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Chemical Pollution Caused By Plastics

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ABSTRACT: Once in the marine environment, plastics can absorb chemical pollutants from surrounding waters and transport them great distances as they move around with ocean currents. When animals eat plastic, these chemical pollutants can leach into their stomachs, causing toxic effects. Many of these chemicals have been banned from production due to concerns about human and environmental health. However, some are so persistent in the environment that they are still found today. Plastic products also contain chemical additives such as flame retardants, UV stabilisers and colorants which are added to the plastics during manufacturing. In our ocean, these chemical additives can leach into surrounding waters—posing another potential chemical threat to marine life. We estimate that combined, these plastic items contribute more than 87,000 metric tons of plastic debris to our oceans and carry with them 190 metric tons of 20 different chemical additives. If plastic pollution continues to increase, this value could almost double to 370 metric tons of additives . This might not sound like very much, but these seven items account for only about 1% of the estimated 8 million metric tons of plastic entering the oceans every year!

KEYWORDS: plastic, chemical, pollution, environment, toxic, debris, additives, human health

I. INTRODUCTION

The world's mounting plastic trash crisis is hard to solve because it has many dimensions: social, technical, and economic. But because chemistry brought the problem into the world, it doesn't seem unreasonable to look to chemistry for a solution. Such a solution will require that today's chemists figure out how to undo the hard work of their predecessors. The polymers we use as plastics were designed to be durable and stable. They're difficult to break down on purpose.[1,2]Now, as the need for finding better ways to handle plastic waste grows, some researchers are finding ways to take plastics apart. Several companies have started up in the past decade to capitalize on these processes. Some methods return plastics to their monomeric form in the hope that the reclaimed building blocks might replace fossil fuels as the feedstock for new materials. Other processes yield fuels or additives for other products. Developing new recycling methods is especially important as the kinds of polymers we use have started to change. A growing number of products and applications, such as cars and wind turbines, are relying on the strength of composite materials made with fiberglass and carbon fiber. These materials use polymer resins that cannot simply be melted and re-formed like other plastics, and chemists are just starting to develop methods for recycling them in research labs.

But other researchers are thinking about recycling as they develop new materials that might not be as difficult to deal with as today's plastics. These projects could yield resins and plastics that are intrinsically easy to recycle. With such developments, it's conceivable that, one day, chemists might deliver a plastic bottle that can be reincarnated infinitely. All plastics are not equal when it comes to recycling. Polyethylene polymers are the easy-to-handle favorites. Poly(ethylene terephthalate) (PET) and high-density polyethylene are the most commonly recycled plastics in the U.S. Products made with these plastics are stamped with a recycling symbol encircling the numbers "1" and "2," respectively. When emblazoned with these numbers, called resin identification codes (RICs), plastics can be shredded, cleaned, and remade into new bottles or lower-quality materials like carpet fiber.On the other end of the scale, many curbside recycling programs don't even accept polystyrene (RIC 6), used in food packaging, packing peanuts, and disposable cutlery. Like polyethylene plastics, polystyrene waste can be processed and reused to make new products. It just doesn't happen often. "Plastic foam is troublesome for most material recovery facilities in the country," says Chris Faulkner, vice president of technology and project management at Agilyx, which has developed a chemical process to recycle polystyrene.[3,4]

A big challenge in recycling polystyrene is contamination. Actually, it's a problem for all plastics recycling; if oily molecules, water, and other contaminants make it into recycled materials, the substances can disrupt and weaken the polymers. Polystyrene clamshell containers and coffee cups are especially likely to be dirty, adding to the cost of processing them for recycling.Agilyx uses pyrolysis to break down polystyrene at its Tigard, Ore., facility, heating it in an oxygen-deprived environment so the plastics don't burn. The company can revert polystyrene back to monomeric styrene, toluene, and ethylbenzene, which is a precursor to styrene. Faulkner wouldn't share the exact details of Agilyx's process but says it can select for different products by tuning the time, temperature, and pressure of the pyrolysis process. Pyrolysis can address the polystyrene contaminant problem. Faulkner says that because the desired products vaporize as the polymer breaks down, the valuable compounds can be separated from some of the dyes, processing aids, pesticides, and food contaminants during the reaction. Later separation steps are still needed, though, he says. Agilyx started out with a more generalized process for turning plastic waste into valuable products. In 2004, then called Plas2Fuel, the company built reactors to convert mixed plastic waste into a mixed hydrocarbon product called Agilyx Synthetic Crude Oil. This mixture can be refined like natural crude oil. Agilyx had built and sold several of these systems to waste management companies across the country before the price of oil dropped in 2013, making the crude alternative less competitive with what comes out of the ground. That's when the company started getting its polystyrene recycling plant on-line. But Faulkner says with oil prices climbing again and China limiting how much plastic waste it will accept from the U.S. and other countries, Agilyx is seeing renewed interest in its oil production process.[5,6]

