Marine plastic pollution: A review of its sources, distribution, impacts and our actions

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Abstract With the high-speed development of plastic industry, most of waste plastic have entered the marine environment, causing a huge threat to animals and humans. This review discusses this significant topic from five aspects. Firstly, it gives a brief introduction of marine plastic pollution from the extensiveness and severity. Secondly, it summarizes the sources, distribution and changes about the plastic debris in marine environment. Thirdly, this review analyzes the impacts from marine plastic pollution on aquatic animals and humans by integrating some toxicology researches. For the fourth part, a general picture about how human beings try to prevent the plastic pollution using their creative ideas and strength is illustrated in detail. At last, a sketch outlook and prediction about future is given, with the hope of embracing the plastic-free life.

Key words Marine pollution, Plastic debris, Sources, distribution, Health impacts, Actions

1. Introduction

Plastic industry has been flourishing since the plastic came out approximately 200 years ago. According to the statistics, in 1950s the world produced only 2 million tons plastics products per year, however in 2015, the annul number reaches up to 381 million tons with a nearly 200-fold increase. (**Figure 1**) **[1]**The sharp contract reminds us our more and more powerful capacity of plastic production.

Every year a large number of plastics are used by our humans and become scrap just in a short life span, which counts a lot in our daily waste. Most of them are dumped or poured into rivers and reach the oceans at last in the form of micro debris. It is estimated that every year， there are 8 million tons (about 3% of global annual plastics waste) of plastic enter the ocean.

In the marine environment, plastics are an unmissable source of pollution because of it is hard to be degraded naturally and can become very small. On one hand, depending on the types, plastics can take between a few decades to potentially hundreds of years to disintegrate in landfill (in other words nearly all the plastic ever created still exists in some form today), on the other hand, most of plastic waste will be broken into microplastic pieces in the ocean and these fragments’ size is often less than 5 mm in length. These two characters determine the difficulty of the solution to marine plastic pollution.

At the same time, plastics are a dangerous threat for many marine animals and they can even impact our health by food chains in the long term, which means the actions are necessary and there is no time to delay.

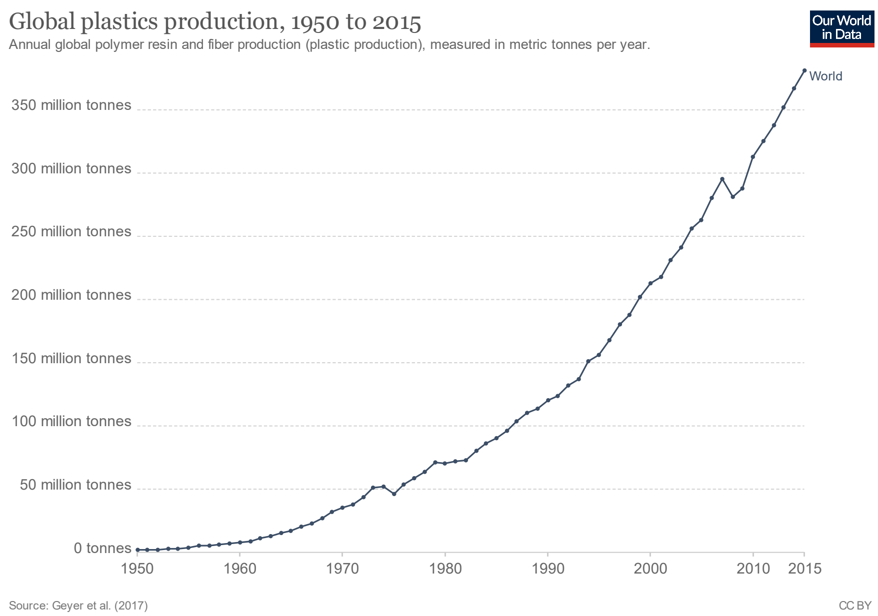

Figure 1. Global plastics production (1950 to 2015)[1]

2. Sources

It is obvious that almost all of the plastics waste on our planet is anthropogenic, it comes from a variety of artificial products related to drinking, eating or packing in our daily life. We can analyze the sources of plastics from two unusual aspects, companies and rivers, which represent the source of market production and transportation patterns respectively.

