



Current influence of China's ban on plastic waste imports

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Abstract

The current global production of plastics is over 300 million tons, 20% of which is produced in China. It has been estimated that about 90% of the discarded plastics are not recycled. China was the world's leading importer of waste plastics, while since January 1, 2018, China's import ban on waste plastics has been put into force, which has had a far-reaching effect on global plastic production and solid waste management. Southeast Asian countries like Malaysia have replaced China as the leading importer of plastic wastes. As the main exporter of waste plastics, EU has released strategy and initiative about plastics to restrict the use of micro plastics and single-use plastics. Meanwhile main European countries like UK, German and France have also taken own active measures to realize the control of packaging waste and non-recycled plastic and the recycling of plastic wastes in several years. As For the US, some areas such as Seattle and San Francisco have positively responded to the global trend of plastic ban. However, the controversy over “plastic restriction” in the whole state obstructed the promulgation and implementation of the national plastic ban. On the whole, major companies and more than 60 countries all over the world have introduced levies or bans to combat single-use plastic wastes. The Chinese government began to rectify the domestic waste plastics market and the Ministry of Industry and Information Technology of China has clarified the threshold of waste plastic treatment capacity for key enterprises. In addition to landfill, direct recovery and waste to energy processes are the main disposal methods of waste plastics. Thermoplastics like PE, PP and PET that are sorted out from the waste stream by citizens can be directly recycled to the primary material. The mixed waste plastics can be used as fuel in waste to energy plants, or as feedstock to pyrolysis plants that transform them to high value-added oil or chemical materials, which are more promising disposal methods of waste plastics.

Keywords Waste plastics · China · Ban · Import · Pyrolysis

Introduction

Plastics are polymer compounds derived from the polymerization of small molecular organic compounds such as ethylene, styrene, etc. and can be classified broadly into thermoplastic and thermosetting plastics. Since the initial invention of plastics, various kinds of plastic products have become excellent substitutes for traditional materials such as paper, wood, metal and ceramics in various manufacturing

industries because of their advantages of light weight, high strength, good insulation, high transparency, excellent corrosion resistance, low cost and ease of fabrication [1]. The current global production is estimated at about 300 million tons and it is expected to reach 500 million tons by 2050, most of which will be single-use products [2].

The various advantages of plastics have led to expansive growth in their production and consumption and this has also resulted in serious problems such as environmental pollution and waste disposal. Plastic debris is the major pollutant listed by the EU (61%) and the USEPA (78%) [3].

However, despite much effort in developing countries, less than 10% of the generated plastic wastes are being recycled to the original materials [4]. As a result, about 75% of the wastes floating in the marine environment are plastics and over two-thirds of which are not biodegradable [5, 6]. A study by JR Jambeck reported that over 5 million tons of

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plastic wastes were discarded into the oceans in 2010 [7]. The plastic debris in aquatic habitats has caused immeasurable potential harm to marine ecosystems and also to the health of terrestrial organisms [8].

Because of the mounting problems due to plastic pollution, governments in many countries have tightened restrictions on plastic products, in particular single-use ones. China is an active participant and promoter of plastic wastes control. In April 2017, the Chinese government approved a ban on imported “recyclable” solid wastes. The ban list included 24 kinds of solid wastes, among which non-industrial plastic wastes is the most prominent. The Chinese ban became effective at the beginning of 2018 and has had a far-reaching effect on global plastic production and on solid waste management.

This study examines the global response to China’s ban on plastic waste imports, the current situation on plastic waste generation and disposition in China and future prospects for sustainable resource recovery from non-recyclable plastic wastes.

