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Prevention and Control of Waste Plastics Pollution in China

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Abstract: The prevention and control of waste plastics is an essential component of China's national strategy. In this study, the sources as well as the current situation and measures for recycling waste plastics in China were comprehensively analyzed. We proposed an all-round tactic for the prevention and control of plastic pollution in China based on a life-cycle assessment of plastics. Technically, waste plastic pollution should be prevented and controlled throughout the entire process of plastic synthesis, processing, utilization, and recycling; specifically, it includes the reduction of waste plastics at the origin by developing new degradable raw materials and environmentally friendly alternatives, the design and processing of high-performance plastic products with extended service life, development of new technologies offering efficient and large-scale capacity for recycling waste plastics, and safe disposal of the ultimate plastic wastes. Policy guidance must be strengthened at the government level, and administrative supervision should be implemented. At the enterprise level, an effective recycling system should be instituted to clarify the recycling responsibilities of producers, sellers, and consumers, providing policy and technical suggestions for the prevention and control of waste plastics. At the public level, the environmental awareness of citizens must be aroused to promote nationwide participation in waste management. These suggestions are favorable for the green and sustainable development of China's plastic industry as well as the national economy.

Keywords: waste plastic; environmental pollution; prevention and control; recycle; full-chain management

1 Introduction

Materials are key components in the development of human society. Polymer materials, such as plastics, rubber, and synthetic fibers, have excellent properties, including low density, easy processing, high performance, and multi-functionality, and they are widely used in various fields [1]. The plastic industry is a pillar in China's national economy. In 2019, China's plastic processed products amounted to 8.184×10^7 t, with the highest production and consumption in the world [2]. However, waste plastics are currently stored in an unresponsible manner because of the low regulation on the production and use of plastic products and the random stacking of plastic waste. Therefore, the severe environmental pollution and waste of the resources must be controlled. Statistics show that approximately 8.3×10^9 t of plastic products have been produced globally, with a waste amount of about 6.3×10^9 t until 2015, while only 9% of this has been recycled [3]. In 2019, 6.3×10^7 t of plastic waste was produced in China, and only 1.89×10^7 t of this was recycled or reused [4]. The prevention and control of waste plastic pollution are of significant importance to people's health and the development of the country's ecological

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environment. This is an important part of building a beautiful China with clear water and green mountains, as per the vision of Chinese Government.

Based on the analysis of the current status of waste plastic pollution and recycling technologies, this paper presents measures and suggestions for preventing and controlling plastic pollution in China, in terms of a lifecycle assessment and all-round waste prevention measures. We thus provide essential policies and technical references for promoting the green and sustainable development of the plastics industry.

2 Analysis of current waste plastic pollution and prevention

2.1 Current pollution of waste plastics

2.1.1 Sources of waste plastics

According to their sources, waste plastics can be divided into four categories: industrial, agricultural, medical, and living. Industrial waste plastics primarily refer to waste materials generated during the plastic production process. Industrial waste plastics are mostly clear and concentrated sources, being raw materials, and have a high recycling value. Agricultural waste plastics include abandoned agricultural mulch films, shed films, agricultural pipelines, and pesticide packaging. Among them, the agricultural waste films, with the highest rate of occurrence and most difficult post-treatment, pose a significant threat to the farmland and ecological environment. Medical waste plastics generally come from disposable plastic products used for medical health and epidemic prevention, such as protective clothing, medical-surgical masks, and protective eyepieces, which are hazardous wastes presenting direct or indirect risks of infection, toxicity, and other hazards. Living waste plastics are waste plastic products produced during daily activities, and are of various kinds and widely dispersed, including plastic bottles, plastic packaging bags, and paper–plastic composite materials.

2.1.2 Hazards of waste plastics

At present, the total annual production of solid waste in China exceeds 1×10^{10} t, of which waste plastic comprises approximately 6.3×10^{7} t, accounting for approximately 0.6% of solid waste [5]. However, plastics do not readily degrade naturally owing to their stable chemical structure. The improper use and disposal of plastics and its cumulative effects have led to severe environmental pollution and a massive waste of resources. In particular, disposable plastic products such as plastic fast-food boxes, plastic packaging bags, and agricultural plastic films with short use cycles are widely used, and most are mixed with domestic waste or soil after abandonment, making recycling challenging. Therefore, the soil, mountains, and ocean are severely polluted, leading to environmental pollution incidents such as the “garbage siege” of cities and the “highest garbage dump” on Mount Everest. Some refractory waste plastics release a large amount of toxic gases during incineration process, which pollute the atmosphere and cause haze. Petroleum resources are scarce in China, with the external dependence exceeding 70% in 2018, and approximately one-third of imported petroleum is used to synthesize plastic products [6]. If waste plastics are not recycled, non-renewable resources such as oil, coal, and natural gas are wasted. Waste plastics are misplaced resources that have a high recycling value. The effective disposal of waste plastics, especially through recycling, is expected to reduce plastic pollution.