2.1 Production: Companies

Companies use resin to produce their goods, and resin is processed from oil. As a result, the market share companies occupying is connected closely to the scale of its plastic productivity in a certain sense. That is the reason why multinational corporations usually have the largest plastic footprints, but the fact is they do not take full responsibility for the externalized cost of their single-use plastic products. According to an investigation carried by the organization *Statista*[2], plastic pieces found in global cleanups are contributed mostly

[1] This figure is copied from the website: https://ourworldindata.org/plastic-pollution By the way, you can use the interactive function of this website to find the dynamic change of plastic production, which is interesting.
[2] *Statista is* one of the biggest business data platforms worldwide. (https://www.statista.com/)

from the products manufactured by Coco-cola, Nestlé, Colgate-Palmolive, Unilever and so on, which are familiar names for us. These companies produce drinks, foods, daily supplies and cosmetics that are convenient a lot to our life, but the material used in the process is almost plastic. In addition, these corporations still use an environmentally unfriendly recycle way, relying on informal waste workers to collect their packaging. The inapposite investment structure these companies continuedly using does not benefit the reduce and reuse of plastic, too. Their teaming up with oil companies will lead to even more plastic production.

2.2 Transportation: Rivers

Rivers' function can be summarized as transportation and connection. Rivers, especially some of the world's longest rivers with large populations alongside them, carry trash over long distances and connect nearly all land surfaces with the oceans. Transportation of the plastics from inland areas to the coast and ocean is important to research, which can inspire us the major sources of marine plastic pollution from the perspective of rivers. According to an article published in 2017, scientists conclude that 10 rivers (including Chang Jiang, Nile, Mekong, Amur etc.) alone carry more than 90% of the plastic waste that ends up in the oceans (**Figure 2**). Among them, the Yangtze alone dumps up to an estimated 1.5 million metric tons of plastic waste into the Yellow Sea.**[2]**

Figure 2. Ten rivers contribute 90% global marine plastics (adapted from **[2]**)

3. Distribution and Changes

After entering the sea, the plastics' fate will be more interesting and complicated, they will be conveyed by different forces and powers provided by ocean currents, which leads to the asymmetrical distribution configuration in the marine environment. Besides, they can react with marine living things and other substances, experiencing the change in shape and composition physically, chemically, even biologically.

3.1 Current Distribution

As for the distribution, concentration of plastic debris is a suitable parameter to quantify and it is accessible and easy to analyze for researchers relatively. Firstly, they use physical model to simulate the move track of plastics under the influence of current and density of sea water in different region. And then they collect sea water samples by cruising at 442 sites around the world sea surface and calculate each sample’s concentration and accumulation of floating plastic debris. Using the processed data, they draw a map below (**Figure 3**) to indicate the distribution profile of global ocean. In this valuable map, grey areas indicate the accumulation zones predicted by the global surface circulation model they developed, and colored circles indicate mass concentrations mainly based on their experiments and sampling.**[3]**

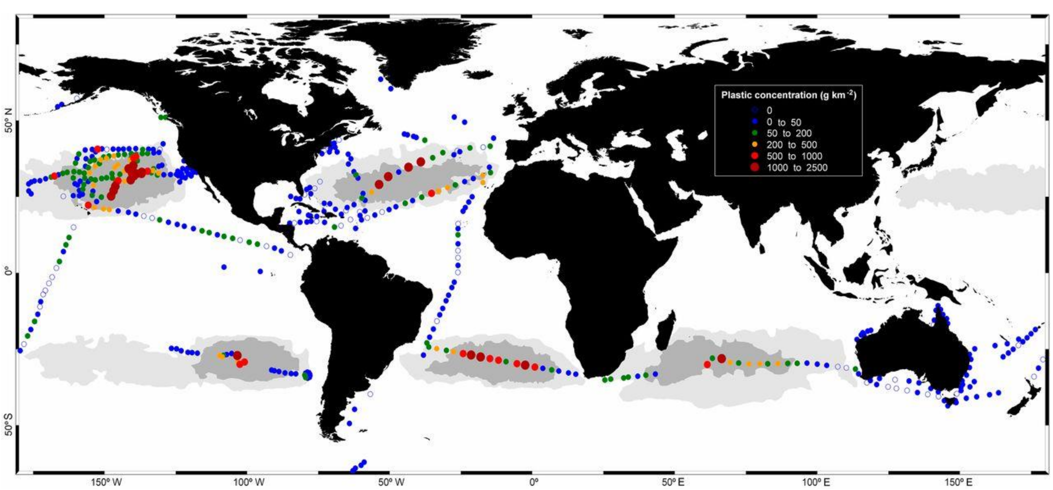

Figure 3. Concentrations of plastic debris in surface waters of the global ocean (from **[3]**)

