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RENEWABLE ENERGY INSTITUTE

Pathway to Decarbonization of Petrochemicals in Japan

Shifting from Mass Consumption, Creating Carbon Circulation and Enhancing Renewable Energy Deployment

Februrary 2024

Acknowledgments
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About Renewable Energy Institute
Renewable Energy Institute is a non-profit think tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Son Masayoshi, Chairman & CEO of SoftBank Group, with his own resources.

Table of Contents

Purpose of this Report

The Synthesis Report of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) of March 2023 warned that "there is a rapidly closing window of opportunity to secure a livable and sustainable future for all." According to the Copernicus Climate Change Service (C3S), the EU's weather information agency, the average global temperature from January to October of this year (2023) was 1.43°C above the pre-industrial level. On some days in November, the temperature was even 2°C higher. Even if the average temperature in a given year reaches "plus 1.5°C," this does not mean that the temperature goal of the Paris Agreement (to limit global temperature rise to 1.5°C) has failed, but it does signal that there is pressing risk of this. It is therefore vital to pursue large emission reductions as soon as possible.

The industrial sector accounts for 37.8% of Japan's energy-related CO_2 emissions. After the steel industry, the second biggest contributor to these emissions is the petrochemical industry. On top of energy-related emissions, large amounts of CO_2 emissions are also generated by the use of petrochemical products and in the process of their waste disposal after use.

The petrochemical industry has long been seen as a "hard-to-abate" sector, but to meet the 1.5°C goal, this sector needs to be decarbonized without delay. Various technologies capable of achieving near zero CO_2 emissions are rapidly being developed. The challenge has more to do with the lack of a shared vision of the future among the many stakeholders that need to collaborate on the decarbonization of petrochemicals. Of course, consumers and local governments also have a very important role to play in rethinking unsustainable consumption and production patterns, as symbolized by the rampant use of disposable plastics.

The main objective of this report is to provide a "big picture" of the action needed to decarbonize the petrochemical industry and petrochemical products.

A major challenge surrounding plastics, which make up 60% of petrochemical products, has become the global problem of marine plastic pollution. International negotiations aimed at striking a new treaty to prevent plastic pollution are currently on track to reach agreement by the end of 2024.

For the sake of petrochemical decarbonization, it is very important that we take the opportunity of this treaty to totally rethink disposable products and promote the recycling of plastic resources.

Plastics and other petrochemical products are consumed in large quantities throughout our daily lives. Rethinking our production and consumption of these products and their recycling has the potential to revolutionize our relationship with materials. The prevention of marine plastic pollution and the decarbonization of petrochemicals should be viewed as an opportunity to radically change our convenience-driven, mass-consumption society and move toward sustainable consumption and production.

Summary

Energy-related emissions from Japan's petrochemical industry total 27.6 $MtCO_2e$ per year. In addition, petrochemical products are themselves composed primarily of carbon from fossil fuels, so the incineration of waste petrochemical products (even after taking account of energy recovery) generates 19.8 $MtCO_2e$ of emissions per year. Another 1.7 $MtCO_2e$ of emissions are generated by the incineration of VOCs recovered from facilities that use solvents.

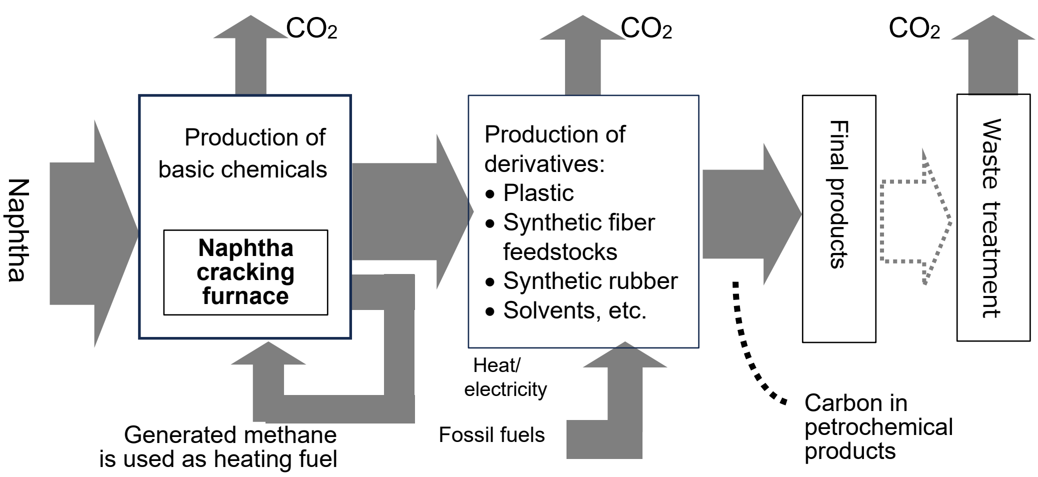
Using naphtha from domestic and overseas oil refineries as a raw material, Japan's petrochemical industry produces a variety of chemical products (petrochemical derivatives), including plastics, synthetic fiber feedstocks, synthetic rubber, feedstocks for paints and solvents, and feedstocks for synthetic detergents. Of this total production volume, plastics make up 63%, synthetic fiber feedstocks 9%, and synthetic rubber 6%, making up 78% of all production.

The facilities that produce "basic chemicals" such as ethylene, propylene, and xylene from naphtha are called "naphtha cracking furnaces." The CO_2 emitted from these facilities accounts for 40% of the energy-related CO_2 emissions of the petrochemical industry.

The processes used to produce plastics and synthetic fiber feedstocks also require large energy inputs, typically provided by fossil fuels or electricity.

Given that the petrochemical industry is likely to be significantly restructured in the coming years, this should be used as an opportunity to promote de-fossilization and decarbonization.

Flow of carbon in the petrochemical industry (outline)



It is essential to consider two aspects of decarbonization: the CO_2 associated with energy consumption in the petrochemical industry and the CO_2 associated with carbon in petrochemical products. For this, the following three things need to be done.

(1) Reducing production and consumption first

Although petrochemical products are indispensable for daily life, industry, medical care, and other applications, it is important to exhaustively promote reduced use of single-use products and products that are used for a minimal time (e.g., fast fashion).

(2) Feedstock transformation: Carbon circulation

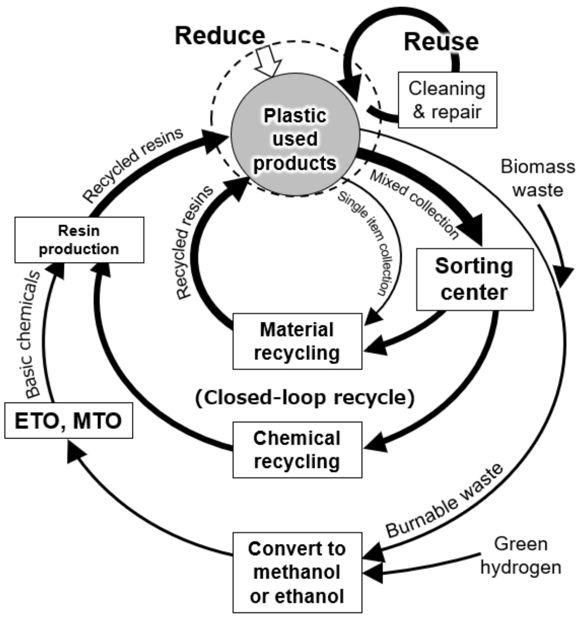
The CO_2 emissions from the input of new fossil fuels and the disposal of used products must be reduced to zero, by recycling the carbon and hydrogen in used chemical products into fresh feedstocks for new chemical products.

When recycling carbon, it is important to have "small loops" to keep energy inputs as low as possible. It is also necessary to find the right combination of high-quality material recycling and "circular chemical recycling" that returns material to plastic again.

(3) Energy transition: Renewables in naphtha cracking and other processes

The energy inputs of petrochemical processes need to be converted to renewable energy. Technologies for converting the heat sources of naphtha cracking furnaces, which are the biggest source of CO_2 emissions, to electricity are under development.

Circular carbon chemistry of plastics (closed loop carbon cycles)



The Japanese government has stated that it will apply its "GX" (green transformation) investment support framework to lead the global effort to decarbonize manufacturing. Naturally, it's important to concurrently promote the development of a variety of technologies simultaneously, but this approach seems to lack any direction.

Furthermore, as already noted, it will take more than innovations in production technology to decarbonize petrochemicals. Instead, the main focus should be on reducing production and consumption and on establishing carbon cycle mechanisms. The necessary production technology will then adapt accordingly.

We offer the following eight recommendations for any future policies on the decarbonization of petrochemicals.

Establish a hierarchy of initiatives

A wide range of initiatives need to be pursued concurrently, so it is important to set clear priorities for the initiatives that each stakeholder should take.

Take an integrated approach to the decarbonization of petrochemical, the recycling of plastics, and the decarbonization of the waste sector

It is especially vital to review the recycling of carbon in an integrated way because it is closely related to the implementation of technologies that use waste plastics and CO_2 as feedstocks.

Promote collaboration and open discussion between the various actors

The decarbonization of the petrochemical industry cannot be achieved solely through the efforts of the petrochemical industry. It will require collaboration between the many actors involved in the supply chains of petrochemical products.

Promote reuse

With reference to the EU's new targets for reusable plastic packaging, consideration should be given to using the system of Japan's Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging to encourage relevant businesses to adopt reusable containers.

Promote use of recycled resins (limit use of virgin resins)

To enable the users and suppliers of recycled resins to cooperate effectively, economic measures such as applying a tax on virgin resins should be considered, in addition to setting medium- and long-term targets for the use of recycled resins.

Promote development of sorting centers

To ensure supplies of high-quality recycled resins, industry, local governments, and the national government need to collaborate as soon as possible to study the development of European-style sorting centers.

Shift to renewable energy as soon as possible

It is essential that core facilities for the production of basic chemicals, as well as various processes for synthesizing resins and chemical fiber feedstocks, are converted to renewable energy as soon as possible.

Supporting the business transformation of SMEs

To enable small and medium-sized enterprises (SMEs) to make a smooth transition to decarbonization, it is necessary to provide them with more effective support measures.

Chapter 1 Petrochemicals and CO_2 Emissions

CO_2 emissions associated with petrochemicals

Japanese industry accounts for 37.8% of the country's total energy-related CO_2 emissions. Of the various manufacturing sectors, petrochemicals and cement is responsible for the second largest chunk of these emissions after the steel industry.