2.2 Current status of global prevention and control of waste plastic pollution

Since the 1990s, increasing attention has been paid to the pollution control of waste plastics worldwide. The United Nations Environment Programme continues to launch large-scale global campaigns to reduce, reuse, and recycle waste plastic products. For example, the global Ocean Cleaning Campaign, launched in 2017, called on governments, industries, and consumers, to reduce the production and overuse of plastics. In 2019, waste plastics were brought into the control scope of the *Basel Convention*. The United States, Europe, Japan, and other developed countries and regions have formulated a series of conventions, policies, and regulations, and established a legal system for the prevention and control of plastic pollution, such as the *Resource Protection and Recycling Law* in the United States, the *EU Plastic Restriction Order* in European Union, and the *Promotion Law on Resources Effective Utilization* in Japan [7]. Developed countries have high labor costs and stringent environmental protection measures and often export large amounts of waste plastics to other countries. For example, according to statistics from the American Waste Recycling Industry Association, the United States exported 2×10^{6} t of waste plastics in 2017, 70% of which was exported to China. Even after China’s bans on the import of foreign waste, dealing with the substantial amount of waste plastics remains an ongoing concern.

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2.3 Current status of prevention and control of waste plastic pollution in China

2.3.1 Current status of waste plastic treatment in China

The disposal methods for waste plastics in China include recycling, incineration, and landfilling (Fig. 1). In 2019, the amount of waste plastic generated in China amounted to 6.3×10^7 t, of which disposable plastic products such as plastic bags, agricultural films, and beverage bottles were the primary sources of "white pollution," with more than 2×10^7 t being produced annually. Additionally, as home appliances, automobiles, and buildings are gradually being abandoned, their plastic parts have become an important source of waste plastics. Thirty percent of waste plastics are recycled, 14% are incinerated for power generation to recover heat energy, 36% are buried in landfills, and 20% are arbitrarily discarded, thereby causing severe environmental pollution.

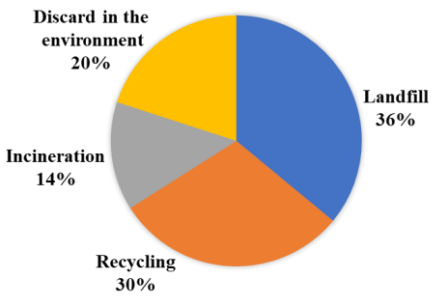

Fig. 1. Statistics on the flow direction of wasted plastics in China from 1949 to 2019 [8].

2.3.2 Main principles and legal system for the prevention and control of waste plastics in China

China emphasizes the importance of the prevention and control of plastic waste pollution. In 1995, the *Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Wastes* was promulgated. The national ministries and local governments have successively issued a series of normative documents to formulate the relevant national and industry standards, gradually improving the legal system for the prevention and control of waste plastics and proposed the principles of "reduce, reuse, and recycle", full-process management, and classified management of solid wastes. Recently, new control regulations on plastic pollution have been introduced. On September 9, 2019, General Secretary Xi Jinping presided over the tenth meeting of the Central Committee for deepening the overall reform to review and approve the *Opinions on Further Strengthening the Treatment of Plastic Pollution*. On January 16, 2020, the National Development and Reform Commission and the Ministry of Ecology and Environment jointly issued the *Opinions on Further Strengthening the Treatment of Plastic Pollution* to regulate the recycling and utilization of plastic waste, promote the standardization, centralization, and industrialization of the resource utilization, and strengthen the guidance of innovation and the support of science and technology to control plastic pollution in an orderly and effective manner. Additionally, a series of policies were issued, such as the construction of "waste-free cities" and "beautiful villages," to promote waste plastic pollution prevention and the recycling industry in China.

