1] "Open dumping" was prohibited and replaced by engineered and regulated landfills, composting and recovery systems.[2] RCRA also specifically called for research to inform solutions, including demonstrations and special studies on measures to reduce the generation of waste, waste collection practices, and economic incentives to promote recycling and waste reduction (among other things).[3] Because of RCRA, we had outstanding progress in solid waste management, just in my lifetime. When I heard about our trash ending up in the ocean in 2001, I knew we must be contributing to it from the land, and started down the path of my current research. In this testimony, I am going to illustrate the direct connection between the solid waste (trash) we produce on land and the plastic found in our ocean, recalling that the human component goes hand in hand with local, state, regional, national and international initiatives to address this problem.

Plastic Marine Debris Introduction

Marine debris has been recognized as a contamination issue for more than 50 years.[4] Recent focus on the issue of trash in our marine environment is now almost exclusively on plastic – why? Plastic is a very useful material and global annual plastic production has increased from 1.7 million metric tons/yr (1950) to 311 million metric tons/yr (2014).[5] Along with a steep increase in production, we have seen a resulting increase in plastic in the waste stream from 0.4% in 1960 to 12.7% in 2012 (by mass) in the U.S.

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[1] Resource Conservation and Recovery Act (RCRA) - Public Law 94-580, October 21, 1976, (42 U.S.C. 6901-6992; 90 Stat. 2795), as amended by P.L. 95-609 (92 Stat. 3081), P.L. 96-463 (94 Stat. 2055), P.L. 96-482 (94 Stat. 2334), P.L. 98-616 (98 Stat. 3224), P.L. 99-339 (100 Stat. 654), P.L. 99-499 (100 Stat. 1696), P.L. 100-556 (102 Stat. 2779)

[2] Code of Federal Regulations (CFR) Title 40, Parts 239 – 282

[3] https://www.epa.gov/aboutepa/new-law-control-hazardous-wastes-end-open-dumping-promote-conservation-resources

[4] Ryan, P. (2015). A Brief History of Marine Litter Research, in Marine Anthropogenic Litter, Bergmann et al. (eds.), Springer, New York, NY.

[5] Plastics Europe, http://www.plasticseurope.org/Document/plastics---the-facts-2015.aspx

Most plastics do not biodegrade, but only fragment into smaller, ultimately microscopic, pieces. Polymers that make up the plastics that we commonly encounter are listed in Table 1.

Table 1. Common Polymers, Uses and Density related to Seawater

Polymer	Recycling Number	Sink or Float in Seawater	Common Use(s)
Polyethylene Terephthalate (PET)	1	Sink	Individual beverage bottles, textiles
High Density Polyethylene (HDPE)	2	Float	Gallon jugs, some personal care product and detergent bottles
Polyvinyl Chloride (PVC)	3	Sink	Piping, siding (construction)
Low Density Polyethylene	4	Float	Retail bags, thin film plastic
Polypropylene	5	Float	Bottle caps, yogurt containers, toys
Polystyrene	6	Sink (expanded floats)	Foamed/expanded PS in packaging
Others	7	Nylon sinks	Fishing nets (nylon)

Plastics also contain additives to alter color, texture, shape, form, antimicrobial surfaces, make it flame retardant, and for other properties.[6] The wide variety of available additives results in thousands of different plastic material compounds for particular purposes, creating a diverse array of plastic materials that end up in our trash, which can make recovery and recycling challenging.