The energy-related emissions from the petrochemical industry amount to 27.6 $MtCO_2e$ annually, which is 50.2% of the chemical industry's total emissions. Other sectors of the chemical industry (besides petrochemicals), such as the soda industry, ammonia production, and production of fine chemicals for pharmaceuticals and semiconductor materials also generate substantial emissions.

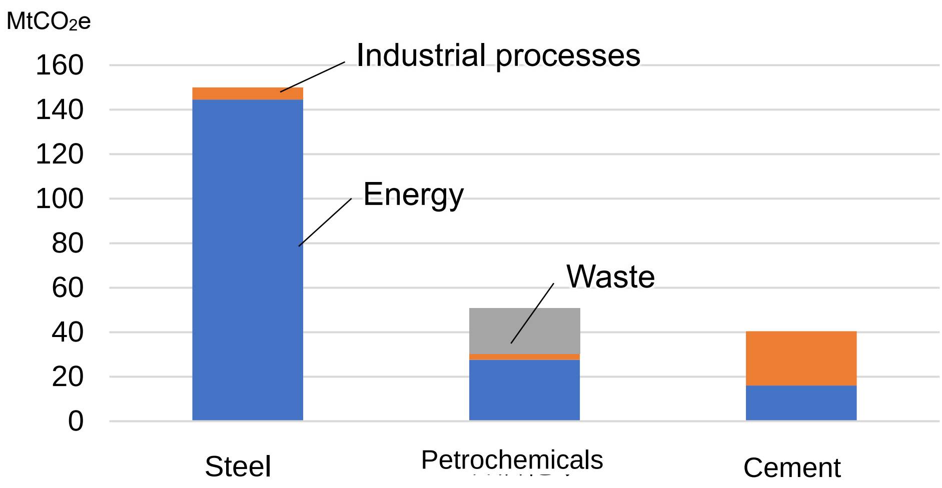
However, petrochemical-related CO_2 emissions do not stop there. Petrochemical products consist primarily of carbon from fossil fuels, amounting to 23.6 MtCe (86.4 $MtCO_2e$) per year. Essentially, this carbon remains in petrochemical products until released into the atmosphere as CO_2 when used products are incinerated. Just within Japan (i.e., ignoring exported petrochemical products), incineration (including waste-to-energy) of waste petrochemical products generates 19.8 $MtCO_2e$ of emissions. The incineration of VOCs recovered from facilities that use solvents generates another 1.7 $MtCO_2e$ of emissions (Fig. 1).

When considered on a life cycle basis, the oil refining industry, which produces naphtha and other products from crude petroleum, and the plastic products manufacturing industry, which uses petrochemical products as raw materials, also generate greenhouse gas (GHG) emissions. Methane leaks during crude petroleum extraction is a serious problem, also.

It is therefore necessary to achieve virtually zero CO_2 emissions not only from energy consumption in the petrochemical industry, but also from carbon contained in petrochemical products and waste.

* Data in this section is based on Comprehensive Energy Statistics (FY2021 Energy Supply and Demand Report) and the National Greenhouse Gas Inventory Report of JAPAN, (2021).

Fig. 1 CO_2 Emissions from steel, petrochemicals, and cement



Source: Created based on data from the National Greenhouse Gas Inventory Report of JAPAN, (2021)

Overview of the petrochemical industry

The oil refining industry distills imported crude petroleum to LPG, naphtha, gasoline, kerosene, diesel, fuel oil, and other petroleum products.

In contrast, the petrochemical industry uses naphtha from domestic and foreign oil refining plants as a raw material to manufacture chemicals (petrochemical derivatives) such as plastics, synthetic fiber feedstocks, synthetic rubber, feedstocks for paints and solvents, and feedstocks for synthetic detergents. These petrochemical products are then processed further by the plastic products manufacturing industry and other related industries, for use in machinery and equipment, construction, daily necessities, and clothing (Fig. 2).

Some companies that are primarily engaged in oil refining have integrated operations up to the stage of petrochemical processing.

A breakdown of petrochemical products shows that 63% of production volume is for plastics, 9% for synthetic fiber feedstocks, and 6% for synthetic rubber. These three categories account for 78% of total production (Fig. 3).

Fig. 2 Petrochemical production flow

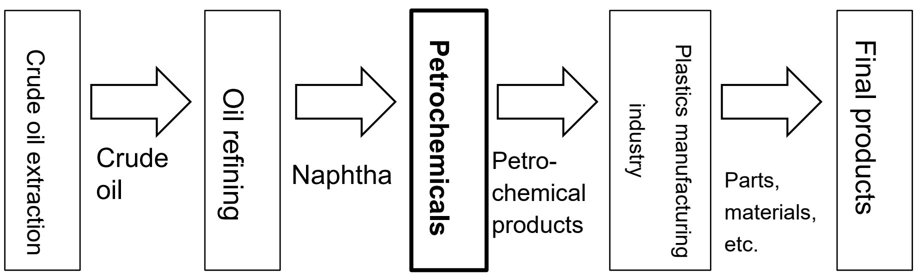
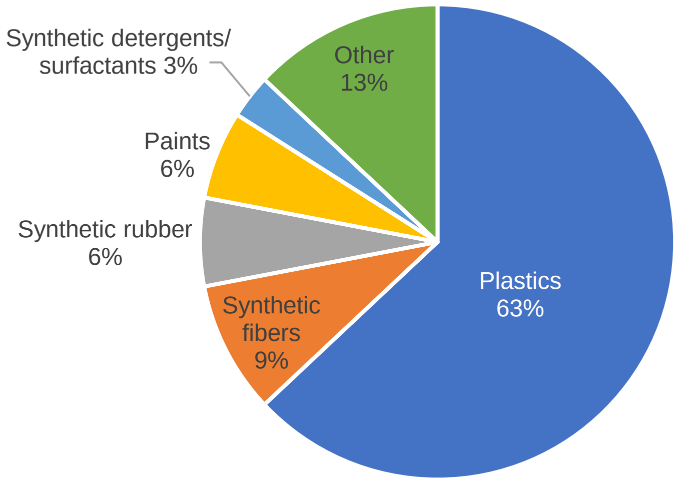


Fig. 3 Domestic demand for petrochemical products by weight (2021)



Source: Created based on data from "State of the Petrochemical Industry 2022" by the Japan Petrochemical Industry Association

The processes of the petrochemical industry can be broadly divided into two.

The first process is the production of "basic chemicals" such as ethylene, propylene, and xylene from naphtha. The facilities that produce these basic chemicals are known as "ethylene centers." At their core is a naphtha cracking furnace ("naphtha cracker"). In a naphtha cracker, naphtha is heated to 820 to 850°C to be cracked (decomposed) into ethylene, propylene, and other substances that can be used as feedstocks for petrochemical products. After cracking, the gases are separated into various substances and fed into the next process. Around 13 to 17% of the naphtha fed into a cracking furnace is converted to methane, which is used as a fuel for heating the furnace. The CO_2 generated by the combustion of methane accounts for 40% of the energy-related CO_2 emissions of the petrochemical industry (Fig. 4).

The second process is the production of various resins and other chemicals (called "derivatives") from basic chemicals. In the case of the familiar plastic polyethylene, many small molecules of ethylene are connected to form a long chain polymer.[1] In the case of polystyrene, there are two steps. Firstly, the styrene monomer molecules need to be made from the basic chemicals of ethylene and benzene. The monomer molecules are then linked together to form the polymer.

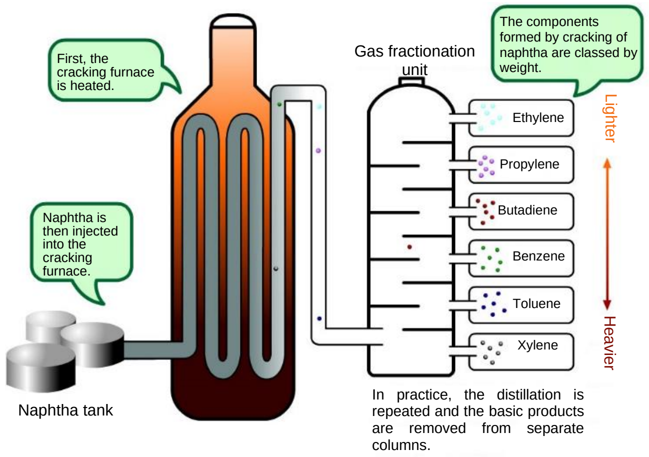
Most major petrochemical products, such as various plastics, synthetic fiber feedstocks (e.g., polyester), and synthetic rubbers are polymers that are made in this way. The

[1] In the case of a typical polyethylene, molecules are composed of 1,000 to 20,000 carbon atoms linked together.

manufacturing processes used to make this diverse range of products are highly complex.

The production of derivatives also requires the input of massive quantities of energy, but since the methane obtained from naphtha cracking has already been used to heat the cracking furnace, new fossil fuels and electricity are needed for making derivatives.