Generally, most plastic debris’ density is larger than sea water, that is why the majority of them sinks to the seafloor. Nevertheless, the small fraction arriving to one of the five great ocean gyres[3], where it might persist for decades, also counts for a lot. It is not hard to identify that the region in the center of Pacific Ocean, which is at the upper left corner of the **Figure 3**, has accumulated plenty of plastics waste. It is famous in oceanography or environmental science and its name is “the Great Pacific Garbage patch”. This patch is located within the North Pacific Gyre, where the Kuroshio warm current and California cold current form an integrated circle to drive the surface sea water to push forward between North Pacific and North Equatorial. Typically, the current has three functions: 1) drive the

[3] To be exact, the North Atlantic Gyre, the South Atlantic Gyre, the North Pacific Gyre, the South Pacific Gyre, and the Indian Ocean Gyre.

so-called oceanic conveyor belt, 2) circulate ocean waters around the globe, 3) draw in the pollution that we release in coastal areas. Under the joint effect of these three aspects, this region becomes a "trap" limiting the spread and movement of plastic debris, which is an interesting mechanism but the concentration there can even reach 2000g/km^2, such a shocking number.

3.2 Physical and Chemical Changes

Next, the analysis perspective will be transferred from horizontal to vertical, it is also an advanced field for scientists to figure out the change plastics experiencing in the whole marine environment. Scholars from different discipline, such as physics, chemistry, biology and so on, cooperate with each other and list three main probable changes occur to the plastic debris in the ocean, biofouling, aggregation and zooplankton uptake. Biofouling is a successive accumulation of organisms on submerged surface. Small and light particles will be covered by different kinds of foulants and often grow a layer of biofilm, and then they become heavier and suspend in the middle depth of ocean, with more or longer biofouling they will sink slowly down and turn into deposition (**Figure 4**). Aggregation occurs when two or more particles, including microplastic debris, cells, detritus and mineral particles, collide and attach to one another, resulting in a kind of larger formation called "agglomerate". Zooplankton uptake refers to the process of ingestion and transfer in zooplankton's digestive system, and they can be evacuated in the form of "faecal pellet" (small particles excreted by organisms).**[4]**

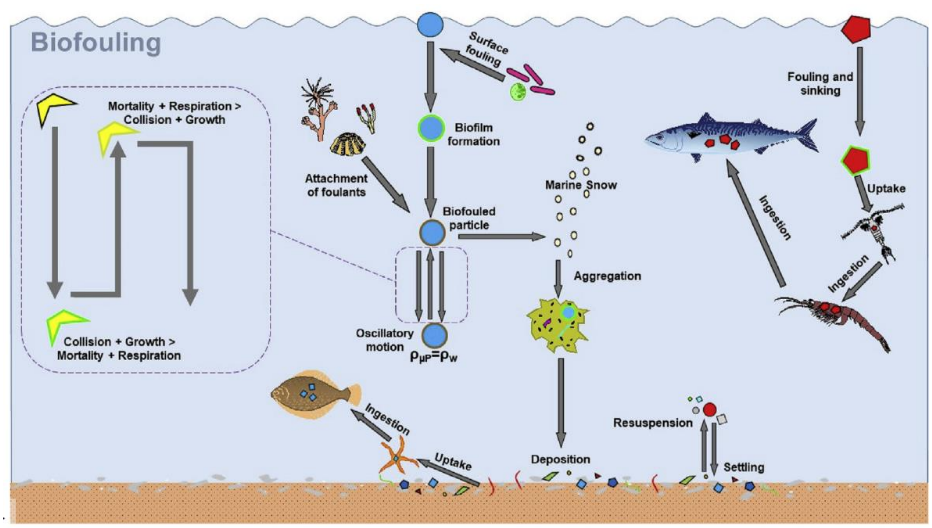

Figure 4. Schematic outlining the process of microplastics biofouling (from **[4]**)

Although it is sure that this classification is kind of rough, in fact, the plastic debris will even experience these three varieties of changes at the same time. For scientific research, however, the sorting of three categories is indeed a significant way to simplify complex changes happening in the ocean world.

4. Impact

4.1 For marine animals

Media often use some frightening photographs in which the marine animals are strangled by plastic bags or starve to death for eating too much indigestible “plastic food” to remind us the urgency of protecting our ocean. That is not exaggeration at all pitifully. From 1970s, some biologists had observed the phenomenon that many living things near the sea got hurt by plastic garbage, and more and more stunning cases prove the huge danger hiding behind plastic debris. Entanglement and ingestion are two commonest sorts the animals have to tolerate.