Other companies are hoping to turn waste plastics into valuable chemical products or feedstocks. A lot of the attention has focused on polyethylene. GreenMantra Technologies in Brantford, Ontario, employs a thermocatalytic process to turn plastic into waxes for asphalt roads and roofs, as well as additives for plastics, adhesives, and coatings. Domenic Di Mondo, vice president of technology and business development, says those products haven't typically come from recycled materials. "We're driving a circular economy and in most cases creating products with even higher value than the virgin starting material," he says.

When the company started in 2010, its first target was polyethylene. GreenMantra uses a heterogeneous thermocatalytic process to turn the plastic into different specialty chemical products. Di Mondo says the process requires lower temperatures than pyrolysis and gives the company a high degree of control over what gets produced. Di Mondo wouldn't specify what catalysts GreenMantra uses, but patent documents related to the polyethylene process describe it as using an iron- and copper-based catalyst. Di Mondo says that because the method uses a solid catalyst and no solvents and has a small physical footprint, the process can be easily scaled up. The company now processes polyethylene and polypropylene at its Brantford facility, and it plans to open a polystyrene pilot plant in 2013. But it hasn't targeted all types of plastic. Chlorine in poly(vinyl chloride) poses too many health and environmental risks for most recyclers, even the ones using mechanical recycling, and Di Mondo says GreenMantra has not focused on PET because existing recycling processes are sufficient to keep large amounts of it out of the landfill.[7,8]

II. DISCUSSION

Another class of polymers called thermosets presents a unique set of recycling challenges. Unlike thermoplastics, such as polyethylene, polystyrene, and polypropylene that can be melted and molded into new forms, thermoset polymers harden irreversibly thanks to covalent cross-linkers that bridge polymer strands. These polymers are increasingly used as resins and combined with carbon fiber or other materials to achieve tensile strength and elasticity that the polymers alone don't have.The makers of cars, planes, and wind turbine blades rely on these composite materials because of their high strength-to-weight ratio. Unlike plastic bottles, these products don't get thrown away every day. But when their lifetimes do end, a lot of thermoset-polymer-based composites get sent to landfills."We really have no way of dealing with those polymers," says Megan Robertson, a chemical engineer at the University of Houston. Jinwen Zhang, a polymer scientist at Washington State University, is one person trying to change that. He's developed mild catalytic processes to break down ester linkages in amine-cured epoxy resins, a type of thermoset that is common in composite materials. Zhang showed he could dissolve resin in carbon-fiber scraps from a major aircraft maker using a $ZnCl_2$-ethanol catalyst at 250 ºC. His group recovered carbon fibers and un-cross-linked oligomers from the resin. A scanning electron microscope showed that the fibers were still smooth, indicating that they were mostly undamaged by the process .[9,10]Although Zhang says he has licensed some of his technology to a Chinese company and has had interest from others, these methods are a long way from commercial applications. As a result, Zhang and others are working on a possibly easier path to recycling thermosets: designing new polymers with recycling in mind. Such research could save the chemists a lot of trouble trying to break down the materials when they're thrown away.