Fig. 4 Naphtha cracking furnace



Source: Japan Petrochemical Industry Association website

Fig. 5 Carbon flow in petrochemical processes (outline)

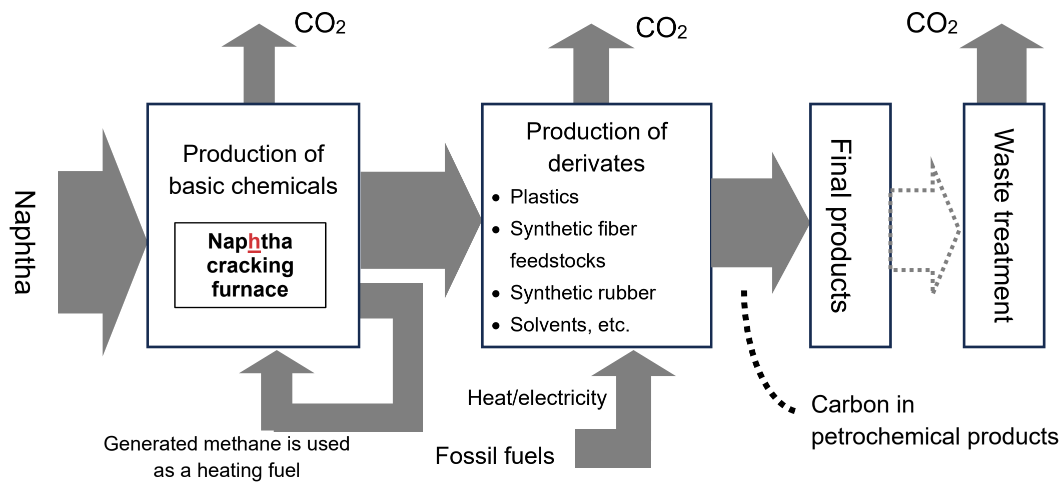
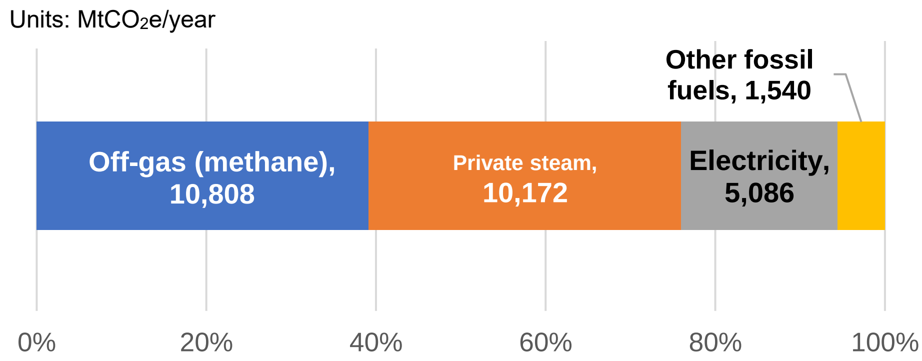


Fig. 6 Breakdown of CO_2 emissions from final energy consumption in the petrochemical industry



Source: Created based on Comprehensive Energy Statistics (FY2021 Energy Supply and Demand Report)

In Japan, petrochemical products are produced from naphtha using the method described above. Naphtha is widely used as a feedstock in Europe too.

In the U.S., on the other hand, ethylene is being increasingly produced inexpensively from the ethane contained in shale gas. In China, some plants even use coal as a feedstock.

Japan's petrochemical industry faces a period of restructuring

The Japanese petrochemical industry is currently set for a period of major restructuring. There are currently 10 ethylene centers that produce ethylene and other basic chemicals, not counting those whose core naphtha cracking furnaces are shut down (Fig. 7). Compared to Europe, North America, and China, Japan's petrochemical industry is small, both in terms of the companies involved and the size of plants. In the Asian market, Japan faces fierce competition in basic chemicals from producers in China, South Korea, the Middle East, and elsewhere (Fig. 8). For this reason, major Japanese chemical manufacturers have been shifting their focus to high-value-added products.

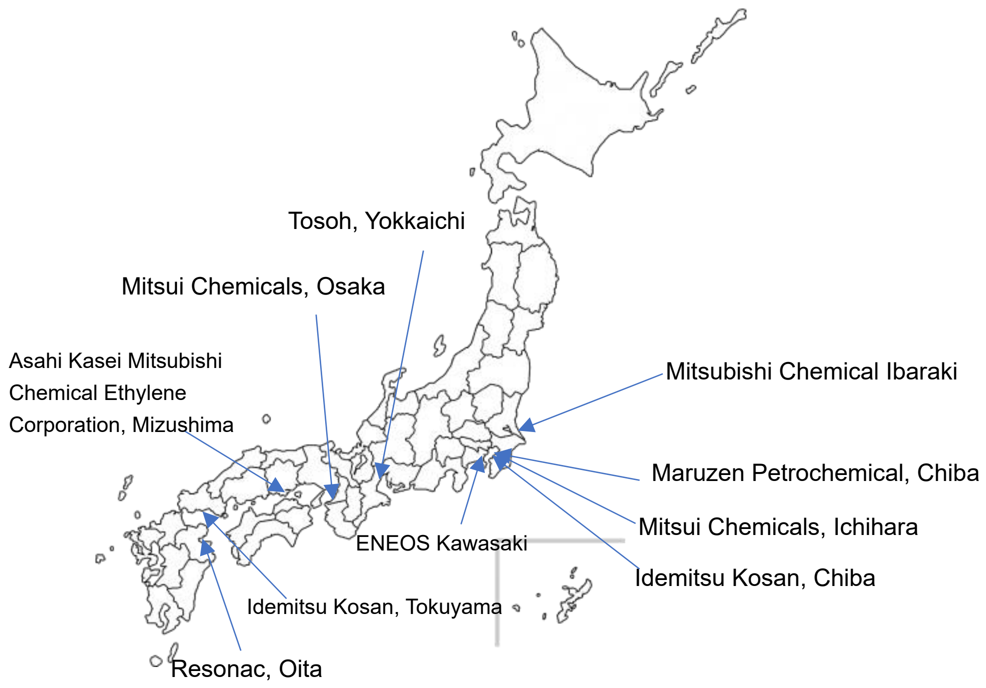
Since the summer of 2022, Japan's ethylene centers have been facing difficulty, because their utilization rate is now hovering around 80%, well under the 90% level that is considered the threshold for economic viability (according to a survey by the Japan Petrochemical Industry Association).

Against this backdrop, some of the major manufacturers are moving to restructure the industry in various ways, including the consolidation of ethylene centers.

This expected restructuring of Japan's petrochemical industry in the coming years needs to be used as an opportunity to promote the phasing out of fossil fuels and decarbonization of the petrochemical industry.

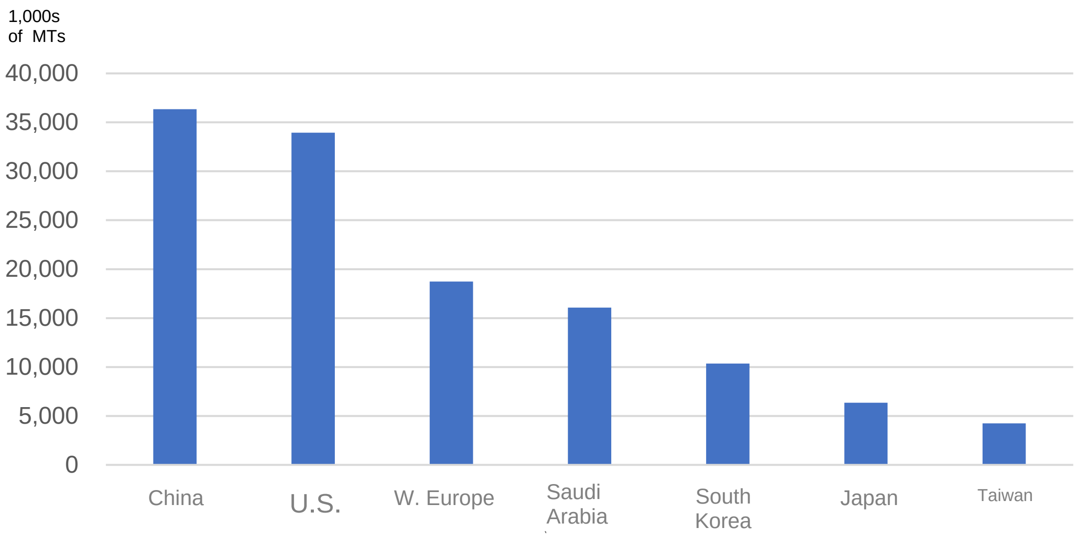
Fig. 7 Ethylene centers in Japan

(Facilities with shut-down naphtha cracking furnaces are excluded.)



Source: "Japan's Petrochemical Industry 2023," The Heavy & Chemical Industries News Agency, p61-104

Fig. 8 Ethylene production in major producing countries (2021)



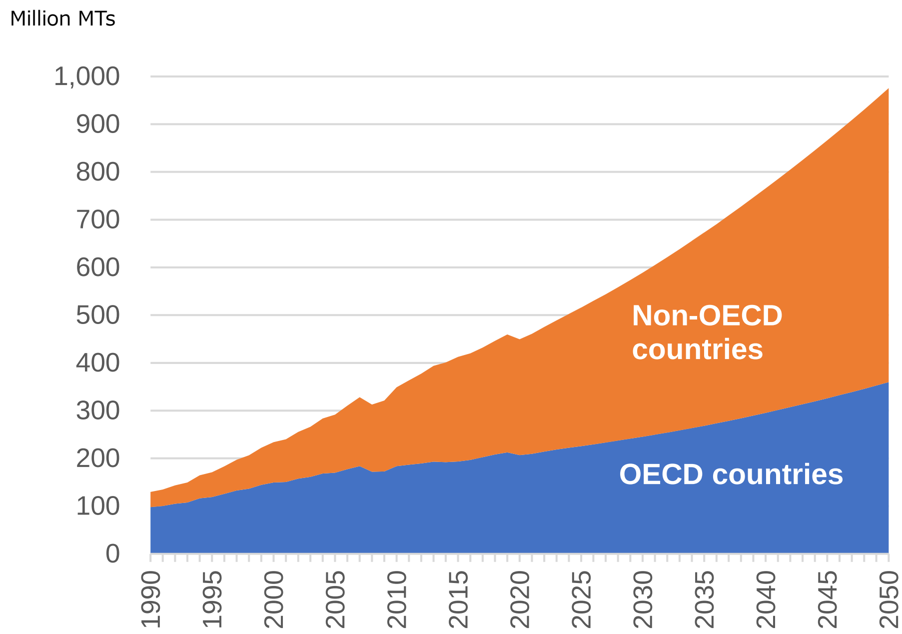
Source: Created based on data from "State of the Petrochemical Industry 2022" by the Japan Petrochemical Industry Association

Global plastic consumption, which is growing rapidly, especially in emerging and developing countries, is projected to double to nearly 1 billion metric tons per year by 2050 (Fig. 9). To ensure that CO_2 emissions from plastic production and waste plastic processing do not increase in proportion to this growth, developed countries need to urgently design a road map for decarbonizing petrochemicals.

If Japan can take advantage of this petrochemical industry restructuring as an opportunity for decarbonization, it can offer the rest of the world a model to follow.

Fig. 9 Projections of global plastic consumption (OECD)

(Baseline scenario)



Source: Created based on data from "Global Plastics Outlook: Policy Scenarios to 2060," OECD, 2022

Chapter 2 Moving to Decarbonize Petrochemicals

As mentioned, decarbonization must be considered in terms of both the CO_2 associated with energy consumption in the petrochemical industry and the CO_2 associated with carbon in petrochemical products.

Chemical recycling techniques and various technologies that contribute to the decarbonization of petrochemicals are currently being developed. It is necessary to concurrently promote a variety of initiatives.

