Agricultural Pollution
Plastics

WORLD BANK GROUP

Why Care about the Use of Plastics in Agriculture?

Although the agricultural sector is not the largest user of plastics,[1] their rapid appearance on farms the world over is quietly turning into a substantial pollution concern. Versatile and economical as they are, plastics are found all over farms. From machines to mulches, they are the stuff of bags and tubs, of tubes and tools, of tags and trays, and of pots and twine. Plastic films are used to cover greenhouses and hug plants around the root zone (see figure 9). Other kinds of plastics are used as ingredients in chemicals. Farms use millions of tons of plastics each year, costing them billions of dollars, a testament to how useful they are. To the extent that they can help to save water, dissuade pests, suppress weeds with less reliance on chemicals or fire, and save fuel by lightening equipment and containers, some of their wide-ranging benefits include ecological ones. Yet more than unsightly, discarded plastics can damage farmland and cause harm to humans and wildlife alike, making their celebrated durability a long-term pollution and public health worry.

Given the ubiquity of plastics in agriculture and beyond, it is perhaps encouraging that plastics range in toxicity, and that their drawbacks have much to do with how these are formulated, designed, used, and discarded. Collecting, landfilling, recycling, and deriving energy from agricultural plastics offer potential for mitigating some of the worst effects of discarded plastics. Yet these are far from panaceas, and both materials and process innovation are needed to slow the progression of the pollution problems to which agricultural plastics are contributing.

Nature and Magnitude of the Problem

Most agricultural plastics are single-season use and sooner or later, nearly all plastics end up in landfills, incinerators, waste-to-energy plants, or places where they were never intended to go—or remain. Used plastics can be too costly to remove from farms, and hence are left to pollute the land. Plastics are also pouring into the world's oceans. In 2010 alone, 4-12 million tons of plastic were estimated to wash offshore overall, causing greatest concern in parts of the ocean where these wastes are concentrating (up to 580,000 pieces per km^2). Yet deadly plastic masses such as the Great Pacific Garbage Patch (see figures 1 and 6)—a vortex of floating plastic waste that is twice the size of France and killing wildlife on its way[2]—represent mere islands in the sea of plastic waste that has already accumulated in the ocean.[3] Most agricultural plastics do not biodegrade (within a human lifetime), but plastics do break down in many environments, leading some to be ingested by humans and wildlife depending on how they are disposed of.

Figure 1: Plastic Debris in the Pacific

Source: © The Ocean Cleanup.

While it can be plain to recognize (as in the cases described above and others, figures 1 and 7), plastic pollution is difficult to define and even harder to estimate. It can take decades or even centuries for plastics to fully degrade, and some plastics do not degrade at all when shielded from ultraviolet radiation or the right kinds of bacteria (for example, in certain landfills). This raises the question of whether the very act of producing plastics is a form of pollution, regardless of their final destination, or whether plastics only become polluting in certain environments or forms. The latter might include when they enter bodies of water, break down and are ingested, or are burnt and their uncontrolled emissions inhaled. Limited data on the production, use, and disposal of agricultural plastics are available in the public domain, meanwhile, making it difficult to draw boundaries on the nature or magnitude of this global pollution problem.

Data on the broader plastics market help to put figures on agricultural plastics in perspective, but also

1 Agricultural uses accounted for around 3.4 percent of the plastic use in the European Union (EU) in 2014.
2 Countless seabirds, turtles, and marine mammals die from getting entangled in plastic each year.
3 At least 250,000 tons (Eriksen et al. 2014). At the current, estimated rate of plastic refusal (from all sources), oceans will carry about 1 kg of plastic for every 3 kg of fish by 2025, and more plastics than fish by weight by 2050 (World Economic Forum 2016).

This note was written by Emilie Cassou. Full references and acknowledgments are available online.

Figure 2: Plastic Films Headed for Burning in the Republic of Korea

Source: © Joshua Kraemer.
Note: Agricultural plastics commonly used to form greenhouses in the Republic of Korea are burned by farmers once worn out, contributing to dioxin contamination.

project a trend of rapidly rising use (especially in emerging economies). Global plastics production has risen exponentially since the 1950s, rising twentyfold in 50 years from 15 million tons in 1964 to over 311 million tons of plastics in 2014.[4] China was the leading producer that year (at around 26 percent), followed by the EU and the United States (around 20 percent each), and quickly gaining ground.

