REPORT
of the National Think Tank

COMPREHENSIVE RESEARCH REPORT

on Chemical Recycling of Waste Plastics

废塑料化学循环综合性研究报告

Institute of Economic System and Management,
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FOREWORD

At present, plastic pollution has become a hot environmental issue of global concern, and countries are negotiating international instruments on plastic pollution. China attaches great importance to the control of plastic pollution. In recent years, relevant government departments have continuously issued a series of policy documents to strengthen the control of plastic pollution. From the practice of China, the European Union, Japan and other advanced countries in the materialized recycling of waste plastics, restricted by the structure of plastic products, the engineering plastics and rigid hollow plastics for packaging with good resource value have basically achieved physical recycling, but the low-value waste plastics, such as flexible packaging and film bags, accounting for about 46% of plastic output, can hardly meet the standard technological and economic conditions of physical recycling, and are generally treated by incineration or landfill. Therefore, once a country or region reaches a materialized recycling rate of about 30% for waste plastics, it will face a huge bottleneck in further increasing its recycling rate, and it is an urgent need to find a new solution.

Chemical recycling of waste plastics refers to the process of using waste plastics as raw materials to convert waste plastics into a certain proportion of plastic monomers and other chemical components as by-products chemically, and further producing plastics and other chemical products.

Research suggests that:

(1) Chemical recycling and physical recycling are two major methods for the materialized recycling of waste plastics. Through chemical recycling, the resource utilization of low-value waste plastics that cannot be realized physically can be achieved. And the materialized utilization of waste plastics can be achieved by the combination of the two methods.

(2) Compared with physical recycling, chemical recycling owns significant advantages, it has a wide range of raw material adaptability, able to recycle the low-value waste plastics and composite packaging that cannot be effectively and economically recovered physically. It can even recycle waste plastics that have been stockpiled historically in landfills or nature, and transform them into plastic raw materials of the same quality as those produced crude oil, so as to achieve the closed cycle in the plastics industry, to provide a new solution to global plastics pollution.

(3) Chemical recycling can turn "white pollution" into "white oil fields", providing a strong guarantee for energy and resource security. In 2022, China produced more than 60 million tons of waste plastics, including about 42 million tons of incineration or landfill. If 50% of them had been chemically recycled, an oil field of more than 60 million tons would have been developed; and recycling 1 billion tons of the existing stock of plastic wastes will be equivalent to developing a super-large-scale "urban oil field" at a lower cost.

(4) Chemical recycling is at a key stage of industrial development: after decades of technological development, chemical recycling technique has gradually matured, and mainstream technologies

based on pyrolysing, depolymerization and gasification have been formed. Large-scale enterprises at home and abroad such as SINOPEC, China National Petroleum Corporation, Qingdao Huicheng Environmental Technology, Wanhua Chemical, ExxonMobil, Shell, BASF and Saudi Basic Industry Corporation have carried out demonstration and application of the chemical recycling of waste plastics, promoting the chemical recycling of waste plastics to enter a new stage of industrialization.

(5) Compared with incineration and landfill, chemical recycling owns more comprehensive benefits: according to incomplete calculation results, t he net income of chemical recycling of waste plastics i s about 850 yuan per ton without government subsidy, which is significantly higher than that of incineration and landfill. Disposing 1 ton of waste plastics by chemical recycling can save 1.12-1.22 tons of crude oil, which can obviously save energy resources, better than incineration, which can only save 0.77 tons of standard coal. Landfill does no good to resource saving. In terms of environmental benefits , the environmental impact potential of chemical recycling is lower than that of incineration, while that of landfill is long-term.

Research suggestions:

(1) Defining the strategic positioning of chemical recycling of waste plastics: take it as an important component in building China's plastic pollution control system and strategic security guarantee of energy resources, incorporate it into the policy and regulation system of plastic pollution, circular economy planning and waste material recycling system planning, and take it as a core means to cope with plastic pollution.

(2) Defining the industrial development positioning of chemical recycling: take chemical recycling as an important technical route for waste plastics recycling. In terms of industrial layout, take chemical recycling projects as the comprehensive utilization of resources, prioritize the centralized layout and operation management in chemical parks, and give the top guarantee to carbon emission index, energy-use index and land-use index, and exclude them from the management of Two-High projects, and not limited by chemical projects capacity.

(3) Establishing a waste plastic classification and recycling system compatible with chemical recycling: accelerate the reform and improvement of the existing domestic waste sorting system, dispose low-value plastic waste as low-value recyclables, add special recycling bins (barrels) for waste plastics in urban and rural residents' domestic waste sorting, and build an urban low-value recyclable sorting center to sort out low-value waste plastics from domestic wastes for chemical recycling enterprises to utilize.

(4) Promoting the construction of chemical recycling demonstration pilot projects: drive large-scale enterprises to increase investment in chemical recycling of waste plastics, build a number of demonstration projects about chemical recycling of waste plastics, support key enterprises to launch industrialization demonstration by newly building or utilizing existing installations, and encourage the construction of demonstration projects for the integrated development of upstream and downstream industrial chains.

Prospects:

It is estimated that by 2035, the annual output of plastic products in China will reach 155 million tons, and if the utilization rate of chemical recycling among them reaches 30%, the overall materialized recycling rate of waste plastics will exceed 60%, and the annual plastic waste will be reduced by nearly 36 million tons through chemical recycling, and the carbon dioxide emission will be reduced by 22.32 million tons compared with the incineration of waste plastics, and the oil resources will be saved by about 108 million tons, which is equivalent to recreating two Daqing oil fields, and the output value will exceed 160 billion yuan.

It is expected that by 2035, the global plastic production will be doubled, and the annual global plastic production will reach 734 million tons. If the global recycling rate of waste plastics can increase from the current 9% to 30% through chemical recycling, 150 million tons of recycled plastics will be added each year, reducing carbon dioxide emissions by 93 million tons compared with waste plastic incineration, which is equivalent to saving 450 million tons of oil resources, to reach 67.8% of the total consumption of 663 million tons of oil of Europe in 2022, and the output value will exceed 680 billion yuan.

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01

Connotation of Chemical Recycling

Chemical recycling of waste plastics refers to the process of using waste plastics as raw materials and using chemical methods to convert waste plastics into a certain proportion of plastic monomers as well as by-products of other chemical components, and to further produce plastics and other chemical products.

1.1 Definition of Chemical Recycling

Some institutions at home and abroad have defined the connotation of chemical recycling of waste plastics. The European Chemical Industry Council (ECIC) believes that the purpose of chemical recycling is to convert waste plastics into chemicals by changing the chemical structure of polymers and converting them into chemical components, which include plastic monomers and can be used as raw materials for the chemical industry[1]. American Chemical Society (ACS) considers that chemical recycling can decompose plastics into their chemical components through chemical processes such as depolymerization and thermal pyrolysing to make new polymers or for other uses[2]. The British Plastic Federation (BPF) defines chemical recycling as a series of emerging technologies used in plastic waste control, able to recycle plastics that are difficult to physically recover or cannot be economically recovered[3]. The Technical Specification for Pollution Control of Waste Plastics issued by the Ministry of Ecology and Environment of People's Republic of China, puts forward the definition of chemical regeneration of waste plastics, that is, the process of chemically reconverting waste plastics into resin monomers, oligomers, pyrolyzing products, or syngas.

This report considers that chemical recycling of waste plastics refers to the process of using waste plastics as raw materials, using chemical methods to convert waste plastics into a certain proportion of plastic monomers as well as by-products of other chemical components, and further producing plastics and other chemical products.

[1] Plastic Europe. Chemical Recycling [EB/OL], http://plasticseurope.org/sustainability/circularity/recycling/chemical recycling. 2024-01-29.

[2] Zheng J, Arifuzzaman M, Tang X, Chen XC, Saito T. Recent development of end-of-life strategies for plastic in industry and academia: bridging their gap for future deployment[J]. Mater Horiz. 2023 May 9;10(5):1608-1624.

[3] British Plastic Federation. Chemical Recycling Briefing Paper [EB/OL], https://www.bpf.co.uk/Publications/chemical-recycling-briefing-paper.aspx.

1.2 Features of Chemical Recycling

At present, the global waste plastics disposal and utilization methods are mainly divided into four ways, including physical recycling, chemical recycling, incineration and landfill disposal. The materialized recycling of waste plastics can be achieved through physical recycling and chemical recycling, which are the two main techniques for the development of plastics circular economy. Compared with physical recycling, chemical recycling has the following four advantages:

1.2.1 Wide adaptability of raw materials

Currently mainstream physical recycling techniques at home and abroad need to classify waste plastics according to the material, which is mainly applicable to waste plastics with relatively single material and high monomer value, but can hardly be applied to the recycling of composite and mixed plastics, making it difficult to realize economic recycling of low-value plastics, such as soft plastic packaging. The adaptability of chemical recycling raw materials is very wide, basically able to achieve the recycling and utilization of all kinds of waste plastics generated in production and life without fine classification. Especially for low-value waste plastics and composite plastic products that cannot be effectively and economically recycled, such as disposable plastic lunch boxes, plastic express packaging bags, disposable plastic cups, disposable plastic knives, forks and spoons, foam plastics, disposable plastic shopping bags, and all kinds of commodity plastics packaging, and agricultural film, the chemical recycling has better adaptability.

1.2.2 The same products quality as that of native products

Physical recycling does not change the molecular structure of plastics. The modified product is a semi-homogeneous structure, which cannot completely replace the native material, and are commonly downgraded for use, with lower added value of the products. Chemical recycling adopts reaction processes such as depolymerization and pyrolysing, which can not only convert the plastic components into monomer compounds, but also remove coloring colorants, flame retardants and other additives in plastic products. The final polymer has exactly the same quality and performance as the polymer produced by fossil raw materials such as oil, and can replace the native materials and can be used in the production and use of all downstream plastic products including food contact packaging, which can significantly improve the economic added value of recycled plastics.

1.2.3 High technical threshold

The core process of physical recycling is the sorting, crushing, cleaning, melting and modification of waste plastics, which is relatively simple and belongs to the traditional renewable resources recycling industry, and the technical threshold for the industry is relatively low. Chemical recycling needs to go through several chemical reaction processes, with complex process flow, harsh reaction conditions and extremely harsh safety production conditions, requiring more professional and technical personnel, higher investment in R&D, advanced technology and equipment, standardized management, and strong clean production and comprehensive control of pollutants. It is an important part of the modern advanced chemical industry, with a generally higher technical threshold for the industry.

1.2.4 Large-scale in general

The physical recycling single production line is relatively flexible, which can be processed in small batches or in large-scale chemical plants. At present, China's enterprises engaged in physical recycling of waste plastics are mainly small and medium-sized ones, with more than 15,000 enterprises and an average annual treatment scale of only 1,200 tons. The design scale of raw material processing of chemical recycling projects is generally above 100,000 tons, with high construction investment intensity, and the back-end deep-processing production, especially the resin reduction process, needs to rely on the production process and equipment of modern chemical industry. At present, only large-scale petrochemical enterprise groups at home and abroad are carrying out chemical recycling industrialization.