However, the most important thing is to focus on a social and economic transformations to shape a decarbonized society, or to act in the direction of "redesign of economy" as called for in the National Diet's Climate Emergency Resolution.[2]

Like other materials industries, the petrochemical processes need big facilities, so capital investment aimed at achieving carbon neutrality by 2050 and "carbon negativity" beyond that time is particularly important.

Petrochemical decarbonization and the circular economy

An important aspect of "redesign of economy" is the shift to a circular economy. Although there is no fixed definition of the circular economy, we understand it here as an economic system to replace the linear economy based on "take-make-waste," in which products and raw materials retain their value and continue to be used for as long as possible.

Although circular economy policies overlap considerably with earlier measures to promote a more recycling-oriented society in Japan, it should be noted that these are understood as essential initiatives for decarbonization and biodiversity loss prevention, rather than as measures to address waste problems. According to a report by the Energy Transitions Commission on the decarbonization of hard-to-abate sectors, promoting a circular economy has the potential to cut CO_2 emissions from the production of plastics, aluminum, steel, and cement by 40% (globally). Emissions from plastics alone could be cut by 56%.[3]

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[2] Climate Emergency Resolution. Passed by the House of Representatives on November 19, 2020 and approved by the House of Councillors on November 20, 2020

[3] Energy Transitions Commission. Mission Possible: Reaching Net-zero Carbon Emissions from Harder-to-abate Sectors by Mid-century. 2018 https://www.energy-transitions.org/publications/mission-possible/

Many plastics are used for single-use products, containers and packaging. Recycling of these has been inadequate. The situation with synthetic fibers is similar.

Up to now, we have used petrochemicals excessively and too casually. For this reason, there is a lot of room for cutting back on the production of new products and the CO_2 emissions they generate by shifting to a circular economy.

What is needed for decarbonizing petrochemicals

To decarbonize the petrochemical industry and petrochemical products, it is necessary to (1) reduce production and consumption; (2) convert feedstocks = recycle carbon; and (3) convert energy used for naphtha cracking and other processes to renewable energy. Actions (1) and (2) are closely linked to the circular economy concept outlined above.

(1) Reduction of production and consumption first (from p.18)

Although petrochemical products are indispensable for daily life, industry, medical care, and other applications, it is important to exhaustively promote reduced consumption of disposable products and products that are used for a minimal time or for nonessential purposes (e.g., fast fashion).

(2) Feedstock transformation (Carbon circulation) (from p.21)

The CO_2 emissions from the input of new fossil fuels and the disposal of used products must be reduced to zero, by circulating the carbon and hydrogen in used chemical products into fresh feedstocks for new chemical products.

(3) Energy transition to renewables in naphtha cracking and other processes (from p.28)

The energy inputs of petrochemical processes need to shift to renewable energy. Development of technologies for switching to renewable energy sources in cracking furnaces, which are the biggest source of CO_2 emissions, to use electricity or green ammonia for heating has been underway.

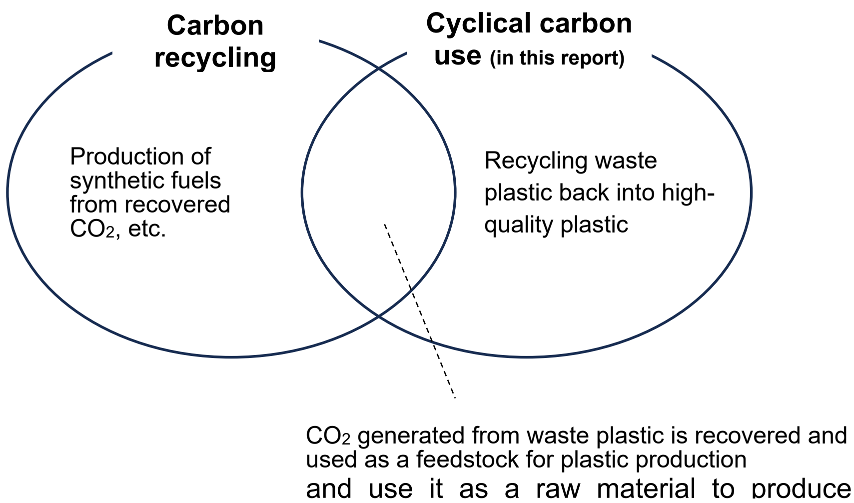
The petrochemical industry cannot successfully implement measures (1) and (2) alone. It is essential that a wide range of stakeholders throughout the petrochemical supply chains work together on these initiatives, including final product manufacturers (brand owners), retailers, consumers, local governments, and the “venous industry.”

The technology and scale of petrochemical processes will change dramatically in accordance with (1) and (2), so measure (3) needs to be pursued in accordance with them.

These three measures will be discussed in more detail in the next chapter.

The “cyclical carbon use” described in this report is different in concept to so-called “carbon recycling,” although there is a degree of overlap between the two. Carbon recycling broadly includes the use of CO_2 recovered from emission sources for another purpose. However, when CO_2 is reused as a feedstock for synthetic fuels, for example, the carbon is emitted again as CO_2 when the fuel is used. On the other hand, “cyclical use of carbon” here refers to the repeated use of carbon contained in chemicals, with the aim of keeping carbon within a “closed loop” so that it is not released into the environment (Fig. 10).

Fig. 10 Relationship between “cyclical carbon use” and “carbon recycling” in this report



From petrochemicals to circular carbon chemistry

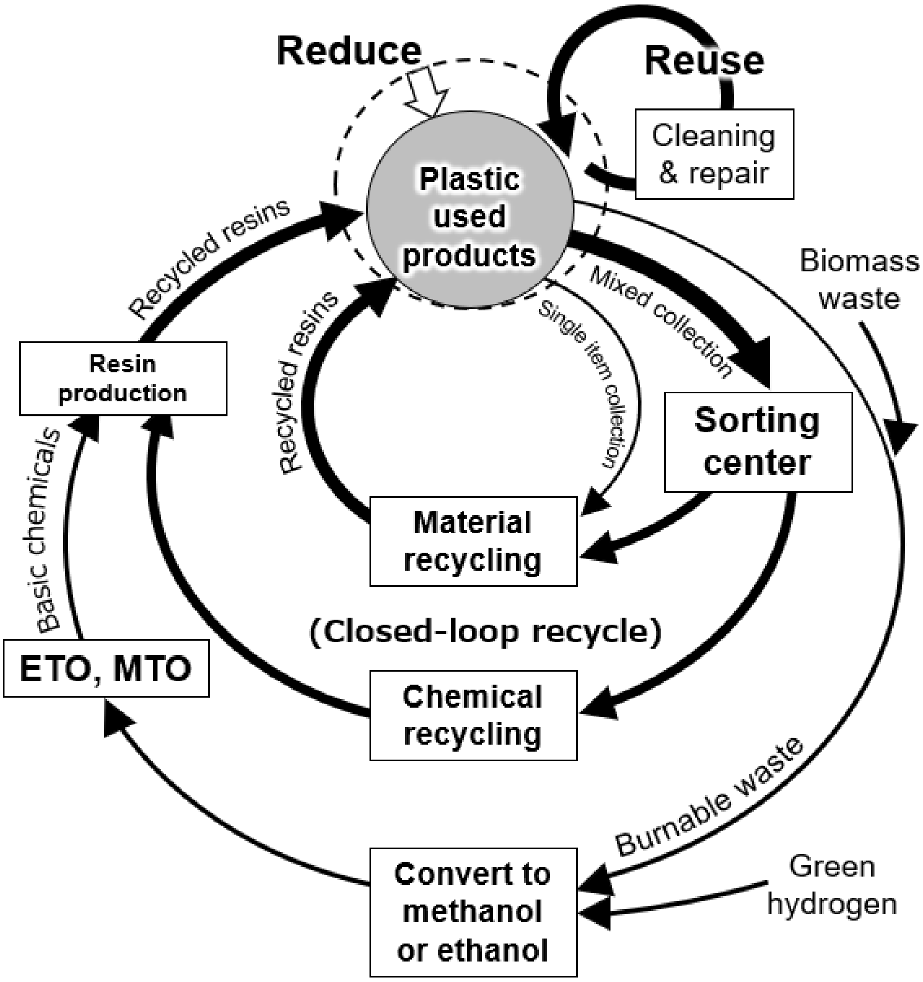
A variety of high-performance materials are produced by chemical synthesis in the petrochemical industry, most notably carbon materials. The superior functionality of these materials is essential for a wide range of uses, including food, clothing, housing, transportation, medical care, and information services. (This is not necessarily true of the single-use products and fast fashion mentioned above.)

However, as long as the carbon from petrochemical products comes from fossil fuels extracted from the earth, it will eventually be released into the environment and transformed into CO_2. Whatever carbon comes in must go out. Of course, carbon can be stored as a solid for a long time by recycling it as building materials or disposing of it in landfills, but this can only be done for a limited quantity of carbon.

Consequently, the only way to continue using synthetic chemical products is to make cyclical use of the carbon from used products, instead of using new fossil fuels as feedstock (Fig. 11).

Since 2014, the Japan Petrochemical Industry Association has been working on a concept it calls “Circular Carbon Chemistry,” which is very suitable for the challenges discussed here.[4] This concept should be pursued for everything from minimizing dependence on fossil resources to achieving zero dependence on fossil resources by 2050.

Fig. 11 Circular carbon chemistry of plastics (closed loop carbon cycles)



ETO stands for “Ethanol to Olefin” and MTO for “Methanol to Olefin.” “Olefin” is a generic term for hydrocarbons with one double bond, such as ethylene and propylene.

In the following pages, we will examine the three measures mentioned above in detail, focusing on plastics. Firstly, however, let us review the current state of the plastics cycle in Japan.

According to the Plastic Waste Management Institute, domestic consumption of plastic products is around 9 million MT per year (in 2021; same applies to other figures below), of which 8.24 million MT are disposed of as waste plastic. A breakdown of this disposal is shown in Fig. 12.