Since plastic "degrades" through fragmentation, the result is microplastic (smaller than 5 mm in size) in the environment. Secondary microplastics are formed by the fragmentation of larger items. Primary microplastics are manufactured in these small sizes. Some sources of primary microplastic are resin pellets and microbeads. Resin pellet loss has been addressed by the industry though their Operation CleanSweep program,[7] and recent federal legislation requires a phase out of microbeads in personal care products by 2018.[8] Secondary microplastic is found on our coastlines, in our sediments, and floating in the ocean aggregating in the five oceanic gyres. Using the largest available ocean microplastics dataset, a recent study estimated that 15 to 51 trillion particles, with a mass of 93 to 236 thousand metric tons, are floating on the sea surface globally; this is equivalent to only about 1% of the estimated input of plastic waste to the ocean from land in a single year.[9] Where the remaining plastic debris is in the ocean remains a major unanswered question. The majority of field sampling to date captures only particles larger than approximately one-third of a millimeter in size, but increasing numbers of reports of synthetic fibers (from clothing and woven ropes, for example) in freshwater and marine environments, and even in air, make microfibers an emerging concern.[10] And, while many people think

[6] Additives have been mixed into plastic compounds since they have been in the consumer market: Deanin, R.D. (1975). Additives in plastics, *Environmental Health Perspectives*, 11: 35-39.

[7] https://opcleansweep.org/

[8] https://www.congress.gov/114/plaws/publ114/PLAW-114publ114.pdf

[9] van Sebille E, Wilcox C, Lebreton L, Maximenko N, Hardesty B D, van Franeker J A, Eriksen M, Siegel D, Galgani F and Law K L 2015 A global inventory of small floating plastic debris, *Environmental Research Letters*, 10 124006

[10] Woodall, L. C., Gwinnett, C., Packer, M., Thompson, R.C., Robinson, L.F., Paterson, G.L. (2015). Using a forensic science approach to minimize environmental contamination and to identify microfibres in marine sediments. *Marine Pollution Bulletin*, 95(1), 40-46; Watts, A.J.R., Urbina, M.A., Corr, S., Lewis, C., Galloway, T.S. (2015). Ingestion of Plastic Microfibers by the Crab Carcinus maenas and Its Effect on Food Consumption and Energy Balance, *Environmental Science & Technology*, 49 (24), 14597-14604.

of marine debris as being only in the ocean environment, the Great Lakes are also considered to be contaminated with plastic marine debris and not to be overlooked are inland riverine inputs.[11]

In the last decade, scientific research into marine debris, and especially plastic, has increased.[12] In 2011, a scientific working group was convened at the National Center for Ecological Analysis and Synthesis (NCEAS) led by Dr. Kara Lavender Law (Sea Education Association) and Dr. Steven Gaines (Bren School, UC-Santa Barbara). I was honored to be a part of this working group that spent three and a half years synthesizing data to describe the scale and impact of trash in ocean ecosystems. Nine scientific articles have been produced from this group describing information to date,[13] and advancing the science. The NCEAS work, along with other recent scientific work, has brought attention to the issue of plastic in the oceans further validating action at the global scale by the Global Ocean Commission, U.S. Department of State, G7, Prince of Wales Sustainability Unit and the United Nations.

Similar to RCRA in the 1970's, sound science should be used when determining solutions. Today, we have sufficient evidence to guide action to reduce inputs of plastic into the ocean. In parallel, new scientific information should be created to help us better understand the sources, sinks and impacts of plastic in our oceans.

Impacts from Plastic Marine Debris

In 1966, two U.S. Fish and Wildlife Service employees, Karl W. Kenyon and Eugene Kridler, were among the first scientists to document plastic and wildlife interactions when they discovered plastic was consumed by seabird (Albatross) chicks that had died in the Hawaiian Islands National Wildlife Refuge.[14] Since that time, many individuals of a multitude of different species of wildlife have been found to be impacted by marine debris, and especially plastic. Like in the Albatross chicks in 1966, ingestion of and entanglement of debris are the most commonly reported interactions. According to a recent summery paper, the number of marine species with reports of fatal entanglement and ingestion increased from 260 to nearly 700 in fewer than 15 years.[15] A comprehensive critical review of the literature on marine debris impacts was led by Dr. Chelsea Rochman in the NCEAS group. Of the 296 perceived threats of debris to wildlife that were tested, 83% were demonstrated (proven), and 82% of those were from

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[11] McCormick, A., Hoellein, T.J., Mason, S.A., Schluep, J., Kelly, J.J. (2014). Microplastic is an Abundant and Distinct Microbial Habitat in an Urban River, *Environmental Science & Technology*, 48 (20), 11863-11871; Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., Glas, M., Schludermann, E. (2014). The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river, *Environmental Pollution*, 188, 177-181,

[12] Ryan, P. (2015). A Brief History of Marine Litter Research, in Marine Anthropogenic Litter, Bergmann et al. (eds.), Springer, New York, NY.

