House Transportation and Infrastructure Subcommittee hearing on Water Resources and Environment titled "Emerging Contaminants, Forever Chemicals and More: Challenges to Water Quality, Public Health and Communities."

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Written Testimony of Captain Charles Moore, LLD

Honorable Chair DeFazio, Ranking Member Sass, and Sub Committee Chair Napolitano

Since discovering the Great Pacific Garbage Patch a quarter of a century ago, I have been warning of the threat to Water Quality, Public Health, and Communities posed by plastic; not only plastic waste, but plastic in common use by all types of consumers. It only took three generations for man-made polymers, once an exotic material, to attain ubiquity. We wear them, sit on them, drive in them, carpet our homes with them, and sleep on them. Single use and many washable face masks are made of plastic fibers. We have made plastics the packaging system for nearly all our food and nearly every product we purchase. The road to technical modernity is paved with unintended consequences, and synthetic polymers have surprised us with unwanted outcomes that are only now being studied. From space junk in orbit, to trash on the slopes of Mount Everest, down to bottles at the bottom of the deep ocean, vagrant plastics symbolize technical know-how's dirty secret: developing exciting new products and materials is profitable, but issues of safety and recovery are often externalized, becoming "someone else's problem."

Key Concepts

- We live in the Plastic Age, but there is general ignorance about the plastic materials humans use most in their daily lives.
- Plastics are polymers, meaning that single molecules called monomers are joined together by modern chemistry into long chains composed of thousands of monomers, making them Giant Molecules[1].
- The vast majority of plastics in common use do not break down through biodegradation, or any other means, fast enough to matter. Thus plastic accumulates in the environment over time[2,3]. Cracking and breaking of polymer chains by sunlight and oxidation results in the creation of microplastics (plastic smaller than 5 mm in size)[4].
- Microbeads are manufactured microplastics that have been purposely added to toothpaste and cosmetics, now largely banned through legislation[5]. The Clean Water Act regulates all plastic over 5 mm in size[6], however, most microplastics are unregulated, including fibers shed from clothing and those derived through fragmentation of larger objects.
- Manufacturers of plastic products largely divorce themselves from the issue of recovery of the material after its useful life. Collection and recovery of their

vagrant plastic waste is left to municipalities, organized and informal recyclers, non-governmental organizations and concerned citizens. Unfortunately, current efforts fail to collect millions of tons per year worldwide[7].

- Plastics are often made from harmful chemical monomers, e.g., styrene, vinyl chloride, and bisphenol A; a percentage of which is still free even after most have been chained together by polymerization. Other chemical additives give desired characteristics to consumer plastics. These mixed in monomers can and often do leach out into things touching the plastic. The diversity of plastic materials represents a serious challenge for managing and predicting the impacts of plastic on the environment[8].
- Increasing numbers of studies are documenting developmental derailments, including hormonal disruption and cancers, attributable to certain plastic monomers, e.g., bisphenol A, styrene, and plastic additives, e.g., phthalates, brominated flame retardants and nonylphenols, at environmentally relevant doses[9].
- Plastic is now recognized as constituting a “Planetary Boundary Threat,” which disrupts essential planetary systems.
- The political landscape is changing. Policy measures to combat plastic pollution are increasing rapidly at all governmental levels, national, state and local.

A Brief History of Plastic

Natural polymers, such as lignin, rubber and silk are abundant, but nature's plastics have not been implicated in persistent environmental or health issues, principally because they biodegrade. The post-World War II era has been increasingly dominated by man-made polymer materials designed to defeat oxidation and other natural decay processes. During WWII the warring nations were cut off from traditional supply routes for raw materials. This created an urgent need for ramping up production of important synthetic replacements which had been invented in the 1930's, such as nylon, polyvinyl chloride (PVC) and acrylic (polycarbonate/plexiglass). After the war, this new mass production technology would not be left idle. It would serve as an addition to the post-war economy of Keynesian consumerism, ushered in with a "Life Magazine" article from August, 1955 titled "Throw Away Living." The article included the famous photo by Peter Stackpole of a nuclear family--mom, dad and their daughter-- throwing disposable food service items into the air next to a trash can. It claimed that the modern housewife would soon be liberated from the chore of doing dishes; she would simply throw them away and buy more. A decade later, in 1967, the father figure in the movie "The Graduate" famously exhorts the young protagonist, Benjamin Braddock (Dustin Hoffman): "There's a great future in plastics." This scene is often invoked by those concerned with plastic's dark side as an example of prophesy fulfilled, but with unforeseen consequences. If an age in history is defined by the material most used by the citizens of that era, then we live in the plastic age. With the help of polymer chemists, about half of all the world's chemists, plastic production at around 3 million tons in 1970 went up a hundred fold to over 300 million tons in 2020[10].