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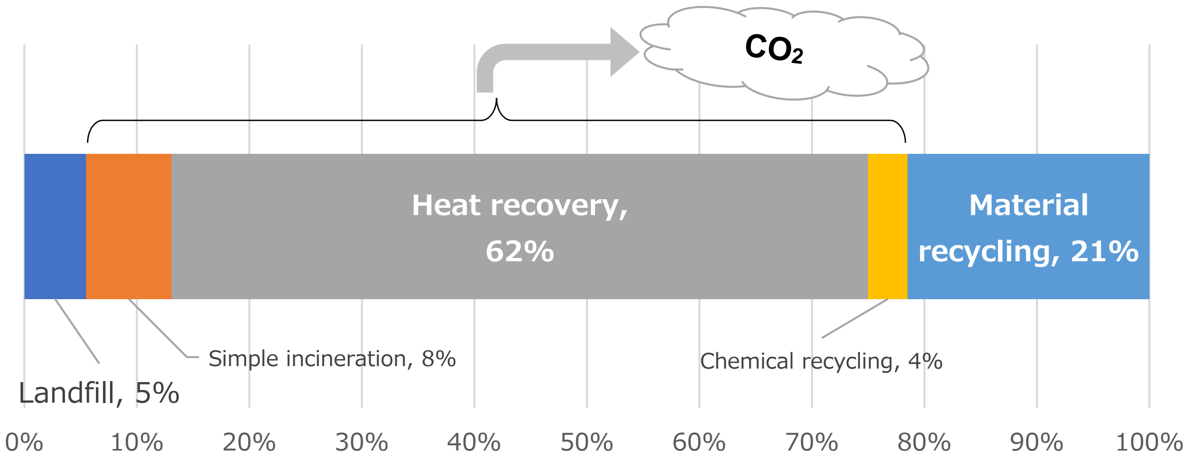
[4] “Petrochemical Guidebook,” Japan Petrochemical Industry Association, 2022, p.52–54

Fig. 12 Waste plastic disposal in Japan



Source: Created based on "An Introduction to Plastic Recycling 2022" (Flowchart of plastic products, plastic waste and resource recovery 2021), Plastic Waste Management Institute

Landfill disposal has been successfully limited to 5%, but 74% of the total ends up as atmospheric CO_2 emissions in one form or another. (In current chemical recycling processes, carbon is emitted as CO_2 after it is used to reduce iron ore.)[5]

(1) Reduction of production and consumption first

While plastic consumption in Japan has been leveling off, as noted in Chapter 1, the global trend shows a marked increase in developing countries. If the current dependence on single-use plastic materials for distribution and consumption remains unchanged, it is inevitable that per capita consumption in developing countries will rise toward the level of developed countries. Developed countries therefore need to lead the way, by working together to cut the use of disposable products, containers, and packaging, as well as short-lifespan clothing and other wasteful applications. Like this, they can offer an economic model that does not rely on the mass consumption of plastics.

In other words, in "3Rs" policymaking, more emphasis needs to be placed on the 2Rs of reduction and reuse.

To promote more "reduce," Japan has been focusing effort on cutting the amount of resin without sacrificing product utility, for example by making PET bottles thinner (higher efficiency). While this is good, it is still necessary to reduce and avoid consumption itself as far as possible.

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[5] What is now called "chemical recycling" includes conversion to coke oven chemical feedstocks, blast furnace feedstocks, and ammonia chemical feedstocks.

Charging money for plastic bags at checkouts has also been widely implemented. The charging of a fee was mandated by ministerial ordinances (of the Ministry of Finance, Ministry of Health, Labour and Welfare, Ministry of Agriculture, Forestry and Fisheries, and Ministry of Economy, Trade and Industry) in accordance with “Matters to Be Standards of Judgment for Business Operator” in Article 7–4 of the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging. This initiative was intended to reduce the use of plastic and to encourage consumers to review their lifestyles in other ways too (other than use of plastic bags at check-outs). Subsequently, a similar system for plastic products other than containers and packaging (12 items, such as plastic cutlery, specified in a Cabinet Order) was set up under the newly enacted the Act on Promotion of Resource Circulation for Plastics, but there are no clear provisions that obligate the charging of fees, so this measure effectively only encourages voluntary efforts by business operators.

“Packaging and containers” accounts for 48.7% of the total domestic consumption of plastics, so it is especially important to bolster the system of measures based on the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging.

At the same time, interesting new business practices and trends have emerged in recent years, such as the sale of products without packaging (package-less sales) and the provision of products and beverages in reusable containers. For now, however, the scale of such practices is very limited. In many cases, companies seem to be using reusable containers for some of their products only as part of PR efforts to promote their environmental credentials. In the coming years, policies should aim at spreading these practices and making them mainstream.

As for synthetic fibers, the business of fast fashion needs to be looked at closely. The expansion of fast fashion has fueled rapid growth in the production of polyester fiber, with total global production in 2020 hitting 57.1 MT, a remarkable 58% higher than in 2010.[6]

Polyester is a highly durable material and polyester garments can be used for many years, but due to their low cost, they tend to be replaced very frequently. It’s also important to note that wearing and washing polyester clothing releases large amounts of microfibers into our air and water systems.[7]

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[6] TextileExchange. Preferred Fiber & Materials Market Report 2021. 2021, 73p. https://textileexchange.org/app/uploads/2021/08/Textile-Exchange_Preferred-Fiber-and-Materials-Market-Report_2021.pdf

[7] De Falco, F. et al. Microfiber Relkease to Water via Laundering, and to Air via Everyday Use : A Comparison between Polyester Clothing with Differing Textile Parameters. Environ. Sci. Technol. 2020, 54, 6, 3288–3296 https://pubs.acs.org/doi/10.1021/acs.est.9b06892

Box 1 New Business Models for Reducing Disposable Plastic

Loop is a circular shopping platform business "for reuse" that offers products in reusable containers developed by U.S. company TerraCycle. As of November 2023, Loop was available in six countries, including Japan. In Japan, 12 companies offer daily necessities, food and beverages in Loop's refillable containers, available at AEON stores and online shopping service. Customers pay a deposit for the container to purchase the products. Loop Japan LLC also offers Loop Professional, a reusable container service for BtoB businesses.

https://exploreloop.com/ja/

Other business examples

- Totoya: Zero-waste supermarkets that sells products in bulk, or in the "buy-by-weight style" without packaging
  https://totoya-zerowaste.com/
- Re&Go: Sharing service for reusable containers
  https://www.reandgo.jp/
- MIWA: A method of selling products in bulk using reusable containers developed in Europe.
  https://www.miwa.eu/miwa-in-action

Overseas, one NGO promoting ESG has submitted a shareholder proposal to a major fast-food chain requesting a report on alternatives to single-use containers. It will be interesting to see what emerges from this initiative.https://www.wsj.com/articles/mcdonalds-to-study-pros-and-cons-of-reusable-packaging-a07db889

(2) Feedstock transformation: Carbon circulation

If new fossil fuels cannot be used as inputs, utilizing the carbon contained in used chemical products made from fossil fuels as a raw material becomes extremely important.

There are various ways of cyclical use of carbon, as outlined below, but reuse needs to be kept within "small loops" to minimize the required energy input. Leaving aside the reuse mentioned above, the smallest loops can be achieved by material recycling; utilizing the polymers that make up plastics, synthetic fibers, and synthetic rubber without changing them. In contrast, combining CO_2 generated from the processing of used products with hydrogen to form hydrocarbons again requires large quantities of energy, resulting in large loops.

Currently, the petrochemical and related industries are developing a variety of technologies concurrently. These include material recycling, chemical recycling, waste to ethanol, biomass utilization, and CCU (CO_2 capture and utilization), but it is important to always aim for the smallest possible loops.

Optimally combining material and chemical recycling

Up to now, material recycling and chemical recycling have not always resulted in high-quality recycled resin.

With material recycling, the quality of the materials typically deteriorates, except when homogeneous and uncontaminated industrial waste plastics or sorted waste PET bottles are used as raw materials. For this reason, general applications have been limited to things like construction materials and shipping pallets.

However, with the development of advanced sorting technology, deinking technology to remove ink, and technology to restore physical properties, the situation has been changing significantly in recent years. New technologies that use solvents to extract only specific resin molecules are also being used now. Manufacturers of products that use plastic will be able to obtain high-quality recycled resins, similar to virgin resins, by promoting recyclability at the product design stage.

Up to now, "chemical recycling" has most typically been used for making coke to use as a reducing agent for blast furnaces in the steel industry, and for making hydrogen for ammonia production through pyrolysis. In both these cases, the waste plastics are used as an alternative to fossil fuels, and therefore the carbon from fossil fuel-derived plastics is eventually released into the atmosphere as CO_2. To decarbonize steel manufacturing, it is essential to move away from the use of carbon for reducing iron ore, and to stop the use of carbon from plastic as a reducing agent. Note too that when ammonia is used as a raw material, a high concentration of CO_2 is obtained. Although, it is used for industrial applications (e.g., dry ice, shielding gas for arc welding, carbonated beverages), the CO_2

inevitably ends up in the atmosphere after use.

In recent years, new "circular chemical recycling" technologies have been developed. These are methods that temporarily break down the polymers of plastic into smaller molecules (monomers and basic chemicals) before combining them into polymers again. This approach makes it possible to recycle even contaminated waste plastics into plastics (recycled resins) of the same quality as those made from fossil fuels. However, the quantity of energy required to pyrolyze polymers is very high compared to material recycling, and it is difficult to recover all the carbon with this method, which means that some of it ends up as CO_2.

Therefore, to create a system for obtaining high-quality recycled resins, it is necessary to start with material recycling with low energy input, before appropriately combining some chemical recycling.

Table 1 lists the main methods of material recycling and chemical recycling technologies that are being developed.