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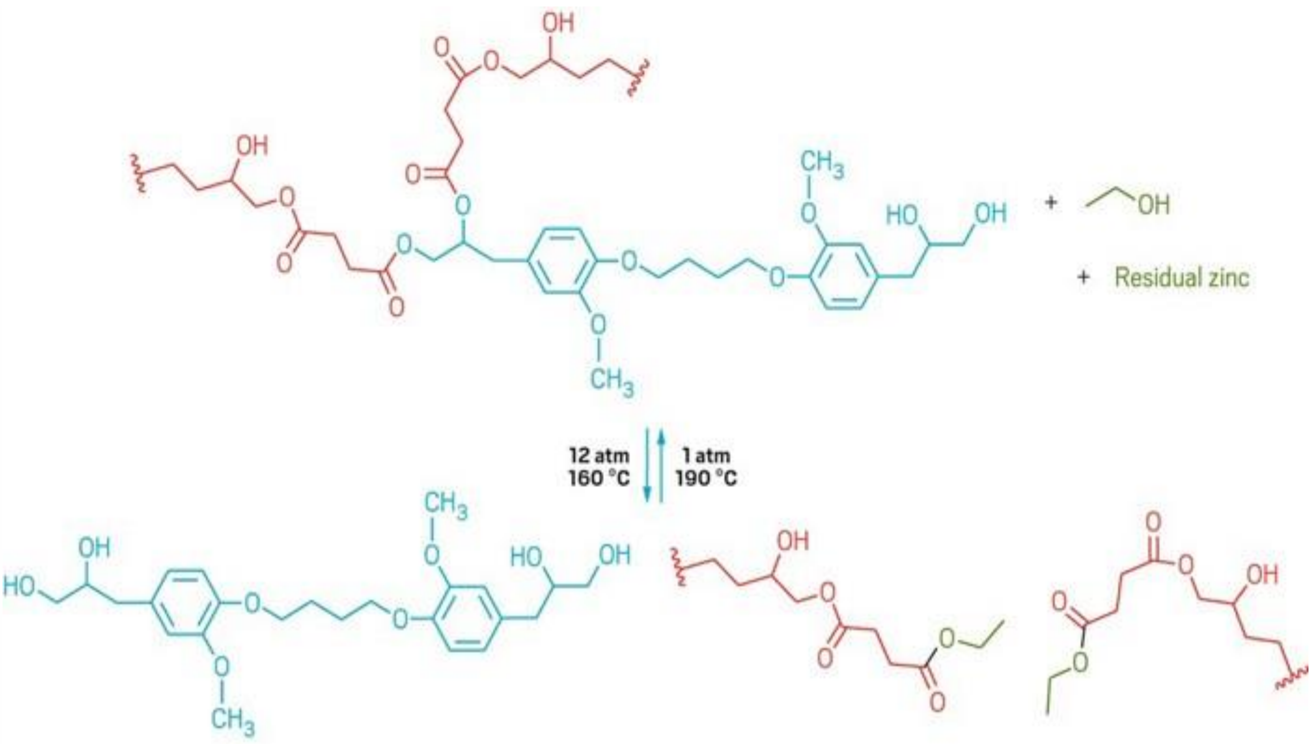
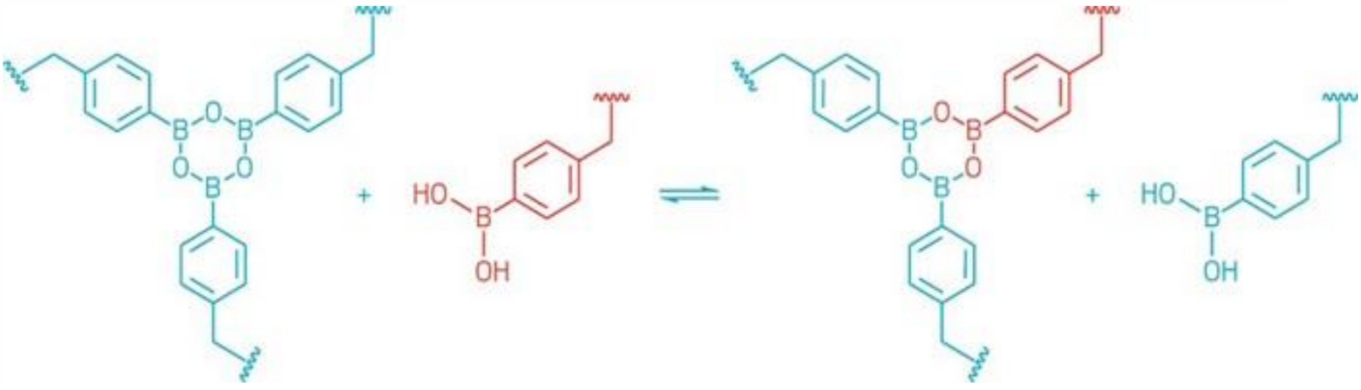