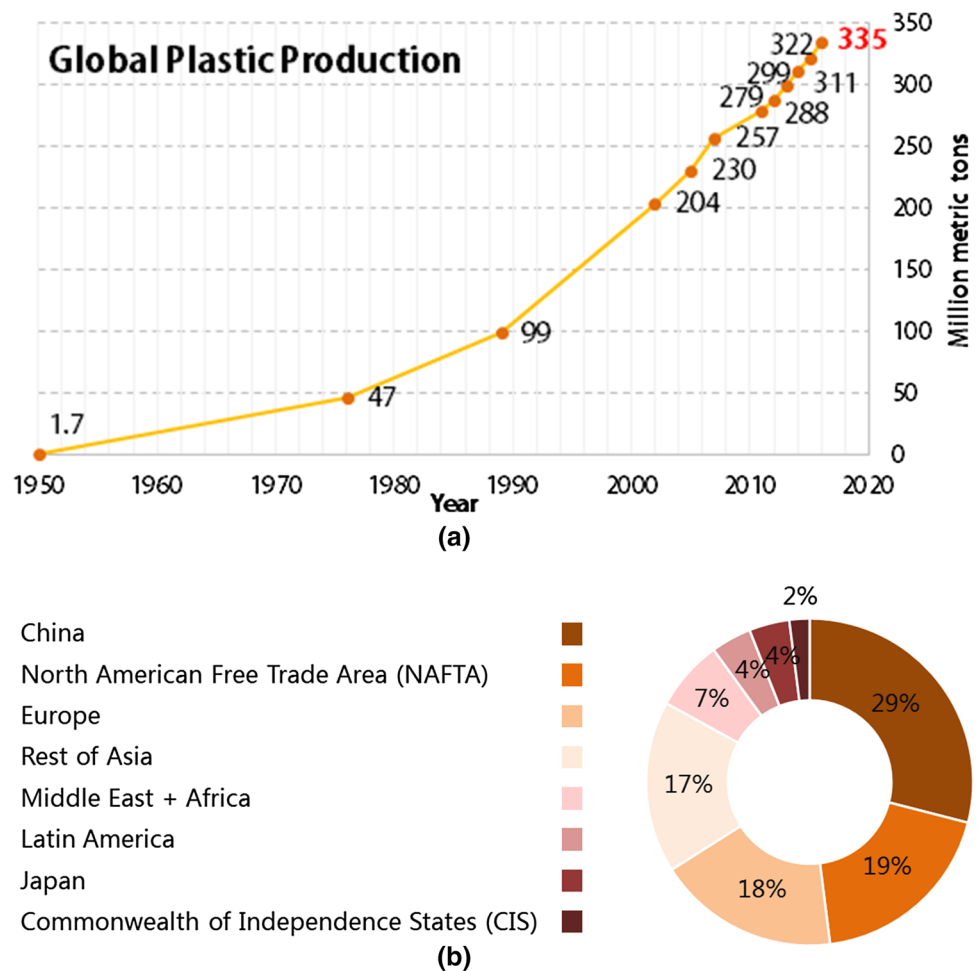
Plastic wastes in the world

Key facts: plastics and plastic wastes

Plastic production in the whole world, Europe and the US

Plastics are versatile materials which could be widely used in the fields of industrial production and our daily lives. Current production of plastics consumes 6% of the global oil production and, if the current trend continues, it will increase to 20% by 2050 [9]. As shown in Fig. 1a, the annual production of plastics in the world reached 335 million tons by 2016, with an annual growth rate of about 4% [10]. China is the largest producer of plastic products, accounting to about 29% of worldwide production, followed by North American Free Trade Area (NAFTA) (19%) and Europe (18%). Asia accounts for nearly half of the world’s plastic production.

Fig. 1 Global plastic production (a) by year and (b) by area, in 2016 Data source: Eurostat



Types and use of plastics

Take Europe for example. The dominant plastic products are polypropylene (PP), low density polyethylene (LDPE) and high-density polyethylene (HDPE); these three compounds amount to 49.1% of all plastics in Europe (Fig. 2 [11]).

1. Polypropylene (PP)

Polypropylene is a semi-crystalline thermoplastic plastic. It is widely used because of its high impact resistance, strong mechanical properties and resistance to a variety of organic solvents, acids and alkalis. The main applications of PP include the production of long and short polypropylene fibers, woven bags, packaging bags, injection molded products which are used for electrical, telecommunications, lighting, lighting equipment and TV sets of flame retardant parts. PP contributes about 24% in plastic wastes category which are the largest amount of plastics found in MSW [12]. The high demand of PP in daily life causes the amount of PP wastes to increase each year.

2. Low-density polyethylene (LDPE)

Low-density polyethylene (LDPE), also known as high-pressure polyethylene, is suitable for various molding processes. Unlike HDPE, LDPE has more branching that results in weaker intermolecular force, lower tensile strength and lower hardness. The main LDPE products include thin film products, such as agricultural film, ground cover film, agricultural membrane, vegetable shed film, packaging film such as candy, vegetables, frozen food and other packaging, liquid packaging with blow molding film (milk, soy sauce, juice, soy milk); Heavy packaging bags, shrinkage packaging films, elastic films, lined films; building films, general industrial packaging films and food bags, etc.

3. High-density polyethylene (HDPE)

High-density polyethylene (HDPE), also known as low-pressure polyethylene, is a translucent film with high crystallinity and a certain degree of non-polarity. It is an opaque white material with specific density lower than water (0.941–0.960). It is soft but slightly harder than LDPE and slightly stretchable. Due to its high-strength properties, HDPE is widely used in manufacturing of milk bottles, detergent bottles, oil containers, toys and more [13]. In addition, HDPE is also used to produce packaging film, ropes, woven mesh, fishing nets, water pipes, injection molding of lower grade daily necessities and housings, non-bearing load components, rubber boxes, turnover boxes, extrusion blow molding containers, hollow products, etc.

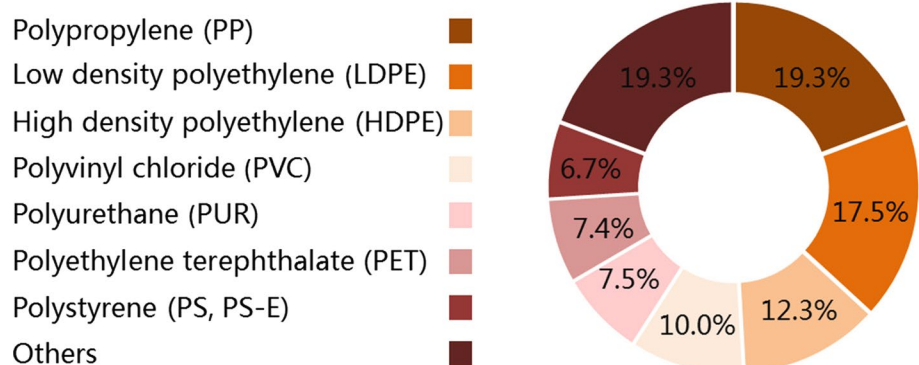
4. Polyvinyl chloride (PVC)

PVC is formed by the polymerization of the monomer ($H_2C=CHCl$) and, therefore, consists of about 56% chlorine and 44% carbon plus hydrogen [14]. Some minor compounds, such as plasticizer and anti-aging agent are added in the manufacturing process to enhance the heat resistance, toughness and ductility of PVC; they may be potentially toxic so PVC is generally not used to store food and medicine. The compatibility of PVC with other additives makes it a versatile plastic. Regular PVC products include wire and cable insulation, window frames, boots, food foil, medical devices, blood bags, automotive interiors, packaging, credit cards, synthetic leather, etc.