Lack of Recovery Infrastructure

According to the Ellen MacArthur Foundation, nearly one-third of all plastics are not collected by any waste management system and end up in and on land, lakes, rivers and the ocean[11]. The quantity of plastic waste "improperly" disposed of per year worldwide by cities with an ocean coastline has been estimated at 31.9 mil metric tons[7]. Given the ominous proliferation of plastic in the environment, the question arises as to why more plastics are not recovered for reuse and recycling. There are several reasons, principal among them is that the cost to recover, clean and reprocess the used plastic exceeds, in nearly all cases, the cost of virgin plastic resin. Plastics are hydrophobic/lipophilic molecules that readily sorb (adsorb/absorb) oily contaminants that are not easily washed off. Plastics melt at low temperatures, which fail to oxidize these contaminants before becoming new plastic feedstock. For this reason, recycled plastics cannot be used in food contact applications and would require an expensive process of lining a recycled plastic container with a protective layer of virgin plastic. Furthermore, nearly all plastic products fashioned from recovered waste plastics require a significant percentage of virgin resin in order to meet specification requirements.

Due to the lack of profitability in recycling the innumerable different types of plastic, and the constant introduction of new plastics, nearly all recycled plastics are traditional resin types with a large market share, such as high density polyethylene (HDPE #2), Polyethylene terephthalate (PET #1) and Polyproylene (PP #5). Still, many of these require subsidies by government or industry in order to be profitable. State bottle bills that require a deposit are one example. The lack of take back infrastructure for unprofitable plastics is a contributing factor in the proliferation of plastic waste in the environment.

Burning and so-called “chemical recycling” that processes mixed plastics for fuel create greenhouse gasses that contribute to climate change[12]. Theoretically, chemical recycling can create a feedstock for new plastics, but this is not currently the focus of that industry, as virgin feedstocks are far less expensive.

The Planetary Boundary Threat of Plastic Pollution

Plastic pollution is crossing what is termed a planetary boundary threat[13]. Three criteria are used to determine if plastic pollution is a planetary boundary threat:

1) Is it pooly reversible?
    a. This has clearly been met. It will be impossible to remove plastic waste from most niches of the environment, e.g. deep sea[14].
2) Are there effects only visible at a planetary scale?
    a. Villarrubia-Gomez[15] states: …” the mismanagement of discarded plastic is already implicated in globally systemic alteration to food webs, habitats, and biogeochemical flows.” If it is not clear that criteria #2 has already been met, it shortly will be. In my own research, I have identified large areas of the ocean where surface plastics outweigh and in some cases outnumber the associated zooplankton[16]. The San Francisco Estuary Institute and the 5 Gyres Institute surveyed river and stream plastic inputs to San Francisco Bay. They estimated annual discharge of microplastics to the Bay via stormwater was 7 trillion.[17]

3) Is there a disruptive effect on Earth-system processes?

   a. Criteria #3: I believe there is enough evidence from widely diverse sources to make the claim that the fitness of earth's biology as a whole is negatively affected by plastics and their associated chemicals. Oceanographer Curtis Ebbesmeyer has termed ocean plastic pollution, "the greatest infection of the sea," and plastic pollution of air and fresh water threatens the circular loop of the water cycle as a clean source for drinking.

Health Effects

The volume of research in this area is growing exponentially, with new revelations of worrisome effects every year. As mentioned above, thousands of monomer molecules are linked together to produce a single giant polymer molecule, but industrial polymerization never succeeds in uniting 100% of the monomers. Three plastics in particular have been singled out because of the toxicity of their unbonded monomers: polycarbonates, polyvinyl chloride and polystyrene. The monomers of all three are ranked among the highest volume chemicals produced worldwide, each at billions of pounds annually.