To create these new recycling-ready materials, Zhang has zeroed in on the source of thermoset stability—the cross-linkers. The materials he's making are known as vitrimers, a subset of thermosets with cross-linking bonds that form and break depending on temperature. In a way, they act like a glass, malleable at high temperatures and hardening when they cool. If manufacturers used such vitrimers as resins in composite materials, the resulting products could be recycled through mechanical processes similar to those used for thermoplastics.Zhang developed a vitrimer based on eugenol, a renewable phenylpropene found in nutmeg, cinnamon, and other plants .When heated with ethanol and some zinc catalyst left over from the polymerization process, the vitrimer breaks down at its ester linkages. Zhang says he's also experimented with lignin, which can be extracted from plants, as a vitrimer. University of Houston's Robertson has also developed recyclable thermosets by finding renewable chemicals to replace some or all of bisphenol A (BPA), which is used as an epoxy precursor in many resins. The BPA alternatives she's identified include epoxidized soybean oil, salicylic acid, and other plant derivatives. Robertson says key features she looks for in these biobased molecules are convenient functional groups for conversion to epoxides and aromatic rings to provide strength, mimicking the chemical structure of BPA Because many of these molecules contain esters, Robertson says, chemical recycling methods under development for polyesters could be applied to her thermoset polymers.[11,12]



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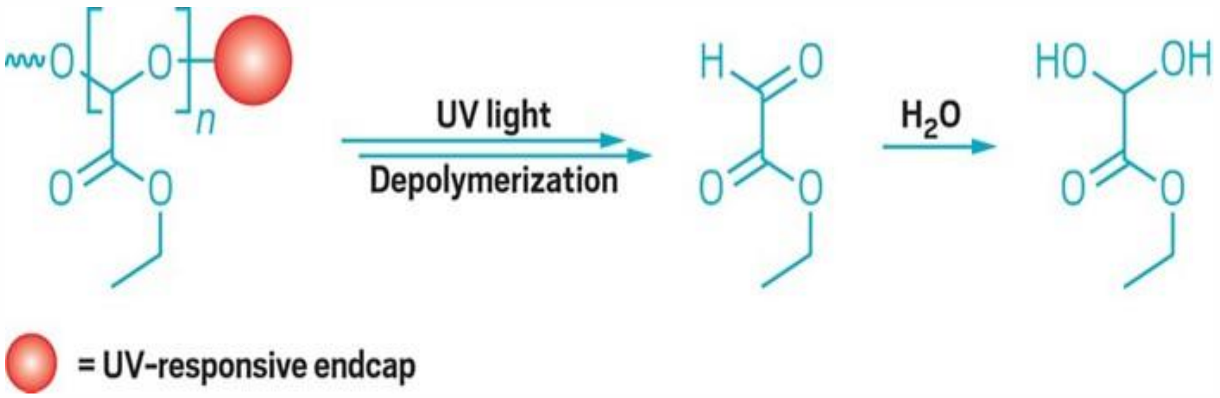
A research group at the University of California, Irvine, led by Zhibin Guan has turned to boroxine rings to produce recyclable thermosets . These rings form through reversible reactions between boronic acid groups on the monomers, a property that also allows the thermoset to be reshaped and re-formed. In boiling water, the polymer breaks down to its monomers.Researchers at IBM are also interested in chemically recyclable thermoset polymers because computers use the materials in many ways, including as insulators for electronics and in the cases that house them. Jeannette Garcia, a chemist at IBM, created poly(hexahydrotriazine), which can be converted back into its monomer with an acid catalyst that selectively hydrolyzes the hexahydrotriazine linkers .Thermoset polymers aren't the only materials that chemists are designing to be easily recycled. Some researchers have turned to the field of self-destructive, or so-called self-immolative, polymers to develop new thermoplastics. Pioneered by chemist Doron Shabat of Tel Aviv University, self-immolative polymers are inherently unstable but have an endcap that prevents their depolymerization. When triggered by light or a specific chemical, the endcap releases and triggers depolymerization. "Self-immolative polymers embody that ideal notion of how we could potentially recycle plastics," says Elizabeth Gillies, a chemist at the University of Western Ontario.[13,14]

Gillies developed an ethyl glyoxylate polymer that reverts to its monomer, ethyl glyoxylate, when the polymer's endcap is removed via light, hydrogen peroxide, or mild acid . In theory, that's an ideal system for a recyclable polymer. In reality, she says, the current versions of these polymers can't compete with the properties or cost of PET and other commercial plastics.



