



# Microplastics

*The hidden hazard*

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## Executive Summary

This white paper provides a holistic overview of the microplastics problem, including the various components and sources of microplastics, their distribution and abundance, and the impacts of microplastics on the environment and human life. The goal of this paper is to make the public aware of the hidden hazard of microplastics, and thus take appropriate actions to mitigate the hazard.

Due to the wide variety of plastics and the many different degradation processes of plastics, the composition, shape and size of microplastics vary greatly. Microplastics are divided into two categories; primary microplastics, that are directly released into the environment, and secondary microplastics, that are broken down into secondary particles under environmental conditions. The major sources of microplastics include land-based waste, wastewater treatment plants, cleaning and washing products, textile and clothing, road runoff, plastics manufacturing, agriculture, aquaculture and fisheries, and atmospheric fallout.

Because of the high mobility and buoyancy of microplastics, they are ubiquitous in oceans and freshwater systems around the world, and are found in surface water, sediments, drinking water and aquatic organisms.

The widely distributed microplastics affect aquatic environments at all depths. The particle itself and the released additives are ingested by aquatic organisms, such as algae, zooplankton, and larger organisms, and thus negatively affect the bio-network of trophic levels and ecological niches.

There are several removal solutions for microplastic contamination, including source control, recycling and advanced removal techniques for wastewater treatment, such as membrane bioreactors. The main solution for mitigation rests with public awareness and government legislation.

To date, the research on microplastics has been concentrated on aquatic environment and organisms. The study of the impact of microplastics on human health is still in its infancy, and further long-term research of human effects is needed.

Immediate actions should be taken regarding this hidden hazard, including minimizing the consumption of plastics, introducing laws and regulations to ban industrially produced microplastics, more long-term impact research, and introducing educational tools to raise the awareness of the hidden hazard.

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# 1. Introduction

Plastic is indispensable and ubiquitous in our daily life. Plastic products are used in various ways, and can be seen everywhere. It is estimated (Geyer, et al., 2017) that 9.1 billion tons of unrecoverable plastics have been produced to date, of which only 9% of the plastic waste was recycled, and 12% was incinerated; the remaining 79% of plastic waste was deposited in landfills and in the natural environment. This produced 7.2 billion tons of plastic contamination.

In 2010, global plastic production was 270 million tons, and 275 million tons of plastic waste was produced in 192 coastal countries in the same year. It is estimated that 8 million tons of untreated plastic waste was discharged into the oceans in 2010. The size of the population and the quality of the waste treatment system largely determine which countries contribute more to marine plastic contamination. If global waste treatment systems are not improved, the cumulative amount of plastic waste discharged into the ocean is expected to double by 2025 (Jambeck et al., 2015).

For example, in China, the food delivery industry has developed rapidly. Young people and the elderly favor the timely manner and convenience of delivered food that suits their efficient and fast pace of life. According to a BBC report, at the end of June 2017, the number of registered users using online ordering services in China reached nearly 300 million. This number is increasing and the trend is spreading all around the world. According to estimates, the consumption of delivered food will increase from \$25 billion in 2016 to \$36 billion in 2018. It is estimated that about 65 million plastic food containers from delivered food are thrown away as trash every day. This has raised serious questions. Where are these plastics going after food delivery? Are our waste management systems capable of coping with this sudden increase in plastic waste?

People take it for granted that the waste and wastewater treatment plants will handle all contaminants. We use deep cleaning products, wash clothes (most of the clothes are made of synthetic fibers), not knowing that microbeads and microfibers are running through the sewers. The problem is just that we are not aware of this hidden hazard!

“Beat Plastic Pollution” was the theme of the 2018 World Environment Day on June 5<sup>th</sup>, 2018. Governments, industries, communities and individuals are urged to come together to find sustainable alternatives and reduce the production and overuse of single-use plastics to avoid polluting the marine and destroying the freshwater ecosystems, aquatic life and threatening human health. Plastic pollution is considered a global emergency that affects all aspects of our lives. It exists in the water we drink and the food we eat, the air we breathe, in the form of microplastics. It is penetrating every inch of the earth, and jeopardizing our beaches, oceans, and icebergs. We must act soon, to save our oceans and the earth.

Due to its relatively low cost, relatively simple process of production, versatility, and impermeability, plastics are used in a large and growing number of products ranging from water bottle to spacecraft;

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they are ubiquitous in our lives. Plastics have become perfect replacement for many conventional materials including metals, wood, glass, cotton, etc. We use them, consume them, and dispose of them. Plastic wastes have become the "number one common enemy of the earth". However, the public is generally unaware of one particular type of plastic—microplastics, the processes that generate microplastics, how they end up in the environment and the harm they create, it is the "hidden hazard"!

Digging deeper into the world of plastics, a surprising reality emerges, microplastics! Extremely small, often microparticles are found in the fish we eat and the water we drink! Unfortunately, few people are aware of this type of contamination and the potential environmental and human health hazards: hence, the "hidden hazard".

## 2. Major Objectives

The major objective of this white paper is to provide a holistic overview of the sources of microplastics, their distribution and abundance, the processes that break down plastics into microplastics and their effects on the environment and human health and the associated challenges. The aim is to make the public aware of the hidden hazard of microplastics.

## 3. The Problem

### 3.1 Main types of plastics

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The term plastic is derived from the Greek words "plassein" which means to mold or reshape something soft (Sellinger, et al., 2017). It refers to the plasticity of plastics in the manufacturing process, allowing them to be cast and processed into a variety of shapes, such as films, fibers, plates, tubes, bottles, and boxes.

Understanding the diversity of plastics and the wide range of their applications is needed to understand and study the hazard of microplastics.

The following table summarizes 9 common types of plastics (for more complete information please see the *appendix 1*).