Table 1. Comparison of Waste Plastic Disposal and Utilization Ways

Ways of Disposal	Introduction	Major Advantages	Major Disadvantages
Landfill	Waste plastics go directly to landfill.	Low in difficulty and cost.	Cause waste of resources, land encroachment and secondary environmental pollution, and the government bears great disposal costs.
Incineration Utilization	Waste plastics are directly incinerated or generated electricity.	The disposal technique is relatively mature and stable.	Cause waste of resources, produce pollutants such as dioxins, and the government bears great disposal costs.
Physical Recycling	Waste plastics are collected, sorted, washed, pelletized, and used in product production.	Reduce environmental pollution (land, sea, air, etc.) reduce greenhouse gas emissions, and can regenerate new products.	Disposable waste plastics are limited in type, require fine sorting at the front end, are difficult to classify and recycle, and are commonly downgraded for use and cannot be recycled indefinitely.
Chemical Circulation	Through a series of chemical processes, waste plastics are converted into plastic monomers and other chemical components to produce new plastics and other useful chemicals as by-products.	Reduce environmental pollution (land, sea, air, etc.), reduce greenhouse gas emissions, raw materials have strong adaptability, and the quality and performanwwce of recycled products are completely the same as those of native materials.	High in difficulty and the industrial chain needs to be improved, still in the initial stage of industrialization.

1.3 Industrial Positioning of Chemical Circulation

It is the most ideal development state of plastic recycling economy to open up the reverse process from waste plastics to plastics and realize the closed cycle of plastics. Therefore, this report holds that: (1) The materialized recycling of waste plastics is the direction that should be given the highest priority, in which physical recycling should be given priority to, and chemical recycling should be vigorously promoted if physical recycling cannot be carried out. (2) Incineration power generation is the sub-optimal choice and bottom-up plan for the current inability to realize the materialized recycling and the option in case of temporary inability to physically or chemically recycle; and should not be promoted and encouraged. (3) Landfill disposal is a helpless way to prevent plastics from leaking into the natural environment, and should be gradually reduced or eliminated.

Currently, in terms of materialized recycling, the plastic parts contained in end-of-life automobiles, used home appliances and other products, as well as rigid hollow plastics for packaging with lower recycling costs and difficulties, and higher economic value. Materialized recycling has been basically realized through physical recycling. For low-value mixed and composite material waste plastics that are difficult to decompose by physical recycling, chemical recycling can be used to materialize and utilize these plastics, as shown in Table 2.

To sum up, chemical recycling is one of the two major ways of materialized recycling of waste plastics together with physical recycling, and the combination of the two can basically realize the materialized utilization of waste plastics. Among them, chemical recycling can realize the same-quality original regeneration of waste plastics, which is the core means to build a closed-cycle green plastic industrial system.

Table 2. Priority Level of the Promotion and Application of Chemical Recycling of Waste Plastics

Concrete Product	Priority Level
Agricultural plastic film, and paper waste plastics.	★★★
Waste plastics in small towns and rural areas with a daily production of less than 300 tons of domestic waste, and low-value waste plastics in other urban domestic waste with sorting conditions.	★★
Historic piles of plastic waste in landfills.	★

Note: *The priority development level in the table does not represent the applicability grading of chemical recycling technique, but only from the difficulty degree of industrial promotion, and the more ★ represents the higher priority development order.*

02

Development Background and Significance

Chemical recycling can turn "white pollution" into "white oil field", providing a strong guarantee for energy and resource security: it is estimated that in 2022, China will produce more than 60 million tonnes of waste plastics, of which about 42 million tonnes will be incinerated or landfilled, and if 50 per cent of them can be chemically recycled, it will be equivalent to the development of an oil field with a capacity of more than 60 million tonnes; and if it is possible to recycle and use the existing 1 billion tonnes of stock of plastic wastes, it will be equivalent to the development of a super-large-scale "urban oil field" with a low cost.

2.1 Development Background

2.1.1 Plastic pollution control will enter a new stage of international legal constraints

Plastic pollution, climate change, biodiversity are currently the three major public environmental issues of global concern. In 2022, the Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Choices released by the World Organization for Economic Cooperation and Development pointed out that the global waste plastics increased from 156 million tons in 2000 to 353 million tons in 2019, of which only 9% received materialized recycling, 19% was incinerated, about 50% was landfilled, and the remaining 22% was discarded in unmanaged garbage dumps, burned in the open or leaked into the environment. At present, the United Nations is in intense negotiations on reaching an international instrument on plastic pollution by the end of 2024. With the final signing of the instrument, an international agreement on plastic pollution control with international legal binding force will be formed.

2.1.2 Plastic pollution control in China is in urgent need of new path and breakthrough

In recent years, the production and consumption of plastic products in China have been rising rapidly, posing higher pressure on plastic pollution control. China attaches great importance to plastic pollution control. The National Development and Reform Commission and the Ministry of Ecology and Environment issued the Opinions on Further Strengthening. the Control of Plastic Pollution in 2020, making a comprehensive deployment of plastic pollution control in the new era. China adheres to the whole-life-cycle governance of plastics, comprehensively promoting the reduction of plastics at source, material substitution and standardized recycling. In 2022, the recycling rate of waste plastic materials in China reached 30%[4], which takes lead worldwide. However, like other countries and regions, China also encountered the bottleneck in the enhancement of materialized recycling rate, in urgent need to explore new chemical recycling path.

2.1.3 Chemical recycling becomes a new direction for plastic pollution control at home and abroad

Chemical recycling of waste plastics has attracted great attention both at home and abroad owing to its huge potential in the development of plastic circular economy and the ultimate solution to plastic pollution. The European Commission issued the European Strategy for Plastics in a Circular Economy.in January 2018, proposing to strengthen the recycling of waste plastics and promote the chemical recycling of waste plastics. In November 2021, the Ministry of Industry and Information Technology issued the 14th Five-Year Industrial Green Development Plan to encourage the chemical recycling of waste plastics. In May 2022, the Ministry of Ecology and Environment issued the Technical Specifications for Pollution Control of Waste Plastics, proposing that the chemical recycling of waste plastics is applicable to the treatment of waste plastics that

[4] Source: China National Resources Recycling Association.

are more difficult to physically regenerate. In October 2023, the National Development and Reform Commission and other four departments issued the Guiding Opinions on Promoting Green Innovation and High-quality Development of the Oil Refining Industry, encouraging the development of low-energy pyrolysis and purification pretreatment for waste plastics, and accelerating the pilot demonstration of chemical recycling projects for waste plastics. Under the guidance of relevant policies, domestic enterprises such as SINOPEC, China National Petroleum Corporation and Qingdao Huicheng Environmental Technology, as well as multinational enterprises such as ExxonMobil, Shell, BASF and Saudi Basic Industry Corporation have carried out the exploration and practice of chemical recycling industrialization.

2.2 Significance

2.2.1 Chemical recycling can realize the closed cycle in the plastics industry

At present, the materialized recycling of waste plastics is mainly based on physical recycling, which is mainly applicable to plastic wastes with single quality and high cleanliness, but incapable of dealing with low-value mixed waste plastics such as mulch film and express delivery packaging. Through chemical recycling, most waste plastics can be efficiently recycled, even some resin products such as leather and some textiles, effectively avoiding the flow of waste plastics to incineration plants, landfills and the environment. At the same time, through chemical recycling, waste plastics can be transformed into plastic raw materials with the same quality as virgin plastics, so as to achieve the closed cycle and green development in the plastics industry, contributing to the green transformation and sustainable development of chemical industry.

2.2.2 Chemical recycling provides a fundamental solution to plastic pollution

From the perspective of source management, the ecological design of products and green substitution of materials can only alleviate but not eradicate plastic pollution. From the physical recycling of waste plastics in China, EU, Japan and other countries and regions, the materialized recycling rate will encounter a bottleneck after reaching 30% or so restricted by technical and economic conditions, leaving other waste plastics that cannot be physically recycled the biggest difficulties. Chemical recycling can effectively break through the limitations of physical recycling application scenarios and the development bottleneck of materialized recycling of waste plastics, thus providing a fundamental solution to plastic pollution.

2.2.3 Chemical recycling contributes to energy and resource security

Chemical recycling can recycle all kinds of waste plastics and even those stockpiled historically in landfills or nature, so as to reduce the consumption of primary resources such as oil, turning “white pollution” into “white oil fields” to provide a strong guarantee for energy and resource security. In 2022, China produced more than 60 million tons of waste plastics, including about 42 million tons of incineration or landfill[5]. If 50% of them had been chemically recycled, an oil field of more than 60 million tons would have been developed[6]; and recycling 1 billion tons of the existing stock of plastic wastes[7] will be equivalent to developing a super-large-scale “urban oil field” at a lower cost, carving out huge space and precious land resources.

2.2.4 Chemical recycling contributes to the realization of carbon peak and carbon neutrality

The role of circular economy in carbon neutrality has been widely recognized by the international community. In the EU’s New Green Deal, circular

[5] Source: China National Resources Recycling Association.
[6] 3 tons of oil are consumed for every 1 ton of plastic produced.
[7] Source: Ma Yongsheng, member of the CPPCC National Committee: Strengthen the key core technology research of CCUS. Xinhua, 9 March 2022 http://www.news.cn/politics/2022lh/2022-03/09/c_1128453428.htm.

economy is regarded as an important means to address climate change. In the Carbon Peak Action Plan issued by the State Council, circular economy is listed as one of the ten major tasks to help achieve carbon peak. According to the comprehensive calculation of this report, disposing of 1 ton of waste plastics through chemical recycling can reduce carbon dioxide emissions by an average of 0.67 tons compared with using oil to produce plastics. If all 42 million tons of waste plastics landfilled or incinerated in China in 2022 had been chemically recycled, carbon emissions could have been reduced by 28.14 million tons compared with using crude oil to produce plastics, and a large amount of carbon dioxide emissions caused by the incineration of waste plastics can be avoided, which greatly contributes to carbon emission reduction[8].

[8] Source: See Chapter 4 for details.

03

Status Quo of Chemical Recycling and Industrial Development

After decades of technological development, the chemical recycling technology has gradually matured, forming the mainstream technology process mainly based on cracking method, depolymerization method and gasification method. Large domestic and foreign enterprise groups such as Sinopec, PetroChina, Qingdao Huicheng Environmental Protection, Wanhua Chemical, ExxonMobil, Shell, BASF, Saudi Basic Industries, etc. have carried out the demonstration and application of industrialization of chemical recycling of waste plastics to promote chemical recycling of waste plastics to enter into a new stage of industrialization and development.

3.1 Development History of Chemical Recycling

Beginning in the 1960s, chemical recycling technique has gradually developed from the initial stage for energy substitution to the new stage for plastic recycling.

3.1.1 Initial stage for the purpose of energy substitution

Since the 1970s, several oil crises have broken out around the world, leading to a sharp rise in crude oil prices. Developed countries began to pay attention to oil security and actively look for alternative energy sources. During this period, enterprises in the United States, Europe and Japan carried out a lot of research on waste.plastic.pyrolysis.to fuel.oil, and established a number of small-scale production devices. At the same time, a large number of "local oil refining" projects emerged in China. However, these techniques have not been widely promoted and applied due to the poor quality of the oil produced, the heavy environmental pollution, and the inability of the devices to operate continuously and stably for a long time.