2.3.3 Scientific and technological support for prevention and control of waste plastic pollution in China

National ministries and commissions pay great attention to founding scientific projects for the prevention and comprehensive utilization of waste plastics. The Ministry of Science and Technology has set up a series of scientific research projects on pollution prevention and the comprehensive utilization of waste plastic products. During the 13th Five-Year Plan period, the National Key Research and Development Program of China involving "solid waste recycling" was carried out to guide technological innovations, such as fully biodegradable plastics and related products, intelligent recycling and the reuse of waste plastic products, and high-value utilization of secondary resources. A comprehensive recycling chain of waste plastics was initially formed to promote the rapid development of the waste plastic recycling industry, as shown in Fig. 2.

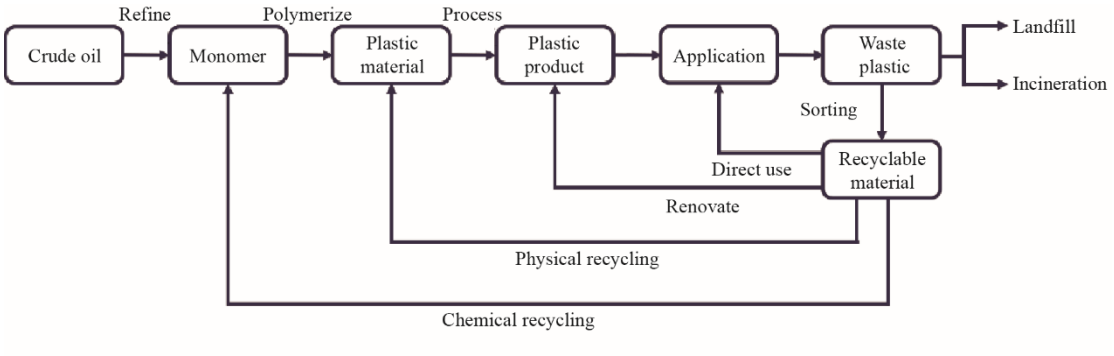

Fig. 2. Technology system for the complete recycling of waste plastic in China.

2.3.4 Current status of the waste plastic recycling industry and enterprises in China

Waste plastic recycling is a strategic emerging industry with great development potentials. In recent years, the construction of waste plastic recycling systems has been strongly promoted in China. Relying on the three major industry associations of China, namely the Plastics Processing Association, China Synthetic Resin Association, and China Material Recycling Association, many large-scale trading markets and processing centers of recycled plastics have been developed, and 25 industrial parks have been established for the renewable resource–circular economy, including 21 waste plastic recycling parks [9]. Statistics show that the amount of domestic waste plastic recycling was 1.89×10^7 t in 2019. The recycling rate was close to 30%, and the total economic value of recycling was more than 100 billion yuan. More than 3000 registered enterprises have been engaged in waste plastic processing in China, of which 300 enterprises have a recycling capacity of more than 1×10^4 t/a and 50 enterprises have a capacity of more than 5×10^4 t/a [10].

2.4 Recycling technology of waste plastic

The recycling of waste plastics can be classified into material and energy recycling. The primarily recycling methods are shown in Fig. 3. According to the priority order of recycling, the International Recycling Standard Guide divides the recycling of waste plastics into four levels. The first and second levels comprise material recycling, namely physical recycling; the third level is chemical recycling, and produces chemicals or oil; and the fourth level is incinerating waste plastics to recover energy [11].

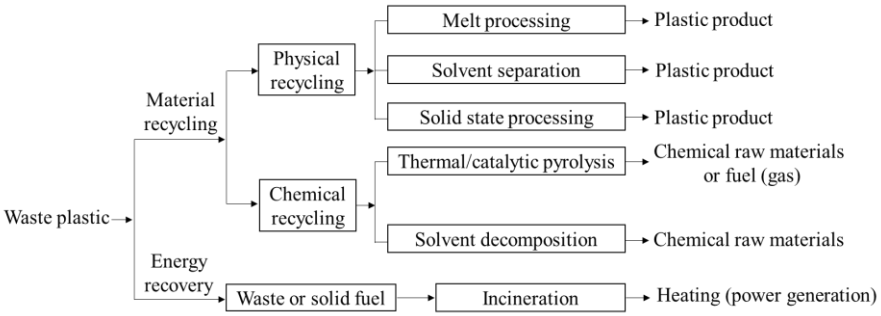

Fig. 3. Recycling technologies for waste plastics.