III. RESULTS

Scott Phillips, a chemist at Boise State University, has designed self-immolative polymers with responsive endcaps, including phenoxides and alkoxides . When these molecules get cleaved off the polymer, they liberate two electrons that then cascade down the polymer, selectively breaking off monomers.But not all recyclable thermoplastics need to rely on self-immolation. Eugene Y.-X. Chen, a chemist at Colorado State University, recently described a fully recyclable polymer with properties on par with plastics on the market right now .Chen has long focused on ring-opening reactions to synthesize polymers. "Ring-opening polymerization is a highly effective way of making high-molecular-weight polymers in a short period of time," he says. He recently reported polymerization of a strained, two-ring monomer called 3,4-T6GBL into either a linear or cyclic polymer, depending on the metal catalyst used. Using heat and a $ZnCl_2$ catalyst, Chen and his team can return the polymer to 3,4-T6GBL, a process they think can be repeated infinitely.[15,16]

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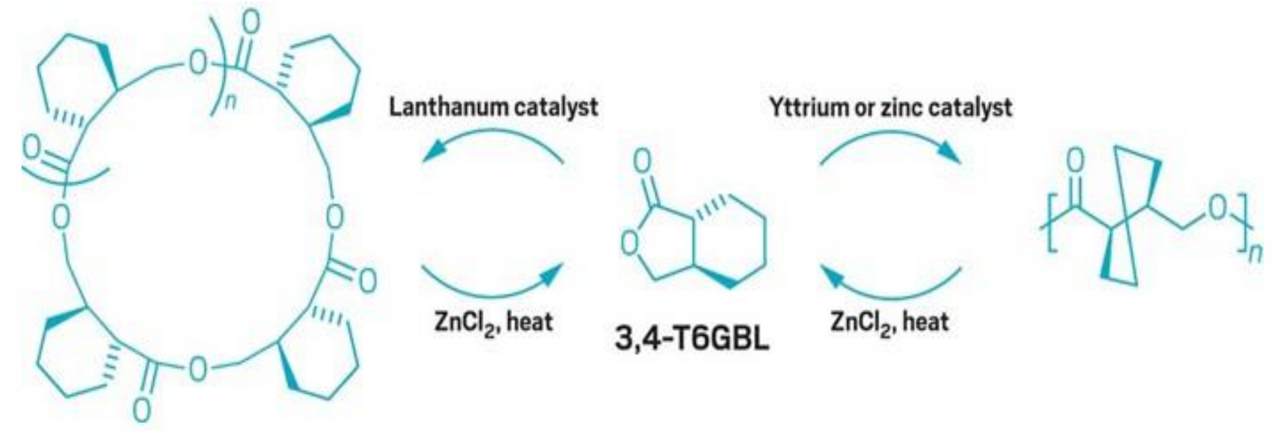

“The design of the monomer is the key for developing chemically recyclable polymers with high depolymerization selectivity and useful materials properties,” he says. Ensuring that its core structure can be chemically recycled is the first step, according to Chen. Then adding functional groups can achieve desirable physical properties.One of Chen’s former postdocs, Miao Hong, now developing her own recyclable polymers at the Shanghai Institute of Organic Chemistry, says chemically recyclable polymers are the best solution to the problem of plastic trash. Such materials could not only make possible the infinitely recyclable plastic bottle but also avoid issues of quality loss, seen with mechanical recycling, and the inability to recover valuable products from biodegradable polymers. Still, intrinsically recyclable plastics are a long way from commercial reality. Besides technical hurdles, there are also economic ones. For manufacturers, it’s usually easier to use a tried-and-true material than a brand-new one, Garcia says. Although the barrier to adoption is high, it isn’t insurmountable. So she and other chemists continue to work on chemical solutions to the rapidly growing problem of plastic trash.The distribution of plastic debris is highly variable as a result of certain factors such as wind and ocean currents, coastline geography, urban areas, and trade routes. Human population in certain areas also plays a large role in this. Plastics are more likely to be found in enclosed regions such as the Caribbean. It serves as a means of distribution of organisms to remote coasts that are not their native environments. This could potentially increase the variability and dispersal of organisms in specific areas that are less biologically diverse. Plastics can also be used as vectors for chemical contaminants such as persistent organic pollutants and heavy metals. Plastic pollution has also greatly negatively affected our environment. "The pollution is significant and widespread, with plastic debris found on even the most remote coastal areas and in every marine habitat".This information tells us about how much of a consequential change plastic pollution has made on the ocean and even the coasts.[17,18]