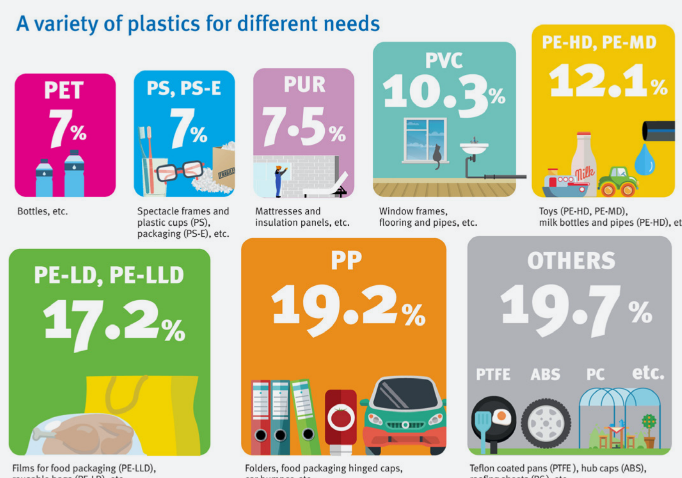
Turning to the sparse figures available on agricultural plastics specifically, in the EU, demand for agricultural plastics was estimated at around 3.4 percent of overall plastics demand, or 1.6 million tons of agricultural plastics in 2015,[5] not including plastics used in packaging or vehicles (which are tallied separately). At that level, if EU demand for agricultural plastics hypothetically accounted for 15–20 percent of the global demand, this would place the global demand for agricultural plastics around 8–10 million tons. Separately, the global agricultural market for plastic films alone was valued at US$5.87 billion as of 2012, corresponding to over 4 million tons sold, and was expected to nearly double by the end of the decade by an industry analyst's estimate (2013). China now has the largest agricultural area under plastic films in the world because of its rapid expansion into fruit and vegetable production—a response to dietary diversification there and abroad. Plastics have notably enabled that expansion to occur in cold and dry climates. The area under plastic cover in China grew more than 150-fold between 1982 and 2014, when it reached over

Box 1: What Are Plastics?

Plastics encompass a wide range of synthetic and naturally occurring substances that are capable of flow, at which point they can be molded, extruded, cast, spun, or applied as coating. Synthetic plastics, also known as plastic resins, refer to several dozen families of organic high polymers, which are large, chainlike molecules that contain carbon. Polymers are formed by causing short-chain hydrocarbon molecules, or monomers, to bond though a process known as polymerization. These monomers are typically oil- or gas-derived, though bioplastics are derived from alternatives to fossil fuels such as vegetable fats and oils, plant starch, and microbiota. The first synthetic polymer was derived at the turn of the 20th century, and during the 1940s and 1950s, the mass production of synthetic plastics began in earnest.

Plastics are broadly appreciated for being low-cost, lightweight, strong, durable, resistant to corrosion, and nonconductors of electricity. Yet plastics are extremely diverse and versatile (figure 3). There are several dozen families of resins, each of which counts a vast array of grades, varieties, and characteristics. Two broad categories of plastics that are commonly recognized are thermosets, which cannot return to their original form once cooled and hardened, and thermoplastics, which soften when heated and can be reshaped to form fibers, packaging material, and films. Both are found across a multiplicity of applications on farms. Widely used resins in packaging and films include polyethylene terephthalate (PET), high density polyethylene (HDPE) used for chemical containers, vinyl (polyvinyl chloride [PVC] used to make breathable film), low density polyethylene (LDPE), which is clear and flexible, polypropylene (PP), and polystyrene (PS).

Figure 3: European Plastics Demand by Polymer Type, 2014



Source: © PlasticsEurope, Consultic, myCeppi.
Note: EU-28 + Norway and Switzerland.

4 Not all resins are counted in this tally by PlasticsEurope. Includes plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings, and sealants). Does not include the following fibers: PET, Polyamide (PA), PP, and polyacryl fibers.

5 Of 46.3 million tons overall, counting plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings, and sealants), but excluding PET, PA, PP, and polyacryl fibers. Source: PlasticsEurope.

Figure 4: The Spread of Plastic Mulch in China, 1991, 2001, 2011

Source: *China Rural Statistical Yearbook* for 1992, 2002, 2012.
Note: Red, orange, and yellow shading indicate the most intensive use of agricultural plastics in kilograms per hectare.