5. Polyurethane (PUR)

Polyurethane is the most common plastic in the thermosetting family of plastics which accounts for only a small fraction of the plastic waste stream. Polyurethane (PUR) is a polymer with a repeating structural unit of the carbamate chain made from isocyanates and polyols. The density of PUR soft foam ranges from 0.015 to 0.15 g/cm. PUR products are divided into foaming products and non-foaming products. The foaming products include soft, hard, semi-rigid PUR foam, while non-foaming products include coatings,

Fig. 2 Main types of plastics demanded by Europe in 2016 [11]



adhesives, synthetic leather, elastomers and elastic fibers. Foam is the most widely used PUR product.

6. Polyethylene terephthalate (PET)

Polyethylene terephthalate is formed by the polymerization of the monomer $(C_{10}H_8O_4)_n$ and, therefore, it consists of about 33% oxygen with the balance carbon and hydrogen. PET plastics have good transparency, excellent dimensional stability and electrical insulation. Containers made of PET have high strength, good transparency, are non-toxic and easy to fabricate; other applications of PET include electrical insulation, printing sheets, magnetic tapes, X-ray and other photographic films [15].

7. Polystyrene (PS)

Polystyrene is made by polymerization of the monomer $(C_8H_8)_n$. As other plastics it can be colored by means of additives. It is heat resilient and it offers strength and very low density which make this polymer suitable for use in many applications, such as food packaging, electronics, construction, medical, appliances and toys. The wide range of applications results in a large volume fraction of PS in the MSW stream [13].

The distribution of use of plastic products in various industries is shown in Fig. 3.

Waste plastics production

The global consumption of plastics in 2016, by region, is shown in Fig. 4. The per capita consumption of plastics in developed countries is much higher than in other regions. Plastic consumption in NAFTA has reached 139 kg/person,

Fig. 3 Main market demand for plastic products in 2016 [11]

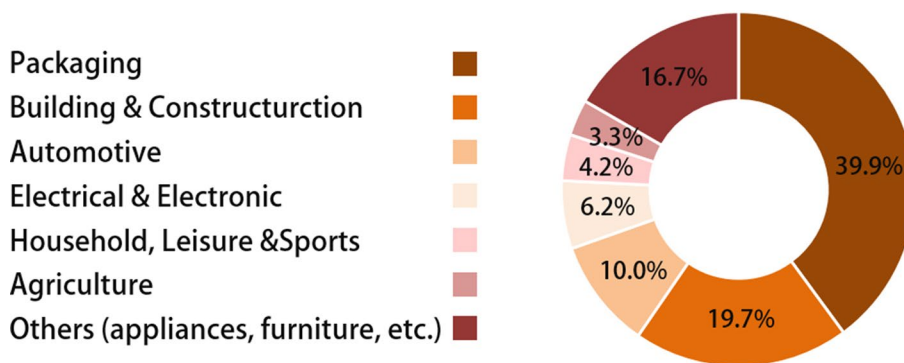


Fig. 4 Per capita consumption of plastics (in kg/person) [16]

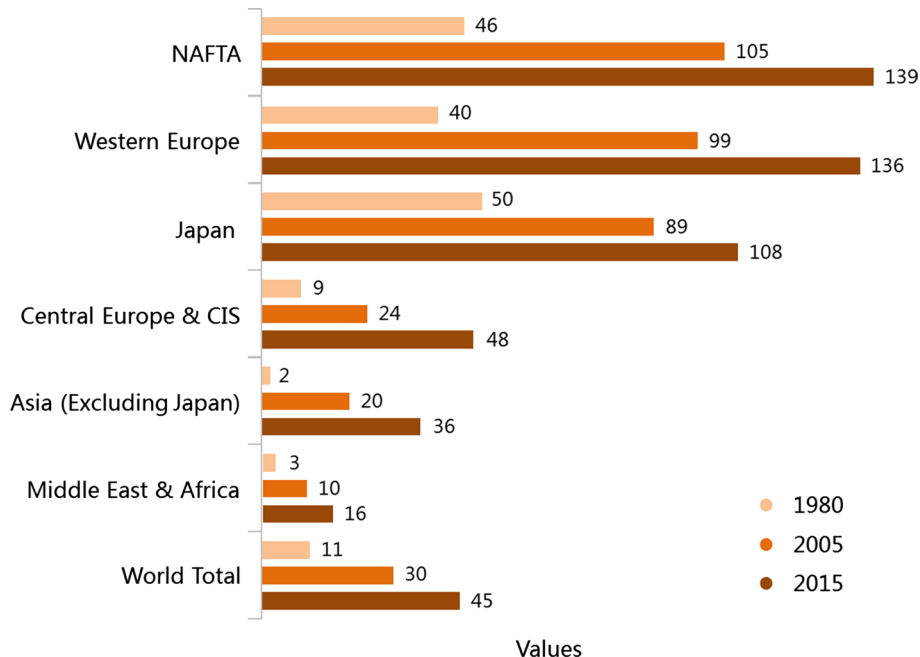


Fig. 5 Cumulative plastic waste generation and disposal (1950–2015) and projection of historical trends to 2050 [17]