[13] I reference some of them in this document, but the full list is available online here: https://www.nceas.ucsb.edu/projects/12645#

[14] Kenyon, K. W., & Kridler, E. (1969). Laysan Albatrosses swallow indigestible matter. Auk, 86, 339–343, also referenced in Ryan, P. (2015). A Brief History of Marine Litter Research, in Marine Anthropogenic Litter, Bergmann et al. (eds.), Springer, New York, NY.

[15] Hardesty, B.D., Good, T.P., Wilcox, C. (2015). Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife, *Ocean and Coastal Management*, 115: 4-9.

plastic. There is evidence of impacts to individual animals and to assemblages of organisms suggesting decision-makers should take action in order to avoid risk of "irreversible harm."[16]

Lost fishing equipment (e.g., nets and traps) can "ghost fish," or drift while continuing to catch fish and kill wildlife. This can have an impact on the fishing and shellfish industry. One study in Puget Sound alone analyzed 870 recovered "lost" gillnets and found 31,278 invertebrates (76 species), 1036 fishes (22 species), 514 birds (16 species), and 23 mammals (4 species); 56% of invertebrates, 93% of fish, and 100% of birds and mammals were dead when recovered.[17] When experts were asked which marine debris item poses the greatest risk to marine life, fishing-related gear ranked first, followed by balloons and plastic bags.[18]

Marine debris can present physical hazards to shipping, boating, fishing and industrial systems by blocking navigation, fouling boat propellers, clogging water intakes or blocking pumping systems. Coastal tourism is also affected by marine debris and other litter. In the 1980s, when medical waste was found on some beaches, communities lost millions of dollars from a decline in tourism and increased costs for beach cleanup maintenance.[19] A 2014 study by the NOAA Marine Debris Program in Orange County, CA found that 1) residents are concerned about marine debris, and it significantly influences their decisions to go to the beach, 2) No marine debris on the beach and good water quality are the two most important beach characteristics to them, and 3) Avoiding littered beaches costs Orange County residents millions of dollars each year. If the debris were reduced by just 25%, it would save residents roughly $32 million dollars in reduced travel to other beaches.[20] UNEP estimates the financial damage of plastics to marine ecosystems globally is $13 billion each year.[21]

Plastic also hosts an entire microbial community termed the "plastisphere."[22] Plastic can transport non-native species and provide habitat for microbes that might not otherwise thrive, but we don't yet know the full extent of this microbiome on ocean microbiology or the broader ocean ecosystem. Plastics in the ocean are associated with chemicals. This includes organic compounds like flame retardants, pesticides, and polychlorinated biphenyls (PCBs) that accumulate on the plastic from surrounding water. It also

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[16] Rochman, C.M., Browne, M.A., Underwood. A.J., van Franeker, J.A., Thompson, R.C., Amaral-Zettler, L.A. (2016). *Ecology*, 97(2), 302-312.

[17] Good, T.P., June, J.A., Etnier, M.A., Broadhurst, G., (2010). Derelict fishing nets in Puget Sound and the Northwest Straits: Patterns and threats to marine fauna, *Marine Pollution Bulletin*, 60(1), 39-50.

[18] Wilcox, C., Mallos, N., Leonard, G.H., Rodriguez, A., Hardesty, B.D. (2016). Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife, *Marine Policy*, 65 (2016), 107-114.

[19] NRC (National Research Council) Committee on Shipborne Wastes, Clean Ships, Clean Ports, Clean Oceans, National Academy Press, Washington D.C., 1995.