2.4.1 Physical recycling

Physical recycling does not change the chemical composition of plastics but instead prepares recycled plastic products through collection–rough classification and selection–simple cleaning and crushing–melt processing. It is widely used to recycle single-material waste thermoplastics, such as for recycling waste polyester bottles to prepare recycled polyester fibers and waste polystyrene foam to prepare decorative products. However, more than 60% of plastic products are structural and functional parts used in aerospace, electronics, transportation, and other fields. High-performance and multi-functions are realized through blending, compounding, cross-linking, etc., and these materials cannot be easily recycled. For traditional melt processing methods, it is difficult to classify and separate blended composite products with poor component compatibility, significant melting point differences, mismatched melt viscosity, and large domain sizes. As a result, the obtained products exhibit poor performance, and their applications have a low value. Cross-linked plastics are infusible and insoluble and thus cannot be

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reprocessed. They are treated via landfilling or incineration methods, creating environmental pollution and energy waste, which is a bottleneck and difficulty for solving plastic pollution.

2.4.2 Chemical recycling

Chemical recycling involves the degradation of waste plastics into reusable fuels (gasoline, diesel, etc.) or raw chemical materials (ethylene, propylene, etc.) using cracking technology. However, practical applications are difficult from an economic point of view because of the complexity of the chemical recovery equipment and high energy consumption [12]. In recent years, chemical recycling technology has developed rapidly, and many companies have achieved commercialization and are planning to expand their application in the future. However, some intrinsic issues of high-temperature thermal cracking, such as high temperature requirements, long reaction time, low yield, complex products, and substantial production of harmful exhaust gases, lead to secondary pollution and a poor economic value. Catalytic cracking and solvolysis are believed to have potential for use in chemical recovery, but the catalyst efficiency needs to be improved, and green solvents need to be developed [13].

2.4.3 Energy recycling

Energy recycling, which generates heat energy by burning, is primarily applicable to waste plastics that have serious pollution and cannot be recycled by traditional physical and chemical methods. In this case, high-temperature gas is generated by waste incineration for power generation. However, incineration produces toxic gases, such as hydrogen chloride, dioxins, and polycyclic aromatic hydrocarbons, which cause secondary air pollution. The development of advanced high-temperature incineration equipment should be promoted to achieve safe and clean incineration.

3 All-rounded tactic for the prevention and control of plastic pollution

3.1 Lifecycle assessment of plastics

The lifecycle management of plastics is based on a comprehensive environmental assessment of its products. The entire process is tracked to evaluate the potential impact of all inputs and outputs during the entire lifecycle on the environment, starting from the initial crude oil extraction, synthesis, processing, and application to the final waste treatment, as shown in Fig. 4. At the same time, the synthesis and processing can be guided in turn according to the application and processing methods, which can improve the techniques and management, promoting the recycling of plastics, and minimizing plastic pollution. Adopting efficient methods to manage the lifecycle of plastics and develop integrated technologies for the safe use of resources can improve the use efficiency of plastics and can reduce their impact on the environment.

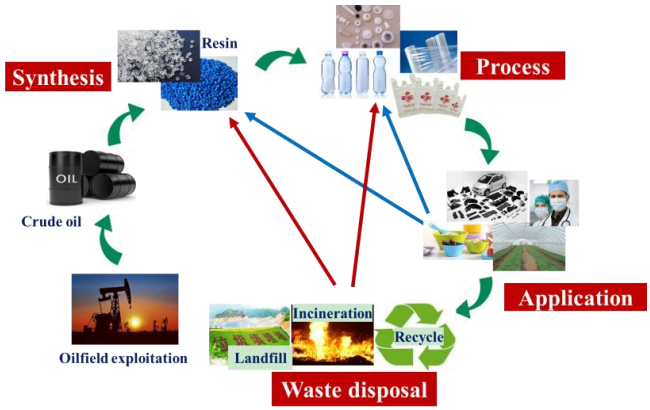

Fig. 4. Lifecycle of plastics.

3.2 Prevent and control waste plastic pollution in an all-round chain including synthesis, processing, application, and waste treatment

By evaluating and analyzing of the entire lifecycle of the synthesis, processing, application, and waste disposal of plastic products, it is proposed that the prevention and control of waste plastic pollution must adhere to the fundamental national policy of saving resources and protecting the environment. The prevention and control of waste plastic pollution can be carried out through measures such as the reduction of plastic products, the substitution of raw materials and products, high-value utilization of waste plastics, and safe treatment.