Bisphenol A (BPA)

Probably no single plastic constituent has been studied as extensively or generated as much debate among scientists, industry and regulatory agencies as BPA, the key monomer in the synthesis of both polycarbonate plastics (including food packaging) and the resin lining of many food and beverage cans and water pipes. Though BPA was never used as a drug, it was first synthesized to be an oral synthetic estrogen. This came well before the discovery that reacting BPA with phosgene (a chemical warfare gas used in WWII) created polycarbonate, a clear material that is so shatter-proof that it performed well as windshield material in WWII aircraft. This welcome finding led to widespread use of polycarbonates in common non-breakable items like baby bottles, sippy cups, 5-gallon water bottles, dinnerware, medical devices, eyeglass lenses, CDs and DVDs. BPA's high production volume, estrogen mimicry and especially widespread infant exposure triggered an avalanche of research, starting with the 1997 publication of a ground-breaking finding by developmental biologist Frederick vom Saal. He discovered that feeding very low doses of BPA to pregnant mice produced prostate enlargement in male offspring[18,19]. That BPA is also widely used in thermal paper receipts, where it is free (non-polymerized) and directly adsorbed dermally while handling[20], has recently intensified concerns about the risks of exposure in adults too. The National Institute of Environmental Health Sciences defines endocrine disruptors (EDs) as chemicals that "may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife." Unraveling the ED properties of BPA has helped overturn two traditional notions in toxicology: that the dose makes the poison and that the relationship between dose and toxicity is linear. Thus, the response to low dose exposure cannot be predicted by what happens at high doses, and detrimental effects seen at low doses can be absent at high doses. Low dose exposure effects are seen in the picomolar and nanomolar ranges at which natural hormones are active. Hormonal systems are so designed that even modest changes in hormone concentrations within the low dose range can trigger significant biological effects.

BPA was among EDs selected by The Endocrine Society in a detailed 2012 explanation of how ED's exploit these sensitively engineered hormone systems. In essence, BPA and some similar molecules derail normal cellular function, organ development and behaviors, especially during fetal and neonatal periods which are specifically sensitive to chemicals that alter endocrine signaling[21,22]. Consequently, exposure in adulthood can have negligible impact at the same exposure levels which have profound effects at critical points in early development. BPA binds not only to the nuclear and membrane estrogen receptors, but also to the thyroid hormone and androgen receptors, which likely explains its many affected endpoints in animal studies: prostate, mammary gland, brain development and behavior, reproduction, immune system, cardiovascular system and metabolism. In under just two decades, the volume of laboratory studies alone numbers in the hundreds, so a complete review of all the reports of harm is not possible here. However, the changes seen in mammary gland histology and rise in mammary (breast) cancer incidence are viewed as conclusive, though there is ample evidence also that the development of the prostate gland is affected by fetal or perinatal low dose exposure.

Vinyl chloride

Polyvinyl chloride (PVC) is sometimes dubbed *the poison plastic* because of toxicities associated with all stages of its lifecycle, starting with synthesis. Its vinyl chloride monomer is made from chlorine and ethylene and is a highly flammable and explosive gas. By far, the number one use of vinyl chloride is producing PVC polymer for plastics like shower curtains, window frames, house sidings, household plumbing, garden hoses, medical tubing, carpeting, upholstery, school lunch boxes and backpacks. Many studies dating back as far as the 1930s demonstrated that even short-term exposure to vinyl chloride in laboratory animals and factory workers caused liver damage, and by the early 1970s, studies linking rare hepatic tumors (angiosarcoma) to chronic workplace exposure via inhalation or dermal contact had the attention of industry and governments[23]. Worldwide, air pollution in communities around factories using vinyl chloride also became an issue.

Styrene

The styrene monomer is the building block of polystyrene plastics. The International Agency for Research on Cancer (IARC) has determined that styrene is a possible carcinogen, and the National Toxicology Program classifies styrene as “reasonably anticipated to be a human carcinogen.” For the general public, breathing indoor air, as well as ingestion of styrene migrants into foods and beverages packaged or served in polystyrene are primary routes of exposure. For example, several studies have documented styrene contamination of hot beverages (like tea, milk and coffee) served in crystal or foamed polystyrene cups and in water bottled in polystyrene, with increasing contamination as the beverage temperature, fat content and time in the container increase[24].

Additives to Plastic Polymers

The categorical list of allowed additives is alone alarming: catalyzers, hardeners, strengtheners, softeners, flame retardants, lubricants, antioxidants, colorants, texturizers, stabilizers, UV protectors and blowing/foaming agents. Industry has multiple options within each category. Additives can be over half the mass, and the number in a finished product can easily be in the double digits, all of which are unknown to the consumer because the ingredients are deemed proprietary.

Furthermore, some products have multiple plastic parts, like baby bottles with a nipple, ring, bottle and cap, multiplying the number of additives present. Unlike a plastic's monomers, the additives are not chemically bonded to the polymer, just mixed in, and thereby free to migrate out depending on conditions the product encounters. Heating, freezing, acidity, microwaving, dishwashing, UV radiation, storage duration and impact stress are all conditions which can promote leaching out of additives. This discussion focuses on two high production volume additives associated with health hazards: phthalate plasticizers and polybrominated diphenyl ether flame retardants.

