COMMENTARY

# The Technological Challenges of Dealing With Plastics in the Environment


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Plastic pollution has been at the forefront of national news and social media with shocking images of wildlife impacted with plastics. Plastics are found in remote places, from mountain tops to the bottom of the oceans and from the North Pole to Antarctica, and are a sign of the widespread impact of human activities. Plastics that are the most known to the public are the macroplastics (in other words, "the ones we can easily see"); because we use them on a daily basis, they are an integrative part of our life (from the grocery plastic bag to the water bottle or the parts of car or furniture) and are the ones that we consider "disposable" and of single use (like straws and plastic utensils or cups).

"And so what?" one might ask.

The problem with these plastics is that they were made to last "forever," meaning that their degradation in the environment is slow, although over the years, these macroplastics undergo weathering and break down in smaller and smaller pieces (called microplastics) that are easier to enter the foodweb. Once in these biological processes that are critical for the well-being of ecosystem functions, the effects of microplastics are still not fully understood, although they are widely accepted to be negative. This is exacerbated by the fact that it is difficult (if not impossible) to remove such microplastics from the environment. Or, at least, the technology of today to do so at such a large scale is still not ready. Hence, most of the technological innovations related to plastic targets the macroplastics only; even though this size fraction might not be the most abundant or damaging, at least, it can be removed and hence prevent its further fragmentation in the environment.

In this article, we briefly identify the technologies that are proposed to address the issues of macroplastics in the oceans, while addressing the research and policy framework of this global issue in human society.

## Plastics: Issue at Large, Making All of Us Responsible

Plastic pollution has reached some dimensions that have gone out of control. It became one of the most pressing environmental issues, as rapidly increasing production of disposable plastic products overwhelms the world's ability to deal with them. Plastic debris has become such a ubiquitous material used daily by people from all over the world that it recently prompted efforts to write a global treaty negotiated by the United Nations and is the focus of key foundations such as the Ellen McArthur Foundation pushing for new plastic economy (https://www.ellenmacarthurfoundation.org/our-work/activities/new-plastics-economy) and global commitments from a list of countries to manage the balance between environmental health and the plastic economy (https://www.ellenmacarthurfoundation.org/news/a-line-in-the-sand-ellen-macarthur-foundation-launch-global-commitment-to-eliminate-plastic-pollution-at-the-source).

## Plastics: Impact on Society and Public Health Still a Well-Kept Mystery

Despite being one of the most pervasive materials on the planet, plastic and its impact on human health is poorly understood. Yet, exposure to plastic is expanding into new areas of the environment and food chain as existing plastic products fragment into smaller particles and concentrate toxic chemicals. As plastic production increases, this exposure under different forms will only grow, and the impacts can only be speculative at this stage.

Indeed, currently, uncertainties and knowledge gaps undermine the full evaluation of health impacts but also limit the ability of consumers, communities, and regulators to make informed choices and heighten both acute and long-term health risks at all stages of the plastic lifecycle and for all stages of the lifespan of living creatures.

## Plastics: What Do We Know, and What Should We Know?

Plastic research has been booming over the past decades, and more information is now available spanning from the sources, the distribution in the environment, and also the techniques developed to assess the emerging contaminants adsorbed, leached, or produced from the polymer compounds. However, there are still some important gaps that need to be addressed to understand the global impact of this major anthropogenic pollutant.

Clearly, the techniques and environmental processes driving these contaminants depend on their size. The smaller the polymer fractions are, the more difficult it becomes to detect, extract, quantify, and qualify them. Processing time also increases as the samples get smaller.

In order, to discriminate the different detection and removal techniques, we make the distinction between three types of polymers: macroplastics, microplastics, and microfibers.

### Macroplastics: The "Popular Ones" You Can See

Large visible plastic debris (>5 mm in diameter) is defined as macroplastic. Macroplastic debris can be degraded and broken down into smaller particles, named microplastic debris, through different degradation processes such as photodegradation (ultraviolet radiations), mechanical degradation (i.e., physical stress, action of waves), oxidation, and biodegradation. Their sources are wide and include the mismanagement of plastic waste on land, sewer (sewage and storm water), beachgoers, boaters, landfills, commercial fishermen, vessels, and industrial products. Single-use plastics (SUPs), durable goods, and fishing material are the categories of macroplastic mostly found in the environment (Figure 1).

