thesis

Plastics are forever

Bruce C. Gibb explains why plastic isn't always fantastic.

Plastics are marvellous. There is no getting away from them. Through their intrinsic properties, plastic materials have found ubiquitous application in building and construction, electronics, automotive design, a myriad of health applications, packaging, paints and coatings, adhesives and energy production; the list goes on and on. It is hard to think of any area of life that hasn't been massively impacted by plastics; indeed, life without plastics seems unimaginable today. However, plastics have a dark side.

Since the mass production of plastics began in 1950 (when roughly 2 million metric tons were produced), there has been an 8.4% compound annual growth rate in their production[1], reaching somewhere in the region of 348 million metric tons in 2017. Globally, an estimated 8.3 billion metric tons has now been manufactured[2]. That can be subdivided into 7.3 billion metric tons of resins and additives (resinous plastics are on average 7% additives)[1], and 1 billion metric tons of fibres. Think about that for a minute. Earth's surface area is 5.10×10^8 km^2, so that's 1.6 metric tons for every square kilometre; or one small water bottle for every square metre. Put another way, at a density of 0.98 grams per cm^3 that equates to a solid plastic sphere over half a kilometre in diameter. That's no moon; it's a (plastic) space station.

And of course, the production of plastics is accelerating. Now, if all of this plastic was in the form of granny's Bakelite thermos flask that you still use and treasure, this quantity of plastic may arguably not be an issue. The problem, of course, is that this is not the case. Plastics are typically designed to have a service life of 1–50 years and by far the largest sector for plastics is short-term, single-use packaging for food, beverages, tobacco products and the like. Thus, of the ~348 million metric tons produced in 2017, ~40% was for single-use products composed of (linear) low, medium and high-density polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET). Not surprisingly, these polymers are three of the four most heavily utilized plastics, accounting for roughly two-thirds of the production of non-fibre plastics. Only the key construction material polyvinylchloride (PVC) rivals these numbers (it accounts for ~12% of the market). Polystyrene, and thermosetting polyurethane are way behind, and every other polymer you can think of or name pales into insignificance[1,3].

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So, coming up on half of all plastics used today are for single-use items. For those of us who are old enough to remember what life was like 20 or more years ago, an unfortunately uncommon refrain is, 'how did we get to this?' Take for example the ubiquitous 330 ml plastic bottle of water. Somehow, not too long ago, life went along fine without them. Now, in the US, a bottle of water is offered at every meeting as a courtesy; it can be bought on every train or offered free on every plane journey. Everywhere we go there are bottles. We take, we drink (typically only half), we throw away.

Most people don't bat an eyelid at that because we recycle; don't we? Well, no, we don't. Or to be more accurate, we're pitifully bad at it. As Jenna Jambeck and co-workers at the University of Georgia have revealed, only 9% of all plastic ever produced has been recycled; and most of that is down-cycled, that is, turned into (less recyclable) plant pots, garden furniture and other such items[4]. Instead, an estimated 60% of all plastic ever made has been simply dumped[1]; swept under the polyester carpet by a society hoodwinked into believing that everything is being done to compensate for the decadence of a throw-away plastic-bottle culture. The simple fact is that although the wealthy countries of the world have relatively advanced recycling infrastructure, they simply cannot handle the amount of plastic being thrown away. Moreover, it's just not good economic sense for wealthy countries to handle their own plastics recycling. When a boat from the Far East disgorges its cargo of fridges and televisions and has to head back to home port for more, why not fill it up with used plastic bottles? It costs next to nothing to do so.

China was the number one destination for all this plastic. The country, either directly or via Hong Kong, has imported an estimated 72% of all plastic waste[4]. But after doing this for a while it became clear to China that this was not sustainable. More than a decade ago they started implementing more rigid waste-import policies, and in the 2013 'Green Fence' program China implemented policies aimed at increasing the quality of the plastic waste it was receiving, while also reducing illegal foreign smuggling and trading[5]. Then, in 2017, China announced a permanent ban on the importing of non-industrial plastic waste[6]. At the beginning of 2018 this sent the market into turmoil, which had the positive effect of highlighting the problem with single-use plastics, but the negative effect of redirecting all of the industrialized nations' wastes either to domestic incinerators or to other Asian countries woefully unprepared for doing anything with the waste except dumping it…badly. Consider that China has a relatively advanced solid-waste management infrastructure, yet still an estimated 1.3–3.5 million metric tons of plastic enter the oceans annually from its coastline[7]. Most other countries now taking the waste are far leakier. So, the answer to the question as to where all that single-use PE, PP and PET goes is straightforward: everywhere! This is not a new revelation; the issues of plastic waste in the environment were first identified in the 1970s[8]. But it is getting worse; an estimated 4–12 million metric tons of waste plastic enter the oceans annually[7], and the total amount of plastic there is expected to double by 2025.