Table 1 Typical material recycling and chemical recycling methods (examples)

(for obtaining recycled resin of the same or very similar quality to virgin resin)

Type		Method/features	Relevant plastics	Involved companies
Material recycling	General mechanical recycling	Pellets are formed by heating, melting, and blending with additives, etc.	Single resins such as PE, PP, PS, PVC, PET, free of contaminants	Polymer compounding companies
	PET bottle to bottle	Sorting → alkaline cleaning → recondensation polymerization. Quality close to virgin resin	PET (bottles)	Kyoei Industry, etc.
	Solvent-based	Only PP is extracted with solvent. Quality similar to colorless virgin resin.	PP-rich waste plastic	(U.S.) PureCycle Technologies, etc.
Chemical recycling	Depolymerization	Breakdown to monomers (building blocks of polymers) → Purification → Repolymerization. Same quality as virgin resin	PET, PS, PMMA	JEPLAN, PS companies, Mitsubishi Chemical, etc.
	Direct Cracking	Thermal decomposition and catalytic reaction to obtain ethylene, propylene and BTX	General (no details available)	R PLUS JAPAN + Anellotech, Sumitomo Chemical and Maruzen Petrochemical, etc.
	Conversion to oil	Waste plastic is converted to oil → basic chemicals are obtained in naphtha cracker	Mainly PE, PP	Mitsubishi Chemical, etc.
	Conversion to ethanol	Ethanol is synthesized using biotechnology from syngas obtained by pyrolysis. Ethylene is obtained from ethanol.	General. Can be mixed with biomass waste.	Sekisui Chemical+ Sumitomo Chemical

PE: Polyethylene, PP: Polypropylene, PS: Polystyrene, PET: Polyethylene terephthalate, PMMA: Acrylic resin

Sorting centers are crucial

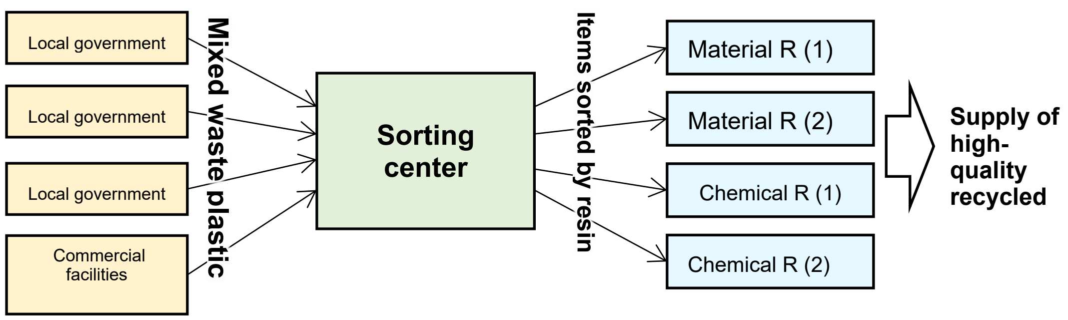
While it is relatively easy to recycle single-material, uncontaminated waste plastics, in practice, most waste plastic, such as container and packaging plastic, contains a mixture of different plastics and many types of resins, with a large amount of contamination and foreign materials. To take full advantage of the various methods of material recycling and chemical recycling, sorting technology is very important for separating mixed plastics to suit each recycling method.

Although there are facilities in Japan that separate waste plastics by resin, recycling facilities that operate under the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging only sort a limited number of resins, such as polyethylene, polypropylene, and polystyrene. The purity of the obtained resins is not high. Other unsorted resins are sent to energy recovery facilities, where they end up as CO_2.

In contrast, the large sorting centers that are mainstream in Europe are equipped with a large number of sorting machines for high-purity sorting of waste plastics based on resin and whether or not they are colored. Sorted materials are sent on to specialized recycling facilities for each resin. This kind of sorting center is likely to be vital for achieving high-quality material and chemical recycling, so their prompt deployment in Japan should be seriously examined.

Sorting centers are also important logistics centers that are indispensable for the efficient transportation of widely dispersed used plastics to a limited number of advanced recycling facilities (Fig. 13).

Fig. 13 Role of sorting centers



(Example of a sorting center in Europe)

The "Site Zero" facility of Svensk Plaståtervinning in Sweden (world's largest plastic sorting plant) boasts an annual throughput of 200,000 tpa (tonnes of plastic per year).

https://www.svenskplastatervinning.se/

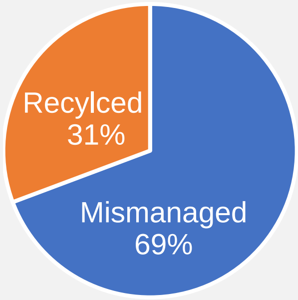
A video of the sorting process is available on the company's website.

Box 2 Imports of Carbon Resources Are Also Needed

The use of plastics is also growing rapidly in developing countries without petrochemical industries that lack systems for adequately disposing of waste plastics, with the result that large amounts of waste plastic end up in the oceans and environment. Thus, to circulate carbon resources effectively, Japan also needs to promote plastic recycling in developing countries as part of its international cooperation efforts, including importing recycled raw materials for use in Japan.

Waste disposal site in Dhaka, Bangladesh (includes a huge amount of plastic film)

Waste plastic disposal in Bangladesh



"Mismanaged" means disposal at an open dumping site without any protection against dispersal, leaching, etc., or dumping into a river.

Source: Created based on "Towards a Multi-sectoral Action Plan for Sustainable Plastic Management in Bangladesh," World Bank (2021)

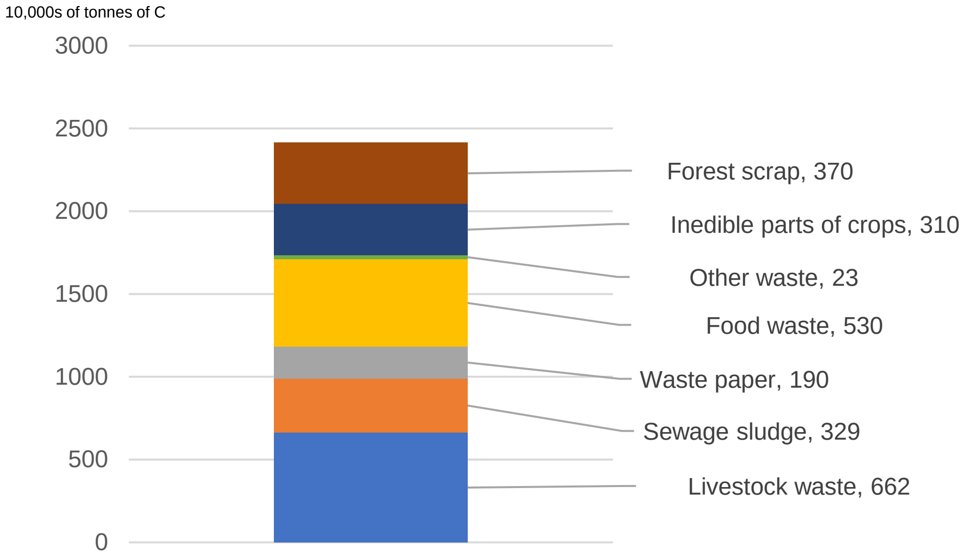
Utilizing waste biomass effectively

The quantity of carbon that can be obtained solely from plastic products used in Japan is insufficient to meet demand. This is, firstly, because the exports of basic chemicals and plastics exceed imports. The second reason is that the yields of various chemical reactions and processing steps are not 100%. And thirdly, it is difficult to collect and recover 100% of used products.

While it may be possible to use biomass to make up for any lack of carbon resources, most current biomass plastics are made from plant-based sugars and fats (first-generation biomass), resulting in competition with food resources.

Priority should be given to using waste biomass and unused biomass (second-generation biomass), a resource that is estimated to amount to 24 MtCe per year (Fig. 14).

Fig. 14 Potential of unused biomass resources in Japan (by weight of carbon)



Source: "Positioning of the Carbon Circulation Leading to Control of Marine Plastic Litter," Toshiaki Yoshioka, *Material cycles and waste management research*, 2020, Vol. 33, No.5, p332–339

To make better use of waste-based biomass, the first priority should be to try and expand the use of recovered wastepaper as a raw material for papermaking. However dirty or smelly paper cannot be reused for papermaking. Wastepaper is easy to use as a carbon resource, however, because lignin is removed in the pulp manufacturing process. R&D has also been done on technologies for saccharification and fermentation of this material to obtain ethanol. Technology is also being developed to produce synthesis gas (syngas), a combustible gas composed of carbon monoxide and hydrogen, by pyrolyzing combustible waste, including biomass waste and waste plastics that cannot be recovered, and then using biotechnology to produce ethanol from the synthesis gas. Once ethanol is obtained, it can be converted to ethylene, which can serve as a feedstock for various chemicals.

Waste biomass is also expected to be useful as a feedstock for SAF (Sustainable Aviation Fuel), so there may be some competition for this resource between SAF and chemicals in the future.

The naphtha generated as a byproduct when SAF is produced from waste cooking oil or other types of oil (bionaphtha) can be used as feedstock for naphtha cracking furnaces in the same way as naphtha derived from petroleum.[8]

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[8] The amount of bionaphtha produced depends on the SAF feedstock and production process, but when waste cooking oil is used as feedstock, the yield is reported to be about 10% of SAF production, a rather limited quantity.

Using CO_2 as a feedstock to produce plastic

There is technology in development to recover CO_2 from exhaust gases for use as a feedstock for manufacturing plastics. Methanol can be synthesized from CO_2 and green hydrogen, after which ethylene and propylene, which are basic chemicals, can be obtained from methanol.

There is a variety of challenges to overcome, however.

The first one is that a large quantity of green hydrogen is needed. The reaction for synthesizing methanol from CO_2 and hydrogen is as follows.

$CO_2 + H_2 \rightarrow CO + H_2O$, $CO + 2H_2 \rightarrow CH_3OH$

A simple calculation shows that 430,000 tons of hydrogen are required to produce 1 million tons of ethylene or propylene.