3.1.2 Transitional stage from energy substitution to recycling

Since the 1990s, the concept of circular economy and sustainable development has been universally recognized. Confronted with the increasingly serious global plastic pollution, strengthening plastic recycling has become an international consensus and a universal choice. In addition to physical recycling, some enterprises at home and abroad pyrolyse mixed waste plastics that cannot be physically recycled to obtain various kinds of non-standard oil products. At this stage, the technical equipment and process for the pyrolysis of waste plastics have been improved, but the chemical recycling is not taken as the industrial development goal. The industrial development is not standardized and stays in the gray area in general.

3.1.3 New stage with plastic recycling as the goal

Since the beginning of this century, the international community has paid increasing attention to plastic pollution. For example, in the newly revised Packaging and Packaging Waste in 2022, the EU promised that all packaging in the EU market should be reused or recycled in an economically reasonable way by 2030, and required manufacturers to add a certain proportion of recycled materials to the new plastic packaging. In this context, large-scale petrochemical groups at home and abroad have joined the research, development and industrialization of the chemical recycling of waste plastics, promoting the industry to enter a new stage of green development with the main purpose of obtaining plastic raw materials such as oil.

It should be pointed out that while having gone through a long development stage, the chemical recycling technique focusing on realizing the closed cycle of plastics is still in the early stage of industrialization and has not yet formed a large-scale industrialized application.

3.2 Status Quo of Chemical Recycling

The main techniques in use or under development with domestic and oversea industrial practitioners for waste conversion include pyrolysis, depolymerization and gasification.

3.2.1 Pyrolysis

Pyrolysis is referred as the sort of processes where the polymer chains of waste plastics (commonly polyolefins or other thermoplastics) are broken down by heating at high temperature with absence of oxygen, giving yield of products having smaller molecules that are often akin to the property of crude, a petroleum fraction, or monomer mixtures. Catalysts maybe used to lower the thermal reaction temperature. This technical route has a certain technical foundation with smaller development difficulty, lower investment, and good adaptability of raw materials, so it has been adopted by many enterprises at home domestic and abroad, with cases of industrialized operation. The technical routes of waste plastic pyrolysis mainly include non-catalytic pyrolysis and catalytic pyrolysis, of which the former has a higher degree of maturity and is the mainstream technique at present.

(1) Non-catalytic pyrolysis: including general non-catalytic pyrolysis and microwave pyrolysis. Among them, the general non-catalytic pyrolysis refers to the process of converting waste plastics into small molecules of mixed hydrocarbons by heating to 400-600˚C.in the absence of oxygen. The pyrolysis oil is in usual subjected to steam cracking/catalytic cracking to obtain monomers, which are then polymerized to produce plastics. This is the current mainstream technique. In addition, the supercritical water cracking method has been commercially developed by companies, and the test unit already exists.

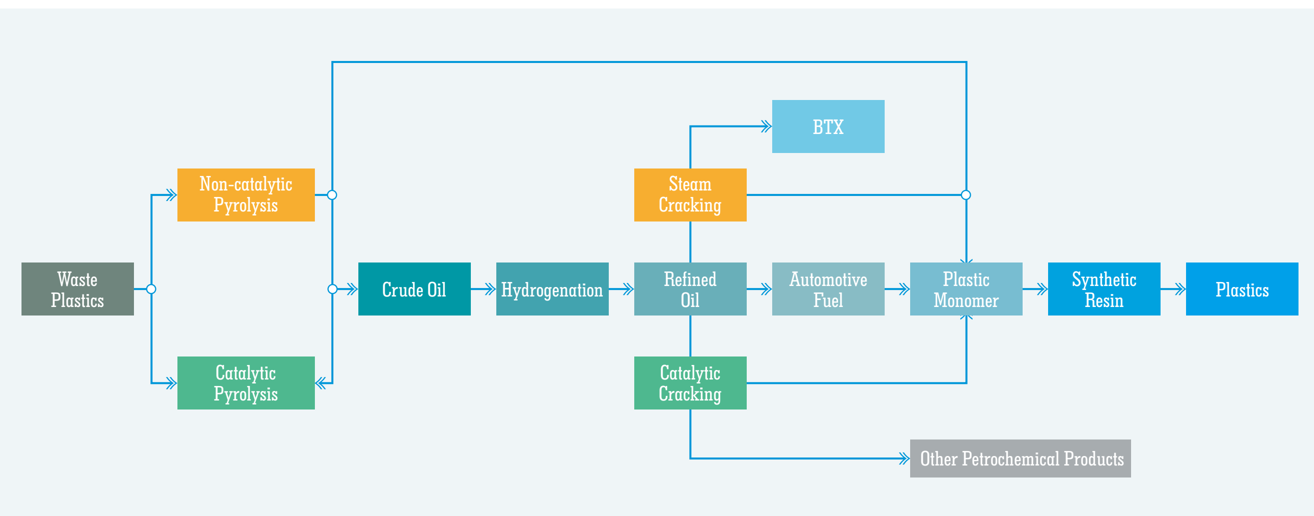

Figure 1. Waste plastic pyrolysis and post-possessing process route

Microwave pyrolysis refers to the process of heating the reaction system to more than 1000˚C by using microwave heating and carbon-containing materials to conduct heat, and cracking waste plastics into olefin monomers. This technique is suitable for mixed waste plastics without polyvinyl chloride (PVC), but there are problems such as engineering amplification difficulties in microwave reactors and industrial application has not yet been realized.

(2) Catalytic pyrolysis: referring to the process of thermal cracking of waste plastics to produce oil or low-carbon olefin and further produce plastic monomer under the action of catalyst. Low cracking temperature of the technical route is attainable (300-700˚C), while the reaction speed is maintained fast. In addition, product quality may be improved with the presence of a catalyst due to the catalytically promoted decontamination effects. The catalyst after the reaction can be partly regenerated and recycled or disposed. However, due to the large consumption of catalysts and the complex process of feed preparation, the recycling cost of this technical route is relatively high, and the industrial application is difficult to achieve.

3.2.2 Depolymerization

Depolymerization of waste plastics refers to the technical route for polyester plastics, through chemical means including hydrolysis, alcoholysis, ammonia, glycolysis and ion exchange, to depolymerize the plastics with special structures to plastic monomers. At present, depolymerization is relatively mature and has entered the stage of industrial development, and a number of industrialized production units have been built at home and abroad.

(1) Hydrolysis: referring to a plastics depolymerization method that uses specific waste plastics such as polyethylene terephthalate (PET) or polyurethane (PU) as raw materials, and produces polyols (such as ethylene glycol) or aliphatic amines (such as MDA) by adding superheated steam at a certain temperature.

(2) Glycolysis: using specific waste plastic products such as PET as raw material, under the action of catalyst, waste plastic reacts with ethylene glycol to produce BHET.

(3) Alcoholysis: using alcohol hydroxyl groups (such as methanol) to depolymerize certain types of waste plastic products in high temperature or even supercritical state, mainly applicable to PET waste plastic products, and the main products are dimethyltryptamine (DMT) and glycol.

(4) Ammonolysis: the degradation reaction between waste plastics and amines and catalysts occurs under certain temperature and pressure, mainly applicable to PET waste plastic products, and the main products are BHET or MEG+ Trephthalamide.

(5) Ionic liquid directional depolymerization

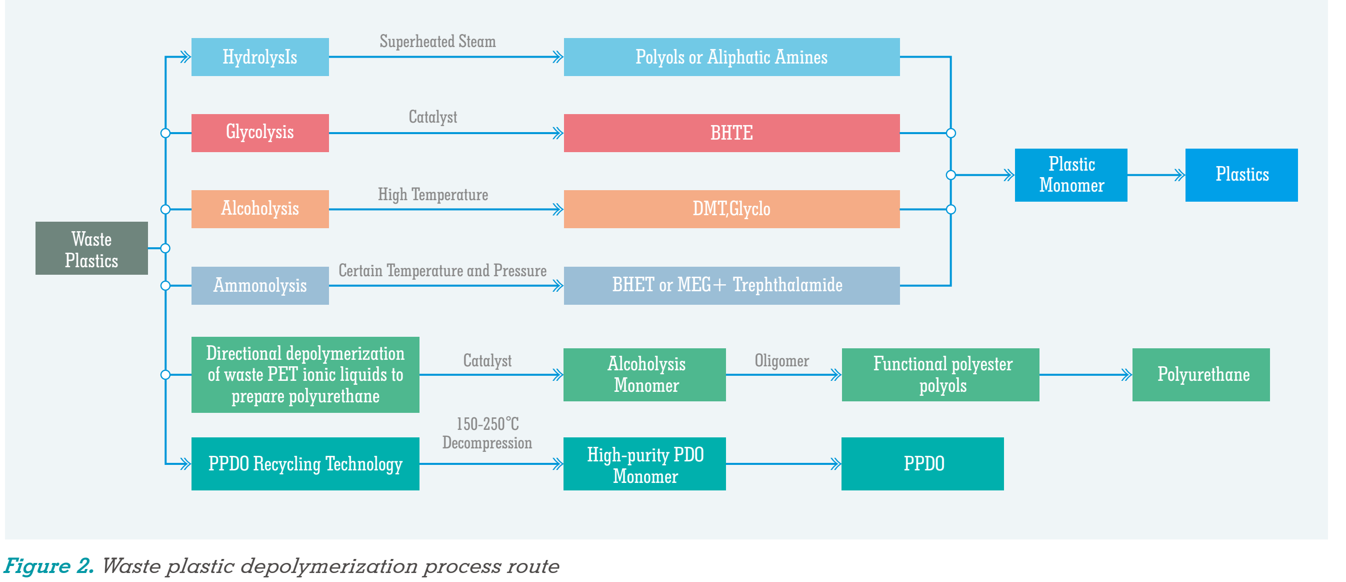

Figure 2. Waste plastic depolymerization process route

preparation of polyurethane technology: using ionic liquid catalysts to chemically degrade PET waste plastic products, producing oligomers and synthesize functional polyester polyols with PET alcoholysis monomers, and then producing polyurethane.

(6) PPDO recycling technology: poly-p-dioxanone (PPDO) is an aliphatic polyester-ether, which is mainly used for the preparation of degradable surgical sutures. This technology can efficiently depolymerize PPDO into high-purity PDO monomers under 150-250°C decompression, and the monomers can be repolymerized into new PPDO.

3.2.3 Gasification

Gasification of waste plastics refers to the conversion of waste plastics into carbon monoxide and hydrogen (syngas) by partially oxidiation using oxygen and/or steam at elevated temperature (above 1400°C) and the production of plastic monomers through a series of chemical processes. This technical process does not require fine pretreatment of waste plastics, and can decompose mixed waste plastics. However, due to the long process, difficulty of the feeding technique, and high energy consumption, there are few cases of industrialized application.