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Table 1. Common types of plastics (Creative Mechanisms) (Aronson, 2015)

TYPES OF POLYMER	TYPES OF POLYMER	CHARACTERISTICS	APPLICATIONS
POLYETHYLENE	PE	Colorless, odorless, non-toxic; easy molding, lightweight, and high level of impact resistance; corrosion resistance, insulation, and impervious	Various containers; toys; submarine cable
POLYPROPYLENE	PP	Lighter, harder, more transparent, and better heat-resistant than PE; good mechanical strength; good acid and alkali resistances	Various containers; car door accessories; woven products; acid and alkali resistant pipes
POLYSTYRENE	PS	Colorless and transparent; good insulation and ability of response to high vibrations; easy to process and color	Radar; models and toys
POLYVINYL CHLORIDE	PVC	Low permeability, good insulation, and resistance to aging; easy to be colored	Hard PVC (plastic buckets), soft PVC (raincoats), transparent PVC (agricultural plastic film), and non-transparent PVC (pipe), artificial leather
POLYMETHYL METHACRYLATE	PMMA	The most transparent plastic, light, good fire resistance, high strength, good impact resistance	Car and train windows; artificial corneas
PHENOL FORMALDEHYDE RESINS	PF	Thermoset, inexpensive, easy to process, heat resistant, corrosion resistant, high pressure resistant, and insulating	Sockets, switches; PF foam
POLYURETHANE	PU	Strong elasticity, toughness, oil resistance, abrasion resistance, aging resistance, and tear resistance	Cushions, building insulation materials; tires; leather goods
POLYAMIDE RESIN	PA	Good tensile strength, impact strength, is abrasion and heat resistance, and low coefficient of friction	PA fabrics; gears
POLYTETRAFLUOROETHYLENE	PTFE	Resistant to acids, alkali, and various organic solvents, insoluble; high temperature resistance; low friction coefficient	Lubricant, coating material for non-stick pan

In addition to the diverse polymers formed by different chemical structures, the above types of plastics also incorporate a wide variety of plastic additives that, without seriously affecting the molecular structure of the plastic, improve their properties or reduce production costs. The main purpose of adding plastic additives is to improve the processability, physical and chemical properties of the plastics, so that the plastic meets the desired properties of the target products.

The following table summarizes 6 common categories of plastic additives (for more complete information please see the *appendix 2*).

Table 2. Common categories of plastic additives (Hahladakis et al., 2018)

ADDITIVE CATEGORY	APPLICATIONS
ANTIOXIDANTS	Delay the oxidative decomposition of plastics
ANTISTATIC AGENTS	Avoid electricity accumulation and discharge static electricity
FOAM-BLOWING AGENTS	Trigger foaming processes to build cellular structure in plastic body
FLAME RETARDANTS	Enable plastics to suppress the spread of flame, prevent smoke
PLASTICIZERS	Increase the plasticity or decrease the viscosity of plastics
COLORANT	Color the plastics

With such a wide variety of molecular structures of polymers and a wide range of plastic additives, different plastic materials with different purposes, textures and shapes have met all types of needs of

various industrial sectors, making the applications and development of plastic products limitless. Thus, plastics have occupied every corner of the earth like the reproduction of viruses. The complex compositions and additives make the research on plastics wastes very challenging, particularly since they persist in the environment for thousands of years after disposal. When we study plastics and microplastics contamination, it is important to understand that due to the heterogeneous physical and chemical properties of different plastics, they cannot be treated as one single contaminant.

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### 3.2 Degradation of plastics into microplastics

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In order to prevent the deterioration of plastics, various additives are added during processing to prevent the plastics from reacting with various substances (water, oxygen, heat, acid and alkali, and ultraviolet light) that they may come into contact with. This prevents the plastics from being completely degraded. Plastics tend to accumulate after entering the environment, cause long-term environmental and waste management problems. Degrading waste plastics is considered as one of the ways to solve this environmental problem (Karaduman, 2002). Various plastics can be degraded by photolysis, photo-oxidation and thermal oxidation reactions. Plastic degradation can be classified into the following types (Singh, et al., 2008):

- Photo-oxidative degradation. Photo-oxidative degradation is one of the main degradation processes for plastics. The degradation process decomposes materials by the action of light. Most synthetic polymers are susceptible to degradation by UV and visible light. Photo-oxidative degradation alters the physical and optical properties of the plastics, and causes the polymers to readily lose their mechanical integrity and strength, and its average molecular weight decreases.
  - Thermal degradation. Thermal degradation is also classified as oxidative degradation, and thermal degradation of synthetic polymers is a combination of random and chain degradation (depolymerization reaction), which is induced by thermal and UV light (Teare, et al., 2000).
  - Ozone-included degradation. Atmospheric ozone typically causes polymer degradation when other oxidative degradation processes are very slow allowing polymers to retain their properties for a significant period of time. Even if the concentration of ozone in the air is very low, it still has the ability to significantly accelerate the degradation process of polymer materials (Kefeli, et al., 1971). The degradation process changes the molecular weight of the polymers, decreases their mechanical and electrical properties.
  - Mechanochemical degradation. The mechanochemical degradation of a polymer is mechanical stress such as shear and mechanical force breaks the molecular chain with the aid of chemical reactions (Singh, et al., 2008).
  - Biodegradation. According to ASTM standard D-5488-94d, biodegradation is "a process which is capable of undergoing decomposition of plastic into CO<sub>2</sub>, methane, water, inorganic compounds or biomass in which the predominant mechanism is the enzymatic action of micro-organisms..." (ASTM standard D5488-94de1, 2002). The biodegradation of polymers includes the following mechanisms: dissolution, ionization, hydrolysis, enzymatic degradation and
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microbial degradation. Degradation can occur by any of the above mechanisms, either alone or in combination. Biodegradation is the only process that can degrade plastics into carbon dioxide or methane and water of all the degradation processes, instead of breaking down plastic into small particles. Therefore, biodegradation is considered to be one of the most promising approaches for solving plastic and microplastic problems.

But complete degradation means plastics have to be degraded into carbon dioxide, or methane, and water, and plastics first only break down into smaller and smaller pieces over time, eventually becoming microplastics. Research is being carried out on these two contradictory themes of plastic stabilization and natural degradation.

There are some differences between degradations of plastics in marine system and freshwater system. In marine systems, degradation processes may also have varying degrees of physical forces, such as storms and wave action (Andrady, 2011), but plastics in freshwater systems undergo mainly physical and chemical degradation or potential biodegradation.