Entanglement accounts for 13–29% of the observed mortality of gannets at Helgoland, German Bight according a research conducted in 1987. (*Schrey and Vauk, 1987*) Among all of the animals, seals get much attention from biologists whose research direction is animal behavior. They found that young fur seals are likely to be attracted by floating plastic debris and dive and roll about in it(*Mattlin and Cawthorn, 1986*), the explanation offered by these zoologists considers it as a habit of them, seals are interested in approaching objects in the water and like to poke their heads into loops and holes. (*Fowler, 1987; Laist, 1987*) The consequence can be imagined that a number of seal pups grow into the “plastic collars”, and in time as it tightens, the plastic severs the seal’s arteries or strangles it, which is really heart-struck. (*Weisskopf, 1988*) In fishery industry, many waste fishing nets or rods, whose nickname is the “ghost fishing gear”, are commonly throwed into the sea directly, influencing the sea birds and other animals’ normal life by entanglement for another example.

Ingestion means animals are deceived by the appearance of plastics, treat them as their food and eat them by mistake. It is very hard for plastic to be digested completely in their bodies, leading to the smaller and smaller storage of stomach, at last they will starve. In fact, the more detailed pattern may be quite complex. From a 1972’s article, various species of fish with plastic debris in their guts but only white plastic spherules (tiny balls) had been ingested, indicating that they feed themselves using selective plastics. (*Carpenter et al. 1972*) Furthermore, in 1988, a scientist performed an experiment with domestic chickens to establish the potential effects of ingested plastic particles on seabirds with the help of the similarity between seabirds and chickens. He found that ingested plastics reduce meal size by reducing the storage volume of the stomach and the feeding stimulus, which is under our previous guess and expectation. (*Ryan, 1988*) **[5]**

4.2 For human-beings

Environmental health is an area targeting at the relationship between pollution and our health. Recently, experts from this major appeal strongly that we should pay more attention on the health effect of marine plastic pollution to our humans. Unfortunately, there are not so many authoritative achievements until now. One kind suspicious substance whose health effect has been researched relatively clear is Bisphenol A and it is usually marked with the abbreviation form, BPA. In industry, BPA is a precursor to polycarbonate plastics (**Figure**

5), that is why many plastic products we use in our life has a close connection to the BPA. The largest exposure humans have had to BPA is by mouth from sources such as food packaging, metal food cans, and plastic bottles, so scientists consider it as a critical source of health negative influence from the plastic. BPA's health impact on humans include three aspects, reproduction (such as reduced sperm quality), development (such as childhood asthma) and metabolic disease (such as diabetes or obesity), which shows the breadth of its health impact for us.**[6]** It must be admitted that our knowledge about the potential health effect of plastics, to say nothing about marine plastics, is not enough nowadays, much is unknown. **[7]**

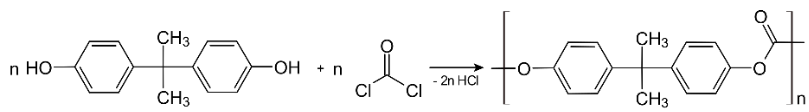

Figure 5. The chemical equation of polycarbonate plastics' production (BPA, the left molecule, is the precursor)[4]

How the plastics end up on consumers' plate? It is another intractable question for scientists. A convincing theory is illustrated in **Figure 6** for an example. Bivalves can filter the marine plastic debris and sea water, during the process of absorption and excretion, they are cultivated and the microplastics are accumulated at the same time. After harvesting, they will be kept in much cleaner water to get rid of the contaminant's pollution, which can help reducing the plastic debris content to a relatively stable level in their body.**[8]** Yet what we can do to lower this level is still undiscovered now.

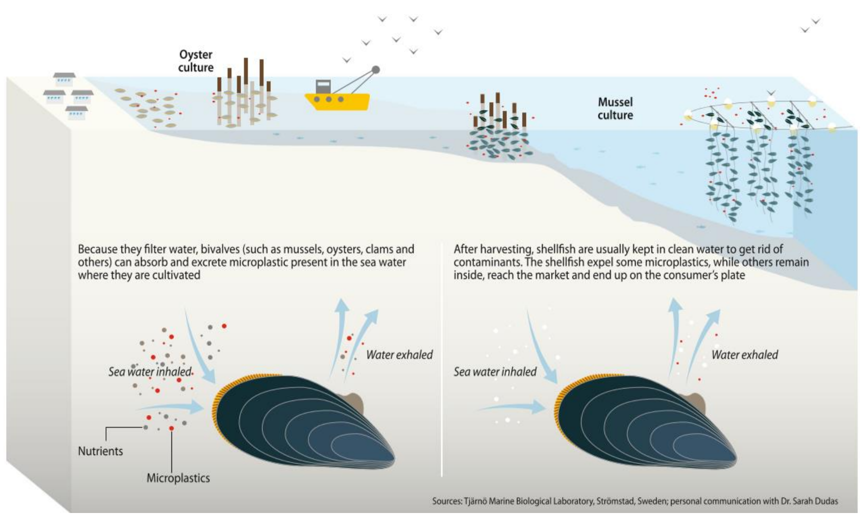

Figure 6. An example of how microplastics could end up on a consumer's plate (from **[8]**)