[20] Chris Leggett, Nora Scherer, Mark Curry and Ryan Bailey, Assessing the Economic Benefits of Reductions in Marine Debris: A Pilot Study of Beach Recreation in Orange County, California, Industrial Economics, Inc., for the NOAA Marine Debris Program, 2014.

[21] Raynaud, J. (2014). Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry, UNEP, Plastic Disclosure Project, Trucost.

[22] A recent summary article that references multiple scientific references on this: Samoray, C. (2016). Ocean's plastics offer a floating fortress to a mess of microbes, Science News Magazine, February 9, 2016; Zettler, E.R., Mincer, T.J., Amaral-Zettler, L.A., (2013). Life in the "Plastisphere": Microbial Communities on Plastic Marine Debris, *Environmental Science & Technology*, 47 (13), 7137-7146.

includes the additive ingredients of the plastic that can leach into the surrounding environment. Thus, plastic can transport these compounds around the world and be another potential source of contaminants to wildlife.[23] Some of the additives to plastic have come under question for toxicity[24], but we don't yet know the full impact they have on aquatic systems.[25] Still, there has been evidence of the transfer of chemicals from plastic to fish in the lab, causing liver toxicity and impacting functions of the endocrine system and to other organisms in the field.[26] Plastic particles and fibers have also been found in the stomachs of fish, and in shellfish sold for human consumption.[27]

Input into the Ocean from Mismanaged Plastic Waste

In the NCEAS group, as we started compiling information about sources and inputs of plastic into the ocean, we quickly concluded that mismanaged solid waste (trash) made up a large portion of the input. Other inputs include, but are not limited to, commercial fishing gear, shipping, recreational boating and fishing, and catastrophic events. Our first objective was to quantify mismanaged waste from land. To make the estimate of plastics entering the ocean from waste management, we developed a comprehensive framework (Figure 1).

Our methods for this estimate were to look at per person waste generation rates in 2010 from 192 countries with a coastline in the world. Because people's activities nearest the coast are responsible for most of the plastic going into the water, we limited our analysis to a 50km strip of the coastline. From there, we looked at what percent of that waste is plastic, and what percentage of that is mismanaged waste (which means litter or when waste is not captured and dumped on the land). From there we had three scenarios of input into the ocean: low, mid and high.

The results were that in 2010, we estimate that 275 million metric tons (MMT) of plastic waste was generated in 192 countries. Of that, 99.5 MMT of this waste was generated within 50km of the coastline, and 31.9 MMT was mismanaged. We then estimated that between 4.8 and 12.7 MMT (a mid-

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[23] Same as note 6. Plus, a good overview is Rochman, C. (2015). The Complex Mixture, Fate, and Toxicty of Chemicals Associated with Plastic Debris in the Marine Environment, in Marine Anthropogenic Litter, Bergmann et al. (eds.), Springer, New York, NY.

[24] For example, antimicrobial – Yueh, M. and Tukey, R.H. (2016). Triclosan: A Widespread Environmental Toxicant with Many Biological Effects, *Annual Review of Pharmacology and Toxicology*, 56: 251-272; flame retardants – Agency for Toxic Substances and Disease Registry, Toxic Substances Portal - Public Health Statement for Polybrominated Diphenyl Ethers (PBDEs), September 2004 (accessed May 11, 2016) http://www.atsdr.cdc.gov/phs/phs.asp?id=899&tid=94

[25] Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Björn, A., … Takada, H.. (2009). Transport and Release of Chemicals from Plastics to the Environment and to Wildlife. *Philosophical Transactions: Biological Sciences*, 364(1526), 2027–2045.