Phthalates

Phthalates are a family of esters used as softeners primarily in PVC plastics. They allow the polymer molecules to slide along one another. By weight they can comprise as much as half of the final product. Common consumer items containing phthalates include food containers and wrappers, shower curtains, raincoats, floor tiles, rubbery or squishy toys, vinyl upholstery and car interior/dash components (that *new car smell*). Plastic medical devices like infusion bags and tubing often derive their flexibility from phthalates, a concern in both adults undergoing hemodialysis and in neonatal intensive care units where exposure can be continuous for extended periods. Early life exposure in male rodents has identified a *phthalate syndrome* with many features of androgen deficiency and feminization of male reproductive development: reduced testosterone production, **decreased sperm counts**, malformations of the epididymis, seminal vesicles, vas deferens and prostate, as well as hypospadias, cryptorchidism, nipple/areolae retention and a reduced anogenital distance indicative of demasculinization of the perineum. Phthalates are also known obesogens in animal models. Exposure *in utero*, in newborns, or in adulthood all cause weight gain with increased number and size of adipocytes[25]. Because of the clear cut anti-masculine effect of early life exposure in rodents and an emerging literature documenting similar effects in humans, the U.S. Congress, in 2008, placed permanent bans on three phthalates – DEHP (di-2-ethylhexyl phthalate), DBP (dibutyl phthalate) and BBP (benzyl butyl phthalate) – and an interim ban on three others – DINP (di-isononyl phthalate), DIDP (di-isodecyl phthalate) and DnOP (di-n-octyl phthalate) – in childcare items designed for children 3 years and under that can be placed in a child's mouth: includes toys, baby bottles, sippy cup, sucking aids and teethers. The permanent ban is most restrictive as it applies to any children's toy. Similar bans on the same phthalates were enacted three years earlier in the European Union. Manufacturers of child care items are free to use any other phthalates or substitute plasticizer they deem safe, based on industry's internal assessment of safety.

Polybrominated diphenyl ethers (PBDEs)

PBDEs arose as a replacement for the legacy pollutant PCB. They are a family of flame retardants widely used in products like upholstery, textiles, bedding, televisions and electronic appliances where flammability is an issue. Because they are not chemically bonded in plastics, PBDEs migrate out into air and dust and are a worldwide environmental contaminant. PBDE levels are especially high in offices because of computers and other electronic devices. Whereas indoor air and diet are thought to be main routes of exposure for most adults, dust may be more important for toddlers because of greater hand to mouth activity. The breast milk levels of North American women indicate the highest body burden in the world, 40 times higher than the highest levels reported for Swedish women. Like PCBs, PBDEs are structurally similar to the thyroid hormone thyroxine (T_4), so it's not surprising that laboratory studies find thyroid-disrupting effects attributable to PBDEs. In 2003, California passed a bill to phase out certain PCBs by 2008. The flame retardant industry argues that the benefits accrued through saving lives by fire prevention outweigh any medical consequences. Over time, however, the cost/benefit ratio is likely to shift[26].

Key Actions and Policy Measures to Reduce Plastic Pollution

Prevention efforts work better than recovery at reducing impacts to the environment[7,27]. Cleanup cannot address the waste going into the environment today[27]. Ending waste means rethinking waste management. Waste materials are actually resources waiting to be reused. Landfills will be and are being mined for raw materials as they become scarce. Additionally, landfilling requires valuable space and is not part of a circular economy. The plastic never creates new products. We need to embrace the cradle to cradle concept and encourage the circular economy to increase the value of materials. Bans, such as the plastic bag ban in California, the Microbead-Free Waters Act of 2015 microbead ban, and local municipal Styrofoam bans have been shown to drastically reduce those types of litter from ending up in the environment. Corporate social responsibility initiatives, even volunteer ones like Operation Clean Sweep, if adhered to, result in reductions[28]. Extended Producer Responsibility measures like those proposed in the Break Free From Plastic Pollution Act of 2021 are gaining prominence based on the idea that prevention and cleanup should be subsidized by the producers most responsible for the waste. The bill has critically needed features such as a moratorium on virgin plastic production, minimum recycled plastic content, a national bottle bill and attention to environmental justice implications. We have to make sure that funds go directly to cities and counties to build the needed infrastructure. The EPR provisions of the bill have to support local decision-making. The American Recycling Infrastructure Plan (prepared by the National Recycling Coalition, Zero Waste USA and Institute for Local Self-Reliance) provides the guidelines for investments.

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