In January 2013 a group of scientists defined a planetary boundary for "novel entities" (pollution, including plastic pollution) and found it has already been exceeded. According to co-author Patricia Villarubia-Gómez from the Stockholm Resilience Centre, "There has been a 50-fold increase in the production of chemicals since 1950. This is projected to triple again by future". There are at least 350,000 artificial chemicals in the world. They have mostly "negative effects on planetary health". Plastic alone contain more than 10,000 chemicals and create large problems. The researchers are calling for limit on chemical production and shift to circular economy, meaning to products that can be reused and recycled.

The problem of ocean plastic debris is ubiquitous. It is estimated that 1.5–4% of global plastics production ends up in the oceans every year, mainly as a result of poor waste management infrastructure and practices combined with irresponsible attitudes to the use and disposal of plastics. The weathering of plastic debris causes its fragmentation into particles that even small marine invertebrates may ingest hence contaminating the food chain. Their small size renders them untraceable to their source and extremely difficult to remove from open ocean environments. In the marine environment, plastic pollution causes "Entanglement, toxicological effects via ingestion of plastics, suffocation, starvation, dispersal, and rafting of organisms, provision of new habitats, and introduction of invasive species are significant ecological effects with growing threats to biodiversity and trophic relationships. Degradation (changes in the ecosystem state) and modifications of marine systems are associated with loss of ecosystem services and values. Consequently, this emerging contaminant affects the socio-economic aspects through negative impacts on tourism,

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fishery, shipping, and human health".In 2013 a new report "Plastic and Climate" was published.[19,20] According to the report, in 2013, production and incineration of plastic will contribute greenhouse gases in the equivalent of 850 million tonnes of carbon dioxide (CO_2) to the atmosphere. In current trend, annual emissions from these sources will grow to 1.34 billion tonnes by 2030. By 2050 plastic could emit 56 billion tonnes of greenhouse gas emissions, as much as 14 percent of the earth's remaining carbon budget. By 2100 it will emit 260 billion tonnes, more than half of the carbon budget. Those are emission from production, transportation, incineration, but there are also releases of methane and effects on phytoplankton. Plastic pollution on land poses a threat to the plants and animals – including humans who are based on the land. Estimates of the amount of plastic concentration on land are between four and twenty three times that of the ocean. The amount of plastic poised on the land is greater and more concentrated than that in the water. Mismanaged plastic waste ranges from 60 percent in East Asia and Pacific to one percent in North America. The percentage of mismanaged plastic waste reaching the ocean annually and thus becoming plastic marine debris is between one third and one half the total mismanaged waste for that year.

In 2013 a report conducted by the Food and Agriculture Organization stated that plastic is often used in agriculture. There is more plastic in the soil that in the oceans. The presence of plastic in the environment hurt ecosystems and human health and pose a threat to food safety. Chlorinated plastic can release harmful chemicals into the surrounding soil, which can then seep into groundwater or other surrounding water sources and also the ecosystem of the world. This can cause serious harm to the species that drink the water. Plastic waste can clog storm drains, and such clogging can increase flood damage, particularly in urban areas. A buildup of plastic garbage at trash cans raises the water level upstream and may enhance the risk of urban flooding. For example, in Bangkok flood risk increases substantially because of plastic waste clogging the already overburdened sewer system.