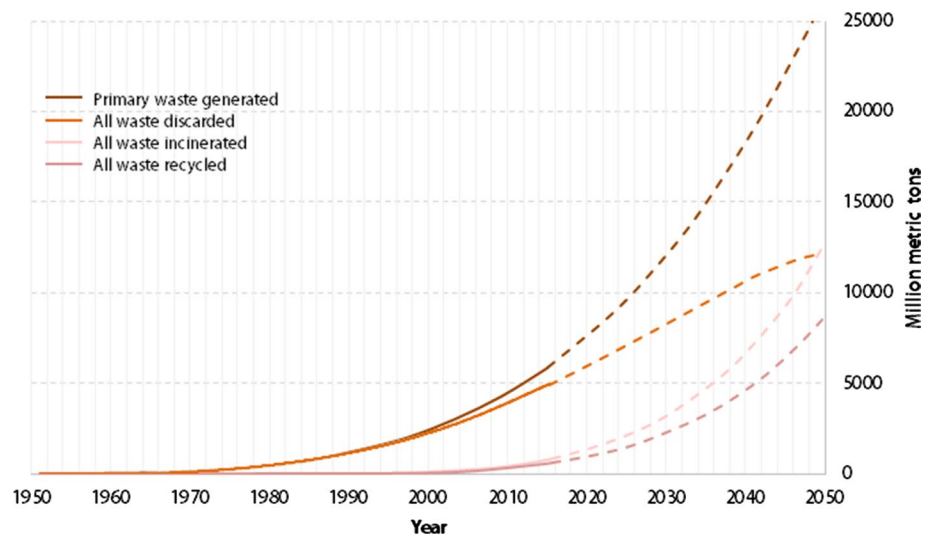


Table 1 Distribution of life-span of four types of plastics

Type	1–2 years (%)	3–5 years (%)	6–9 years (%)	More than 10 years (%)
PE	67	20	10	3
PP	38	20	34	8
PS	40	25	35	0
PVC	35	15	20	30
Average	45	20	25	10

which is the highest in the world. The per capita consumption in Asia is lower than the world average.

Figure 5 shows that the accumulation of plastic waste has reached 5.8 billion tons by 2015. And if the current trend continues, it will exceed an astonishing 25 billion tons by 2050, with around 50% still undisposed [17].

Table 1 lists the distribution of life-span of four of the most common plastics: PE, PP, PS and PVC. Around 67% of the PE products have a life-span of less than 2 years. Moreover, more than half of the PP and PVC products have a life span of less than 5 years. Polyolefins (PE and PP) are mainly used to produce packaging materials, such as plastic bags, milk bottles, packaging films, sweet and snack wrappers, etc. while the life-span of plastic products used for packaging usually does not exceed one month, which has led to the rapid accumulation of PE and PP-based plastic wastes [18].

Table 2 Weight ratios of typical plastic species in plastic wastes in some regions

Weight ratios	Country or region	References
LDPE:HDPE:PP:PS:PVC = 27%:21%:18%:16%:7%	The U.S. and Canada (1992)	[19]
PE:PP:PS = 68%:6%:16%	Portugal (1999)	[20]
PE:PS:PP:PET:PVC = 42.2%:24.1%:17.6%:8.9%:5.1%	Sapporo, Japan (2003)	[21]
PP:HDPE:LDPE:PS:PET = 30.4%:26.5%:22.8%:18.0%:2.3%	Czech Republic (2004)	[22]

The weight ratios of common compounds (PE, PP, PS etc.) in the waste stream, as estimated by four separate studies are shown in Table 2. These numbers indicate that plastic products made from PE, PP and PS have a much shorter life-span.

Global response to China’s ban on plastic waste imports

As noted earlier, China’s ban on non-industrial plastic wastes began on January 1, 2018. Prior to this ban, China (45%) and other developing countries in East Asia were the main destinations of the estimated 70% of plastic wastes exported in 2016 by higher-income countries [23].

China’s ban on plastic wastes has resulted in higher consumption of virgin plastic. Morgan Stanley has predicted that China’s ban would change by about 2% the polyethylene supply in the world, from recycled plastics to virgin plastic [24].

Prior to the Chinese ban, Europe and Central Asia were the main exporters of plastic wastes (32%), followed by North America (14%) [23]. The responses of the main exporters, active followers and participants are summarized in the following section.

Response of Europe

The European Commission has indicated that by 2030, all plastic packaging will be recyclable on the EU market and the intentional use of micro plastics will be restricted [25]. The effort of European Commission in this new year started with the publication of *European Strategy for Plastics in a Circular Economy (COM/2018/28 final)*, on January 16, 2018, which listed the future EU measures for implementing this strategy and its recommendations to the member states and the industry. The measures contain 39 actions divided in four aspects:

1. Improving the economics and quality of plastics recycling;
2. Curbing plastic waste and littering;
3. Driving investment and innovation towards circular economy solutions;
4. Harnessing global action.

This first-ever *European Plastics Strategy* highlights the gaps between the current legal and policy framework about marine plastic wastes and starts to change the ways in which plastic products are designed, produced, used and recycled in Europe. On May 28, 2018, E.C. released the *Proposal for a Directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment (COM/2018/340 final—2018/0172 (COD))*. This initiative identified gaps between the existing actions and legislation and reinforced the EU systemic approach to plastic waste problem. On October 24, 2018, the European Parliament adopted a plan which banned single-use plastics like plates, cutlery, straws and cotton swabs in participating countries by 2021.

In the UK, China's ban on waste plastics has forced the UK to shift its waste exports to other Asian and European countries. Malaysia has become a major importer of waste plastics from the UK, with a total import volume of 105,000 tons in 2018, which was 42,000 tons (68%) higher than in 2017. Turkey, Poland, Indonesia and the Netherlands followed closely, with imports of plastic wastes increasing by 60,000 tons in 2018 [26]. Also, in response to the global trend of plastic limitation, the Prime Minister Theresa May announced a plan to ban the sale of plastic straws, drink stirrers and plastic-stemmed cotton buds by April 2017.

In Germany, the German Federation of Waste, Water and Raw Material Management stated that the total export of plastic wastes from Germany to China has dropped from 346,000 tons in 2017 to only 16,000 tons in 2018. A new German law focuses on reducing packaging waste and was approved by the upper house of the German parliament on May 12, 2017. This law was enforced as of January 2019 and aims to recycle 63% (from 36% in the past) of the plastic

packaging materials and reach a target of 70% reusable beverage packaging.