**FIGURE 1**

Macroplastic debris at Unalau Bay, Kauai, Hawaii. Photo credit: S.J. Royer.

### Microplastic: The Ones That Are Difficult to See

As of now, there is no legally internationally standardized definition for microplastics in terms of size and composition. Generally, it summarizes as being plastic particles that are small plastic debris of less than 5 mm in size. Microplastics encountered in the environment (Figure 2) can be of primary or secondary origin. Primary particles are purposefully designated as manufactured granules for further conversion processes as well as fine powders for technical applications or for addition to cosmetics. Secondary particles are derived from the disposal of macroplastic items and its subsequent breakdown mostly occurring in the environment.

### Microfibers: Anthropogenic Material Coming From Clothing

A microfiber can be considered as a very fine yarn that has a diameter that varies between 3.4 and 36.2 μm (ca. 1/5 the diameter of a human hair; Figure 3). Microfibers are often discussed as being under the umbrella of microplastics; however, it is important to recognize that microfibers are not exclusively plastic-based material and can be of natural origin (e.g., cellulose-based compounds, cotton, hemp, linen, wool) as well as modified natural material (semisynthetic), mixed (i.e., polyester and cotton), and fully synthetic (polyester, nylon, lycra, polypropylene). Overall, synthetic fibers account for approximately 60% of the total global fiber production with polyamide (nylon) and polyester (polyethylene terephthalate) as dominating fibers (McArthur Foundation; https://www.ellenmacarthurfoundation.org/our-work/activities/make-fashion-circular; https://www.

## FIGURE 2

Microplastic debris at James Campbell National Wildlife, O'ahu, Hawaii. Photo credit: S.J. Royer.

## FIGURE 3

Images of microfibers in fluorescence after sample filtration on glass fiber filter and imaged under stereoscope fluorescence microscopy (excitation 390 nm, emission >420 nm with Nikon Long Pass Filter). Stereoscope is a Nikon SMZ1500 model, equipped with a digital camera (MicroPublisher 6, Photometrics/Q-Imaging), fluorescence filter cubes setups, and Bright Field imaging settings with white light LEDs light source, as well as optical zooming. Images were acquired and managed with the QCapture-Pro software interface and not exposed to any postprocessing (images were taken at a magnification of 6× zoom). Photo credit: Deheyn Lab.

ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics-catalysing-action).

Microfibers are mostly generated from apparels and textiles and, therefore, as opposed to other plastics, originate in majority from land with access to the ocean via two routes: waterborne and airborne. The main source of microfibers released to the environment is through the washing of clothes. Indeed, washing synthetic textiles in industrial laundries and households creates primary microplastics through abrasion and shedding of fibers. A recent publication indicated that the number of fibers released from washing 6 kg of laundry could reach more than 700,000 fibers (Napper & Thompson, 2016). The fibers are then discharged in sewage water and potentially end up in the ocean (Magnusson & Norén, 2014).

Given that the majority of clothing fibers are synthetic, their degradation adds to the sources of (macro) plastics (that can degrade into microplastics) into the marine environment. Other nonpoint sources of microfibers related to the shedding of our clothing is while wearing and drying clothes in a dryer. Indeed, these microfibers are smaller than the lint retained on a dryer filter and are released directly into the atmosphere. Once airborne, these microfibers can travel worldwide until settling in remote terrestrial or aquatic environments, exposing isolated organisms to man-made synthetic materials produced far away.

Because these three categories of anthropogenic materials (macroplastics, microplastics, microfibers) are different in size, shape, material composition, and abundance, their detection and possible removal techniques need to be addressed separately for each material type. In parallel, there is also an urgent need to find alternative materials to plastics and find materials with similar properties that can fully degrade in the environment in a timely manner.