18 million hectares, or roughly half the area of the Netherlands (see increasing intensity in figure 4).

Looking to plastics' end-of-life, an estimated 275 million tons of plastics waste was generated in 2010,[6] and over 60 percent of that waste is thought to have originated from plastic packaging, which is primarily designed for single use. Globally, plastic waste accounts for over 10 percent of landfilled waste by mass. Plastics disposal varies widely by region and country, however. In the EU, of nearly 26 million tons of plastic that reached the waste stream in 2014, most went to energy recovery (nearly 40 percent) while nearly equal shares (of around 30 percent) were recycled and landfilled. That said, landfilling remains the number one destination for plastic waste and the destination for more than half of it in many European countries. China and Indonesia, meanwhile, were the leading sources of plastic leakage—making them the largest contributors to the 4.8 to 12.7 million tons of plastic waste estimated to be entering the ocean each year (as of 2010, see figure 5). While the final destination of agricultural plastics is rather opaque, recycling seems to be limited (possibly around 10 percent in the United States) and complicated by the presence of pesticide, soil, and hay residues, as well as the low recycling value of materials such as plastic films. In the United States, farms that use black plastic systems generate 18–22 kg of plastic waste per hectare, and this waste typically goes to landfills.

Impacts

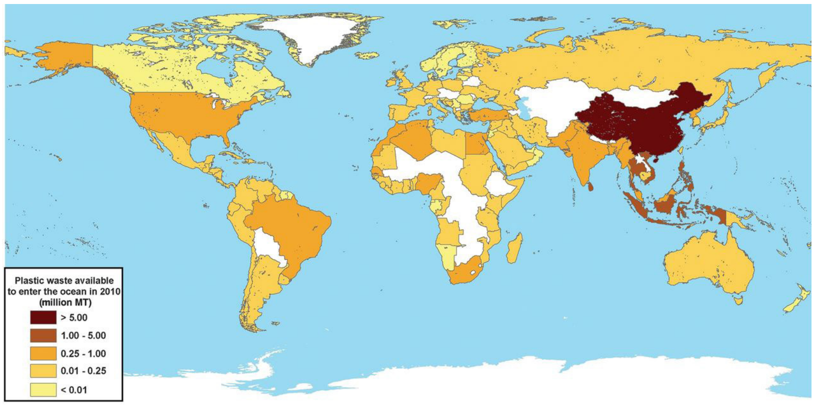
The impact of plastics pollution is not only related to their composition and form, but also critically with their life cycle from manufacture to disposal, and with exposure to these. That said, and notwithstanding their tremendous versatility and usefulness, the actual use and fate of many agricultural plastics is evidently not without harm. Many plastic substances are endocrine-disrupting, and some are carcinogenic and harmful to the nervous and immune system, resulting in their unintended ingestion posing a risk to humans and wildlife alike. These risks often originate at the time of manufacture, when a range of chemicals including plasticizers, flame retardants, stabilizers, antimicrobials, and antioxidants are used to give plastics their unique properties or to enhance their performance. Common additives such as bisphenol A (BPA), phthalates, and polybrominated diphenyl ethers (PBDE), for example, are known for their potential to act like a hormone in the body and may increase cancer and other risks.

One issue is that these substances can leach into soils and the environment. In China, the use of plastic agricultural films may be one of the main sources for phthalic acid ester contamination in agricultural soils, with concentrations rising roughly one-and-a-half to threefold in soils under greenhouses or directly covered by films. Uncontrolled emissions from the combustion of plastics can also be acutely toxic, carcinogenic, and endocrine-disrupting when inhaled. Burning has, for example, been a common fate of plastic greenhouse covers in the Republic of Korea (see figure 2).[7] Although emissions vary by substance, burning plastics can emit a range of gases and fine particles, including persistent, bioaccumulative pollutants such as dioxins, mercury, polychlorinated biphenyls (PCBs), and furans.

Whether or not plastics are burnt, a key concern from a health perspective comes from the tendency for plastics to bioaccumulate within organisms and to concentrate up the food chain. This makes the ingestion of plastics by animals and wildlife a (toxicological) concern not only to the species that are directly affected, but also to higher trophic ones. The ingestion of plastics by marine life is a potential risk to consumers of fish products, for

6 Because it is from a different source and may correspond to a different definition of plastics, this figure cannot be compared directly to the amount of plastic produced.
7 At least as of 2013.