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### 3.3 Definition and classification of microplastics

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#### 3.3.1 Definition of microplastics

Microplastics are plastic particles including textile fibers that have a very small particle sizes. There is no general consensus on the specific size of microplastics. It is generally accepted that plastic particles with a particle size of less than 5mm are microplastics. The growing presence of microplastics in the environment and their contamination has attracted increasing attentions of scientists. It may be the largest amount of plastic debris in the current marine environment, and the amount will continue to increase (Law, et al. 2014).

#### 3.3.1 Classification of microplastics

Residues of plastic or microplastics (<5 mm) in the environment undergo physical and chemical weathering to further break into smaller particles. For example, a piece of plastic with a particle size of 200 mm (macroplastic) can be gradually broken up into 10000 pieces of microplastics with a diameter of 2mm, and then 62500 pieces of smaller microplastics with a particle size of approximately 0.8 mm (Eriksen, et al. 2014).

There are two major types of microplastics:

- The first type of microplastics is called **primary microplastics**. Primary microplastics are directly released into the environment as small plastic particles (<5 mm). Including industrially produced micron-sized particles, such as friction agents and “microbeads” commonly found in health, beauty, and household products. As an example, one tube of facial scrub can contain more than 300,000 plastic microbeads, each the size of 0.3mm. Also, primary microplastics can be derived from breakdown of large plastic products via manufacturing, use, or maintenance.
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For instance, breaking off from aged tires during driving, or from synthetic textiles during washing (Boucher, et al., 2017).

- The second type is called **secondary microplastics**, which are derived from the degradation of large plastics, the degradation processes that occur in the environment. It is the most common type of microplastics in marine ecosystem and they are typically much more diverse in shape, size, color, and composition than primary microplastics (Andrady, 2011).

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### 3.4 Major sources of microplastic contaminants and release pathways

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The currently known sources of microplastics include land-based waste, cosmetics, textile and clothing, plastics manufacturing, and coastal tourism. Microplastics are released from land use activities (e.g. agriculture and industrial activities) and other production activities (e.g. aquaculture and fishery), and moved into the aquatic environment. It is estimated that 80% of marine plastic debris originates from industrial production and land use activities (Boucher, et al., 2017).

Microplastics in one area often have multiple sources. The contribution of land-based waste may be the largest.

- **Land-based wastes.** According to estimates by Jambeck et al. (2015), in 2010 alone there were 4.8-12.7 million tons of plastic wastes that entered the ocean. And as the current situation is worsening, if the waste management infrastructure is not improved, the accumulated plastic wastes entering the oceans is expected to increase by an order of magnitude by 2025. These plastic wastes will continuously degrade into microplastics in the oceans. Therefore, microplastics associated with this source are mostly secondary microplastics.
  - **Wastewater treatment plants.** At the global level, around one third (29.5%) of the population is connected to a wastewater treatment system (Boucher, et al., 2017). In general, the currently used wastewater treatment systems are capable to effectively remove 99% of microplastics from wastewater through their primary and secondary treatment processes. Although the effective removal of microplastic contamination is possible, final effluents, which are continuously discharged in large volumes, have become the main source and pathway of microplastic contamination into the aquatic environment.
  - **Cosmetics, cleaning, washing products** and other toiletries we use in daily life are also a major source of microplastic contamination. When you hear the slogan "Deep Cleansing, Deep Care" of cleansing products, this product likely contains tiny plastic balls called "microbeads" (Miscellaneous Agency, 2015). These "microbeads" are added to remove skin keratin and deep clean pores and are typical manufactured microplastics. Products associated with this source are primary microplastics.
  - **Textile and clothing.** Microfibers produced by washing machines are also an important source of microplastics. Researchers have found that up to 1900 plastic fibers can be produced per wash of a synthetic fiber garment by testing the wastewater from household washing machines (Boucher, et al., 2017). This is the major source of primary microplastics.
  - **Roads.** The erosion of tires via driving, road markings, and other applications that generate plastic particles make roads a major source of microplastics (Boucher, et al., 2017). The microplastics that fall on the road may be flushed into the drainage system by road runoff,
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which are then discharged into the environment, or suspended by the wind and redeposited on land surfaces or into water sources.

- **Plastics manufacturing.** In the manufacturing process of plastics, large plastic objects are subject to abrasion during processing and shaping, resulting in a large amount of microplastics being produced (Lehmphul, 2015). It is estimated that the loss of plastic pellets during plastic manufacturing is in the order of 15,000 tonnes per year (Alliance, 2016).
- **Coastal tourism.** A study by Retama, et al. (2016) on microplastics in Mexico shows that in the studied region, the main sources of microplastics are tourism-associated activities and the wastewater from hotels and restaurants along the beach.
- **Agriculture, aquaculture, and fishery.** The wear and tear from the mulch film commonly used in covering in agricultural production, as well as the abrasion of ropes and nets made of synthetic plastics used in aquaculture and fisheries, are also sources of micro-plastics. In addition, plastic equipment that is discarded for long periods of time, abandoned or stored outdoors is a source for the gradual release of microplastics (Sundt, et al., 2014).
- **Freshwater** is a potential transportation route for plastic debris to enter the oceans. Lechner et al. (2014) found that the input of plastic litter in the Black Sea through the transportation of the Danube River is estimated to approximately  $7.5 \text{ g per } 1000 \text{ m}^3 \text{ s}^{-1}$  at mean flow of  $6444 \text{ m}^3 \text{ s}^{-1}$  (second).
- **Atmospheric fallout.** Atmospheric deposition is considered another main source of fibers including microplastic fibers, that originate from clothes and houses, degradation of plastic products, landfill, etc., that are transported by wind in the air, and deposited into the aquatic or terrestrial environment.

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## 3.5 Distribution and abundance of microplastics in the aquatic ecosystem

### 3.5.1 Distribution and abundance of microplastics in the aquatic ecosystem

Understanding the distribution and abundance of microplastics in the global aquatic environment will not only help to understand the extent and breadth of microplastic contamination, but also help provide scientific evidences for legislation.