**FIGURE 4**

Manta trawl used for scooping the ocean surface and collecting plastic debris in the North Pacific Garbage Patch. Photo credit: University of Hawaii.

## Detection of Plastics in the Environment

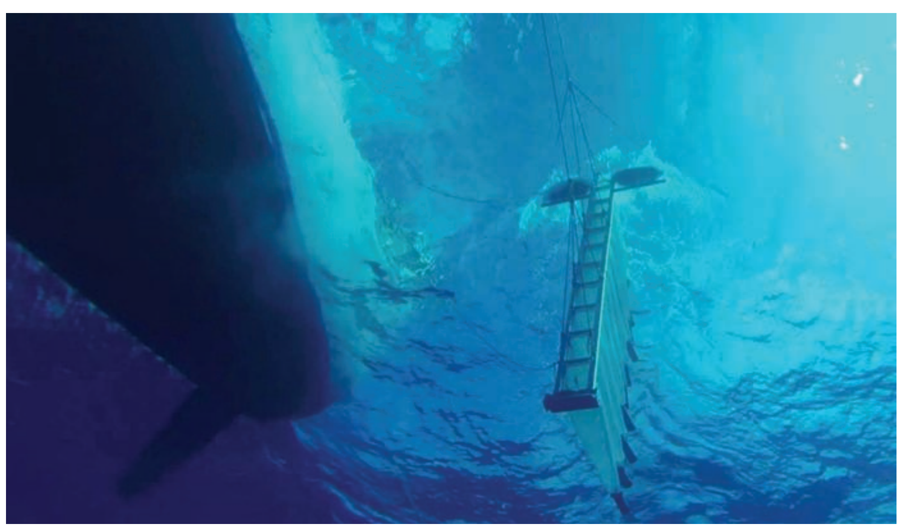
Detection techniques in the field of polymer are still embryonic compared to other fields of scientific research, and the technology used for the various types of anthropogenic materials differs depending on the nature, size, and geographical location (terrestrial vs. marine/aquatic environments) of the polymer.

*Macroplastic* items are visible to the naked eye and the easiest form to detect. The most common ways of monitoring macroplastics under oceanic conditions for polymer debris floating at the sea surface are from a research vessel through *visual surveys* and through the use of a *manta trawl*. Visual surveys are commonly conducted from designated locations onboard vessels using binoculars and for a set period of time on a daily basis. Tows using a manta trawl (Figure 4) scoop the surface water and typically last between 20 and 30 min at an average speed of 1–3 knots depending on the mesh size that varies between 100 and 500 μm (most common size mesh is 333 μm). *Unmanned aerial vehicles* are becoming common for surveying water surface and coastal regions to estimate debris concentration through imagery analysis. At a broader scale, satellite detection imagery would be the most efficient way of covering greater distances, but many challenges remain for detecting debris from space, especially when the debris are submerged in water and/or covered by a biofilm that may alter the detection signal.

Given that a large fraction of the polymer debris discarded into the environment has a density greater than seawater and sinks, new technologies are needed to get a better assessment of the concentrations found in the water column and at the seafloor level. *Multilevel trawls* (Figure 5) were designed to sample polymer debris in the first 5 m of the water column (Kooi et al., 2016) to obtain a better understanding of the buoyancy of plastic particles and the effect on its distribution. An *underwater camera* allows scientists to profile the water column and conduct image analysis for polymer quantification.

**FIGURE 5**

Multilevel trawl collecting plastic in the water column in the North Pacific Garbage Patch. Photo credit: The Ocean Cleanup.



Similarly, a *remotely operated vehicle* can capture images across the water column but also of the seafloor with the possibility of sampling. Finally, *sediment cores* (traditionally used by geologists or scientists studying the seafloor/benthos fauna) allow the collection of a large volume of sediments, sometimes combining surface layers or keeping the sediment layering intact with core depth that may contain different polymer size fractions spread across different sediment layers.

*Microplastics,* although smaller in size compared to macroplastics, can still be collected using a manta trawl, a multilevel trawl, a sediment grabber, captured using an underwater camera and a remotely operated vehicle, but will not be observed using visual and unmanned aerial vehicle surveys. Along the coastlines, the most common sampling technique is through sifting for debris collected in the sand using a density separation technique and high-vacuum system to discriminate organic matter from the polymers.