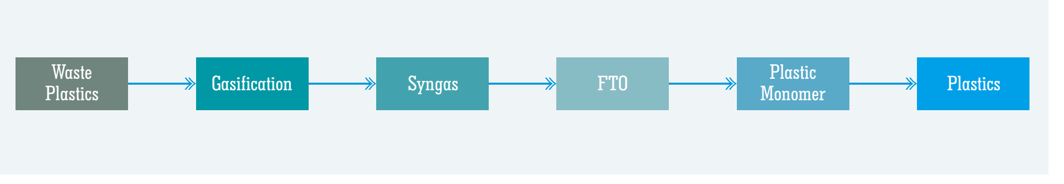

Figure 3. *Waste plastic gasification and post-possessing process route*

3.3 Progress of Chemical Recycling of Waste Plastics at Home and Abroad

In recent years, upstream and downstream enterprises and R&D institutions in the plastic industry chain at home and abroad have carried out the development and exploration of chemical recycling technology for waste plastics, and have made significant progress and breakthroughs in some key technologies and complete sets of equipment. All kinds of technologies have gone through industrial verification, entering the stage of industrialization and application.

3.3.1 Progress of foreign practice

According to incomplete statistics, over 60 chemical enterprises worldwide are exploring waste plastic recycling solutions[9], and it is generally believed that chemical recycling is one of the key paths to the closed cycle of waste plastics. In October 2018, the Ellen MacArthur Foundation and the United Nations Environment Programme (UNEP) jointly launched the "New.Plastics.Economy.Global. Commitment" initiative, with more than 850 enterprises and organizations signing, announcing that a total of 5 million tons of recycled plastics will be used by 2025. At the end of 2022, 12 member companies of the Consumer Goods Forum (CGF) Alliance.to End.Plastic.Waste issued an open letter, expressing their need to purchase chemical recycling materials that comply with environmental protection practices. A broader survey of alliance member companies by CGF shows that 800,000 tons of chemical recycling materials will be needed annually by 2030. International chemical enterprises such as ExxonMobil, BASF, Shell, and Saudi Basic Industry Corporation are actively engaged in chemical recycling practices, and their progress is shown in Table 3.

3.3.2 Progress of domestic practice

In recent years, some petrochemical and environmental protection enterprises, such as SINOPEC, China National Petroleum Corporation, Qingdao Huicheng Environmental Technology, have actively carried out research and development and demonstration and application of chemical recycling technologies for waste plastics. Some enterprises continue to innovate the localized waste plastic recycling mode, actively explore the centralized large-scale recycling mode and automated pretreatment facilities and equipment of low-value waste plastics and waste agricultural film, and select typical areas to carry out the construction of chemical recycling demonstration projects of waste plastics. Among them, the chemical recycling project for abandoned mulch and comprehensive low-value waste plastics has entered the construction stage. The specific progress is shown in Table 4.

[9] Zhang Yiming.Seven representatives of the business community hotly discuss the government work report[N]. China Economic Times,2023-03-06(003).

Table 3. Progress on chemical recycling of waste plastics of foreign enterprises

Name of Enterprise	Progress
ExxonMobil	ExxonMobil has developed ExxtendTM technology that integrates chemical recycling with petrochemical production facilities. As of 2022, the Bay Pond complex in the U.S. has successfully processed over 5,000 tons of plastics waste and has delivered the first batch of certified recycling polymers to customers. To meet the growing customer demand, ExxonMobil is evaluating the potential to create recycling solutions for global plastics production using chemical recycling techniques and is rapidly expanding its ExxtendTM technology using existing production facilities to process a wide range of plastic wastes. It is expected that by the end of 2026, ExxonMobil will achieve 500,00 tons of capacity annually at multiple production sites around the world.
BASF	The ChemCycling. program began in 2018, and during the pilot phase, BASF worked with customers to produce the first batch of prototypes, including mozzarella cheese packaging, transparent refrigerator components, and insulated thermal barriers for sensitive uses. BASF plans to process 250,000 tons of recycled raw materials annually by 2025 to replace fossil raw materials.
Shell	Shell is working across industries with partners at different stages of the value chain, from waste plastics suppliers and sorters to pyrolysis oil producers, and is committed to driving pyrolysis oil business to a commercial and profitable scale. In 2021, Shell invested in BlueAlp, a European cracking oil technology company, to jointly develop and deploy BlueAlp's technology. Two pyrolysis units, with a total capacity of around 30,000 tons of hard-to-recycle waste plastics, are currently under construction in the Netherlands and are expected to be put into operation in 2025. All cracking oil produced will be used to supply its chemical plants in the Netherlands and Germany.
Saudi Basic Industry Corporation	In partnership with a number of globally recognized retailers and chemical producers, it is committed to promoting the recycling of plastics and working with the value chain on closed-cycle projects. The year 2019 saw the launch of the TRUCIRCLETM portfolio of products and services, with an industry-first launch of certified recycling products. Early 2021 saw the start of the construction of a new plant in the Netherlands in partnership with Plastics Energy, which can convert waste plastics into recyclable oil to produce polymers. In 2022, Saudi Basic Industry Corporation set a target of 1 million tons of TRUCIRCLE products by 2030.
TotalEnergies	It has cooperated with a number of companies to carry out the chemical cycling of waste plastics. Cooperating with Saudi Aramco and Saudi Basic Industry Corporation, Saudi Arabia successfully converted oil from waste plastics into ISCC+ certified recycling polymers in the Middle East and North Africa. It worked with Paprec, France to develop France's first advanced plastic film recycling value chain, which is to be put into operation in 2024. It has also converted recycling polymer feedstocks into virgin-quality polymers cooperating with New Hope Energy, Honeywell, TotalEnergies and PureCycle Technologies.
Huntsman	Based on the circular economy and through. the chemical recycling of PET plastics, Huntsman has produced TEROL., a recycled polyester polyol that can be used as a raw material for a wide range of polyurethane products, with up to 60 percent recycled PET content. The annual recycling of PET waste plastics of Huntsman Group is equivalent to 1.44 billion 500 ml PET plastic bottles, which are used to produce polyurethane building insulation materials, synthetic leather, textile fibers, furniture sponges and industrial adhesives.
Honeywell International	It has carried out research and development on chemical recycling for waste plastics and the corresponding commercialization, and developed UpcycleTM, a low-temperature thermal cracking technique for plastics, which adopts an advanced proprietary reaction process design and combines with back-end purification and treatment technologies. The cracking process achieves an oil yield rate of more than 85% without the participation of catalyst, and the products are mainly light oils, which can be directly used as raw materials for ethylene cracking or raw materials for the production of oil refining and petrochemicals (such as catalytic cracking). The commercial projects of this technique are under engineering design and construction.
LyondellBasell	It has adopted its exclusively developed MoReTec to produce Circulen Revive polymer. This technique uses proprietary catalysts to decompose hard-to-process waste plastics into cracked oil and gas raw materials, which is then used to produce new polymers comparable to virgin resins.
SK Chemicals	It is working with partners to improve the pyrolysis, and independently research and develop a treatment process to reduce the pyrolysis oil impurities, exploring the use of waste plastic pyrolysis oil as the raw material of petrochemical plants. At present, the project has been located in Ulsan, South Korea and is about to be built. The project intends to use waste plastics through the chemical recycling to produce recycled oil products that can be used to produce olefins and aromatics.

Name of Enterprise	Progress
Dow Chemical Company	It has announced with Mura Technology that a number of chemical recycling plants will be built in the United States and Europe, with a total of 600,000 tons of capacity annually by 2030. The HydroPRSTM supercritical steam decomposition technique used can decompose plastics, including flexible packaging and multi-layer structural plastics, into raw oils and chemicals, so as to produce products with new properties equivalent to native plastics. This product can be used for food contact packaging.
EASTMAN	It has realized the commercialization of carbon regeneration technology (CRT) and polyester regeneration technology (PRT) in 2019 and 2020 respectively. Its TritanTM Renew copolyester contains up to 50% recycled content from waste plastics, as accounted for in the "material balance".
INEOS	It has developed INEOS Infinia, a plastic recycling technology that converts non-recyclable PET into new and pure PET production materials, reducing the amount of PET going to landfills.

Source: *provided by the enterprise.*

Table 4. Progress on chemical recycling of waste plastics of domestic enterprises

Name of Enterprise	Progress
SINOPEC	Laboratory research and development and 100-ton pilot test have been completed, and a 10,000-ton industrial demonstration plant has been approved. Now the first set of demonstration has been completed, the project is under review for environment and security assessment, and the engineering design has been carried out in full swing. The project takes waste mulch from Xinjiang as raw material, adopts RPCC pyrolysis with independent intellectual property rights of SINOPEC and post-processing technology, producing petrochemical products such as sustainable automobile diesel and aromatics in the first phase, and expanding to 200,000 tons in the second phase to produce plastic monomers. It develops high-quality 34-GL weathering-resistant mulch film, and cooperates with its skid mounted waste mulch sorting equipment to solve the problem of high value-added resource utilization and recycling of waste mulch from Xinjiang. The project is expected to be completed and put into operation by the end of 2024.
China National Petroleum Corporation	It has carried out the development of waste plastics pyrolysis with partners, opened up the process of producing chemicals through chemical recycling of waste plastics, which can convert mixed waste plastics into primary chemicals, contributing to promoting the demonstration of chemical recycling of waste plastics.
Qingdao Huicheng Environmental Technology Group Co.,Ltd.	The 100t/a pilot plant has been completed and is running stably. The 200 kt/a Mixed Waste Plastics Resourceful Comprehensive Utilization Industrial Demonstration Project of Jieyang Dananhai Petrochemical Industrial Park has completed the project establishment, environmental impact assessment and construction permit, and has entered into the stage of engineering construction. The project takes low-value mixed waste plastics as raw materials and utilizes deep cracking chemical raw material technology (CPDC) to directly convert waste plastics into triene triphenylene chemical raw materials, solving the pollution problem of low-value mixed waste plastics that cannot be recycled physically, realizing high-value recycling of waste plastics in garbage, eliminating white pollution and reducing carbon emission.
Wanhua Chemical Group Co.,Ltd.	Based on the molecular structure characteristics and industrial advantages of polyurethane, Wanhua Chemical has developed the chemical method of polyurethane recycling process, which can convert waste polyurethane into high-quality polyols and reapply it to polyurethane foaming, of which the hard foam recycling has undergone pilot experiment verification. The product has been applied to refrigerator thermal insulation layer and has passed the test of the representative enterprises. The soft foam recycling has completed the small pilot process, and the recycling samples has passed the small pilot test verification in leading sponge industries, and is now under the construction of the pilot unit.
Zhejiang Jiaren New Materials Co., Ltd	It has realized the industrialization of 10,000 tons through PET chemical recycling, of which the 30,000-ton capacity of the old plant has been in operation for about 8 years, and the new plant with 150,000-ton capacity has been under construction in 2023. It is expected that the installation of equipment will begin in the second half of 2024.

Source: *provided by the enterprise.*

3.4 Difference Between Chemical Recycling and "Local Oil Refining"

At present, there are some misunderstandings about chemical recycling of waste plastics in the society, which equate chemical recycling with traditional "local oil refining". "Local oil refining" used in waste plastics and tires has been clearly listed as phase-out industries by the relevant state departments due to its backward process and equipment, and environmental hazards. Although some of the current chemical recycling technique routes also use the cracking of waste plastics to make oil, compared with "local oil refining", chemical recycling has significant differences in terms of target products, implementation subjects, technology thresholds, and operation and management levels.