[4] This graph is cited from Wiki. (https://en.wikipedia.org/wiki/Bisphenol_A)

5. Our Actions

It is extremely urgent for our humans to protect ocean environment and control the marine plastic pollution. So far, many organizations, scientists, engineers, policy-makers have participated in the protection and contribute their strength and ideas without reservation to reduce the increasingly serious pollution globally, which is good news shows that the awareness to prevent the marine plastic pollution is more and more popular.

5.1 Engineering

A straightforward but practical thought is collecting the plastic debris floating and suspending in the ocean as much as possible. Maybe this idea sounds crazy, but there are a group of people who devote themselves to this huge project. *The Ocean Cleanup* is such a typical example, this company set a goal that they will remove 50% plastics of the Great Pacific Garbage patch in just five years. The tools they use are especially invented and designed, with a long floater sits at the surface of the water and a skirt hangs beneath it. They also develop a huge floating boom that is able to siphon plastic waste out of the ocean. The creative method they employ shouldn't be underestimated, it is extremely efficient on the contrast of thousands of years and tens of billions of dollars the conventional method (vessels and nets) will take and consume.

To give more details, the **Figure 7** below explains the principle and basic mechanism. We can conclude that this invention's highlight is it takes advantage of natural oceanic forces. The system will be driven and carried on the surface of the sea by two opposite forces, natural oceanic forces provided by the wind, waves and currents, dragging force offered by a sea anchor tied to the system. By comparison, plastic debris will just move under the natural forces freely, with a faster speed than the slowed-down system, as a result, they can be retained and captured successfully.

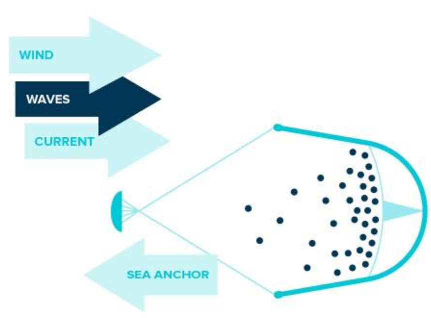

Figure 7. Simplified principle of the cleanup system[5]

[5] Cited from the official website of *The Ocean Cleanup*, https://theoceancleanup.com/oceans/.

5.2 Modeling

To assess the optimal removal locations of plastic debris, the model is a powerful tool without doubt. Scientists build such a model to predict the most suitable sites where a mass of plastic debris accumulate or trapped. The first step is tracer release. With the help of tracer, scientists divide the map in numerous 1° × 1° grids to create six transition matrices P_b, simulate the seasonal ocean circulation variability and input 30 000 different ocean grid cells into the model. The next step is calculating mass removal with sinks of the plastics, whose result is mainly attribute to the model itself. The third step is optimization for each scenario, researchers adjust the parameters used in the calculating process to find the optimal result. At last, the conclusion drawn by scientists has two visions, mass scenario and ecosystem scenario. The former one describes the spots where you can remove the most microplastic in weight, while the latter one would like to reduce the overlap between microplastic and plankton growth, so it is more complexed with the addition of a concept called microplastic-NPP, which means the net primary production of the marine environment microorganism in certain place. There are tiny differences between these two scenarios, but the common point is apparent that vast majority of plastic sinks are located close to coastlines, particularly in Asia (presented in **Figure 8**).**[9]**