Figure 5: Plastic Waste Leakage 2010



Source: Jambeck et al. 2015. Permission required for reuse.
Note: Mismanaged plastic waste generated within 50 km of the coast. Countries in white were not included in the study.

Figure 6: A Mississippi River Fish (U.S.)

Source: © Marcus Eriksen.
Note: Plastic found inside a fish caught in the Mississippi River, United States.

instance. And some animal species have been found to suffer organ damage from leaching toxins.

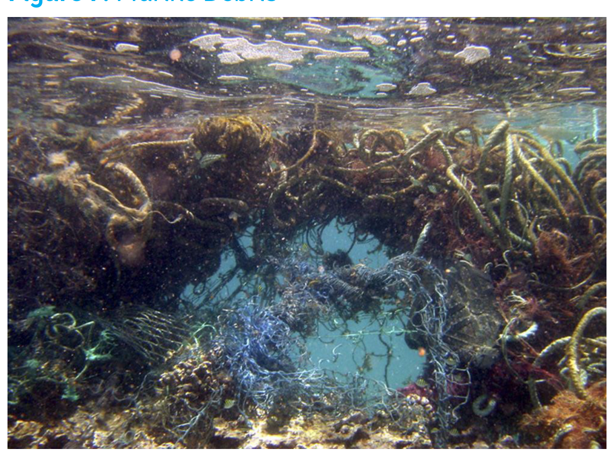
Plastics can also cause mechanical harm to wildlife that come into direct contact with them. Plastics can lead to internal abrasions and gut blockages when ingested (see figure 6). And when they form heaps of debris in which animals get entangled (see figure 7), they can result in injury and death. Far from being hypothetical, these effects are known to be widespread phenomena as a result of the substantial volumes of plastic waste that can now be found from populated coastlines to remote ecosystems and the deep sea. A full 90 percent of seabirds may be ingesting plastics today, by a 2015 study estimate (Wilcox, Van Sebille, and Hardesty). In addition, when plastics form dense patches in bodies of water, the algae and plankton that lie in their shadow (and on which lower trophic species feed) can lack the sunlight they need to photosynthesize, and this too can have ramifications up the food chain.

Notwithstanding the range of technologies plastics makes possible or more affordable, and the far-reaching benefits they provide, they can also have some undesirable effects on farms. For example, a flipside of the sought-out warming effect plastics can have on soils—which helps farmers to manage crop seasonality—is that it can disrupt soil biota (privileging bacteria over fungi), with potentially undesirable effects on soil fertility over time. And while the impervious quality of plastic films makes them useful for retaining fertilizer and moisture in soils, it can also increase runoff volumes (by 40 percent), concentrate agro-chemical loads in field runoff, and accelerate erosion (by 80 percent). Because many plastics used in farming have to be purchased commercially each growing season, these can represent a substantial monetary expenditure for farms. Black plastic ground coverings, for example, cost U.S. farmers around US$100–120 for the material, and another US$8 for disposal, per hectare. A 2014 Rodale Institute study concludes that, although black plastic is allowed within organic agriculture, it is "inherently unsustainable."

Drivers

One draw of plastics is that they can help save water—as when they are used for drip irrigation tape or as a protective soil cover (see figures 8 and 9). In addition to retaining soil moisture, plastic films, as previously noted, can help keep fertilizer on the field when it rains, suppress weeds, dissuade pests, and retain or deflect heat, thus helping farmers to manage the vagaries of weather and pests, and even extend the growing season. Plastics are very useful to farmers, or are at least perceived to be. While they represent a recurring expense that farmers would rather avoid, they are generally seen as a worthwhile cost of doing business—one that allows them to produce more and higher quality products, and to save time and money. In China, plastics (especially films and drip irrigation tubing) have played a central role in allowing fruit and vegetable production to expand in dryland areas. They have also enabled significant (approxi-

Figure 7: Marine Debris



Source: © Ray Boland, National Oceanic and Atmospheric Administration.

Figure 8: Drip Irrigation, a Water-Saving Technology

Source: © Dripndrip.com.

Figure 9: Plastic Mulch

Source: © Fotolia / Chungking.

mately 30 percent) gains in cotton and maize yields.