[26] Rochman, C.M., Hoh, E., Kurobe, T., The, S.J., (2013). Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress, *Scientific Reports* 3, No. 3263; Rochman, C.M., Kurobe, T., Flores, I., The, S.J., (2014). *Science of the Total Environment*, Vol. 493, 656-661; Jang, M., Shim, W.J., Han, G.M., Rani, M., Song, Y.K., and Hong, S. H. Styrofoam Debris as a Source of Hazardous Additives for Marine Organisms, *Environmental Science & Technology*, Article ASAP, DOI: 10.1021/acs.est.5b05485

[27] Rochman CM, Tahir A, Williams SL, et al. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports. 2015;5:14340.

scenario of 8 MMT) reached the oceans[28] (Figure 1). This annual input of plastic is equal to 5 grocery-size bags filled with plastic going into the ocean along every foot of coastline in the world. When we look at what drives the amount of plastic that goes into the ocean in this model, the biggest factor is the population density in the coastlines – the number of people generating plastic waste within 50 kilometers of the sea. Next, how much of what all those people throw away is mismanaged and accidentally ends up in the ocean?

Figure 1. Plastic Waste Inputs from Land into the Ocean in 2010

What countries you will find near the top of the list are mostly middle income countries with rapidly growing economies that have not yet been able to develop waste management systems to handle the increase in waste generation that comes along with economic growth. The U.S. is one high income country on the list, and while our waste management systems are well-designed and very effective, and the only mismanaged waste is from litter, we have a large coastal population and a large waste generation rate. If we look to the future, and assume a business as usual projection with growing populations, increasing plastic consumption and increased waste generation, but no increase in capture of waste, by 2025, the 8 million metric tons doubles – with a cumulative input by 2025 of 155 million metric tons.

[28] Jambeck, J.R., Andrady, A., Geyer, R., Narayan, R., Perryman, M., Siegler, T., Wilcox, C., Lavender Law, K., (2015). Plastic waste inputs from land into the ocean, Science, 347, p. 768-771.

As a parent, I have often filled the bathtub for my kids. Imagine doing this and getting distracted, then returning just as the tub begins overflowing. What do you do first? More than likely you would *not* start mopping and cleaning up the floor – you would turn off the faucet to stop the flow, and then address the clean-up. However, if you saw a precious item on the floor with water running towards it, you might quickly grab that item. Thus it is with plastic in the ocean. Our primary goal is to stop the flow, but there are also problematic items to also be removed now (e.g., derelict fishing gear and accumulation zones like in Alaska and Hawaii).

Once plastic is in our oceans, it becomes a global issue and poses great logistical and economic challenges to get it out. In addition, the plastic is not always visible (although we find it everywhere we look, we have only quantified a fraction in our ocean compared with what is going in), so understanding potential risk to our ecosystems requires two things: 1) understanding the impact and 2) understanding the exposure. Our recent estimate of plastic entering the oceans informs the second part – exposure, just how much plastic is going into the ocean? But it also makes us ask – where is all the plastic going? While we know action will help "turn off the faucet" of plastic input (see potential interventions, below), there are still gaps in the sources, distribution, fate and impacts of plastics in the ocean that need more research if we want to continue to move forward in addressing this issue based upon science.[29]

Interventions and Mitigation Strategies

To be effective at mitigation, we need effective communication and collaboration -- from the production of plastic, through its end of life. Imagine the flow chart below as a pipe. Right now plastic is flowing down this pipe to the ocean (which is like a black hole at this point). But we can look at the point just before it enters the ocean as our last chance. What is the concentration of plastic that we want to see there? Where limits have been set (Trash Total Maximum Daily Loads (TMDLs), for example) this is zero. Now that we have a goal, the rest of the intervention strategies can happen anywhere along that pipeline (value chain), opening up opportunities for creativity and innovation (with appropriate resources).