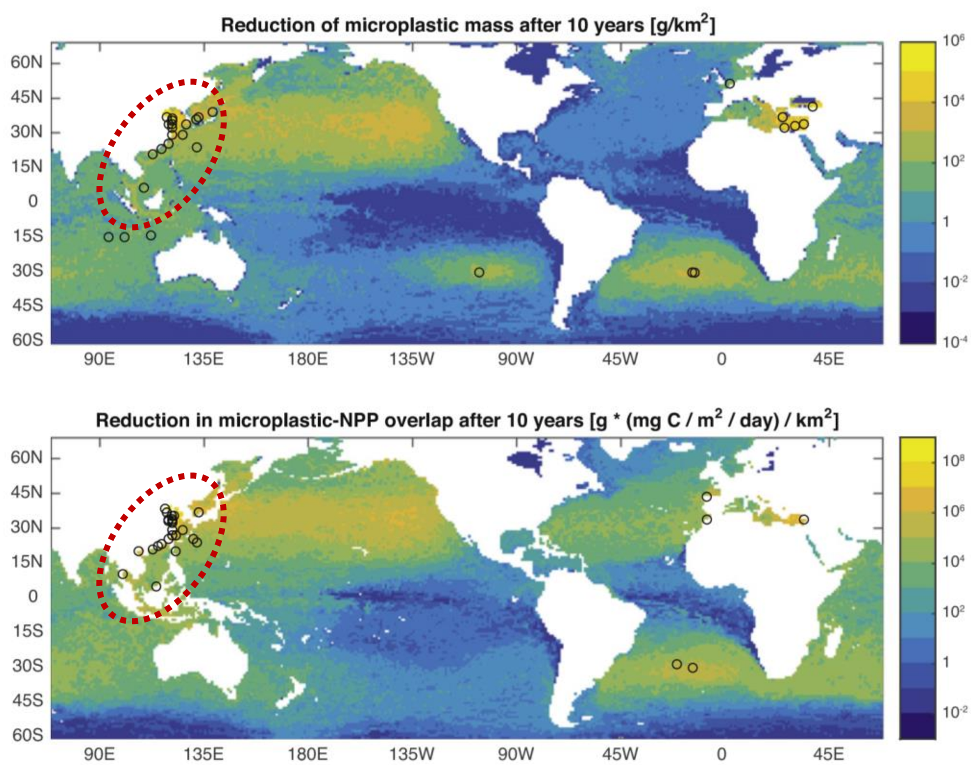

Figure 8. Optimal sink locations in two scenarios (from **[9]**)

5.3 Policy

As we all know, the engineering and modeling methods are both short-time solutions which cannot solve the marine plastic pollution radically. Policies can restrain the consumption of plastic products and encourage the invention and daily use of environmentally friendly materials. According to a worldwide survey in a report published by the United Nation in 2018, masses of countries have approved their legislation about bans or levy aiming at the single-use plastic, most of the laws are in force now, which is uplifting for us. (**Figure 9**)

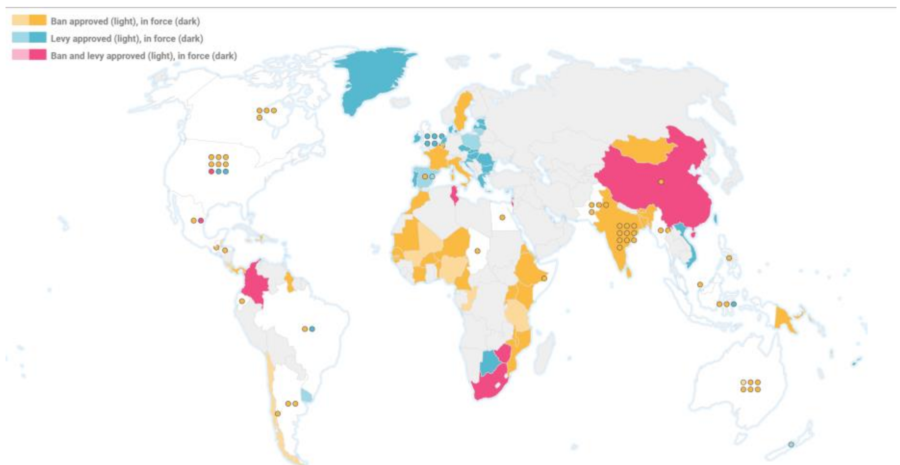

Figure 9. Policies about single-use plastic[6]

Let's consider the manufacturing powerhouse, China, as an example, the road map is clear and forceful. Before 2020, non-degradable plastic bags will be banned in places such as supermarkets and shopping malls in China's major cities. Next, China plans to significantly reduce the use of disposable plastic in e-commerce, express deliveries and takeaway food, which make up a large proportion of plastic consumption now. The terminal goal is set in 2025, China intend to achieve to establish a system for producing, distributing, consuming, recycling and disposing of plastic products so that the management will be much more convenient and quantitative. [7]This grand project can be termed as the China's Three-step Time Schedule vividly.

5.4 Technology

Many chemists and material scientists are active to invent some materials which are similar enough to plastic chemically so that they can replace the conventional hard-to-

[6] The source of this picture is a UN Environment report called *Banning single-use plastic: lessons and experiences from countries* published in 2018.