*Microfibers* are the most challenging types of anthropogenic debris to detect given their small size and the facility in contaminating the samples. Water, rain, and snow samples can be filtered using glass fiber filters (GFF) and nonsynthetic materials followed by stereomicroscopy for quantification. Given the ubiquitous nature of microfibers in air, the Coriolis bio-aerosol sampler (Bertin Technology; https://www.bertin-instruments.com/; Figure 6) shows to be the current method for quantifying airborne particles, which works for microfibers as well. Sediment/soil collection and extraction is the most tedious methodology of all where the extraction process takes many hours per sample. Ultimately, the goal is to have microfibers in solution and to filter the solution for the quantification of the fibers retained by the filter (usually a 0.45 µm GFF). This can be done optically in fluorescence (excitation 390 nm, emission >420 nm) to help detecting and quantifying the fibers (Figure 3). This is a “fast and easy” method used in the laboratory, which, however, lacks the details of providing information about the plastics material being analyzed (the chemical nature of the plastic and thus its identity). Alternatively, optical methods providing the polymer identification include Fourier-transform infrared (FTIR) and Raman spectroscopy imaging, but processing time is lengthy and may take multiple hours of analysis for one single sample as opposed to a couple of minutes for the fluorescence counterpart method. Ultimately, the choice of the analytical method used depends on the questions asked and the time and resources available for the analyses.

**FIGURE 6**

Coriolis bio-aerosol sampler from Bertin Technology collecting aerosols and microfibers in the air in Austria. Photo credit: S.J. Royer.

## Removal of Plastics From the Environment

In use, plastic does not pose a significant threat; rather, the issue arises from the by-products created from the fabrication and the disposal and degradation of plastic. Given that plastic debris has been accumulating in the environment since the 1950s (Geyer et al., 2017) and degrading due to weathering processes, its removal to avoid further negative effects is a high priority. Indeed, large efforts from all over the globe are focusing to find ways of removing plastic debris from the environment; but again, the size, the location, and the type of debris will drive the technique used.

*River/stream cleanups* (targeting mainly macroplastics) are a removal technique adopted by different non-governmental organizations (NGOs) that intend to stop the debris from reaching water systems and eventually make their way to the ocean. The River Cleanup, (https://www.river-cleanup.org/en), the Plastic Soup Foundation (https://www.plasticsoupfoundation.org/en/psf-in-action/clean-rivers/), the Royal Ecosystem (https://wasteecosystem.com/river-cleanup-processor.html), and several other NGOs also include river cleanups in their agenda. Engineering projects such as Mr. Trash Wheel (https://www.baltimorewaterfront.com/healthy-harbor/water-wheel/) in Baltimore also designed a device to harness the power of water and sunlight to collect litter and debris flowing down the river and prevent this debris from reaching the ocean. Smaller devices are also designed to be left passively in rivers and harbor to trap trash floating downstream (https://seabinproject.com/, https://rivercleaning.com/).

*Beach cleanups* are the most common technique for removing plastic debris that are either discarded from the local community or redeposited and from oceanic origin. NGOs conducting such activities are numerous worldwide and the list would be too extensive to be presented here. However, the *International Coastal Cleanup Day* (https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/volunteer/) occurring every year in September began more than 30 years ago, when communities rallied together with the common goal of collecting and documenting the trash littering their coastline, and is a platform that can regroup all NGOs worldwide.