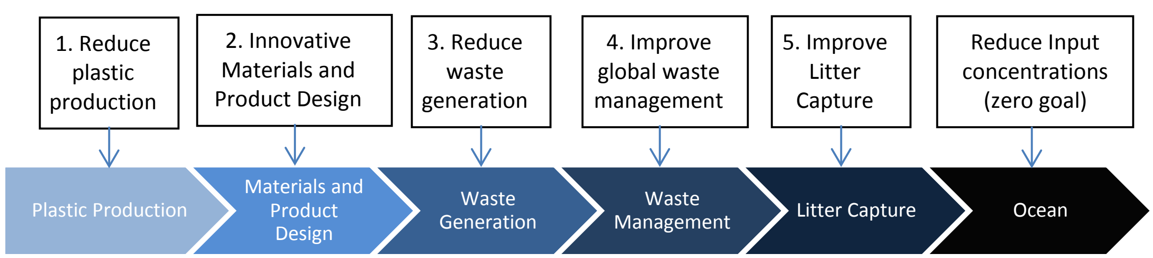

Figure 2. Intervention and Mitigation Strategies along some Points in the Plastic Value Chain

I'll now discuss some potential intervention points identified in Figure 2 in a bit more detail.

[29] A good recent review of why it is important to move forward with science –based solutions is provided in Rochman, C. (2016). Strategies for reducing ocean plastic debris should be diverse and guided by science, *Environmental Research Letters*, 11 014006.

1. Reducing plastic production

Plastic production is one of the "book ends" of the plastic value chain. Other than a few of the past 65 years, global plastic production has increased annually, and is anticipated to continue to do so into the near future. Although it comes from fossil fuels for the most part, and is produced from monomers that come from the processing of oil and natural gas, these monomers (e.g., ethylene and propylene) are used to make many different compounds, not just polymers. As long as other common chemicals are made, it is likely that polymers will continue to be made as well. And, as economies around the world continue to develop, packaged goods become more prevalent. Unless the industry changes its own course, this stage is mostly influenced if levers in other stages are pushed (e.g., demand is decreased for other reasons along the value chain).

2. Innovative Materials and Product Design

New materials development and product design take time to advance, so these activities need to be happening now – and they are, but even more time and resource investment is needed. Overall, I think Green Engineering principles,[30] if followed during material development and product design, would help to avoid many of the externalities of plastic that we are dealing with currently. In addition, circular economy concepts, emerging all over the world now, will be important to also apply to plastic materials. Both of these guiding principles promote "bio-benign" materials – non-toxic materials, ultimately with the capability of biodegrading *and* being recycled. Materials and products made with more homogenous compounds would make recycling more efficient and effective. Materials and products can be designed to retain their value, for collection, recovery and recycling. Several of these concepts are outlined in Ellen MacArthur Foundation's report on the "The New Plastic Economy: Rethinking the future of plastics," which focuses specifically on packaging.[31] The University of Georgia is combining environmental engineering and polymer chemistry in a New Materials Institute with centers on biodegradable polymers and circular materials management to develop and test materials with the intention of reducing the flow of plastic into the ocean. Capitol Hill has seen innovation in the Think Beyond Plastic Innovation Showcase on Capitol Hill (2015).[32] And as a corporate example, Lego, a company who has used the same plastic material (ABS) since its Lego bricks were created in 1932, announced a 1 billion DKK investment to establish a Sustainable Materials Center to find a replacement for ABS for their Lego bricks by 2030.[33]

3. **Reduce Waste Generation**

In places like the U.S., where we already have relatively high per person waste generation rates, we can examine methods of waste reduction. For example, some of us have the luxury of being able to make

[30] http://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/12-principles-of-green-engineering.html
[31] https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics
[32] http://www.thinkbeyondplastic.com/#!capitol-hill-event/ciyj
[33] http://www.lego.com/en-us/aboutus/news-room/2015/june/sustainable-materials-centre

choices about single use items we use daily. The majority of us have access to clean drinking water infrastructure so we can use a reusable water bottle, reusable coffee mug, bring a reusable bag to the grocery store, and say “no” to straws (or get reusable ones). These seem like small and mundane things, but what our research on plastic input showed is that since population density is such a big driver of these inputs, just one small choice, taken collectively, can make a big difference. There is a bit of a “chicken and egg” scenario here though, consumers can make choices, but they also need availability and access to those choices. For example, it might be hard to not buy bottled water if you don’t have access to a drinking fountain or water filling station. But this is also where policies regarding specific items of concern can provide motivation. Waste reduction can also occur from participation in new collaborative and sharing economies. These new paradigms are emerging and technology and social media are helping to move them forward. People are choosing to own less and “share” more. It started with car and bike shares, but has expanded to tools, and even clothing. As people become more aware of the issue of plastic in our environment, they are demanding companies reduce waste themselves, and help provide the right choices and infrastructure for people to reduce their own waste generation.