Because of its high mobility, microplastics have become ubiquitous in the oceans, in surface waters, seawater, and sediments all around the world. They are found even in polar regions, remote islands, continental shelves, and deep oceanic bottoms (Auta, et al., 2017). According to monitoring studies, the concentrations of microplastics in marine system range from  $1.3 \text{ particles per kg}^{-1}$  (German island) to over  $13.5 \text{ particles per kg}^{-1}$  (equatorial Western Atlantic) to  $2175 \text{ particles per kg}^{-1}$  (Italy) (Klein, et al., 2018). In addition, it is assumed that the longer the distance from the shoreline, the lower the microplastic content. The content of microplastics near the pollution sources such as beaches, harbors, and coastal wastewater treatment plants is high (Claessens, et al, 2011). Special hydrogeographic features combined with ocean circulation pattern can create hot spot for microplastics. Many recent studies have shown that the distribution of microplastics is widespread in

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the marine system, but data in freshwater systems and ocean sediments are relatively few (Duis and Coors, 2016).

More recent evidence suggests that microplastics are also present in large quantities in freshwater systems such as rivers and lakes. This has made our drinking water susceptible to microplastic contamination. Studies have shown that in the freshwater environment such as lakes and rivers, microplastics are present with comparable concentrations to those reported in the marine environment. As an example, in European rivers, high concentrations of microplastics were found in the Rhine River (900,000 particles  $\text{km}^{-2}$  for surface water) and as indicated earlier in the Danube River. The microplastic abundance in the Danube was extremely high, suggesting that a significant amount of microplastic contaminants will be transported to the Black Sea via Danube River (Lechner et al., 2014). The content of microplastics in the river that enter the sea areas is higher than that in surrounding sea areas.

Studies on sediments have shown that as biofilms accumulate on the surfaces of microplastics, the floating low-density microplastics will begin to sink and may eventually land on the seabed/lake sediment along with the high-density microplastics. According to reports, the deep sea may be the main depositional environment for microplastics (Woodall et al. 2014). The above-mentioned study in the Rhine River also reported the concentration of microplastics in the lakeshore sediments may approach 4000 particles  $\text{kg}^{-1}$  (Klein, et al., 2018).

Numerous recent reports have shown that high levels occur in some drinking water sources. Orb Media (Orb, 2017), a nonprofit journalism organization, conducted tap water and bottled water studies and reported that microplastics are now found in all water sources. In terms of microplastic particles with the size of 100 microns (about the diameter of a human hair), tap water samples contain 4.45 particles per liter, and bottled water samples, surprisingly, contain 10.4 particles per liter that is more than two times as many of that in tap water samples. They tested more than 250 bottles from 11 brands and the test result revealed that the microplastic contaminants included polypropylene (PP), nylon, and polyethylene terephthalate (PET).

To fully understand the global distribution and abundance of microplastics, more investigations and research are still needed.

### 3.5.2 Factors affecting the abundance and distribution of microplastics in the aquatic ecosystem

- Factors affecting the abundance of microplastics, include population density, the variety of degradation, the type of waste management or wastewater treatment used, the volume of the final effluent, and water body size (Eerkes-Medrano, et al., 2015). As an example, in the densely populated Erie Lake in North America, the number of microplastics reached 466,305 particles per  $\text{km}^2$ , while the less populated Huron Lake with larger area had only 6541 particles per  $\text{km}^2$  (Eriksen, et al., 2013).
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- Factors affecting the distribution of microplastics include various physical forces that affect the transportation and dispersal of microplastics (such as wind-driven surface currents and geostrophic cycles) (Law et al., 2014), as well as their vertical position (such as wind-driven turbulence), the nature of the particles themselves (such as size, shape and density), and other properties such as seawater density, underwater topography and tidal cycles. In fresh water, there are other physical factors that affect the distribution of particles, including flow rate, water depth, seasonal changes, storms, floods, etc. (Eerkes-Medrano, et al., 2015).

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### 3.6 The impacts of microplastic contaminants on aquatic organisms in oceans and freshwater, and evidence or concern about potential human impact.

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#### 3.6.1 Microplastics in marine system

Globally, it is estimated that approximately 1.53 million tons of primary microplastics enter the ocean through various pathways each year (Boucher, et al., 2017). Based on a global population of 7 billion, it is estimated that each person discharges about 0.6 grams of microplastics per day as primary microplastics. These microplastics eventually enter the wastewater treatment plants through the wastewater networks and drainage systems. Although studies have shown that the current wastewater treatment plants can remove 99% of microplastics (Carr, et al., 2016), the final effluent still contains a large amount of microplastics. Wastewater treatment plants are still a significant source of microplastics (Talvitie, et al., 2017).

Microplastic contamination is a neglected environmental problem that has the potential to have more serious consequences. At the second UN Environment Assembly in 2015, it was noted that microplastics contamination has been listed as the second largest scientific issue in the field of environmental and ecological science research. It has become a major global environmental problem, alongside global climate change, ozone depletion and ocean acidification (Galloway, et al., 2016).

In general, the impacts of plastics on marine organisms are as follows:

The influence of microplastics on marine organisms includes accidental eating and ingestion and obstructing feeding organs. Studies have shown that microplastics have been detected in the digestive systems of various marine animals such as fish, clams, dolphins, etc., in addition the amount of microplastics that being ingested is related to the animal's age and body size (Denuncio et al., 2011).

Due to the small particle size of microplastics, they are easily ingested by marine organisms, and then transferred through the food chain through trophic levels, which may affect the global ecosystem. Persistent organic pollutants and heavy metals contained in plastics are also released into the ocean and pollute the marine environment.

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As marine organisms are the basis of the marine ecosystem, the adverse impact of microplastics on various marine organisms will inevitably lead to the destruction of the marine ecosystem and even pose a threat to humans and the global ecosystem. Ultimately, human activities are connected to the oceans, and these connections are reflected in increasing of mortality of marine organisms such as sea turtles, dolphins and whales, and the destruction of coral reefs. Being an important source of chemical pollution may also harm humans by consuming fish and water. Eventually marine ecosystem will recycle everything humans put into it, back to the humans!

As discussed in Section 3.1, each type of microplastic has different characteristics, such as material type, degradation rate, particle diameter, and particle shape. The different contaminant properties of microplastics allow them to be widely distributed in different positions in the water column. They settle at different rates depending on buoyancy. As a result, microplastics are widely distributed at various depths in the water column affecting aquatic organisms at different depth (neuston, pelagic species and benthic species). The microplastic contaminants have significantly negative impact on the aquatic bio-network at all trophic levels and ecological niches (Scherer, et al., 2017).