Meanwhile, the repercussions of using plastics are diverse, diffuse, hidden, and of little direct consequence for farmers, such that little attention is paid to the aggregate environmental and health effects of plastics use on an industry-scale. Even where awareness exists, the underdevelopment of waste collection infrastructure and services in many parts of the world represents a hurdle when it comes to disposing of plastics more safely. These and other benefits are touted in commercial advertising as well as in public extension messaging[8] and no doubt reinforced through peer-to-peer learning. In addition, while some uses of plastics mainly offer a cost advantage over alternatives (that is, more traditional materials), other plastics offer functionality that other materials do not currently offer (at least not affordably).

What Can Be Done?

Conceptually, the major avenues for mitigating plastics pollution involve improving how plastics are managed once they enter the waste stream or even further upstream during their useful life; reducing how much is produced, used, or enters the waste stream to begin with; lessening their intrinsic potential to cause harm; and cleaning up after the fact.[9] The following represent ways to pursue some of these.

Recycling. Recycling is one approach to reducing how much new plastic is produced and how much enters the waste stream. Plastics have been recycled for decades, and a milestone in that regard was the creation and wide adoption of the Resin Identification Coding System (RIC).10 In the farming context, however, recycling can be impractical and represent a net financial or time burden for farm operators—issues that agricultural universities such as Cornell are working to tackle. The plastic materials used in fields are often an unidentified mix of different resins and additives and may be too low in value to warrant recycling. In addition to being dispersed in space and bulky, plastic films tend to get embedded in soils and can require special machinery to rid them of moisture, grit, weed seeds, and soil pathogens. Twine can require hand cleaning to strip off hay and grit, though equipment is being developed to tackle these sorts of challenges. Pesticide containers can require special treatment to scrub off toxic residues, the presence of which precludes certain reuses of these, regardless. More generally, the energy, water, and other resources it takes to recycle plastics can, in some cases, negate its environmental benefits. Nonetheless, agricultural plastics recyclers are open for business (see figures 10 and 11).

Waste-to-energy. Conceptually similar to recycling, waste-to-energy involves turning plastics into fuel or directly into energy (through gasification using pyrolysis and incineration, respectively). As with recycling, however, its effectiveness can be limited by collection challenges upstream. Furthermore, its environmental benefit is not unequivocal, as it requires that energy derived in either process displace existing and dirtier sources of energy. This generally implies the use of advanced (and costly) emission control technology. Waste-to-energy may make the most economic sense in situations of high waste density, a condition that is probably not met by most agricultural operations, thus limiting the relevance of this approach for dealing with agricultural plastics waste. The conversion of plastics to refuse-derived fuel (RDF) for use in manufacturing (for example, to replace coal in cement production) may be an option

8 An example of the bona fide promotion of plasticulture by an extension service can be found here: https://content.ces.ncsu.edu/plasticulture-for-commercial-vegetables.

9 Cleaning up plastics waste is beyond the scope of this note. Notably, however, the efforts of one organization (The Ocean Cleanup) to deploy a 100 km trash collection system in the Pacific Ocean have drawn attention from both skeptics as well as hopeful scientists and financiers (see figure 14). Soils can be remedied through various processes such as degradation, phytoremediation, and adsorption.

10 Originally developed by the Society of the Plastics Industry in 1988, the RIC has been administered by the standards organization ASTM International, since 2008.

Figure 10: Silage Wrap

Source: © RC Baker Ltd. (recycling company).

Figure 11: Film Recycling

Source: © Film-recycling.com.

in low waste density situations, though only with plastics of high residual value—hence, probably not with the plastic films used in fields. That said, technical innovation may be starting to turn these limitations around.[11]

Materials innovation/biodegradable plastics. Thanks to materials innovation, certain plastics can be made biodegradable, thus lessening the likelihood that they will persist for a very long term in their plastic state, as they have the potential to be composted or to photodegrade (or to otherwise degrade). Notably, while bioplastics contain at least some portion of plant-derived cellulose or chitin, other biodegradable plastics are fossil fuel-derived plastics which contain additives that can accelerate their decomposition under the right conditions. Materials such as these offer important potential to reduce plastic waste (see figure 12), though they also present limitations. Biodegradable plastics can be a nuisance for recyclers if they are mixed with other plastics, and can require special conditions such as commercial composting facilities to actually biodegrade. Depending on where they end up, they may not fully decompose or may decompose anaerobically, generating emissions of the greenhouse gas methane. In addition, bioplastics raise a different set of sustainability concerns (pollution, climate, and food security) related to the production and use of their feedstock—though less so when agricultural residues are what is being recycled into plastic. From a toxicological standpoint, biodegradable plastics may also have some of the less desirable (for example, endocrine-disrupting) effects of conventional plastics.