3.4.1 Different target products

"Local oil refining" is for the purpose of obtaining fuel oil. Due to the simple process equipment and low oil production rate, the quality of refined oil products is poor with many impurities. Most of the oil flow to non-standard fuels such as boiler fuel and marine fuel, some of which will illegally flow into small gas stations. Theoretically, through "local oil refining", some "light oil" can be obtained and used to produce plastic raw materials, but the yield is low, generally less than 30%, resulting in a waste of resources.
The modern chemical recycling adopts advanced petrochemical technique, using waste plastics as raw materials, and the main purpose is to maximize the acquisition of plastic monomers. At the same time, by-producing petrochemical products are in line with national standards, with the effective utilization rate of hydrocarbon elements at more than 70%, which is capable of truly realizing the closed recycling of waste plastics.

3.4.2 Different operation entities

The operation entities of "local oil refining" are mostly small-scale waste plastics and waste rubber refining plants or "small workshops", whose fixed asset investments are generally less than 5 million yuan, and comprehensive utilization scales of waste plastics are less than 10,000 tons per year, so the industry is always at the low-end development level which is "small scattered and polluted". At present, the operation entities of global chemical recycling project are basically large petrochemical enterprises and environmental protection companies at home and abroad, twith strong technical research and development capabilities, solid financial strength, and standardized operation and management. The annual chemical cycle design scale of waste plastics for a single project generally exceeds 100,000 tons, and the investment in integrated devices is generally more than 500 million yuan, driving the chemical recycling of waste plastics into a new stage of large-scale development.

3.4.3 Different technical thresholds

The process and equipment of "local oil refining" are simple. Most devices can only work intermittently. The processing scale of a single production line is small, the operation efficiency is low, and most of them are manual or semi-automatic control. It lacks necessary environmental treatment facilities, the emission of environmental pollutants is not up to the standard, and there are many hidden dangers in production security. Chemical recycling and its equipment are advanced, adopting modernized, intelligent and complete sets of equipment, capable of realizing continuous and stable operation and automatic control. The life of the equipment is generally not less than 20 years, with improved environmental treatment facilities for wastewater, waste gas, and waste residue, making environmental emissions and production guaranteed.

3.4.4 Different Operation and Management Level

The "local oil refining" projects are generally not strictly in accordance of the construction approval procedures, and the treatment of the three wastes during the production process cannot meet the environmental requirements, especially under intermittent production conditions, which can hardly realize the closed and clean co-production, and cause unorganized emissions of harmful gases such as dioxins, hydrogen chloride and VOCs during pyrolysis, and the treatment of the waste residue generated is more difficult, and the products generally fail to meet the relevant product standards. The chemical recycling pyrolysis projects are basically located in chemical parks, and the post-processing relies on the existing petrochemical enterprises. After strict approval procedures, the supporting environmental treatment facilities and online environmental monitoring facilities are complete. The pollutants can be discharged in compliance with the standard. The management system is sound and the quality of the products is identical with that of virgin plastics, keeping the green and standardized development of the industry.

04

Comparative Analysis of Chemical Recycling and Existing Disposal Methods

According to incomplete estimation results, under the premise of no government subsidy, the net benefit of chemical recycling of waste plastics is about 850 yuan per tonne, and the economic benefit is significantly higher than that of incineration and disposal in landfills; disposing of 1 tonne of waste plastics in the way of chemical recycling is equivalent to saving 1.12-1.22 tonnes of crude oil, which has obvious resource-saving benefits, higher than that of incineration and disposal with the benefit of saving 0.17 tonnes of crude oil, and there is no resource saving benefit of landfilling. In terms of environmental benefits, the potential environmental impact of chemical recycling is lower than that of incineration, and the environmental impact of landfill disposal is long-term.

Due to the large differences in the technical routes of enterprises and in consideration of the protection of trade secrets, etc., the list of data for the life cycle analysis of chemical recycling, incineration and power generation, and landfill disposal of waste plastics in this report is derived from the literature data, survey data, and provided by experts. In the part of environmental benefit evaluation, considering the availability of data, the raw material for chemical recycling of waste plastics is waste polyethylene; the raw material for incineration of waste plastics for power generation is waste polystyrene, and there is no restriction on the raw material for landfill disposal of waste plastics, so the evaluation of the environmental benefit is only for reference, and it does not have the significance of strict comparison.

4.1 Life Cycle Benefits Analysis of Chemical Recycling

The research scope of the chemical recycling of waste plastics covers the recycling, sorting, pretreatment and chemical recycling of waste plastics (excluding the process of using plastic monomers to produce plastic products). The system boundary of the assessment of the chemical recycling benefits of waste plastics in this report is shown in Figure 4.

4.1.1 Economic benefits assessment

The costs measured in this report refers to the operating cost of chemical recycling of waste plastics, including the recycling cost and pretreatment cost such as sorting for waste plastics, depreciation cost of equipment for chemical recycling projects, energy consumption cost during the operation, and environmental protection cost. The benefit refers to the sum of revenues from all the recycled products, including final plastic monomers and other petrochemicals.

Firstly, the cost of transferring waste plastics recycled by urban sanitation systems or enterprises' own systems to the pretreatment base is $C^{transport}$, for short is C^{t}. Secondly, due to the differences in recycling techniques with regard to the material and mechanical requirements of waste plastics, pretreatment of waste plastics, such as sorting, is required when necessary, and the cost of is $C^{pretreat}$, for short is C^{p}. The cost of energy inputs including electricity, gas, and coal, to support the operation of the chemical recycling system, is $C^{energy\text{-}consumption}$, for short is C^{ec}. The cost of pollutant treatment, i.e. environmental protection cost, generated during the chemical recycling is $C^{environmental\ protection}$, for short is C^{ep}. The depreciation cost of equipment is $C^{depreciation}$, for short is C^{d}. To sum up, the total operating cost of the chemical recycling for waste plastics is:

$$C+C^{t}+C^{p}+C^{ec}+C^{ep}+C^{d}$$

According to the data from the questionnaire for the enterprises, the total operating cost of the whole process from collecting to chemical recycling of waste plastics is 3,700 yuan per ton on average.

It is estimated that under the current technique level, if disposing of 1 ton of waste plastics in the mainstream technique by chemical recycling, the average yield of synthetic resin is about 42%, of aromatics and alkanes is about 17%, of gasoline and diesel is about 10%, of heavy fuel oil is about 6%, and of liquefied gas and coke can be ignored. In this report, the average price of synthetic resin is 7,500 yuan per ton, aromatics 6,000 yuan per ton, alkane

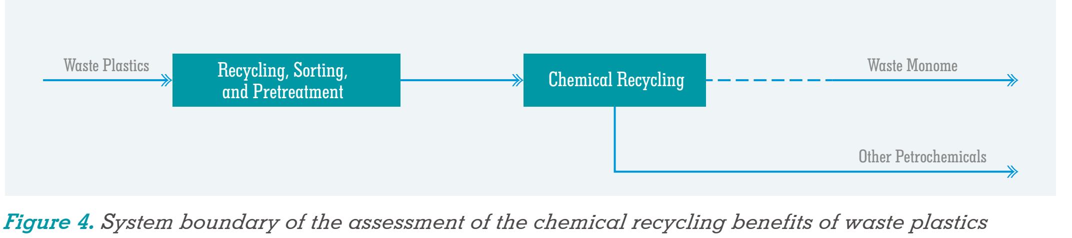

Figure 4. *System boundary of the assessment of the chemical recycling benefits of waste plastics*

2,500 yuan per ton, gasoline and diesel 5,500 yuan per ton, and heavy fuel oil 3,900 yuan per ton, and the output value of 1 ton of waste plastics through chemical recycling can achieve 4,550 yuan per ton.

Considering costs and benefits, the simple comprehensive benefit of chemical recycling of waste plastics is about 850 yuan per ton, and when the government gives a subsidy of 100 yuan per ton, the comprehensive benefit can be around 950 yuan per ton. When the price of waste plastic raw materials is higher than 850 yuan per-ton and without government subsidies, the chemical recycling will be at a loss.

4.1.2 Resource benefits assessment

It is estimated that 1 ton of waste plastic is equivalent to saving 0.9 to 1.0 tons of oil resources according to the ratio of crude oil to distillate oil extraction. At the same time, this technical route will bring fuel gas as a by-product. 1 ton of waste plastics can produce 0.033 tons of fuel gas, which can replace 0.22 tons of oil resources.

4.1.3 Environment benefits assessment

The generation of pollutants in the chemical recycling of waste plastics is contained to the pretreatment, pyrolysis and oil-phase isolation, specifically including atmospheric pollutants such as CO_2, CH_4, N_2O, HC (hydrocarbons), SO_2, NO_X, CO, soot and dust, and water environmental pollutants such as COD and SS (suspended solids), as well as solid wastes such as residues. Taking the catalytic cracking treatment of 1 ton of waste polyethylene as an example, its specific environmental emission inventory is shown in Table 5.

As the specific environmental pollutants generated by chemical recycling, incineration for power generation and landfill are different, for subsequent comparisons, the present report characterizes various types of pollutant indicators to make them linked to potential environmental impacts. After characterization of the pollutant indicators, the environmental impacts are standardized to enable comparison between different types of environmental impacts. Equivalent coefficients for each environmental impact type were determined by reference to relevant literature. Specific environmental impact types and their equivalence factors are shown in Table 6.

The environmental impact potential (IR) of the chemical recycling of waste plastics is determined by the emissions (M) and the corresponding equivalence factor (C), i.e.

$$IR(i)=\sum(M_j \times C_{i,j})$$

In this equation, is the type of environmental impact, is the pollutant indicator, and the unit of is kg.

Based on the formula for calculating the potential environmental impacts and the emissions and

Table 5. Environmental emission inventories for chemical recycling of waste plastics

Environmental Emission	Type of Pollutant	Emission (g)		
		Pretreatment	Decomposition	Total
Gaseous Pollutant	CO_2	90000	561000	651000
	CH_4	305.79	393.73	699.52
	N_2O	7.29	9.31	16.6
Gaseous Pollutant	HC	7.95	10.24	18.19
	SO_2	838.60	1731.00	2569.6
	NO_X	371.57	3915.6	4287.17
	CO	9.40	899.00	908.4
	Soot	443.86	571.51	1015.37
Water Pollutant	COD	22.41	28.85	51.26
	SS	23.13	29.79	52.92
Solid Wastes	Solid Waste	13190	16990	30180

Source: *Wu Yuehui. Research on the assessment of waste plastics recycling technology and potential environmental impacts[D]. Harbin Institute of Technology, 2013.*

Table 6. Environmental impact types characterized by pollutant indicators

Type of Environment Impact	Type of Pollutant	Unit	Equivalent Coefficient
Global Warming	CO_2	kgCO_2eq/kg	1
	CH_4		23
	HC		1700
	N_2O		296
Ozone Depletion	HC	kgCFC-11eq/kg	0.034
Acidification	SO_2	kgSO_2eq/kg	1.2
	NO_X		0.5
Eutrophication	COD	kgPO_4^{3-}eq/kg	0.022
	NO_X		0.13
Photochemical Oxidation	CO	kgC_2H_4eq/kg	0.027
	CH_4		0.006
Soot&Dust	Soot	kg	by emissions

Source: *Wu Yuehui. Research on the assessment of waste plastics recycling technology and potential environmental impacts[D]. Harbin Institute of Technology, 2013.*

Table 7. Potential of Environment Impacts

Type of Environment Impact	Potential of Environment Impact	Type of Environment Impact	Potential of Environment Impact
Global Warming	702.93kg CO_2eq.	Eutrophication	0.56kg PO_4^{3-}eq.
Ozone Depletion	0.00kg CFC-11eq.	Photochemical. Oxidation	0.03kg C_2H_4eq.
Acidification	5.23kg SO_2eq.	Soot&Dust	1.02kg Dust

equivalence coefficients in Tables 5 and 6, the potential environmental impacts of the chemical recycling of waste plastics were calculated and are shown in Table 7.