4. Improve Waste Management Globally

Improving waste management globally could go a long way to keeping a large mass of plastic out of the ocean (realizing mass is not the only meaningful metric for plastic – volume, count, shape, or impact to wildlife are other metrics). For example, in our *Science* paper the top 20 countries’ mismanaged plastic waste encompassed 83% of the total input in 2010. But with a combined strategy, in which total waste management is achieved in the 10 top-ranked countries and plastic waste generation is capped, a 77% reduction could be realized by 2025. That sounds simple. We know how to design waste management systems, but in light of the context I gave at the beginning, waste management is much more than just a design challenge, it also has social and cultural dimensions. So we need to work together at a combination of local and global initiatives, and we need global participation from various stakeholders along the entire value chain of plastic. Per person waste generation is coupled with economic development and, in many cases, the waste stream has fairly quickly changed characteristics to include more plastic. There are still many people in both the U.S. and globally that are unaware of the consequences of plastic in our aquatic environment.

Globally, innovation and creativity is needed in this space and people are heeding the call. Large, global NGOs are partnering with local groups in areas of concern to try to implement culturally appropriate mitigation strategies. Infrastructure is being integrated into existing informal waste management sectors in the hopes of continuing and improving people’s livelihoods. U.S.-based groups can help in efforts for this global problem by connecting with groups who are trying to address these issues in their own countries, and there is a lot of work to be done. Some concepts that can be drivers in this area: zero waste (reduce disposal or destruction of waste to as close to zero as possible) and product stewardship (waste management responsibility is shared or is the entire responsibility of product manufacturers). Plastic reuse and recycling can grow if the right economic structure is in place to motivate the collection of plastic waste and its reprocessing. Many local groups in global communities need some added support to elevate and expand what they are already doing to bring it to scale.

5. Litter Capture

Litter capture and collection is the last point to keep materials from entering the ocean. It is reserved for mostly the litter that occurs from inadvertent littering, lack of awareness and behavior issues. After outreach and education to prevent litter in the first place, there are street sweeping, municipal litter clean-up programs and stormwater catchment systems, all which will only be conducted in their respective jurisdictions. An innovative example of a final catchment device is the Baltimore Water Wheel.[34] Operated off of mechanical and solar energy in Baltimore Harbor, "Mr. Trash Wheel" has booms that skim the surface of the harbor and direct the floating trash to the conveyer system that removes it from the water and places it into a dumpster to be managed properly.

Non-governmental organization and volunteer cleanups to remove litter have been occurring for years. These events certainly help to keep litter from entering the ocean, and they are also a source of data. The Ocean Conservancy's International Coastal Cleanup is now in its 30th year and it not only helped to remove 96,000 tons of debris from beaches, but it has spread awareness and education as well. In 2011, my colleague Dr. Kyle Johnsen and I co-developed a mobile app called Marine Debris Tracker at the University of Georgia funded by the NOAA Marine Debris Program. The Marine Debris Tracker mobile app and citizen science program allow for the collection of global standardized data at a scale, speed, and efficiency that wasn't previously possible [35] It also spreads awareness and education about this issue wherever it is used. Individuals all over the world have helped to clean-up over 910,000 items creating 97,500 data entry points – by simply hitting a few buttons on their mobile phone to tell us what they found. User metrics provide a ranking and our largest group user is the Georgia Sea Turtle Center protecting and caring for Sea Turtles on Jekyll Island, GA and our largest individual user is in Omaha, NE (not far from the Missouri River) where he has collected over 82,000 pieces of litter alone, over the past 4.5 years. We, along with our app users, have fostered an online community through social networks – everyone is supportive of each other's efforts and individuals know that they are a part of a large global effort. There is now enough (opportunistic) data in the database to start to examine characteristics and trends based upon the spatial and temporal data provided by our extremely dedicated users.