Secondly, if CO_2 derived from fossil fuels is recovered and used as a feedstock for making plastics, emissions cannot be reduced to virtually zero. This is because the CO_2 derived from fossil fuels is eventually emitted into the atmosphere when used products are disposed of as waste (Fig. 15)

Fig. 15 Using fossil fuel-derived CO_2 as a feedstock

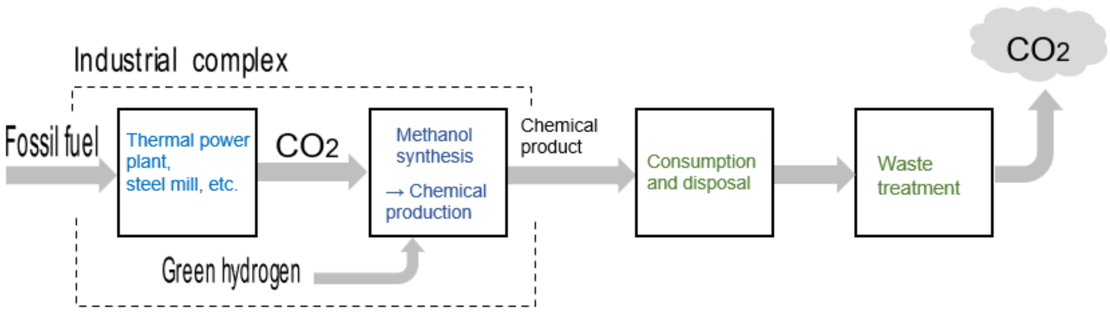
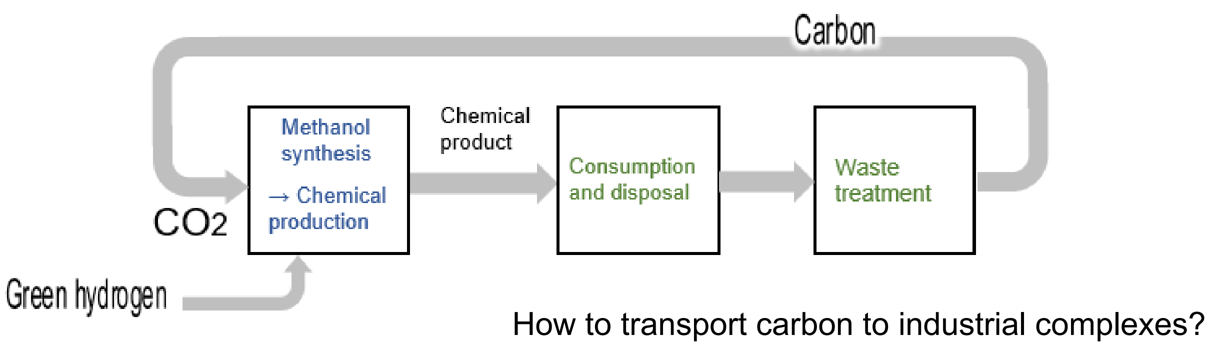


Fig. 16 Using CO_2 derived from used chemical products as a feedstock



A carbon cycle with virtually zero CO_2 emissions is possible if CO_2 generated from the treatment of waste plastics is used as a feedstock, as shown in Fig. 16. For this, however, carbon from waste incineration plants dispersed across the country would need to be transported to methanol conversion facilities that are likely to be located in a limited number of industrial complexes.

If CO_2 were captured at the waste incineration facilities throughout Japan, each one would need to be equipped with facilities for capturing, liquefying, and storing CO_2, and all this liquified CO_2 would need to be transported to petrochemical complexes.

From the perspective of waste treatment facilities, it may be more reasonable to convert combustible waste into SRF (solid recovered fuel), transport the carbon in this solid form to the complex, and then burn it to capture CO_2. But this approach would also require enormous effort to establish the consensus needed to enable transportation of waste on such a wide scale.

Table 2 shows the main carbon cycle technologies that use waste biomass and CO_2.

Table 2 Examples of technologies that use waste biomass and CO_2 as a feedstock

Type		Methods/features	Feedstocks	Companies involved
Use of waste biomass	Convert to ethanol (as shown in Table 1)	Ethanol is synthesized by biotechnology from synthesis gas produced by pyrolysis. Ethylene is obtained from ethanol.	A mixture of waste biomass and waste plastic (combustible waste) is OK.	Sekisui Chemical+ Sumitomo Chemical
	Convert wastepaper to ethanol	Wastepaper is sorted from combustible waste, ethanol is produced by simultaneous saccharification and fermentation, and ethylene is obtained from ethanol.	Wastepaper that cannot be recycled for papermaking	Hitachi Zosen
	Use of bionaphtha	Bionaphtha, a byproduct of producing SAF from waste cooking oil, is fed into a naphtha cracker to obtain basic chemicals.	Bionaphtha from waste cooking oil	Mitsui Chemicals, etc.
Converting CO_2 to a feedstock	Methanol synthesis	Methanol is synthesized from recovered CO_2 and hydrogen, then basic chemicals are obtained from methanol by MTO and MTP.	CO_2	Mitsubishi Chemical, etc.

(3) Energy transition: Renewables in naphtha cracking and other processes

The petrochemical process that produces the largest amount of energy-derived CO_2 emissions is naphtha cracking, in which naphtha is used as a feedstock. The naphtha is heated in a furnace to 850°C. In the 0.3 to 0.5 seconds that it takes to pass through a thin tube in the furnace chamber at approximately 1000°C, the naphtha is decomposed into basic chemicals such as ethylene and propylene.

Currently, off-gas (methane) obtained from naphtha cracking is used as a fuel to heat the naphtha in cracking furnaces. The heat value of the off-gas is approximately sufficient to provide the energy needed to naphtha cracking. According to the Comprehensive Energy Statistics, off-gas has a heat of combustion of 204,117 TJ (approx. 56.7 TWh) and generates 10.8 $MtCO_2e$ of emissions.

Even in circular carbon chemistry in which fossil fuels are not used as feedstocks, as described in Chapter 1 and 2, the technology of naphtha cracking furnaces can be effectively used to produce basic chemicals such as ethylene if oil from chemical recycling or bionaphtha is used as an alternative feedstock. In this case, naphtha cracking furnaces will probably continue to be used for the foreseeable future, even though they are likely to be significantly smaller than at present.

If off-gas is used as a heating fuel for naphtha cracking furnaces, the carbon from the off-gas will be released into the atmosphere as CO_2. It will also be necessary to supply new carbon to the carbon cycle. Consequently, it is vital to convert naphtha cracking furnaces to renewable energy. Additionally, it is essential to return off-gas (that has been used as a heating fuel) to the carbon cycle as a feedstock by converting it to methanol or other substances.[9]

Converting energy for naphtha cracking furnaces to renewables

There are two ways to supply the heat (to around 850°C) required by naphtha cracking furnaces with renewable energy.

(1) Electrification

A naphtha cracking furnace that is electrically heated is called an e-cracking furnace or e-cracker. Currently, three leading global chemical industry players, BASF, SABIC, and Linde, are constructing a large-scale e-cracker demonstration plant at an integrated chemical complex in Ludwigshafen, Germany. Dow, Shell, and Braskem are also

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[9] Off-gas, which is mainly methane, can be used as a feedstock for methanol, or even as a means of obtaining carbon black and turquoise hydrogen through the process of methane pyrolysis.

embarking on electrification. In Japan, NEDO is conducting a commissioned study on electrification (Fig. 17).

Naphtha cracking furnaces are reported to be easier to electrify than cement production or iron ore reduction processes, due to their lower temperature requirements.

If electricity is provided by renewable energy, the energy-related CO_2 emissions of the process can be reduced to zero.

(2) Ammonia

In Japan, NEDO is developing a method that uses ammonia as a fuel for cracking furnaces.

Using green electricity to produce hydrogen and then producing ammonia from that hydrogen is indisputably more wasteful in terms of energy loss than using electricity directly. NEDO's technological development may envision the use of imported green ammonia, produced from renewable energy overseas, but if the length of the ammonia supply chain and safety management issues are considered, it makes more sense to prioritize the electrification.

If ammonia is used, it will be absolutely essential to develop a new technology for synthesizing ammonia at room temperature and pressure, since the current Haber-Bosch process of ammonia production requires high temperature and pressure, which in turn requires a huge energy input.

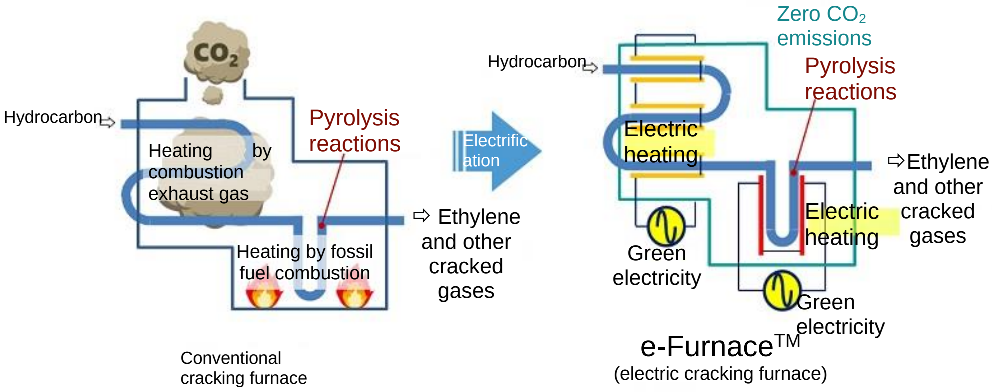
Aside from naphtha cracking furnaces, heat is used in many other industrial petrochemical processes. As with naphtha cracking furnaces, such processes will need to be converted to renewable energy through electrification and other means.

Table 3 summarizes the prevailing trends in the development of these technologies.

Table 3 Trends in development of decarbonization technologies for naphtha cracking furnaces (main)

	Main players	State	Methods	Remarks
Electrification	BASF, SABIC, Linde (Engineering)	Demonstration plant in operation at industrial complex in Ludwigshafen, Germany	Direct heating: Electric current is supplied to a tube to deliver heat by Joule heating Indirect heating: Electric current is supplied to a heating element surrounding the tube to deliver heat by radiation	Supported by German government
	Dow, Shell, Netherlands Organization for Applied Scientific Research, Institute for Sustainable Process Technology	Experiments underway in the Netherlands; pilot plant of several MW set to be in operation by 2025.	Details are unknown	Supported by the Dutch government
	Coolbrook, ABB, Braskem	Pilot plant in the Netherlands is planned.	RotoDynamic Reactor: A technology developed by Coolbrook that heats the furnace internally, using friction and shock waves, rather than externally.	
	Toyo Engineering	Demonstration study in Thailand is planned.	Development of electrification technology for ethylene cracking furnaces and demonstration aimed at commercialization	Commissioned by NEDO
Ammonia	Mitsui Chemicals, Maruzen Petrochemical, Toyo Engineering, Sojitz Machinery	Demonstration period from FY2021 to FY2030	Development of burners for naphtha cracking furnaces tailored to the combustion properties of ammonia	NEDO Green Innovation Fund Project
	The University of Tokyo, Tokyo Institute of Technology, Osaka University, Kyushu University, Idemitsu Kosan, etc.	Demonstration trial from FY2024 to FY2028	Development of technology for synthesizing ammonia at room temperature and pressure using Mo catalyst	NEDO Green Innovation Fund Project