[7] The detailed report is from the website: https://www.scmp.com/news/china/society/article/3046760/china-unveils-plan-reduce-single-use-plastic-2025

degrade plastic. Japan is a unique pioneer among all the countries because of their close relationship with the ocean pollution, such as PHBH (by *Kaneka Corporation*) and PBS (by *Mitsubishi Chemical Corporation*) are both marine biodegradable plastics currently available.

Recently, a group of researchers from Osaka University have developed a marine biodegradable plastic successfully. The raw materials they use are a little surprising, biomasses starch and cellulose which are common in plants. Starch is the main component of the carbohydrates found in corn, tubers, and roots such as potatoes, while cellulose is also the main component of plants and commonly known as cotton fiber.

The composite sheet material invented by scientists demonstrated excellent water-resistance and high strength in addition to its high levels of biodegradability in seawater, which is fantastic and even perfect for substitute of traditional plastic.**[10]** In seawater, the biodegradation mechanism has roughly two sessions, hydrolysis and bacterial decomposition. Hydrolysis stage refers that polymers which are ultra-long molecules will be shredded by breaking ester bonds by enzymes produces by bacteria. Decomposition stage means bacteria eat the finer parts and decompose them into water and carbon dioxide and then disappear. The research has an unavoidable challenge however that there are very few bacteria in seawater, so it can be said that it is a very difficult environment for biodegradation.**[11]**

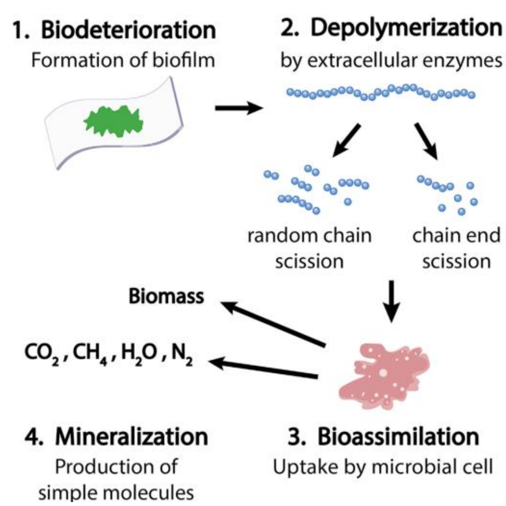

Figure 10. Polymer Biodegradation Process

5.5 Individual

For every individual, changing our life style is essential, many organizations have come up their suggestions about reducing daily plastic use. A controversial statement is “say no to plastic straws”, many drinking stores, such as milk tea store have use paper straws widely to replace plastic ones nowadays. However, there are lots of dissatisfaction and complaints about the paper straw from customers, they think the paper straw has papery or cardboard-like flavor and a chemical taste from the glue used to manufacture it. Another noteworthy proposal is "avoid microbeads", many microbeads existing in our cosmetics such as cleansing milk get washed into the drain and are too small to be filtered out. They enter our waterways and wind up in lakes and streams and even in the tummies of unsuspecting fish, which is a chain reaction impacting ourselves at last. At the same time, carry a reusable bottle, avoid excessive food packaging are valuable advice instruct our life style.[8]

5.6 Two examples

Xiamen is a coastal municipality of China, and it has built a model lately which consists of three parts, monitoring system, forecasting system and "environmental compensation" mechanism. (**Figure 11**) Monitoring system can identify the sources of plastic entering the surrounding sea areas, the elementary conclusion is that the largest two sources were found to be effluent outlets and beach tourism, accounting for over 500 tons of waste a year. Forecasting system works every day punctually at 6pm, it issues a forecast for the following day, making waste collection easier and emergency responses possible. Environmental compensation is a typical concept in environmental management, its goal is to reduce plastic waste entering the Jiulong river upstream in the city of Zhangzhou under the governments' cooperation of Zhangzhou and Xiamen together, if targets are met, Zhangzhou will pay for Xiamen, and vice versa.[9]