The U.S. can be a Global Leader in Addressing this Issue

Once plastic enters the ocean, it quickly becomes a global problem. The United Nations Environment Program has been addressing this issue through the Global Partnership for Marine Litter, with resolutions anticipated out of a meeting later this month. But the U.S. should be a leader in addressing this global issue, and it has in some ways. The U.S. Department of State has worked on this issue through the G7 and Our Oceans conference. The NOAA Marine Debris Program started in 2006 with the Marine Debris Reduction Act (reauthorized in 2012) and is one of the few agencies to provide grant assistance to community groups and research. The U.S. EPA has a Trash Free Waters Program that has expanded recently in bringing in partners and pilot sites around the U.S. NOAA and the U.S. EPA (chair and vice chair, respectively) lead the Interagency Marine Debris Coordinating Committee (IMDCC), a

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[34] http://baltimorewaterfront.com/healthy-harbor/water-wheel/

[35] Jambeck, J.R., Johnsen, K. (2015). Marine Debris Tracker: Citizen-based Litter and Marine Debris Data Collection and Mapping, *Computing in Science and Engineering,* 17(4), 20-26; http://www.marinedebris.engr.uga.edu/

multi-agency body responsible for streamlining the federal government's efforts to address marine debris. Representatives meet to coordinate a comprehensive program of marine debris activities and make recommendations for research priorities, monitoring techniques, educational programs, and regulatory action. The IMDCC participants are the U.S. Army Corps of Engineers, U.S. Navy, U.S. Coast Guard, U.S. Fish and Wildlife Service, Bureau of Safety and Environmental Enforcement, Department of Justice, Environmental and Natural Resources Division, Department of State, Office of Marine Conservation, and the Marine Mammal Commission. Another group that has worked on U.S.-based marine debris issues is the National Fish and Wildlife Foundation. While U.S. scientists, universities, and research groups are at the forefront of the science of marine debris, there have only been a few research grants funded through the National Science Foundation and NOAA. Even while a multitude of domestic agencies and research groups have been working on this issue, resources are limited for addressing this issue and meeting our goals in being global leaders. Multi-agency cooperative programs could further advance the science of marine debris while also providing future economic benefits through startup companies and whole new industries.

Summary

Some key points are:

- With few exceptions, global plastic production has increased annually for 65 years and is anticipated to continue this rapid growth. 311 million metric tons of plastic were produced globally in 2014 and an estimated 8 million metric tons enter the ocean every year.
- Plastic waste continues to be an important environmental contamination issue, with implications for freshwater and soils as well as oceans and wildlife. Individual animals ingest and become entangled in plastic, and microplastic is ubiquitous and persistent in the environment. Economic impacts in contaminated areas are evident.
- Interventions and mitigation strategies can occur along the plastic value chain. They must be informed by science and be culturally appropriate. Investment in science and innovation may also spur economic growth in new industries.

As environmental engineers, we manage all solid waste that comes our way. But by connecting our activities on land with what ends up in our oceans, and through that awareness, realizing that we should be thinking about end-of-life in materials development and product design stages, we can shift the paradigm of "waste" to materials management. Also, the worldwide interest on this topic has put the spotlight on global solid waste management infrastructure needs, and so we need to collectively come up with creative, socially and culturally-appropriate mitigation strategies. Helping every nation develop waste management infrastructure to address this issue is critical. It not only keeps plastic out of the oceans, but also has large economic and public health benefits.

We hold the key to this problem in the palm of our hands. By changing the way we think about waste, designing products for their end-of-life management, valuing secondary materials, collecting, capturing and containing our waste, we can open up new jobs and opportunities for economic innovation, and in addition, improve the living conditions and health for millions of people around the world while protecting our oceans.