Ocean cleanup projects, although logistically more complex, are getting more prevalent since a large part of the debris is found in the ocean. The large-scale project "The Ocean Cleanup" (https://theoceancleanup.com/) consists of a floating screen that sits at the surface of the water and traps and concentrates marine debris. The floater provides buoyancy to the system and prevents plastic from flowing over it, whereas the 3-m-deep skirt stops debris from escaping underneath. Many other ongoing projects intend to create devices to remove plastic from the open ocean, such as The Seacleaner (https://seacleaners.com/) and Ocean United (https://oceansunited.org/). These projects are usually a two-way approach, where the Phase 1 of most of these projects is to remove the debris from the ocean and the Phase 2 is to reuse this plastic, using, for example, pyrolysis technique onboard the vessels to create biofuel, or to ship the material to the closest recycling facilities on land. Effort on new technology is to minimize the transfer back to land and perform direct recycling on board of the collecting vessels, such as proposed by Freylit (http://www.freylit.com/), which consists in a Catamaran with floating flap skimmer system to remove and compact plastic waste from the sea. Similarly, Clear Blue Sea (https://www.clearbluesea.org/) develops a Floating Robot for Eliminating Debris. In contrast, Resynergi (http://www.resynergi.com/), together with the Ocean Legacy Foundation (https://oceanlegacy.ca/), developed a system where plastics can be converted into fuel (oil) by chemical microwave-assisted pyrolysis directly on the collecting vessel.

These are few of the many projects entrepreneurs and philanthropic and environmental foundations are brainstorming about, giving hope that a collective effort can be coordinated to clean up our oceans of macroplastics.

As for the microplastics, although most of the above-mentioned projects could include their removal as well, most systems are not exclusively designed for it. Microplastic-targeted projects are less common given the increase in technical and instrumental difficulties given the small size of the plastic objects. In addition, microplastics do not necessarily float and can sink to the seafloor sometimes more rapidly than macroplastics, making the collection of microplastics from sediment (instead of water) the focal effort of new technologies. Projects such as Hoola One (https://hoolaone.ageg.ca/en/the-project-2/) and, on a smaller scale, Seeds (https://seed.world/educating) are specifically designed to use the buoyancy of the floating plastic to separate microplastic from organic matter and collect only anthropogenic material.

Regarding microfibers, fashion and textile industries are important polluters, and given that 60% of our clothes are synthetic, it accounts for a major fraction of plastic found in the environment. However, the removal of the current microfibers found in the environment is practically impossible given their small size and the limitation in terms of *in situ* detection techniques. So far, it seems technologically impossible to remove microfibers from air, water, or sediment on a large-scale effort, leaving thus the idea that the focus should be rather on limiting the input of new microfibers in the environment. To that extent, Filtrol (https://filtrol.net/) has developed a filter for washing machines that has proven to capture >90% of microfibers from the washing process. More technologies will probably emerge to expand further the idea that each household should reduce its impact on the environment as opposed to reply on larger public systems (i.e., waste water plants) that get overwhelmed by numerous kinds of contaminants and cannot single out macroplastics, microplastics, and microfibers from flowing into our coastal waters. Similarly, an increasing number of industries have started to work on alternative materials to plastics that show similar material properties but are fully degradable and clearly have less environmental impact by the simple fact of decaying well into nonhazardous structures or molecules.

## Is There an Earth-Friendly Alternative to Plastics?

This might be the Gold Rush to plastic research: Can we synthesize or find in nature a material that could have properties close to those of plastics, yet showing complete degradation in the environment and therefore having lesser impact on the wildlife and humans? There are many innovations being put forward, some more disruptive than others, showing that there are material solutions, but that there needs to be compromise with the loss of certain performances (in exchange to degradability). However, these innovations are poorly talked about, often because they are confined to local/regional interests and/or because the dominant plastic industry still has the cutting edge on the public use of plastics for comfort values that have been set by the high performance of the material. Nevertheless, the alternative innovations keep on growing.

In relation to macroplastics, SUP is often the first behavioral change that comes to the mind of consumer to eliminate plastic from our daily life. SUP is an easy fix since these items can easily be replaced by alternative items. However, when it comes to durable goods, the alternatives are very limited, and also the price is often too high for the average consumer. For SUP, there are now many plastic alternatives being developed, and the following innovations are the most common plastic replacement materials.