Studies have found that some bacteria and viruses can develop biofilms on the surface of microplastics as their habitats and aggregation sites, and enter the organism which may cause diseases or have negative affect on marine organisms (Boerger, et al., 2010).

**Algae.** The most important primary productivity in the ocean, algae are seriously threatened by microplastics. For example, the shielding and reflection of sunlight by microplastics on the surface of the oceans will hinder the absorption of sunlight by algae; the nano-scale plastic particles broken up by the long duration degradation of microplastics will reduce the content of chlorophylla in the algal cells and increase the intracellular production of reactive oxygen in the algae cells (Mato, et al., 2001). There are also some algae that can attach and grow on the surface of microplastics, which in turn changes the density of microplastics and affects their distribution in the ocean (Graham, et al., 2009).

**Zooplankton** can ingest microplastics, some of which can be excreted while others will accumulate in the digestive tract, causing the zooplanktons to feel full or obstructing the digestive tract, thereby reducing zooplankton food intake and leading to malnutrition (Von Moos, et al., 2012). Exposure to microplastics also affects the egg production and reproductive capacity of marine zooplankton (Juliana, et al., 2014).

**Sediments and larger organisms.** Microplastics also appear in sediments on the bottom of the oceans as well as in seawater and on the surface of the sea. Therefore, benthic organisms, which are characterized with sediment filter feeding selectivity, are more likely to ingest microplastics from marine sediments. Studies have found that microplastics appear in the digestive tracts of sea otters, sea cucumbers, and sea squirts in different quantities. In mussels and crabs, microplastics not only appear in their digestive systems, but also can be further transferred into the hemolymph and body tissues through digestive tract epithelial cells (Shaw, et al., 1994).

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Although sea birds do not regard the oceans as their habitats, their food is mainly derived from the oceans. Field surveys have found that in many digestive systems of seabirds, microplastics exist in varying degrees (Spear, et al. 1995). The ingestion of microplastic particles by sea birds is closely related to the shape, size, and color of microplastics. The greater the similarity is to the natural food of sea birds, the higher the content of microplastics in seabirds. Because seabirds do not contain enzymes that digest plastics, some of the plastic debris ingested will persist in their digestive systems, affecting their normal digestion of foods, resulting in eating disorders and malnutrition.

In addition, microplastics can not only directly block the digestive tract of marine animals, but cause food ingestion disorders, malnutrition and other consequences, and also combine with other chemical substances and pose a serious threat to the survival of marine organisms (Wright, et al. 2013).

As outlined earlier, in order to make plastics that possess better performance standards, chemical substances such as additives are added to the plastic during its production and processing, and these substances are gradually released during the process of plastics breakdown. In addition, the hydrophobic property and the large specific surface area of microplastics can effectively adsorb trace organic substance in seawater, such as PCBs, DDT, and nonylphenols (Mato, et al., 2001). Adsorption experiments showed that the concentrations of PCBs and DDT on the surfaces of plastic particles were significantly higher than that in surrounding seawater, indicating that the plastic particles have strong adsorption capacity. After these microplastics are ingested by marine animals, high concentrations of chemicals are released into their body and accumulate in tissues with high lipid content, or are transferred to higher trophic levels through the food web (Bjorndal, et al. 1994). This may cause far more damage to marine organisms than the microplastic itself.

Presently, most studies on the toxicity of microplastics in marine system have only focused on individual organisms. Limited research has been conducted on the effect of transformation of microplastics within the marine food chain. It cannot be ignored that the ability of microplastics to pass through the marine food chain and to amplify the toxicity is closely related to marine life and even human beings as a whole. Therefore, on the basis of a clear understanding of the bio-toxicity process and mechanism of microplastics, the research work of microplastics within the marine food chain should be further focused on providing fundamental evidence on impacts and identifying prevention and mitigation measures.

### 3.6.2 Microplastics in freshwater system

To date, research on microplastics has focused mainly on the marine environment. As stated in section 3.4, the freshwater environment is a potential source and transportation route for plastic debris to enter the oceans. Although the research on microplastics in freshwater has shown an increasing trend in recent years (Wagner and Lambert, 2018), the knowledge of the existence of microplastics in freshwater systems is still relatively limited, especially in regions where plastics are produced in large quantities and where plastic waste is under-treated.

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The inland freshwater environment is more closely related to human beings than the marine environment. The research team of the Wuhan Botanical Garden of the Chinese Academy of Sciences has conducted research on freshwater microplastics for several years (Wang, et al., 2018). They surveyed the microplastic contaminations in two large freshwater lakes in the middle of Yangtze River, Dongting Lake and Hu Lake, and found that the presence of microplastics was detected in Dongting Lake and Honghu Lake, with average concentrations of 900-2800 and 1250-4650 particles/m<sup>3</sup> (particles per cubic meter of water). According to the analysis, 60-70% of all particles were attributed to polyethylene (PE) and polypropylene (PP). In addition, there is significant spatial variation in contamination levels found in both lakes, the pollution contamination level in the parts of the lakes that are close to cities is generally higher than in other parts of the lakes, which indicates that human factors play an important role in the production of microplastics and its variable distribution.

Studies on microplastics in Taihu Lake (Zhejiang, China) found that the microplastics exist in the water, organisms, and sediment in the lake, and the level of contamination was reported as the highest for freshwater lakes in the world including freshwater lakes in countries such as the United States and Mongolia. This includes organisms cultured for human consumption (Su, et al., 2016).

As seen in marine environments, microplastics can be taken up from water or sediments by a variety of aquatic organisms, through direct ingestion or uptake by skin contact, and the most importantly, through respiratory surfaces such as gills (Lambert, et al., 2018). In a survey of microplastic contamination assessments of fish in China, microplastics and mesoplastics (with the size greater than 5mm) were found in all 21 marine nearshore fish and 6 freshwater fish species selected. The presence of microplastics has an average abundance of 1.1 to 7.2 particles per individual fish and 0.2–17.2 particles per gram. The characteristics of the plastic are mainly transparent fibers. The plastic abundance in the stomach and intestines of fish showed significant variation in terms of different fish species, and the ingestion of plastics by fish may be closely associated to the intestinal structure and ingestion habits of different fish species (Jabeen, et al., 2016).