4.1.4 Carbon dioxide emission assessment

Based on the calculation above, the catalytic pyrolysis of 1 ton of waste polyethylene produces 0.651 tons of CO_2. In order to better compare this level of CO_2 emission with those of plastics produced by crude oil and incineration for power generation, this report extends the system boundary of the environmental benefit assessment of the chemical recycling of waste plastics in this section to the whole polyolefins and combustion process of refined products, which uses multi-material waste plastics. According to SINOPEC's public research, the carbon emission reduction effect is obvious that 1 ton of waste plastics based on multi-production route of chemicals produces 2.38 tons of CO_2, which is lower than 3 tons of CO_2 emission produced by the incineration of 1 ton waste plastics.

4.1.5 Summary

To sum up, chemical recycling is an important technical route for the resource utilization of waste plastics, which shows better results in economic benefits, resource benefits, environmental benefits and carbon dioxide emission reduction benefits. 1 ton of waste plastics can generate 850 yuan and replace at least 1.12-1.22 tons of oil resources in terms of economic and environmental benefits respectively. The potential value of global warming and other environmental impacts caused by the chemical recycling of waste plastics is at a low level. In terms of carbon dioxide emission reduction, compared with using crude oil for processing plastics, the chemical recycling of waste plastics can reduce 22.0% of carbon emission reduction.

4.2 Whole-life Cycle Performance Analysis of Incineration Utilization

The purpose of resource utilization of waste plastics incineration is thermal energy recovery, and then to generate electricity. The research scope of waste plastics incineration covers the recycling, pretreatment and incineration, and the system boundary of its benefits assessment is shown in Figure 5.

4.2.1 Economic benefits assessment

The economic benefits of waste plastics incineration are measured on the basis of a "cost-benefit" model. The costs measured in this report refer to the operating costs of disposing of waste plastics by incineration, including the costs of recycling and pretreatment, energy consumption and environmental protection. The benefits mainly refer to the income of power generation.

Firstly, the cost of the urban sanitation system to transfer waste plastics from the recycling points/stations to the incineration plants is $C^{transport}$, for short is C^{t}. Secondly, the energy cost arising from the energy inputs, such as electricity, required to support the operation of the incineration system is $C^{energy\text{-}consumption}$, abbreviated as C^{ec}. The cost of the treatment of pollutants including ash (which is a hazardous waste) and flue gases arising from incineration as well as the cost of atmospheric emissions, i.e., environmental protection costs $C^{environmental\ protection}$, abbreviated as C^{ep}. To sum up, the total cost of waste plastics incineration utilization is:

$$C=C^{t}+C^{ec}+C^{ep}$$

According to the survey data, the total cost of incineration of waste plastics is 317 yuan per ton. See Table 8 for details.

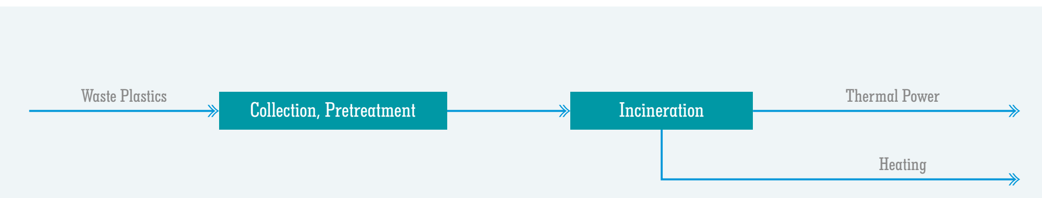

Figure 5. System boundary of the benefits assessment of incineration waste plastics

Table 8. List of costs for incineration of waste plastics — Unit: yuan/ton

	Transportation Cost	Energy Cost	Environmental Cost	Total Cost
Domestic Waste	30	198	287	515
Waste Plastics	30	0	287	317

Note: *Recycling of waste plastics based on existing waste recycling systems.*

The economic benefits of incineration plants include flue gas heat recovery for power generation, heavy metal recovery and slag reuse. As waste plastics are mainly composed of elements such as C and H, the economic benefits of incineration utilization are reflected in the flue gas heat recovery and power generation, excluding heavy metal recovery and slag reuse. Therefore, the economic benefits of waste plastics incineration and resource disposal is the income $Regen_1$ from flue gas heat recovery and power generation of the incineration plant, i.e.

$$Regen_1=RP_e \times A_e$$

RP_e is the unit price of electricity and A_e is the amount of electricity generated.

Assuming that the high temperature incineration oxidation factor of carbon in waste plastics is 100%, the average calorific value of waste plastics in domestic waste is 34.5 MJ/kg[10], waste incineration power generation conversion efficiency of 20% calculation, 1 ton of waste plastic incineration heat recovery of power generation is 1917KWh. According to the current domestic waste incineration power generation pricing policy in China, the amount of electricity generated by tons of waste below 280kWh is 0.65 yuan per KWh, and the excess is based on the local electricity price for coal-fired power generation. In this report, it is calculated as 0.37 yuan per KWh, and the benefits from waste plastics incineration is 788 yuan per ton. The economic benefits of waste plastics incineration are the difference between the electricity price and the above cost. Under the government subsidy (including 0.65 yuan per KWh for power generation and 100 yuan per ton for domestic waste disposal), the economic benefits of waste plastics incineration is 888 yuan per ton, and without government subsidy, the economic benefits of waste plastics incineration is 788 yuan per ton.

4.2.2 Resource benefits assessment

According to the above, 1 ton of waste plastics can generate 1,917 kWh of electricity, which can save 0.77 tons of standard coal according to the standard coal consumption for electricity supply of 0.404 kg/KWh.

Table 9. Environmental emission inventory of waste plastics incineration and utilization

Environmental Emission	Type of Pollutant	Emission (g)
Gaseous Pollutant	N_2O	230
	SO_2	28200
	CO	700
	NO_X	12100
	H_2S	270
	CH_4	9600
Gaseous Pollutant	CO_2	3507200
	HC	250
	Soot	14400
Water Pollutant	COD	700
	SS	720
Solid Wastes	Solid Wastes	414140

Source: *Wu Yuehui. Research on the assessment of waste plastics recycling technology and potential environmental impacts[D]. Harbin Institute of Technology, 2013.*

[10] Source: Gu Lin,He Kun,Liu Haiwei. Research on the calorific value characteristics of waste and its impact on domestic waste incinera-tion power generation projects in China[C]//Chinese Society of Environmental Science, Environmental Engineering Branch. Proceed-ings of the 2022 Annual Scientific and Technical Conference of the Chinese Society of Environmental Science-Environmental Engi-neering Technology Innovation and Application Session (III). China Enfi Engineering Technology Co;,2022:7

Table 10. Potential of Environment Impacts in Waste Plastics Incineration

Type of Environment Impact	Potential of Environment Impact	Type of Environment Impac	Potential of Environment Impact
Global Warming	4221.08kg CO_2eq.	Eutrophication	1.59kg PO_4^{3-}eq.
Ozone Depletion	0.01kg CFC-11eq.	Photochemical. Oxidation	0.077kg C_2H_4eq
Acidification	39.89kg SO_2eq.	Soot&Dust	14.4kg Dust

4.2.3 Environmental benefits assessment

This part takes the waste polystyrene "co-carbonization" technique as an example. During the stages of waste polystyrene crushing, mixing with coal, and coking in the furnace, air pollutants such as CO_2, CH_4, N_2O, HC, SO_2, NO_X, H_2S, CO, soot and dust, and water pollutants such as COD, SS, as well as solid wastes such as residues will be emitted. The environmental emission inventory is shown in Table 9.

Based on the formula for calculating the potential environmental impacts and the equivalence coefficients and emissions in Tables 6 and 9, the environmental benefits of the waste plastics incineration were calculated as shown in Table 10.

4.2.4 Carbon dioxide emission assessment

According to the calculation above, 1 ton of waste polystyrene incineration generates about 3.51 tons of CO_2. If mixed-material waste plastics are used for incineration to generate electricity, according to SINOPEC's public research, the total CO_2 generated from incineration of 1 ton of waste plastics to generate electricity is about 3.0 tons.

4.2.5 Summary

The incineration utilization is relatively traditional but has a significant reduction effect, with an economic benefit of 788 yuan per ton without government subsidy and 888 yuan per ton with government subsidy. In terms of resource benefits, 1 ton of waste plastics can save 0.77 tons of standard coal. In terms of environmental benefits, the potential value of various environmental impacts such as global warming caused by the incineration of waste plastics is at a higher level compared to chemical recycling. In terms of CO_2 emission reduction benefits, the emission level is comparable to that from the using crude oil for processing plastics (3.05 tons per ton of waste plastics), but higher than that of the chemical recycling (2.38 tons per ton of waste plastics).

4.3 Whole-life Cycle Performance Analysis of Landfill

The scope of the study of waste plastics landfill covers the collection and landfill, and the system boundary of its benefits assessment is shown in Figure 6.

4.3.1 Economic benefits assessment

Landfill of waste plastics requires additional waste sorting, removal and landfill, which incurs additional costs and is not economically viable. In practice, landfill of waste plastics is the process of mixing them with domestic waste for landfill. Therefore, the cost of landfill of waste plastics $C^{transport}$, abbreviated as C^{t}, is the same as that of domestic waste, which includes the cost of transferring waste plastics from recycling points/stations to landfill plants by the municipal sanitation system. The cost of landfill operation is represented by $C^{operation}$, abbreviated as C^{op}. The environmental protection cost arising from the disposal of leachate from domestic waste is $C^{environmental\ protection}$, abbreviated as C^{ep}. To sum up, the total cost of landfill disposal of waste plastics is:

$$C=C^{t}+C^{op}+C^{ep}$$

According to the survey, the cost of transporting domestic waste is 30 yuan per ton, landfill operation 60 yuan per ton, and environmental protection 45 yuan per ton, for a total of 135.yuan per ton.

In terms of waste plastics landfill benefit assessment, according to the data between 1989 to 2004, the physical and chemical properties of waste plastics in the landfill process suggest that there is no obvious degradation of waste plastics, and no significant change in its volatile matter, fixed carbon and calorific value. Only the ash content is relatively larger (waste plastics in the landfill layer after a long time of physical and chemical reaction and adhesion or embedded in other impurities). Therefore, the landfill of waste plastics does not generate economic benefits.

To sum up, with the government subsidy of reaches 60~100 yuan.per ton for domestic waste disposal, the economic benefits of waste plastic landfill is -55 yuan per ton (calculated according to the median value of subsidy of 80 yuan per ton). Except from the government subsidy, the economic benefit of waste plastic landfill is -135 yuan per ton.