3.2.1 Prevent and control waste plastic pollution during synthesis

Most plastics originate from non-renewable petrochemical resources. The synthesis process is mature, large-scale, low-cost, and widely used, and the output continues to increase. However, petroleum is a non-renewable resource with an import dependence as high as 70.9% in China. Moreover, the primary chains of the obtained plastic macromolecules are connected by C—C bonds, which are difficult to degrade in nature. However, the structure of thermosetting plastic materials, such as epoxy resin and phenolic resin, are three-dimensional networks, which causes the structure to be insoluble and infusible, thus making it difficult to recycle. The prevention and control of waste plastic pollution must start from the source by 1) establishing a source-reduction synthesis technology system to synthesize high-performance, long-life, and easily recyclable petroleum-based polymer materials; 2) strengthening the development of easily recyclable products; 3) developing cost-effective biodegradable plastics, such as polylactic acid and carbon dioxide copolymers, to achieve controlled degradation and improve the overall performance of materials; 4) developing new low-cost, high-yield polymerization technologies that focus on the development of biodegradable plastic materials, such as polyvinyl alcohol that China has already produced on an industrial scale to replace disposable products that need to be landfilled; and 5) developing advanced technologies for the clean and large-scale utilization of biomass resources, such as cellulose and chitin, to realize the prevention and control of plastic pollution from the source.

3.2.2 Prevent and control waste plastic pollution during processing

The performance of plastic products is not only related to their molecular structure, but also on the multi-level and multi-scale structure formed during processing. Through blending and compounding, filling reinforcement, cross-linking, foaming, and other processing methods, plastic products can be prepared to be high-performance, multi-functional, lightweight, long-living, and ecological. However, it is difficult to classify and separate discarded composite plastics, while cross-linked plastics are insoluble and difficult to melt for reprocessing. Therefore, they cannot be recycled or reused via traditional recycling methods. There is an urgent need to 1) develop advanced plastic processing technologies to reduce blending and compounding and realize homogeneous and heterogeneous enhancement to improve the performance of plastic products, extend the service cycle, and reduce the amount of waste; 2) realize the homogeneous manufacturing of parts and components and develop environmentally-friendly additives to facilitate the recycling and reuse of plastic products after being discarded; 3) design and manufacture plastic products that can be reused multiple times to reduce plastic waste, and 4) develop advanced plastic recycling equipment and technologies to realize high-value and efficient recycling of blended composites and cross-linked plastics, such as extensional rheological plasticization-transportation processing technology[14], solid-state shear milling processing technology [15].

3.2.3 Prevent and control waste plastic pollution during application

China should promote reasonable and appropriate use and consumption of plastic products, encourage recycling, and reduce the amount of waste at the source. Strengthen management to realize “who produces should handle, who buys should return, and who sells should collect.” It should also improve the policy system for recycling waste plastics and increase the public’s recognition of recycling waste plastics; develop legal and appropriate application channels, such as farmland water conservancy, road materials, and outdoor facilities; and provide legal protection for reuse.

Different applications of plastic products have different performance requirements. According to the characteristics of different plastic products, the prevention and control of waste plastic pollution should be carried out during application. For cross-linked industrial structural parts and functional parts made with blended composites, recycling and reuse should be promoted to fully extend the service life of plastic products, and environmentally-friendly polymer recycling technology should be developed. The excessive use of plastic packaging products should be avoided as they are short-lived and difficult to collect after disposal, with a high impact on the environment. Products should be designed so that they can be used multiple times to realize the reduction of plastic packaging products. For agricultural films that are difficult to recover after service, advanced processing technologies should be established to be fully recover and reprocess these materials. Furthermore, research and development of fully biodegradable plastics and the use of biodegradable plastics in disposable plastic products should be promoted. Medical protective equipment should be made of non-toxic polyolefin plastics, and medical waste and hazardous waste plastics should be incinerated at high temperatures.

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3.2.4 Prevent and control waste plastic pollution during waste treatment

Based on the concept of prevention and control of waste plastic pollution in an all-round chain, waste plastic products need to be reasonably and scientifically classified prior to processing or recycling, which can then be treated via different methods for different types of plastic waste. Effective waste treatment can solve the environmental pollution problem caused by the improper disposal of waste plastics and can allow the material and energy reuse of waste plastics. Constructing a complete industrial chain of waste plastic recycling and increasing the recycling rate of waste plastic products can effectively promote the comprehensive utilization of plastic resources. According to the characteristics of multiple production areas, multiple sources, and differentiation of waste plastics, the localization of recycling and utilization models needs to be innovated, and application models need to be popularized. For recyclable waste plastics, priority should be given to the development of environmentally friendly physical recycling technologies, improving the recycling and processing of single-material waste plastics, and breakthroughs in the recycling and processing problems of mixed waste plastics; use only biodegradable plastic packaging in landfill treatment of mixed wet garbage from restaurants and kitchens to achieve safe landfills, and the development of environmentally friendly incineration equipment and processes is necessary for the green incineration of hazardous waste plastics to achieve low emissions and recover energy.