France is planning to introduce a penalty system for non-recycled plastic and use only recycled plastic for packaging by 2025.

Response of the USA

Some regions in the US have also adopted a series of restrictions on plastic wastes. On July 1, 2018, Seattle became the first US city to ban plastic utensils and straws in this city's 5000 restaurants. San Francisco also voted to ban plastic straws and containers as of July 1, 2019. The U.S. Plastics Resin Producers has committed to recycle or recover 100% of the plastic packaging by 2040. Some states or cities are also strengthening the restrictions on single-use plastic products, while in some other regions, the controversy over "plastic restriction" is continuing (Fig. 6).

According to statistics from the US Census Bureau and international trade commission, the exports of plastic wastes from the US to China dropped sharply from about 900 million between January and October in 2017 to about 120 million tons in the same period in 2018. Malaysia has replaced China as the leading importer of plastic wastes from the US, with imports of plastic waste exceeding 192,000 tons in the first 10 months of 2018. In addition, Thailand's imports of waste plastics from the US also increased significantly [26].

China's imports of virgin PE have increased by 19%, and the plastics industry in the US has invested \$185 billion to build new capacity as the response to this development opportunity [24].

Response of other countries and organizations

- On June 5, 2018, India vowed to ban single-use plastics by 2022. In April 2018, Nasarawa State announced that it is collaborating with the Federal Ministry of Environment to establish a plastic recycling plant in the Karu in order to deal with the plastic wastes in major urban centers in the state.
- When the amount of plastic wastes imported increased sharply after the Chinese ban, Thailand announced plans to ban the import of plastic wastes from Western countries by 2021.
- Vietnam has suspended imports of waste plastics after June 25, 2018 and the restriction has been extended until further notice.
- Japan is subsidizing the production of bioplastics to replace petroleum-based plastic products and has made a budgetary provision of ¥5 billion for the researches about the disposal of used bioplastic products.
- Governments in more than 60 countries, e.g. Morocco, Rwanda, Chile, Botswana and Peru have introduced lev-

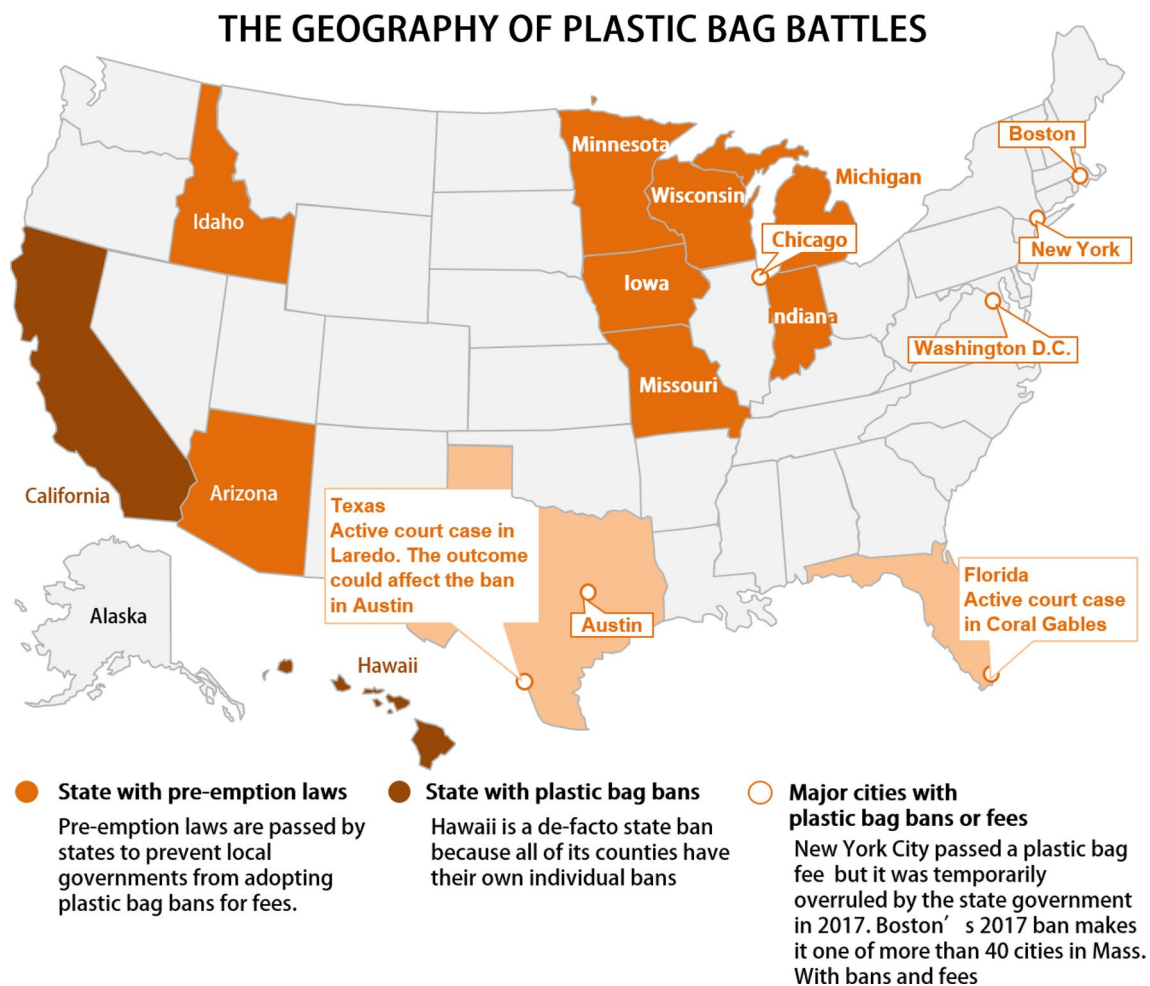


Fig. 6 The geography of plastic bag bans in the US (2018) [27]

ies and bans to combat single-use plastic waste. However, inadequate enforcement has made these bans ineffective.