The oceans are not only transporters that spread plastic around the globe, but the action of waves — combined with UV degradation — means that they are grinders as well[9]. It is now estimated that 51 trillion microplastic fragments can be found on the surface of the oceans of the world[9]. As Liz Bonnin documented in the BBC documentary, 'Drowning in Plastics', flotsam and jetsam become micro-plastics (>5 mm), and micro-plastics become nano-plastics; and at both these scales they enter the food chain. For example, fresh-footed shearwater chicks are fed micro-plastics by parents and these indigestible morsels reduce the workable volume of their stomach meaning that they cannot muster the energy requirements for their first major migration. Lower down the food chain nano-plastics become key. For example, liquid scintillation counting and quantitative whole-body autoradiography reveal that ^{14}C-labelled nano-polystyrene particles (24 and 250 nm diameters) are easily taken up by scallops[10]. The fact that the end of service life was never in the design brief for plastics means that micro-plastics and nano-plastics can be found in zooplankton, mussels and walruses. Combined with the contamination of the land we walk on and the air we breathe[11,12], it's not surprising that they are now turning up in human excrement[13]. The effects of plastic waste are much broader than even this, of course. Plastic waste is also a disease carrier; it can promote microbial colonization by pathogens implicated in outbreaks of diseased corals, and hence the likelihood of disease increases from 4% to 89% when corals are in contact with plastic[14].

Sounds bad, huh? Science Advice for Policy by European Academies (SAPEA) recently published a report concluding that[15], "the best available evidence suggests that micro-plastics and nano-plastics do not pose a widespread risk to humans or the environment, except in small pockets. But that evidence is limited, and the situation could change if pollution continues at the current rate". This is all very reminiscent of the time when the first evidence of the harm of cigarette smoking emerged[16]. The ever-increasing rate of release of plastics into the environmental will surely have a multitude of detrimental effects on life much in the same way as a lifetime of cigarette smoking does. The optimistic among us should hope that we won't have to wait decades for the first Surgeon General's report on plastic, but the pessimists may disagree, and can fully expect to battle contrived opinions as to the advantages and harmlessness of single-use plastics for decades to come; as is still the case with topic such as tobacco use and climate breakdown.

What can we do about single-use plastics? As Richard Thomson at the University of Plymouth has stated, the situation is catastrophic, but not terminal. We can start to disincentivize the production of single-use plastics with taxes. The low-hanging fruit here are plastic bags, but we should realize that other less obvious plastic materials that don't so easily blow in the wind and stick in trees in city centres also present problems to society and planet Earth in general. Tax them and their use will fall. If you want 'proof' of the success of such a strategy, consider that the British Plastics federation sent a letter to Prime Minister Theresa May saying that taxing plastics is not the way forward. Equally as important, taxing single-use plastics will promote a switch to, and research into, biodegradable polymers (that unlike current ones DO degrade in oceans) as well as the development of polymers from renewable sources. Taxation should also promote more research into how to get rid of plastic materials we don't want. Rather than the common practice of incineration without energy recovery, emerging pyrolysis technologies offer the hope of extracting fuel from plastic waste efficiently[1]. As chemists we can also push for a degree of standardization and harmonization of the composition of plastics; the diversity within the market really complicates — and therefore disincentivizes — recycling processes.

Other approaches are needed to denormalize single-use plastics. Individuals can simply decline the offer of bottled water and explain why they are doing so (although if you do so these days the incredulous look you will likely receive will give you a glimmer of the scope of the challenge). More generally, individuals can just avoid as much single-use plastic as they can. They can help in beach clean-ups, they can contribute to the Marine Debris Tracker created by Jenna Jambeck and her colleague Kyle Johnsen to monitor plastics in the ocean or, if they are more ambitious, they can start small organizations such as A Plastic Planet (whose single goal is to dramatically reduce the use of conventional plastic; especially that used to package our food and drink) Choose a resolution that fits your life. Organizations can make the executive decision of banning single-use plastics; well done Trader Joes and the Glastonbury festival! And if you are an individual in a position of real power you can start thinking about the International Basel Convention governing the export of hazardous and other waste. If plastic waste were characterized as a 'waste requiring special consideration' then export could potentially be regulated[4]. Moreover, as Jambeck and colleagues have pointed out, 'the convention also provides a framework for knowledge sharing and promoting the proper management of waste, including harmonization of technical standards and practices, which could help build capacity to properly manage plastic waste around the world.'

What we should not do is make cosmetic changes, such as the banning of microbeads in… well, cosmetics. We should not throw an insignificant amount of money at research into plastics pollution in some sort of token PR-driven gesture, and we should not waste time with two-to-three-decades long voluntary commitments 'aimed' at preventing leakage of plastics into the environment. In short, as chemists we should act now. Otherwise engineers will forever be cleaning up after us chemists, and large segments of society will find another reason to bemoan and malign us. ❐

Bruce C. Gibb

Department of Chemistry at Tulane University, New Orleans, LA, USA. Twitter: @brucecgibb
e-mail: bgibb@tulane.edu

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