As stated earlier, plastic materials may contain many additives, including antimicrobial agents. These additives may be toxic to organisms, such as bacteria and fungi, which play a very important role in functioning within the ecosystem. Thus, the combination of microplastic particles, their leached additives and other degradation products that are released into the water have various potential effects on aquatic and terrestrial organisms (Lambert, et al., 2018).

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### 3.7 Techniques for measuring microplastics

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As the evidence of microplastics in the aquatic environment is increasing, the scope and depth of research on microplastics are expanding gradually. In order to better understand the distribution and abundance of microplastics, as well as their effects, measuring techniques are the focus of most current research. The measuring techniques need to be standardized and improved. In general,

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techniques for assessing the effects of microplastics include sampling, identification, and quantification (Mai, et al., 2018).

1. Sampling. A suitable sampling method is the first step in measuring microplastics. General sampling methods include field sampling, water sampling, porous media sampling, and biota sampling. Field sampling must include air-borne dust; since microplastics are buoyant. Surface water sampling via manta trawls or nets is commonly used (Eriksen, et al., 2013). For microplastics with a density greater than water that tend to sink into a deeper water environment, sampling the sediment and the benthic community is also important. Porous media sampling is suitable for collecting microplastics samples in the surface layer of a beach or lakeshore, or at the sea and lake floor. Since microplastics can be ingested by aquatic life, biota sampling is needed for monitoring microplastics in the aquatic environment. The common biota samples are fish, seabirds, shellfish, and plankton.
2. Separation and purification. Flotation is a density separation method that separates particles with different densities (Dillon, 1964), and the densities of microplastics depend on their polymer structures, additives, and attached biofilm. Sieving and filtration are also used for separating microplastics. They can be separated and classified for further identification by using sieves of different mesh sizes. Purification is the process of removing the organic matter attached to the surface of microplastics of the sample, help to clearly identify the amount and type of plastics. Appropriate concentration of  $H_2O_2$  solution and KOH solution are commonly used to dissolve the attached organic matter.
3. Identification. Visual sorting is conducted on the pre-treated microplastics with the use of stereomicroscopes, which saves time but is prone to errors. Other methods such as Sequential pyrolysis-gas chromatography coupled to mass spectrometry (Pyr-GC/MS), thermodesorption gas chromatography with mass spectrometric detection (TDS-GC/MS), Fourier-transform infrared spectroscopy (FT-IR), and Raman spectroscopy are much more accurate: Pyr-GC/MS can simultaneously analyze polymer types and organic additives for microplastics (Frise, et al., 2013); TDS-GC/MS can be used to analyze the composition of microplastics in larger samples (Dümichen, et al., 2015); FT-IR has excellent performance in determining polymer composition (Harrison, et al., 2012); Raman spectroscopy can be used for microplastic particle analysis with a particle size as small as 1 micron (Lenz, et al., 2015).
4. Quantification. Quantification is used to describe the abundance of microplastics in the environment. For the identified microplastics, they can be manually counted under a microscope or weighed with a scale. The common concentration units of microplastic are particles per  $m^2$  or  $m^3$ , or particle per kg (Mai, et al., 2018).

It should be noted that the selection of sampling points, sampling tools and methods, the operations of separation and purification, and identification processes will all affect the determination of microplastic abundance and the degree of contamination.

## 4. Potential solutions for microplastic contamination

### 4.1 Removal of Microplastics

#### 4.1.1 Source control

- **Plastics manufacturer**— The value of plastics as a material is actually very high, thus the manufacturer should prudently produce plastic products instead of producing single-use plastic products, such as cutlery, containers, and bags.
- **Recycling**— Plastic recycling is the process of collecting waste plastics and reprocessing them into useful products. In order to produce high-quality plastic products, the recycled plastics need to be clean and consisting of only one single type of plastic. Generally, plastics can only be reprocessed in a limited amount of times before they become too degraded (Rudolph, et al., 2017). It is worth noting that in the recycle process, although the containers look the same, in fact, each type of plastic consists of very specific chemical molecules, and recycling them together is like mixing oil and water. It will eventually lead to recycled plastic that becomes waste again (CPIA).

#### 4.1.2 Removal techniques of microplastics

- **Advanced wastewater treatment technologies.** Studies have shown that the current wastewater treatment plants can remove 99% of microplastics, but still leaving the final effluent with a large amount of microplastics. Several advanced wastewater treatment technologies are used after conventional activated sludge (CAS) method, and considered as final-stage wastewater treatment technologies. CAS systems usually consist of an aeration tank for biological degradation and a sedimentation tank used as secondary clarifier, in which the sludge will be separated from the treated wastewater. Processes include (One V Project):
  - Membrane bioreactor (MBR). The MBR method is used to treat primary effluent; it combines existing conventional activated sludge (CAS) with membrane separation, which can significantly improve final effluent quality (Baresel, et al., 2017).
  - Rapid (gravity) sand filter (RSF) is used to treat secondary effluent. In RSF, a layer of sand is used to filter the wastewater to remove suspended solids, the sand layer consists of 1m of gravel with a diameter of 3-5mm and 0.5m of quartz with a diameter of 0.1-0.5mm.
  - Dissolved air flotation (DAF) is used to treat secondary effluent. In DAF process, under high pressure, water saturated with air is pumped to a flotation tank at 1 atm to form dispersed water, by the adhesive power of the released air bubbles in dispersed water, the suspended solids will float to the surface with the bubbles.

Studies show that all above advanced wastewater treatment technologies remove microplastics (>20  $\mu\text{m}$ ) from effluents effectively (Talvitie, et al., 2017). The highest removal efficiency was provided by MBR, which removes 99.9% of the microplastics from primary

effluent, and RSF decreased 97%, and DAF decreased 95% of microplastics from secondary effluent.