- Several major companies, such as Amcor, Ecover, Evian, L'Oréal, Mars, M&S, PepsiCo, The Coca-Cola Company, Unilever, Walmart and Werner & Mertz, which in total produce 6 million tons of plastic packaging per year, are mounting efforts to replace the current plastic packaging with 100% reusable, recyclable or compostable packaging by 2025 or earlier [28]. Also, Aramark and Starbucks have committed to reduce or abolish the use of single use plastics by 2020 and 2022, respectively.

Global trade in plastic wastes after the Chinese ban

As shown in Fig. 7, after China's ban, the import of US plastic wastes to China in 2018 was only one tenth of that in 2017. Since 2016, the importation of plastic wastes has increased by over 100% in India, Thailand, Vietnam and Malaysia. However, other Asian countries, such as Indonesia

and Vietnam have controlled effectively the imports of waste plastics.

Plastic wastes in China

Plastic production in China

Through decades of rapid development, the plastics industry of China has become a major world player in the world. Production and sale of plastic products accounted for about 20% of the global output value [30].

According to the 2018–2023 research report on market prospects and investment opportunities of China's plastic products industry from the China Merchants Industrial Research Institute, the cumulative production of plastics in China was 77 million tons in 2018, and the annual growth rate was around 3.1%. The principal uses and estimated tonnages of plastics in China are summarized in Table 3 [31].

Fig. 7 Exports of “other” plastics (e-plastics, mixed plastics, etc.) from the U.S. to other countries in periods of Jan–Sep 2017 and Jan–Sep 2018 [29]

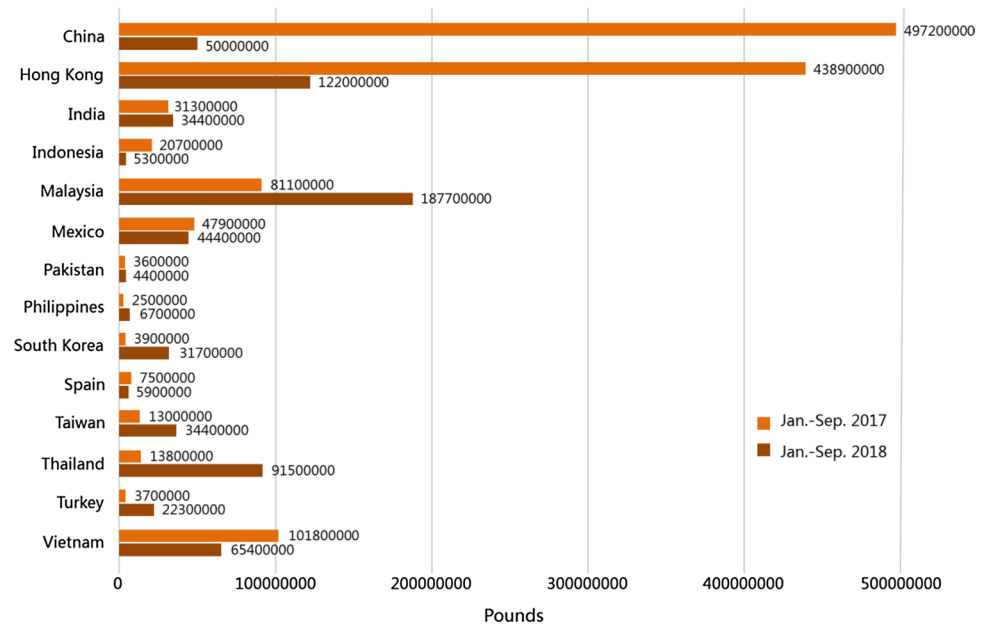


Table 3 Main uses of plastics in China [31]

Industry	Plastics	Main types	Plastic consumption in 2016	
Building materials	Doors and windows	PVC, PE	2.6 million tons	
Cars	Baffle panel	PP	More than 400 thousand tons	
Textile	Clothes	PET, PP	10 million tons	
Agriculture	Mulch	PE	3 million tons	
Industrial packaging	Plastic woven bag, wrapped film	PP, PE	3 million tons of PP, 1.5 million tons of PE	
Daily life of residents	Shopping bags	PE	1 million tons	
	Bottles	PET, PE	5 million tons of PET, 0.5 million tons of PE	
	Washing bottles	PE, PP	1 million tons of PE, 0.5 million tons of PP	
	Composite packaging	PET, PE, PP	1 million tons of PET, 2 million tons of PP, 0.5 million tons of PE	
	Courier bags	PE	0.7 million tons of PE	
	Cushion packaging	EPS, PE	1 million tons	
	Disposable tableware	PS, PP	2 million tons	
	Eisai nonwoven fabric	PP, PET	2 million tons	
	Durable goods	Home appliance	PVC, PP	0.3 million tons
		Furniture	PVC, PP	2 million tons
Storage box		PE, PP	1 million tons	
Wallpaper		PVC	2 million tons	

Policy for treating plastic wastes

The “Industry standard” of the Ministry of Industry and Information Technology (MIIT) defines the threshold of waste plastic treatment capacity of three key types of enterprises.