Product and process innovation. Both product and process innovation can go a long way toward increasing the life of plastics both on and off the farm (that is, their durability or potential for reuse), improving their recyclability (for example, ease of collection and cleaning), or avoiding the need for plastics altogether, thus reducing how much plastic and plastic waste are generated. Bans on the open burning of plastics in U.S. states have reportedly driven some progress in the design of more durable farm products, such as plastic covers that can be used for two or more crops before being replaced or more durable greenhouse structures. Plastics pollution is very much a design challenge and certain actors such as the nonprofit Enviu are treating it as such with initiatives such as the Plastic Fantastic Challenge that aim to mobilize and support the private sector to devise new solutions (with a focus on plastics in general). In the agricultural context, while some innovations focus on smarter uses of plastics, others involve alternative materials, packaged with new technologies or protocols that address cost and convenience. In the first category, Cornell University for instance, has developed farm-level best practices to improve the recyclability of agricul-

Figure 12: Biodegrading Plastic Mulch

Source: © J. Moore-Kucera, Texas Tech University.
Note: Samples of bioTELO® starch-based plastic mulch recovered after being buried in soil for 24 months.

11 The venture-backed company Agilyx , for example, claims to have developed a system to "convert previously non-recyclable and low value waste plastics into crude oil through a patented system that is environmentally beneficial."

Figure 13: Roller-Crimper Pulled by Horse and Tractor

Source: © Yokako Roots Farm (above); © Erin Silva (below).

tural plastics. In the second, the Rodale Institute has for example developed a versatile roller-crimper device and protocols designed to help farmers profitably rely on cover-crop mulch systems to achieve similar results as plastics-based systems without the drawbacks (see figure 13).

Improved collection and waste management. The leakage of plastics into the environment can be stemmed by expanding collection, improving waste transport systems to reduce illegal dumping, and closing or upgrading dumping sites located near waterways. When plastic waste is not collected, it is more than twice as likely to leak into the ocean—not to say that collection stems all leakage. Low rates of plastic collection are a major problem, particularly in emerging economies.

Forms of support. Public sector support for the above can take on a great many forms. The following are illustrative.

- At the highest level, government can advocate for sustainable farming practices and efforts to develop a closed-cycle economy.
- It can fund scientific, materials, and farm management research that contributes to the development of safer and more readily reused or recycled plastics, or plastic alternatives.
- Through support to extension services and other information channels, it can contribute to raising consumer and farmer awareness of and ability to address the challenges of plastics use. In the United States, state funding has allowed agricultural universities such as Cornell to develop knowledge and research platforms that support smarter uses of agricultural plastics and recycling. Funded by the State of Florida, the Southern Waste Information Exchange facilitates recycling by connecting plastics users to recyclers.
- To the extent that the public sector is involved in the development of sustainability certification standards (for example, organic certification in the United States and Tunisia), it can assess the environmental aspects of plastics use and disposal and shape or influence standards accordingly.
- To the extent that government also procures farm products more or less directly, it can also use its consumer power to shape and influence farming practices. The adjustment of standards allows the market to pay premiums to those who meet them, and may contribute to shifting social norms—or what is considered accepted—when it comes to plastics use.
- In its capacity as regulator, the public sector can, with adequate enforcement tools, put a stop to the open burning of plastics, or establish rules on the disposal of plastics.
- Government can invest in waste collection infrastructure and services, and in its procurement capacity, it can set standards on waste management services contracted from private sector vendors.
- To stimulate the materials and process innovation generally, government can provide selective support to entrepreneurs and business ventures that attempt to develop business solutions to the public, environmental challenges posed by rampant plastics use.

Figure 14: Reality within Reach or Distant Dream?

Source: © Erwin Zwart / The Ocean Cleanup.
Note: Rendering of the Waste Collection System that The Ocean Cleanup hopes to deploy in the Pacific Ocean in 2020.