4 Countermeasures and suggestions

4.1 Strengthen government leadership and department linkage

Based on the experience of fighting the COVID-19 epidemic, it has been suggested that joint prevention and control mechanism as well as the mass prevention and control working models should be implemented. Under the unified leadership of the CPC Central Committee and the State Council, the boundaries of departments, regions, and industries should be broken to form a new mechanism for the prevention and control of waste plastic pollution involving government leadership, enterprise implementation, market drive, and public participation. By integrating the pollution control of solids, water, and air, the prevention and control mechanism of waste plastics should be built with clear responsibilities, coordination, and strict supervision, based on experiences in air and water pollution control.

4.2 Improve laws and regulations and accelerate standard development

The prevention and control of plastic pollution should be explicitly incorporated into relevant laws and regulations of China. We should clarify the responsibilities and obligations of the main bodies in the production, sales, consumption, and recycling of plastic products in waste plastic recycling systems. Extended producer responsibility should be perfected, and a deposit refund system should be introduced. Moreover, national standards for recycled plastics and products should be formulated to allow the legal and appropriate application of recycled plastics. The use of recycled plastics and products should be encouraged and enforced. National standards and certification systems for degraded plastic products should be formulated or revised to end pseudo-degradable and fake-degradable plastic products.

4.3 Improve the recycling and utilization of waste plastics

A multi-level and full-coverage network should be established and improved for the prevention and control of waste plastic, and the mode of “who produces should handle, who buys should return, and who sells should collect” needs to be developed. The classification of household plastic waste should be implemented for villages, towns, communities, and individual households. A strategic emerging industrial system for recycling and utilizing waste plastics from a national recycling base to small and micro recycling and processing enterprises should be established to mitigate environmental pollution, reduce pressure on energy and resources, and provide job opportunities. The treatment of waste plastic should be combined with the construction of “zero-waste cities” and “beautiful countryside.”

4.4 Increase financial support and improve preferential policies

We should increase financial investment and preferential tax policies to support the development of waste plastic recycling industries. It is suggested that the stakeholders in the synthesis, processing, sales, and application of plastics should pay the fee for the recycling and disposal of waste plastics, and funds should be devoted to scientific research, enterprises, and treatment departments for recycling waste plastics.

4.5 Strengthen scientific and technological support and lead the prevention and control of plastic pollution

The environmental risk assessment of different plastic products throughout the entire lifecycle should be carried out. New synthesis technologies should be developed for preparing plastics with high performance, long life spans, and easy recovery, in addition to developing low-cost synthesis technologies for biodegradable plastics. Advanced processing methods should be developed for high-performance, lightweight plastic products. Heterogeneous reinforcement could be implemented in materials, with one product comprising of the same material. Reusable products must be generated. New equipment and technology should be developed for high-value, efficient recycling of mixed waste plastics based on the polymer state, using environmentally friendly and energy-saving incinerators, flue gas purification technologies, and ash immobilization technologies. Moreover, new chemical recovery technologies for difficult to recycle plastics and their environmental impact should be studied.

4.6 Strengthen publicity guidance and universal participation in governance

Scientific and authoritative publicity for the prevention and control of plastic pollution should be strengthened. We should not only strengthen management but also avoid the demonization of plastics. Attention must be paid to raising the awareness of citizens for environmental protection, by advocating for reasonable and moderate consumption, conscious and active participation in the prevention and control of waste plastic pollution, and conscious implementation of the standard classification and recycling of waste plastics.

5 Conclusion

The prevention and control of waste plastics not only affects public health but is also related to the construction of ecological civilization and high-quality development in China, which is an important part of the implementation strategy to build a beautiful China with clear waters and green mountains as proposed by the CPC Central Committee. For the prevention and control of waste plastic, it is essential to achieve the reduced production of plastic products, the substitution of raw materials and products, high-value utilization of waste plastics, and safe treatment in an all-round chain from synthesis to waste treatment. Strengthening policy guidance, intensifying administrative supervision, improving scientific and technological innovation of plastic recycling, increasing investment in scientific research, enhancing citizens' environmental consciousness, and encouraging the participation of people are also essential components. Finally, through mass prevention and treatment measures, the recycling of waste plastics can be improved to promote pollution control and resource protection.

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