According to the requirements, (1) the annual waste plastic disposal capacity of new enterprises engaged in regenerated PET bottle flakes producing must be over

30,000 tons and that of established enterprises should be over 20,000 tons; (2) the annual disposal capacity of waste plastics for new enterprises engaged in waste plastic crushing, cleaning and sorting must be over 30,000 tons and for established enterprises over 20,000 tons; (3) the annual waste plastic treatment capacity of new enterprises engaged in plastic recycling and granulation must be over 5,000 tons and for existing enterprises over 3000 tons [32].

Recycling of plastic wastes

According to statistics, the annual output of municipal solid waste has reached more than 210 million tons in China [33], among which the waste plastics account for 11% (about 23 million tons) [34]. As for the recycling and utilization of waste plastics, the average recycling rate in China is only 25%, about 14 million tons of waste plastic are discarded each year [35].

Waste plastic recycling not only saves national resources and promotes economic development, but also makes great contribution to environmental protection. It is a green environmental protection industry that benefits the country and people. At present, waste plastics are piled up without being recycled effectively in many cities, causing severe environmental pollution problems. The waste plastic recycling industry in China is in its early infancy and consists of small- and medium-sized manufacturers.

Plastic wastes treatments

The complexity of plastic types and high cost of separating make it difficult to recycle and reprocess the plastic wastes. According to statistics, only 9% of the plastics were recycled and about 12% were sent to waste to energy (WTE) plant for incineration, while most of the plastics (79%) were disposed as trash and end up in landfill or in the natural environment [4].

Resource recovery from plastic wastes

Thermoplastics like PE, PP and PET that are sorted out from the waste stream by citizens can be recycled to the primary material. Waste PE, PP and PET can be made into finished products after granulation, or be directly processed by simply cleaning, crushing and plasticizing. The utilization mode without any modification is called direct recycling. Direct recycling is characterized with low

operating costs, low equipment and technological requirements. However, direct recycling also has negligible deficiency. It cannot be used in the production of higher quality products. In order to improve the quality of recycled materials, it is often necessary to add a certain proportion of virgin PE, PP, or PET materials, which accordingly increase the manufacturing cost [36]. Modified regeneration refers to the modification of recycled materials by mechanical blending or chemical grafting, which could improve the mechanical properties of the modified regenerated products. Modified regeneration process routes are more complex and some also need specific mechanical equipment [37].

Combustion with energy recovery (waste to energy or WTE)

Mixed plastic wastes have a calorific value of about 35 MJ/kg which is about 85% that of fuel oil. Therefore, they can be used to fuel power plants, in place of coal or oil. Combustion is fully controlled, does not require pretreatment of the mixed waste plastics and is a mature technology practiced in over one thousand plants worldwide and is relatively mature [38]. The flowsheet of a waste to energy process is shown in Fig. 8.

The incineration of waste plastics is accompanied by the production of toxic organic gases such as polycyclic aromatic hydrocarbons, dioxins and furans. Plastic components containing chlorine, nitrogen and other additives will also release inorganic pollutants such as NO_x and HCl during the incineration process, causing secondary pollution.

A report from environmental campaigners has claimed that UK incinerators will cause nearly £25bn of environmental harm during the next 30 years by burning plastics [39].

Swindon Borough Council has proposed temporarily stopping the recycling of mixed plastics and instead send it to Energy-from-Waste. Swindon said this was because of uncertainty about exports and other markets.

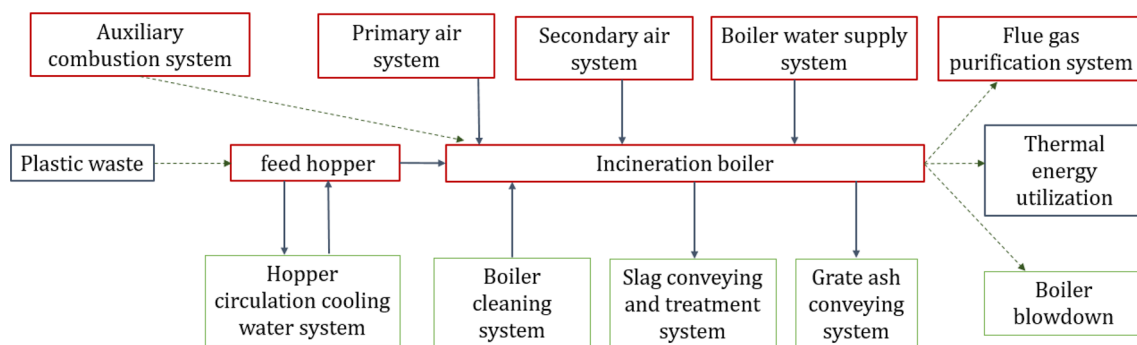


Fig. 8 Process flow chart of combustion with energy recovery

Pyrolysis of plastic wastes to oil

Since petroleum is the principal source of plastics manufacturing, there is great potential for transforming plastic wastes to oil through the pyrolysis process. The oil produced by pyrolysis has a high calorific value comparable to commercial fuels.

Different types of plastics can be defined based on moisture, fixed carbon, volatile matter and ash content (proximate analysis). High volatile content favors the production of liquid oils, while high ash content reduces the amount of liquid oils produced, thereby increasing gaseous yield and coke formation. Most waste plastics have very high volatiles and low ash content. It should be noted that the yield and quality of the pyrolysis products depend on the operating parameters of the pyrolysis process. The main parameters include temperature, reactor type, residence time, pressure, catalyst dosage and the type of fluidizing gas and its flow rate [12]. Figure 9 is a process flow chart of pyrolysis and gasification of township domestic waste.

Gasification

Gasification of waste plastics produces a stream of gases including H₂, CO, CO₂, CH₄ and N₂. A significant advantage of gasification compared to pyrolysis is that it is more flexible. Gasification of waste plastics is mainly for the production of energy-carrying gas (H₂) and synthesis gas

(fuel, dimethyl ether, methanol, etc.), wherein the synthesis gas has an average calorific value of about 6–8 MJ/m³. The composition and application of the gas produced by the gasification process depend on the gasifying agent used [40].