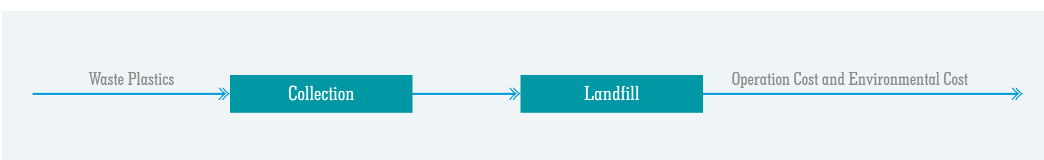

Figure 6. System boundary of benefits assessment of landfill of waste plastics

4.3.2 Resource benefits assessment

Compacting waste plastics and placing them in landfills can reduce the amount of space taken up by waste plastics, but this type of disposal maintains the unavailable state of waste plastics and cannot reduce people's demand for natural resources, such as oil and coal, so the landfill disposal of waste plastics can hardly produce economic benefits.

4.3.3 Environmental benefits assessment

Compared with chemical recycling and incineration, the landfill of waste plastics does not produce significant pollutant emission, but has an indirect environmental impact. With the extension of landfill time, the surface roughness of waste plastics increases, and the surface plastics fall off to form microplastics, which enter the leachate. According to experimental data, the permeate contained 17 kinds of microplastics with an abundance of 24.58 particles per litre. In addition, waste plastics can affect the safety factor of landfills, mainly due to the increase of plastic content in landfills leading to the decrease of shear strength and cohesion of soil, which leads to the decrease of slope stability and the increase of leakage risk of landfills. To sum up, the environmental benefits of waste plastic landfill is negative.

4.3.4 Carbon dioxide emission assessment

Waste plastics are very difficult to degrade under natural conditions, and those entering landfills are usually mixed with other domestic waste such as food waste. As plastics degrade very slowly, the degradation process lasts about 10-1000 years, with an average of 500 years, and the degradation time will be even longer in a closed, oxygen-free, compacted environment such as a landfill site, where the degradation products are unknown. Therefore, this report concludes that in the short term, the level of carbon dioxide emissions from landfill of waste plastics can be considered to be zero.

4.3.5 Summary

Compared with chemical recycling and incineration, the economic benefit of landfill is significantly negative, even with government subsidies at -55 yuan. per ton. The resource saving benefit of landfill is almost 0, and the environmental benefit is negative. The level of carbon dioxide emissions from landfill of waste plastics in the short term can be considered zero.

4.4 Comparison of Three Disposal Ways

According to the results of the whole-life cycle analysis, chemical recycling of waste plastics has the best overall benefits, followed by incineration and landfill successively.

4.4.1 Economic benefits

For waste plastics, the net gain of chemical recycling is about 850.yuan per ton, of incineration with government subsidies is 888 yuan per ton, and of incineration without government subsidies is 788 yuan per ton. For landfill, whether there are government subsidies, the gain is negative.

4.4.2 Resource benefits

Disposing of 1 ton of waste plastics by chemical recycling is equivalent to saving 1.12-1.22 tons of crude oil, by incineration is equivalent to saving 0.77tons of standard coal, and by landfill makes no benefits.

4.4.3 Environmental benefits

Potential environmental impacts of all types of chemical recycling techniques are lower than those of incineration, while the environmental impacts of landfill are long-term. In terms of carbon dioxide emission, 1 ton of waste plastics chemical recycling and incineration can produce 2.38 tons and 3.0 tons of carbon dioxide respectively.

In addition, currently incineration and landfill disposal both require a certain amount of operating subsidies from the government, and it is impossible to achieve stable and effective operations by market forces alone.

Table 11. Comparison of different Disposal Ways

	LCA				Other		
	Economic Benefits	Resource Saving Benefits	Environ-mental Benefits	Carbon Dioxide Emission	Plant Area/m^2	Equipment Investment/ 100million	Government Subsidy
Chemical Recycling	With government subsidy: 850 yuan per ton	1.12-1.22 tons of crude oil	Sound	2.38 tons of waste plastics	7500	5000 yuan per ton investment	None
Incineration	With government subsidy: 888 yuan per ton	0.77 tons of standard coal	Poor	3.0 tons of waste plastic	66700	500-600 thousand yuan per ton investment	(1) Electricity generation subsidy: 0.65 yuan per Kwh for up to 280 yuan per Kwh; 0.37 yuan per Kwh for more than that. (2) Subsidies for domestic waste disposal: 100 yuan per ton on average
	Without government subsidy: 788 yuan per ton						
Landfill	With government subsidy: -55.0 yuan per ton	0	Poor	0	133400	120 thousand yuan per ton investment	Subsidies for domestic waste disposal: 80 yuan per ton on average
	Without government subsidy: -135.0 yuan per ton						

Note: *The floor area of the chemical recycling plant is the mean of the data provided by several enterprises investigated by the research group. The floor area of the incineration plant and landfill is the actual mean of the industry provided by relevant industry associations.*

05

The Key to Chemical Recycling Industrialization and Promotion

At present, chemical recycling of waste plastics is still in the early stage of industrialization, and there are still some key issues to be solved to promote its large-scale development.

5.1 Difficulties and Key Initiatives in Chemical Recycling

5.1.1 Defining the industrial positioning of chemical recycling

Currently relevant departments lack top-level design and overall layout for the chemical recycling of waste plastics, and the industrial positioning is not clear. In terms of project approval and establishment, chemical recycling is often strictly limited to small-scale chemical projects, and it is difficult to get promotion. Given the great potential of chemical recycling in the treatment of plastic pollution, in terms of industrial positioning, chemical recycling should be regarded a vital technique for waste plastics recycling and an important part of energy-saving and environmental protection industry. Firstly, chemical recycling should be included in the national economic industry classification. Secondly, chemical recycling projects should be included in the Guidance Catalogue for Industrial Structure Adjustment, and listed in the category of "Comprehensive Utilization of Environmental Protection and Resource Conservation". Thirdly, chemical recycling projects should be included in the Green Industry Guidance Catalogue as energy-saving and environmental industry. Meanwhile, considering the needs of industrial development and government supervision, in terms of industrial layout, we should take chemical recycling projects as the comprehensive utilization of resources, prioritize the centralized layout and operation management in chemical parks, and give the top guarantee to carbon emission index, energy-use index and land-use index, and exclude them from the management of the Two-High projects, and not limited by chemical projects capacity.

5.1.2 Establishing a waste plastic recycling system compatible with chemical cycling

Currently low-value waste plastics are mixed into domestic waste for incineration or landfill. According to the survey, the waste plastics account for about 20% of domestic waste entering the garbage incineration plant, and can become an important source of raw materials for chemical recycling. With the strengthening of international constraints on plastic pollution control, the materialized recycling of waste plastics should be encouraged, the proportion of incineration and landfill should be gradually reduced, and a recycling system for waste plastics matching the chemical cycle should be established. In terms of residents' waste plastics, we should accelerate the reform and improvement of the existing domestic waste sorting system, dispose low-value plastic waste as low-value recyclables, add special recycling bins (barrels) for waste plastics in urban and rural residents' domestic waste sorting, and build an urban low-value recyclable sorting center to sort out low-value waste plastics from domestic wastes for chemical recycling enterprises to utilize. Concerning waste agricultural land films and other low-value mixed plastics, the establishment of a sound system of centralized collection and pretreatment should be accelerated, and a coordinated connection with end-of-pipe chemical recycling facilities should be realized.

5.1.3 Improving the design of plastic packaging to adapt chemical recycling

Due to product features, the use of PVC plastics and harmful additives will bring security and product quality risks to chemical recycling. Therefore, for some chemical recycling processes, PVC-containing plastic packaging needs to be removed during pretreatment. If the pretreatment does not include sorting, the chlorine element, which could reduce chemical recycling effects, needs to be removed in the back-end chemical decomposition. Consequently, packaging enterprises should be encouraged to reduce the production and use of PVC plastics and harmful additives. Relevant state departments should consider banning or restricting the production, sale, and use of PVC packaging and some additives in certain fields. We should continue to promote the "Easy to recycle and regenerate" design concept of packaging materials, and encourage enterprises to use single plastic packaging materials to replace composite packaging with multiple materials during the design and production of packaging. Enterprises should also be encouraged and supported to promote high-strength films and flexible plastic packaging to better satisfy the raw material recycling of chemical cycle.

5.1.4 Accelerating the industrialization and application verification of key chemical recycling techniques

Currently the main techniques of chemical recycling have completed laboratory development and pilot test validation, some of which can be applied in commercial use after large-scale industrialization verification. The industrialization and application should be combined with demonstration and application projects to improve key techniques of the whole industrial chain, focusing on optimizing the efficient sorting device of waste plastics in domestic garbage by enhancing recycling efficiency, reducing the cost of sorting, upgrading the high-efficient environmental pretreatment of waste plastics, which includes removing impurities, energy-saving and water-saving. We should also accelerate the upgrading of chemical pyrolysis technology of waste plastics and strengthen the stability and continuity of pyrolysing, promote the research, development, and application of intelligent and automated control systems, and thus enhance the comprehensive utilization efficiency of chemical recycling of waste plastics.

5.1.5 Establishing a chemical recycling traceability management system

At present, recycled plastics application enterprises at home and abroad are generally required to carry out the traceability management of recycled plastics to ensure the authenticity of raw material sources and the quantitative management. To stimulate the consumption demand for chemical recycling products, we should establish and improve a traceability management system for the whole life cycle of the chemical recycling of waste plastics. By fully utilizing modern information technology such as big data and blockchain, we can build a comprehensive information management platform that is controllable, traceable, verifiable and certifiable, and launch certification of chemical recycling of waste plastics. Enterprises engaging in the chemical recycling of waste plastics shall establish a green supply chain management system, conduct traceability management of waste plastics recycling, record key information such as the source, quantity, quality, and energy consumption of waste plastics and detail information such as the project's techniques, main products, production volume and product flow, and accept the verification of the relevant departments, industry organizations, and product application enterprises, to prevent falsification.