- **Biology.** “Worm food”. A few species of fungi and bacteria can digest plastics, however this is done slowly. Craig Criddle, a professor from Stanford University, has found that the guts of mealworms contain bacteria, which can break down synthetic polymers (The Economist, 2018). Mealworms can digest one specific type of plastic, polystyrene (PS). In order to expand the use of mealworms, Dr. Criddle turned to polyethylene (PE), which is used more commonly in plastic products than polystyrene, and has very different chemical properties from polystyrene. According to his experiments, wheat bran is capable to increase the digestion rate of polymers by mealworms. The experimental results are ranked as follow: PE + wheat bran > PS + wheat bran > PE > PS. This major result is very promising as the mealworms do not just eat the plastics and leave them in their feces, instead, the bacteria in their guts lead to chemical reactions to convert plastics into carbon dioxide. Furthermore, Dr. Criddle found that the bacterial ecosystem inside the mealworms’ guts were making changes to adapt the “plastics meals”. Using mealworms to digest various types of plastics still requires further research. At the same time, it should be noted that the carbon dioxide generated during the digestion of plastics also has a negative impact on our environment.

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## 4.2 Government legislation and society contribution

### 4.2.1 Government legislation

To achieve risk prevention of microplastics, the first step is to overcome the lack of laws and regulations, and introduce of relevant standards. In China, there have not been any restrictions on the use of microplastic additives in facial products, toothpaste, and shaving foam. Such products are used daily. Legislating against using microplastics in such products require laws and regulations to have a desired effect. In addition, relevant standards must be established to encourage and guide manufacturers to minimize microplastics used in cosmetics, cleaning, and washing products, and require substitute ingredients with more natural, degradable particles including oats, corn, sea salt, almonds or walnut shells (Blackman, 2015). In addition, it is important to strengthen effective public publicity and communication.

At the national level, it is important to raise public awareness of the presence and danger of microplastics. Governments can encourage and guide the public to consciously reduce, or refuse, the use of products containing microplastics (microbeads), as well as single-use plastic products. National and regional plans should be made for the control of plastic waste at all levels, and it is also essential to promote the enactment of relevant legislations and regulations and improve plastic waste management system for reducing marine litter.

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The European Union, Canada, Australia, Austria, Luxembourg, Belgium and Sweden have successively carried out programs to address the concerns related to the elimination of microplastics or enacted relevant laws and regulations (Popular Science, 2014). Some well-known international companies in the world have also promised to reduce or stop using microbeads. It is reported that Illinois, will be the first state in the United States to ban the use of manufacturing microplastics (microbeads) often found in cosmetics and personal care products by the end of 2018, and also to ban the sale of such items by the end of 2019. California and New York will also ban the use and sale of microbeads in the near future.

There is no legislation for microplastics as contaminants in food, this gap must be filled (EFSA, 2016).

#### 4.2.2 Society contribution

- Social awareness  
It should be noted that in the long term, we need to fundamentally change the way we think about plastics and microplastics. We can no longer think of them as something that can be discarded carelessly after use, because of their persistence in the environment. We should start to regard plastic as a valuable resource. They are not inexhaustible, and our environment will not accept them endlessly. This means that the production and consumption of plastics must be reduced. At the same time, presence of microplastics must be made known to the world. It is just like us understanding and getting familiar with global warming. It took a long time and was a gradual process, but extremely important. Only by knowing enough about microplastics can we make this “hidden hazard” unhidden, so that every individual on the earth can work together to reduce, and combat microplastics.  
Dr. Harsh Vardhan, Minister of Environment, Forest and Climate Change said on 2018 World Environment Day: *“If each and every one of us does at least one green good deed daily towards our Green Social Responsibility, there will be billions of green good deeds daily on the planet.”*
- Behavioral changes. As a member of the public, one can reduce the use of disposable single-use plastic products in daily life and choose alternative products that can be recycled, or refusing to use disposable lunch boxes, and using cloth shopping bags to avoid plastic wastes and thus reduce the potential sources of microplastics.
- Education. Posters, workshops, lectures as providers of information could be introduced as educational tools in schools and communities.

## 5. The relationship and interaction between society and microplastics

Since the plastics industry began to boom in the 1960s, humans had to face the problem of plastic contamination. Most plastic wastes are piled up in landfills or in the environment; they will not disappear but will only slowly break down into smaller pieces, this property of plastics is and will be closely bound to the fate of humans, from generation to generation. The consequences of plastic

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contamination have penetrated all aspects of human life, from overexploitation of resources to the deterioration of living environment. The abuse of plastics has not only caused tremendous trauma to the environment and the ocean, but also profoundly affected humans around the world.

At present, the research on microplastics toxicology mostly focus on fish and invertebrates. There are few studies on humans, and as of now there are no studies that have shown potential impacts on humans from microplastics. However, according to a study conducted by the European Food Safety Authority in 2016, *"microplastics smaller than 150  $\mu\text{m}$  may translocate across the gut epithelium causing systemic exposure"*, additionally, 90% of microplastics found in bottled water are in the size range of 100 and 6.5 $\mu\text{m}$ , suggests that the extremely small plastic particles you ingest in food or drinks might interact with your body in a variety of ways (EFSA, 2016). It cannot be ignored that the combined toxicological effects of microplastics and their combined compounds, serve as a carrier of other contaminants, forming complex contaminants, which are harmful to humans, especially heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls.

Although it is very important and beneficial to public health, the study of the impact of microplastics on human health is still in its infancy, and further long-term research of human effects is required.

If the day were to come when microplastics are proved to be harmful to humans, would we still use "deep cleaning" products or plastic bags?

## 6. Summary and recommendations

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### 6.1 Summary

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- Raise the public awareness level of the hidden hazard — microplastics — by providing a holistic overview of microplastics.
  - Plastic is not plastic, it consists of various types of polymers, and additives for different purposes. Understanding the degradation processes of plastics into microplastics is important.
  - Microplastics are particles less than 5 mm, and are classified into two major types: primary microplastics and secondary microplastics.
  - Major sources of microplastic contaminants include land use activities, and processing and production activities.
  - Microplastics have become ubiquitous in the oceans, surface water, seawater, and sediments all around the world.
  - Microplastics show greatly negative impacts on both marine and freshwater system, with the pathway of land, surface water, sediments, to aquatic organisms.
  - Measuring and identification techniques for microplastics contribute to better understanding the distribution, abundance and the effects of microplastics.
  - Source control or advanced wastewater treatment technologies, as well as legislation and social awareness are promising to mitigation microplastic problem.
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## 6.2 Recommendations

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- Minimize the consumption and use of plastics products by individuals.
- Introduce laws and regulations to ban the use of manufactured microplastics in certain products, and minimize or restrict those plastics that rapidly degrade into microplastics at the national level.
- Improve wastewater treatment and plastic waste management techniques.
- More research is needed on the long-term impacts of microplastics on human health.
- Conduct more microplastic monitoring programs to gain better understandings of the fate of microplastics and their long-term effects on the environment.
- Introduce educational tools to make the public aware of microplastics and increase the knowledge regarding this hidden hazard.