The main problem of plastic gasification is the high tar content in gas products, which is usually higher than the tar content in biomass gasification. Therefore, gasification of waste plastics requires a very efficient gas cleaning system.

Gasification is expected to maximize the conversion of plastics into gas products or syngas. Tar and carbon are the main undesirable by-products. Gasification process includes complex chemical reactions: gas-phase drying, pyrolysis, reforming and heterogeneous carbon gasification, which is summarized in Fig. 10.

Direct recycle has advantages of low operating cost, less equipment and processing requirements, but it can not be used to produce high-quality regenerated products [41]. Incineration can realize energy recovery and volume reduction of waste plastics effectively whereas it will bring severe secondary pollution and the quality of the product is relatively low [42]. Gasification has high process flexibility and high product quality. However, the tar in syngas has become a serious problem in large-scale application of gasification technology [43]. Pyrolysis is not as mature as incineration, but the mild reaction conditions, easily controlled reaction process, high value-added products and less secondary pollution make it a promising technology [44].

Fig. 9 Industrial flow chart of pyrolysis gasification treatment technology

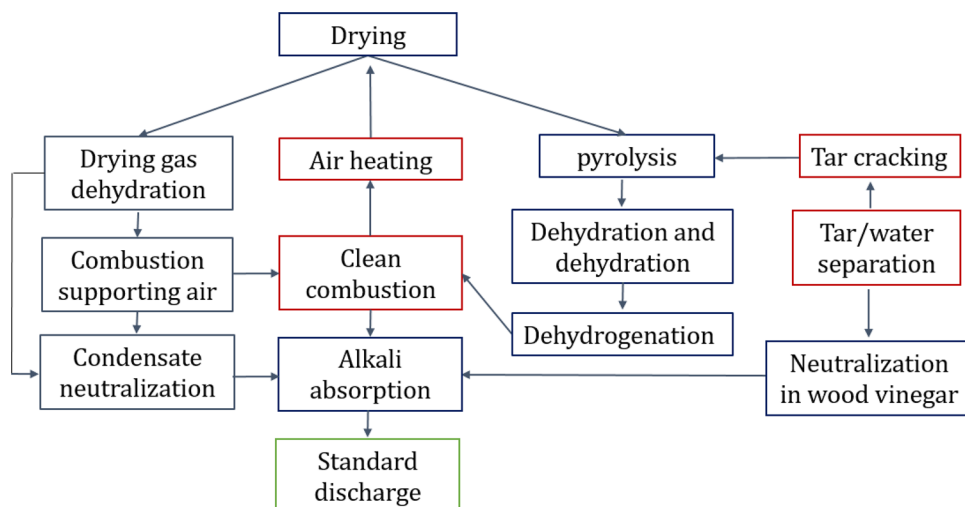
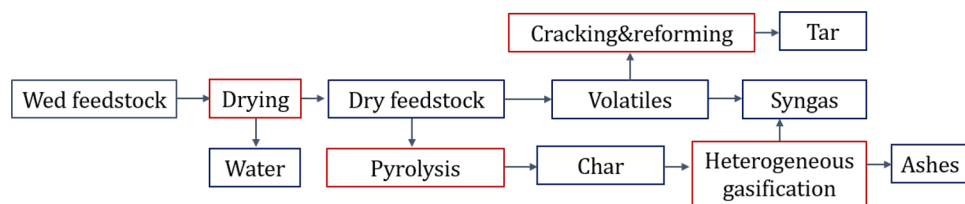


Fig. 10 Flow chart of plastics gasification



Discussion about the impact of China's ban on plastic waste treatment

At present, the main means of disposal of waste plastics are landfill, incineration, recycling, pyrolysis and gasification, etc. For countries with systematic garbage classification, such as the EU and Japan, the high-quality waste plastic components (such as PP, PE and PET) can be directly used as the raw material for plastic regeneration. As a result, direct recycle becomes the main disposal means of waste plastics at present and in the future. For countries that do not have a complete waste classification system, incineration is the most economical, efficient and convenient method to realize the treatment of large-scale mixed waste plastics in a long time. In addition, because of the low requirement of raw material, controllable high-quality of products and less environment pollution, pyrolysis as a disposal means of waste plastics has attracted worldwide attention and research interest. High-quality fuel and chemical materials produced by pyrolysis could meet the world's energy and industrial development needs [12]. Thus, WTE technologies represented by pyrolysis are more promising methods to realize resource reuse in the long term.

Conclusion

This review provides concise summary of the global response to China's ban on plastic waste imports, the current situation on plastic waste generation and disposition in China and sustainable resource recovery technologies from non-recyclable plastic wastes. China's import ban on waste plastics has been put into force since January 1, 2018, which led to the changes of waste plastics policy and market waste plastics globally. Southeast Asian countries like Malaysia have become the leading importer of plastic wastes. EU and the US have positively responded to the China's ban, strategy and initiative released about plastics to restrict the use of micro plastics and single-use plastics. Meanwhile, main European countries like UK, Germany and France have also taken their own active measures in response to the China's ban on waste plastics. In addition to the ban on waste imports, the Chinese government has also made certain regulations on the domestic waste plastics market. The global recovery rate of waste plastics is only about 10%. Waste to energy technologies based on pyrolysis and other thermal disposal means are promising technology to realize the utilization of non-recycled plastic wastes. Through comparing a variety of waste plastic disposal technologies, pyrolysis is more promising method because of its mild reaction conditions, easily controlled reaction process, high value-added products and less secondary pollution.

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