*Plant-based plastics,* also commonly referred to as bioplastics, are made from a variety of sources such as corn, which is broken down into polylactic acid (PLA). PLA can be used to make drinking bottles, various food-grade containers, as well as films (plastic wrap for food). *Mushroom root* (Mycelium) is also used for alternative packaging items and to gather agricultural waste, which is mixed with the mycelium in molds. *Bagasse* is a byproduct of sugarcane processing, and due to its malleability and stickiness, it can be easily molded into packaging suitable for food delivery and food service, similar to polystyrene. Most bagasse items are certified biodegradable and compostable. *Seaweed water bubbles* have been created to provide the convenience of plastic bottles while limiting the environmental impact, being edible, and consisting in a water bubble made of seaweed. *Shower-friendly paper* is outer recyclable, card recyclable, compostable, glue free, and water resistant. The inner liner is made with recyclable plastic and uses 60% less material than regular plastic bottles. *Stone paper and plastic* is an innovation that has several possible packaging applications and can be used as a paper or plastic alternative, being printable, recyclable, and waterproof. It is made from calcium carbonate that has a production process using less water, has a lower carbon footprint, and is more energy efficient than regular paper production. This can be used for making paper (supermarket singlet) bags, takeaway food cartons, greaseproof paper wraps, as well as Ziplock® bags. *Palm leaves* use areca palm to create the oyster-like cases for handmade soaps. The leaves fall naturally from the areca palm and then are collected and molded into the desired shape with a final biodegradable packaging. *Corn starch and sorghum loose fill* is made from corn starch or sorghum (a crop similar to popcorn) and can be used the same way as regular polystyrene loose fill. *Edible six-pack ring* is biodegradable, compostable, and edible and made of barley and wheat remnants, which are a by-product of the brewing process. *Silberboard-metalized paper* is developed as a sustainable alternative to traditional composite metalized papers and boards and both recyclable and compostable. *Wood pulp cellophane* is the sustainable younger brother of cellophane, which is made from Forest Stewardship Council-certified wood pulp and certified biodegradable. It can be used for fresh produce and dairy, snacks, coffee, tea, chocolate, confectionery, as well as home and personal care items. *Prawn shell plastic bags* are made from chitosan from prawn and crab shells, which are usually a waste product. Although not commercialized, the material has the potential to replace plastic in packaging for food and drinks. Finally, *milk plastic* is made from casein, the protein found in milk, and combines the protein with clay and a reactive molecule (glyceraldehyde), which makes the plastic much stronger but still biodegradable. Further options to macroplastics are probably found elsewhere or will probably emerge soon. The remaining issue is to be able to scale up these innovations for the world market.

As for microplastics, especially primary origin ones (i.e., microbeads in cosmetic products), these materials can be completely removed or, for example, other natural material such as fine grain of sand (silica), sugar, or other "natural crystals" can be used as a replacement. Preproduction plastic pellets are one of the main concerns in terms of primary microplastics, and alternative products are similar to the ones above mentioned in regard to macroplastics.

With regard to microfibers, the situation is different, because microfibers have been generated for centuries as a natural product from animal fur and plant products (e.g., cotton, hemp, silk, plant fibers) and only recently (in the past 40–50 years) been replaced by synthetic fibers. The production of natural fibers is still ongoing but, of course, is more limited because it depends on plant resources as opposed to synthetic fibers that rely solely on oil-based source and associated chemistry.

One "innovation" that is several decades old already but that is gaining momentum because it is associated to the possibility of "mass production" relatively independent from any cycle of the plant source is in the cellulose-based materials, such as Tencel® or Veocel® from the Austrian company Lenzing (https://www.lenzing.com/). The products from this company are made entirely of cellulose (extracted from trees) and show biodegradability properties, while still showing attractive material properties closer to those of synthetic fibers in terms of performance, although with the added side to being natural and hence likely degradable in nonharmful products. The ability of mass production seems to become a selective criterion for any eco-friendly alternative to plastic, considering the size of the market to be able to supply.

## Conclusion

The science of plastic is booming, and although there are many aspects currently being developed and implemented for detection, analysis, and finding solutions for alternative materials, it is widely accepted that we are just at the onset of the plastic science and many more innovations are still to come. This field of science is starting to identify itself and to find its own set of standards and parameters, but more importantly its own instrumentation for fieldwork as well as laboratory analyses.

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