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## Appendix

### 1. Common types of plastics

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- Polyethylene (PE) - the simplest plastic  
Because PE is colorless, odorless, non-toxic, it can be used to make various containers, such as bottles, lunch boxes, and other tableware and kitchen supplies, and food packaging bags; and also because of its easy molding, lightweight, and high level of impact resistance, it can be used to make toys, or motorcycle accessories. Other characteristics of PE such as corrosion resistance, insulation, and impervious, make PE preferred material for making submarine cable. However, absorbing ultraviolet light will cause PE discoloration, brittleness, and cracks. It will contribute to producing microplastics.
  - Polypropylene (PP) - The largest volume of production  
PP is lighter, harder, more transparent, and better heat-resistant (not deformed at 100 degrees Celsius) than PE, so it can be made into a variety of containers, plastic packaging, etc. Due to its good mechanical strength, PP can be used in car door accessories, and a wide range of woven products, and also often used as fiber fabric (polypropylene fiber); in addition, its good acid and alkali resistances are perfect for making acid and alkali resistant pipes.
  - Polystyrene (PS)
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PS is colorless and transparent, its transparency is second only to plexiglass in plastics, and the price of PS is much cheaper than plexiglass, but plexiglass has better fire resistance than PS; because it has good insulation properties, and the ability of response to high vibrations, PS is suitable as insulating materials in radar, and is also particularly easy to process and color, PS can be used to manufacture models and toys. But its shortcomings are high brittleness and poor heat resistance, and these make PS susceptible to disintegration into microplastics.

- **Polyvinyl chloride (PVC)** - the most diverse plastic  
PVC has many properties such as low permeability, good insulation, and resistance to aging. Thus it is suitable to be made into a variety of products with different appearance, including hard PVC (plastic buckets, combs, plates), soft PVC (curtains, raincoats, shoe soles, slippers), transparent PVC (agricultural plastic film), and non-transparent PVC (pipe); PVC is easy to be colored, so it is good for manufacturing plastic products with bright colors; artificial leather made by PVC (clothes, wallets) is easier to be processed and more resistant to water than leather.
- **Polymethyl methacrylate (PMMA/plexiglass)** - the most transparent plastic  
PMMA has a transparency of 93%, which is greater than 91% of glass, while its weight is only half of glass; it also has good fire resistance, high strength, good impact resistance, make it suitable for manufacturing car and train windows and lenses; it is also widely used in the manufacture of artificial teeth and artificial corneas. However, the surface hardness of PMMA is low, so it is easily scratched, causing the release of microplastics.
- **Phenol formaldehyde resins or phenolic resins (PF)** - The oldest plastic (produced since 1872)  
PF is thermoset, inexpensive, easy to process, heat resistant, corrosion resistant, high pressure resistant, and insulating. It is widely used in products in the electrical industry such as sockets, switches, etc.; PF foam can be used for sound insulation, heat insulation and shockproof packaging materials; most packaging plastics are single-use, increasing the burden on the environment.
- **Polyurethane (PU)** - the most leather-like plastic  
PU has strong elasticity, toughness, oil resistance, abrasion resistance, aging resistance, and tear resistance. Soft PU can be used as foamed plastics, sponge, etc. and manufactured into cushions or packaging materials; foamed plastics made by hard PU are suitable for building insulation materials. PU has better tensile strength and tear strength of PU than rubber, and is the preferred material for making tires, shoe soles, and conveyor belts. PU is also widely used in the manufacture of leather goods and clothing.
- **Polyamide resin (PA/nylon)** - the most wear resistant plastic  
The plastic products made of PA are called nylon, and they have high level of tensile strength, impact strength, is abrasion and heat resistance, and low coefficient of friction; PA is suitable for manufacturing fabrics, fishing nets, ropes, etc. It is also used in mechanical components such as gears, axles, chains, etc.; micro-fibers that eventually release into water by washing PA fabrics, and fish nets used in marine environments and freshwater environments have become major sources of microplastics and have harmful effects on the aquatic environment.
- **Polytetrafluoroethylene (PTFE)** or Teflon – the most non-stick plastics  
Polytetrafluoroethylene is resistant to acids and alkali and also to various organic solvents, and PTFE is almost insoluble in all solvents. At the same time, PTFE has the characteristics of high

temperature resistance, its friction coefficient is extremely low, so it can be used as a lubricant, and it has become an ideal coating for the inner layer of non-stick pan and water pipe.

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## 2. Common categories of plastic additives

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- Antioxidants - Delay the decomposition of plastics due to oxidation and prolong the life of plastic products. There are a wide variety of antioxidants, such as alkyl phenol, and organic phosphites.
- Antistatic agents - The main function of antistatic agents is to impart conductivity to plastics so that it does not accumulate static electricity caused by friction and helps to discharge the static electricity. Commonly used electrostatic agents are quaternary ammonium salt, and sulfonated wax.
- Foam-blowing agents - Trigger some foaming processes in the plastic body, resulting in a cellular structure, and reduce the weight of plastics. Common foamed plastics are PS, PVC, PU, PE, and PP.
- Flame retardants. When the flame retardant-added plastic is exposed to a flame, flame retardant-added plastic is capable of suppressing the spread of the flame on its own, preventing the formation of smoke, and stopping the combustion when there is no flame.
- Plasticizers – Low-molecular substances; as most synthetic resins have their own plasticity, but their plasticity is at variable. Adding plasticizers can increase the plasticity or decrease the viscosity of the synthetic resins, make them easy to be plasticized and also give the products flexibility, durability and stretchability (62 Hahladakis et al., 2018).
- Colorant– Including dyes and pigments, the characteristics of the polymers and the applications of the plastic product determine the choice of the colorant. For instance, dyes are used in strong and transparent plastics such as polystyrene, while pigments are preferred over dyes as they have opacifying ability and broader chroma.