5.2 Development Roadmap

Based on the status quo and developing trend of the chemical recycling of waste plastics, the report divides the development of chemical recycling industrialization into three periods, including the incubation period (2024-2025), development period (2026-2030), and maturity period (2031-2035), and the measures that should be prioritized in each phase are as follows:

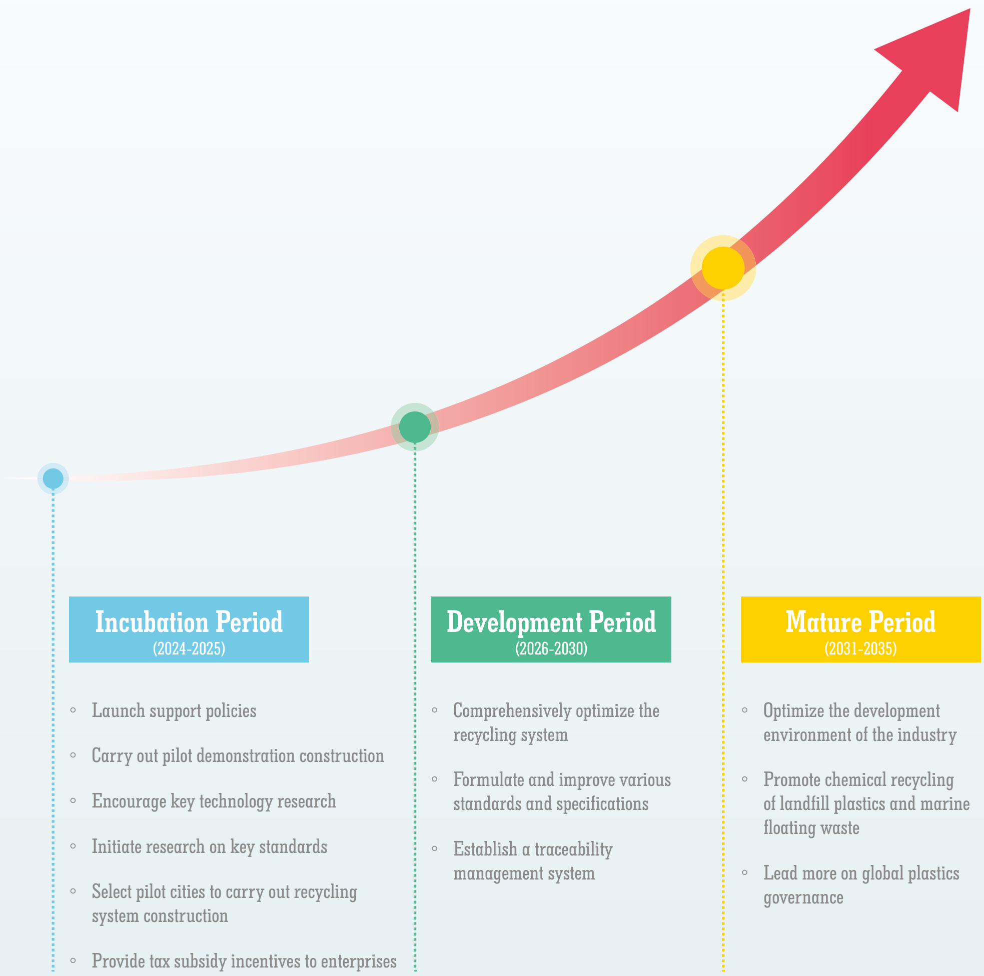

Figure 7. Development Periods of Chemical Recycling of Waste Plastics

5.2.1 Measures to be prioritized during incubation period

Centering on support for industrial development, demonstration pilot construction, and encouragement of technological research, we shall issue relevant policies or industry development guidance to clarify the government support and encouragement to the chemical recycling of waste plastics. Efforts should also be made to select leading enterprises of the industry to construct demonstration projects for the chemical recycling of waste plastics, initiate the research and formulation of key standards for chemical recycling, define pilot cities to build a waste plastics recycling system compatible with chemical recycling, and offer policy support such as investment and operation subsidies, tax concessions, and land guarantees to relevant enterprises and demonstration projects, in order to encourage enterprises to undertake key national science and technology research and development projects.

5.2.2 Measures to be prioritized during development period

We shall improve the industrial policy system centering on the large-scale and market-oriented application and standard development. Efforts should be made to comprehensively reform and improve the garbage collection system, and establish a recycling system for waste plastics compatible with chemical recycling. We shall formulate and improve various standard and regulation systems for chemical recycling of waste plastics, and clarify specifications on the collection and transportation of raw materials, selection of factory sites, project construction, technical process, product quality, and disposal of three wastes of the industry. We shall establish and improve the traceability management system of chemical recycling, encourage enterprises producing and using plastic products to use more raw plastic materials of chemical recycling, which shall be incorporated into the green and low-carbon development strategy of enterprises.

5.2.3 Measures to be prioritized during maturity period

We shall continue to optimize the development environment of the industry, and encourage the innovation-oriented development of all market entities across the industrial chain of chemical recycling. We shall take chemical recycling of waste plastics as the core initiative to cope with plastic pollution control in combination with the global trend and China's progress in terms of plastic pollution control, and orderly promote the centralized cleanup and chemical recycling of landfill deposited plastic wastes as well as floating plastic wastes in the ocean. We shall proactively participate in international collaboration on plastic pollution control, promote the application of chemical recycling technology for waste plastics globally, and thus comprehensively increase China's contribution to global plastic pollution control.

06

Policy Suggestions
for Promoting the Industrialization of Chemical Cycling

First, to clarify the strategic positioning of chemical recycling of waste plastics: as an important component of building China's plastic pollution control system and strategic security of energy resources, it is included in the plastic pollution control policy and regulation system, circular economy planning and waste materials recycling system planning. Secondly, improve the policy support system: the construction of chemical recycling projects into the central budget investment support, enjoy the renewable resources industry value-added tax that is refundable, income tax concessions and other tax incentives. Third, promote the construction of demonstration projects: Promote large petrochemical enterprises to increase investment in waste plastics recovery and chemical recycling. Fourth, encourage the synergistic development of recycling:take leading chemical recycling enterprises as the core, play a leading role in the industry, and unite upstream and downstream enterprises to build an industrial ecosystem for chemical recycling of waste plastics. Fifth, strengthen international cooperation and exchange:actively participate in the governance of global plastic pollution, take the initiative to participate in the formulation of global plastic pollution prevention and control rules, and promote international scientific research and technical cooperation.

6.1 Strengthening coordination and top-level design

We should define the strategic positioning of chemical recycling of waste plastics, take it as an important component in building China's plastic pollution control system and strategic security guarantee of energy resources, incorporate it into the policy and regulation system of plastic pollution, circular economy planning and waste material recycling system planning. We should also issue guiding opinions and development plans to promote the industrialization of the chemical recycling of waste plastics, improve series of standard systems for the construction of waste plastics recycling systems, pollution control during production, product quality, traceability certification and recycling, strengthen the access management of chemical recycling projects, clarify the pre-condition for approval, prevent low-level competition and repetitive construction, to form a stable ecology for chemical recycling.

6.2 Improving policy support system

The construction of chemical recycling projects shall be included in the scope of central government budgetary investment, and enjoy tax incentives such as VAT instant refund and income tax incentives in the renewable resources industry. The building of recycling outlets and sorting centers for waste plastics shall be included in the scope of central and local financial subsidies. We should also incorporate the chemical recycling of waste plastics into national scientific and technological innovation system, increase investment, and actively carry out the research and development, demonstration and application of chemical recycling technology for waste plastics. Efforts shall also be made to establish a traceability and certification system for chemical recycling products, and incorporate such products into the scope of green products, increase government procurement, and encourage enterprises and consumers to prioritize the use of raw materials and products of chemical recycling respectively.

6.3 Advancing the construction of demonstration projects

We shall drive large-scale enterprises to increase investment in chemical recycling of waste plastics, build a number of demonstration projects about chemical recycling of waste plastics, support key enterprises to launch industrialization demonstration by newly building or utilizing existing installations, and encourage the construction of demonstration projects for the integrated development of upstream and downstream industrial chains. We shall also encourage local governments and sanitation enterprises to cooperate with enterprises engaging in chemical recycling of waste plastics, establish a low-value waste plastics recycling and specialized sorting system compatible with chemical recycling, build centralized sorting centers for waste plastics, and enhance automated sorting ability. Efforts shall also be made to encourage waste film recycling, sorting, and chemical recycling projects in Xinjiang, Gansu, and other areas where films are used frequently. Pulp mills (paper mills) should be encouraged to cooperate with chemical recycling enterprises in dealing with sorted waste plastics to establish demonstration and application projects of chemical recycling.

6.4 Encouraging coordinated development of recycling and reusing

We shall center on leading enterprises engaging in chemical recycling to take the lead in the whole industry, and unite upstream and downstream enterprises to build an industrial ecosystem for chemical recycling of waste plastics. We shall encourage chemical recycling enterprises to develop raw material recycling, cooperate with professional recycling enterprises to establish a plastic waste recycling and sorting system to promote the integrated development of waste plastics collection, pretreatment, and chemical recycling. Efforts shall also be made to encourage the coupling development of waste plastics pyrolysing enterprises and petrochemical enterprises, promote the integrated development of waste plastics pyrolysing and plastic production, provide downstream enterprises with customized, standardized and green development plans on waste plastics recycling, and thus to build a closed-cycle system for plastics recycling industry.

6.5 Strengthening international cooperation and exchanges

China will actively participate in global plastic pollution control, take the initiative to join in the formulation of global rules on plastic pollution prevention and control, and promote international scientific research and technological cooperation. We will make plastic pollution prevention and control as a major part of bilateral and multilateral environmental cooperation among partner countries of the Belt and Road Initiative, share China's concepts and practice of plastic pollution control, and advance knowledge-sharing, technology exchanges, and capacity building. We also encourage qualified chemical recycling enterprises to cooperate with countries along the Belt and Road in plastic pollution control. We aim to cooperate more with international chemical enterprises and encourage the joint construction of chemical recycling demonstration projects. China will also proactively participate in the clean-up of marine waste plastics and chemical recycling initiated by international organizations.

07

Prospects

At present, plastic pollution control is a global issue, especially against the acceleration of negotiation on the International Plastics Convention, the chemical recycling technology of waste plastics has a promising prospect for application and promotion, and has become a strategic high point for the green future of petrochemical industry. With the continuous innovation of technology and exploration of industrialization, chemical recycling of waste plastics will be increasingly economical and feasible, and is expected to provide a brand-new solution for plastics pollution control, truly realizing the closed-cycle plastics recycling.

From the potential of China's chemical recycling of waste plastics, according to the relevant data of the Ministry of Industry and Information Technology, China's output of plastic products in 2022 was 77.716 million tons. According to the report of the China National Resources Recycling Association, China produced 60 million tons of waste plastics in 2022, of which only 18 million tons were physically recycled, accounting for 30%, and the rest were disposed of by incineration or landfill. It is estimated that by 2035,. the annual output of plastic products in China will reach 155 million tons, and if the utilization rate of chemical recycling among them reaches 30%, the overall materialized recycling rate of waste plastics will exceed 60%, and the annual plastic waste will be reduced by nearly 36 million tons through chemical recycling[11], and the carbon dioxide emission will be reduced by 22.32 million tons compared with the incineration of waste plastics, and the oil resources will be saved by about 108 million tons, which is equivalent to recreating two Daqing oil fields, and the output value will exceed 160 billion yuan.

From the potential of global chemical recycling of waste plastics, according to the analysis data of the Plastics Europe, it is expected that by 2035, the global plastic production will be doubled, and the annual global plastic production will reach 734 million tons. If the global recycling rate of waste plastics can increase from the current 9% to 30% through chemical recycling,. 150 million tons of recycled plastics will be added each year, reducing carbon dioxide emissions by 93 million tons compared with waste plastic incineration, which is equivalent to saving 450 million tons of oil resources, to reach 67.8% of the total consumption of 663 million tons of oil of Europe in 2022, and the output value will exceed 680 billion yuan. According to OECD statistics, about 5.3 billion tons of waste plastics were abandoned in landfills or nature worldwide by 2017, if 50% of which could be chemically recycled, the potential effect could be equivalent to developing an oil field of nearly 8 billion tons.

[11] Assume that the ratio of the amount of waste plastics produced to the amount of plastic products produced is con-stant.

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