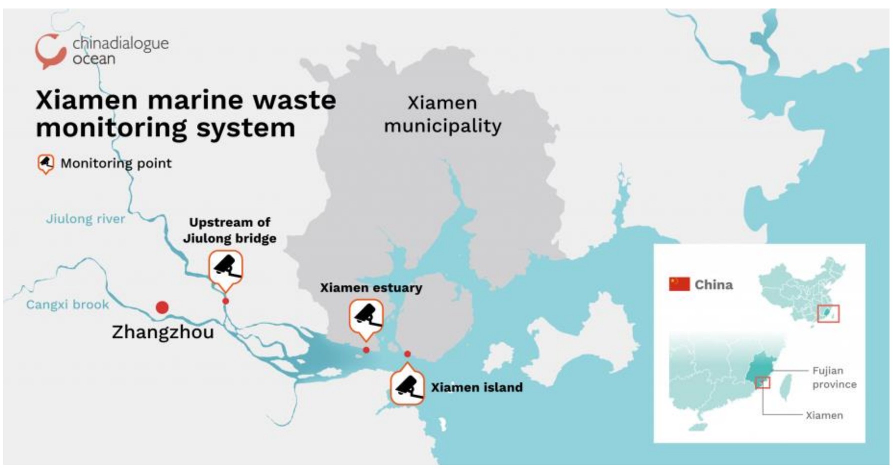

Figure 11. Xiamen is using cameras to help recover marine plastic and identify its sources (from the website in footnote **8**)

CLOMA, the abbreviation of the Japan Clean Ocean Material Alliance, is another example shows the determination and responsibility of enterprisers from different industries. Established in January 2019, CLOMA will try to resolve the problem of marine

[8] You can find more suggestions about reduce plastic use provided by an organization Greenpeace on this website: https://www.greenpeace.org.uk/news/9-ways-reduce-plastic-use/

[9] More information about the effort Xiamen has made on tackling ocean trash can be found in this website page: https://chinadialogueocean.net/12586-ocean-trash-xiamen-china/

contamination caused by plastic waste. To reach this purpose, plenty of companies and firms spanning upstream and downstream portions of the supply chain join this alliance, including materials makers, food and everyday item-makers that use containers and packaging, logistics and retail companies, recycling services providers and so on. For example, the chairman of CLOMA, *Michitaka Sawada*, is the president and CEO of Kao Corp. (a chemical and cosmetics international company) Their overall target is recycling 100 percent of plastic products by 2050, which sounds like sort of ambitious but it is reasonable regarding the complete and detailed road map they have conceived. (**Figure 12**)

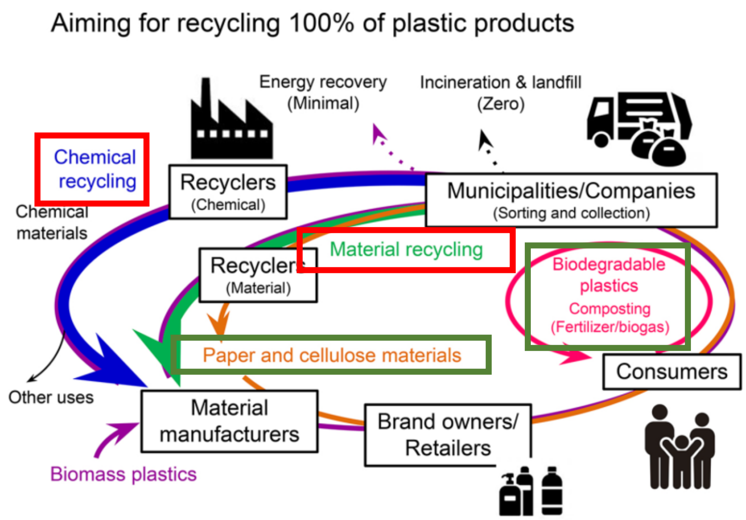

Figure 12. CLOMA's road map for recycling 100% of plastic products

It is a difficult question to predict which method is most effective for the decrease of oceanic plastic pollution in the long run. From my perspective, with the guidance of modeling, engineering is a good method to directly remove the dirty plastic in most polluted regions. In addition, if we need a more influential measure, we should break the thought of "Treatment after Pollution" which has been proven not beneficial for the whole world to tackle plastic pollution. What we need most is plastic-free lifestyles, instructive and forceful policies, all-round recyclable production process and more biodegradable materials, and they can construct and support our future ultimately.

6. Conclusion and An Outlook

"The science we need for the ocean we want" is the motto of UN decade of ocean science (2021-2030). [10]We can conclude from the evidences presented above that we indeed need more knowledges about the sources, distribution, change and health impacts

[10] This is the official website of United Nations Decade of Ocean Science for Sustainable Development: https://www.oceandecade.org/

of marine plastic pollution. Besides, extensive and powerful actions are important to prevent the damage of pollution. Only if every individual, scientists, companies and governments work together and balance the interests of all parties, can we make our goals come true and embrace a cleaner and beautiful ocean without plastic waste in the future.

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