Compounds that are used in manufacturing pollute the environment by releasing chemicals into the air and water. Some compounds that are used in plastics, such as phthalates, bisphenol A (BRA), polybrominated diphenyl ether (PBDE), are under close statute and might be very hurtful. Even though these compounds are unsafe, they have been used in the manufacturing of food packaging, medical devices, flooring materials, bottles, perfumes, cosmetics and much more. Inhalation of microplastics (MPs) have been shown to be one of the major contributors to MP uptake in humans. MPs in the form of dust particles are circulated constantly through ventilation and air conditioning systems indoors. The large dosage of these compounds are hazardous to humans, destroying the endocrine system. BRA imitates the female's hormone called estrogen. PBD destroys and causes damage to thyroid hormones, which are vital hormone glands that play a major role in the metabolism, growth and development of the human body. MPs can also have a detrimental effect on male reproductive success. MPs such as BPA can interfere with steroid biosynthesis in the male endocrine system and with early stages of spermatogenesis. MPs in men can also create oxidative stress and DNA damage in spermatozoa, causing reduced sperm viability. Although the level of exposure to these chemicals varies depending on age and geography, most humans experience simultaneous exposure to many of these chemicals. Average levels of daily exposure are below the levels deemed to be unsafe, but more research needs to be done on the effects of low dose exposure on humans. A lot is unknown on how severely humans are physically affected by these chemicals. Some of the chemicals used in plastic production can cause dermatitis upon contact with human skin. In many plastics, these toxic chemicals are only used in trace amounts, but significant testing is often required to ensure that the toxic elements are contained within the plastic by inert material or polymer. Children and women during their reproduction age are at most at risk and more prone to damaging their immune as well as their reproductive system from these hormone-disrupting chemicals. Pregnancy and nursing products such as baby bottles, pacifiers, and plastic feeding utensils place infants and children at a very high risk of exposure.[21,22]

Human health has also been negatively impacted by plastic pollution. "Almost a third of groundwater sites in the US contain BPA. BPA is harmful at very low concentrations as it interferes with our hormone and reproductive systems. This quote tells us how much of a percentage of our water is contaminated and should not be drunk on a daily basis. "At every stage of its lifecycle, plastic poses distinct risks to human health, arising from both exposure to plastic particles themselves and associated chemicals".. This quote is an intro to numerous points of why plastic is damaging to us, such as the carbon that is released when it is being made and transported which is also related to how plastic pollution harms our environment.

IV. CONCLUSIONS

Efforts to reduce the use of plastics, to promote plastic recycling and to reduce mismanaged plastic waste or plastic pollution have occurred or are ongoing. The first scientific review in the professional academic literature about global plastic pollution in general found that the rational response to the "global threat" would be "reductions in consumption of virgin plastic materials, along with internationally coordinated strategies for waste management" – such as banning export of plastic waste unless it leads to better recycling – and describes the state of knowledge about "poorly reversible" impacts which are one of the rationales for its reduction.

Some supermarkets charge their customers for plastic bags, and in some places more efficient reusable or biodegradable materials are being used in place of plastics. Some communities and businesses have put a ban on some commonly used plastic items, such as bottled water and plastic bags. Some non-governmental organizations have launched voluntary plastic reduction schemes like certificates that can be adapted by restaurants to be recognized as eco-friendly among customers.[23]

In January 2013 a "Global Alliance to End Plastic Waste" was created by companies in the plastics industry. The alliance aims to clean the environment from existing waste and increase recycling, but it does not mention reduction in plastic production as one of its targets.[23]

On 2 March 2013 in Nairobi, representatives of 175 countries pledged to create a legally binding agreement to end plastic pollution. The agreement should address the full lifecycle of plastic and propose alternatives including reusability. An Intergovernmental Negotiating Committee (INC) that should conceive the agreement was created. The agreement should facilitate the transition to a circular economy, which will reduce GHG emissions by 25%. Inger Andersen, executive director of UNEP called the decision "a triumph by planet earth over single-use plastics".Every year, 5 June is observed as World Environment Day to raise awareness and increase government action on the pressing issue. In 2013, India was host to the 43rd World Environment Day and the theme was "Beat Plastic Pollution", with a focus on single-use or disposable plastic. The Ministry of Environment, Forest, and Climate Change of India invited people to take care of their social responsibility and urged them to take up green good deeds in everyday life. Several states presented plans to ban plastic or drastically reduce their use[24]

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