Fig. 17 Electrification of a naphtha cracking furnace



Source: Website of Toyo Engineering Corporation

Chapter 3 Pathway to Decarbonization

Current policies of the Japanese government

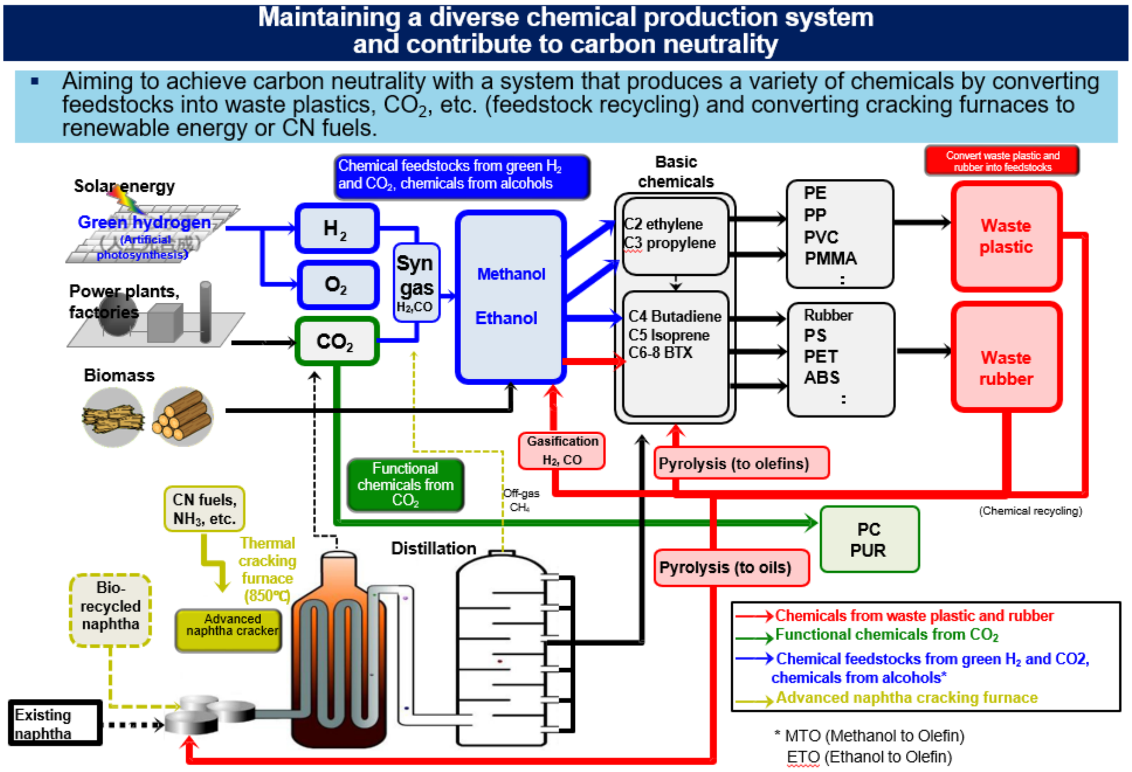
So, what measures is the Japanese government planning to implement in its effort to decarbonize the petrochemical industry?

At a meeting of the GX (Green Transformation) Implementation Council held on November 28, 2023, Prime Minister Fumio Kishida stated that the GX investment support framework will be applied to the steel and chemical sectors, which make large contributions to total carbon emissions and require a radical shift in production methods that will alter the course of industrial history, as part of Japan's aim to become a world leader in investments to decarbonize manufacturing.

In a sector such as petrochemicals, decarbonization will undoubtedly require substantial transformations of production processes, necessitating large investments in a short period of time. The government's policy of investment support is important to this. We should watch closely to see how this investment framework takes shape.

The big question is what kind of technology to invest in. Looking at the direction of technological development indicated by the Ministry of Economy, Trade, and Industry (METI), a variety of technologies are being tabled for consideration, including chemical recycling, CO_2 feedstock conversion, bionaphtha, and conversion to carbon-neutral (CN) fuels for naphtha cracking furnaces. Naturally, it is important to promote development of multiple technologies simultaneously, but the government's strategy seems to lack any clear direction (Fig. 18).

Fig. 18 Direction of technological development that Japan should undertake (based on METI data)



Source: "Domestic and International Trends in Chemical Industry Decarbonization," Working Group on Energy Structure Conversion, Green Innovation Project Subcommittee, Industrial Structure Council, January 25, 2023

As we have seen, the decarbonization of petrochemicals requires more than just innovations in production technology. The reduction of production and consumption and carbon cycle mechanisms are more important. Production technology will need to adapt to these changes.

Now, what about measures related to resource recycling?

The Resource Circulation Strategy for Plastics, formulated in May 2019, was prepared in time for the 2019 G20 Osaka Summit. At that time, Japan had not yet committed itself to carbon neutrality by 2050. Decarbonization was only mentioned quite abstractly, and although 2030 was referred to as a milestone, it was unclear what this milestone was intended to lead to. This document therefore needs to be revised as soon as possible.

Act on Promotion of Resource Circulation for Plastics, which took effect in April 2022, was enacted as a system for addressing resource recycling throughout the entire plastics supply chain. It incorporates a variety of systems, ranging from the design of plastic-containing products to the recycling of used products. While this sounds good on paper, the reality on the ground is somewhat lacking. For one thing, there is no forum for information exchange between the "artery industries" (i.e., product manufacturers) and the "venous industries" (i.e., recycling businesses) regarding the design of products suitable for recycling.

What about measures to tackle the CO_2 emissions generated by the incineration of used petrochemical products?

In August 2021, the government presented a medium- to long-term scenario (draft) for reducing greenhouse gas emissions of the waste and recycling sector to near zero by 2050. The relevant basic policy based on the Act on Waste Management and Public Cleansing, revised in June 2023, includes a strategy for achieving decarbonization by 2050. The approach to waste treatment taken up to now, centered on incineration, needs to be radically transformed. However, local governments and incinerator manufacturers are still largely unaware of this challenge.

Table 4 Current major policies of the Japanese government

<table>
<tr><th>Type (see Chapter 2)</th><th>Current major policies</th><th>Challenges that should be tackled</th></tr>
<tr><td>Reduce production and consumption</td><td rowspan="2">• Charging for plastic bags
• Plastic resource circulation strategy
• Enactment of the Act on Promotion of Resource Circulation for Plastics
• Study of new systems to promote the use of recycled products</td><td rowspan="2">• Effective reduction of single-use plastic to follow charging for plastic bags
• Revised plastic resource circulation strategy aimed at decarbonizing petrochemicals</td></tr>
<tr><td rowspan="2">Cyclical use of carbon</td></tr>
<tr><td rowspan="2">GX investment*
[recycling industry]
• Deployment of plastic recycling facilities, etc.
[chemical industry]
• Conversion of CO_2 to feedstocks
• Chemical recycling
• Ammonia-fueled naphtha cracking furnaces
• Investment in energy conversion and reduction</td><td rowspan="2">• Support for developing infrastructure for reuse and material recycling (e.g., sorting centers)
• Clearly defining and implementing decarbonization strategies in the waste sector</td></tr>
<tr><td>Convert to renewable energy</td></tr>
</table>

*According to "The Basic Policy for the Realization of GX: Reference Materials," (February 2023).

What policies need to be emphasized from now on

We would like to make the following eight policy recommendations for achieving effective decarbonization of petrochemicals over the coming years. The first three recommendations are more general; the latter five are more specific.

(1) Establish a hierarchy of initiatives

A wide variety of initiatives need to be pursued concurrently. At the same time, it is important to set clear priorities for the initiatives that each stakeholder should take.

Firstly, the highest priority should be given to comprehensively reviewing mass consumption of products that depend on petrochemicals, including single-use plastics, fast fashion, etc. Next, in promoting the carbon circulation, priority should be given to “small loops.” Specifically, material recycling that enables the use of waste plastics as feedstocks should be implemented first, followed by chemical recycling.

(2) Take an integrated approach to the decarbonization of petrochemical, the recycling of plastics, and the decarbonization of the waste sector

68% of waste sector CO_2 emissions come from the incineration of petrochemical products. Nevertheless, it very much seems that the decarbonization of petrochemicals, the recycling of plastic and synthetic fibers, and the decarbonization of the waste sector have always been discussed as separate topics.

It is particularly vital to examine the question of carbon circulation in an integrated manner, because of its fundamental importance to the implementation of technologies that use waste plastics and CO_2 as feedstocks.

(3) Promote collaboration and open discussion between the various actors

As repeatedly stated, the decarbonization of the petrochemical industry cannot be achieved solely through the efforts of the petrochemical industry. It will require collaboration between the many actors involved in the supply chains of petrochemical products. For example, reducing the consumption of single-use plastics and rethinking fast fashion are challenges that need to be addressed collectively by product manufacturers, retailers, and individual consumers, rather than unilaterally by the petrochemical industry.

In order for this diverse group of actors to strive consciously to help decarbonize petrochemicals, the government and petrochemical industry need to educate them by distributing easy-to-understand information. For example, the terminology used to describe the processes in the Ministry of Economy, Trade and Industry (METI) figure of Fig. 18 may be difficult for people from other fields to understand.

Considering the massive levels of GX (Green Transformation) investment support for the chemical industry that will be needed over the coming years, open discussion is essential in terms of public accountability.

(4) Promote reuse

Around half of all the plastic consumed in Japan is used for containers and packaging. An effective way to cut this consumption is to make use of reusable, as described in Chapter 2. However, as long as the volume of reusable containers handled remains low, costs will inevitably remain high. That is, it is difficult for this change to take root if everything is left to market forces. As with the introduction of fees for plastic bags at shopping checkouts, ways of utilizing the mechanisms enabled by the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging to encourage business operators to deploy reusable containers should be investigated.

The EU has set targets for the deployment of reusable containers by category of containers and packaging. Germany has also mandated that cafes and other establishments be allowed to serve beverages in reusable containers. These systems should be studied.

As the systems designed for food and beverage services and retail businesses can be introduced on a municipality bases, progressive local governments are expected to lead the way in getting the new practices established.

(5) Promote use of recycled resins (limit use of virgin resins)

To get the carbon circulation moving, the expansion of the use of recycled resins is indispensable. METI has just started examining a new system to promote the use of recycled materials. However, to enable the manufacturers of final products, such as daily necessities that use recycled resin as a material, and the "veinous industry" and local governments responsible for waste treatment, recycling, and the supply of recycled materials to tackle this challenge in a coordinated manner, medium- to long-term targets for the use of recycled resins should be set.

Since the price of high-quality recycled resin is likely to be higher than that of virgin resin produced from fossil fuels, economic measures such as a tax on virgin resin, like the one introduced in the EU, should be considered.

(6) Promote development of sorting centers

To create a system for supplying high-quality recycled resin to replace fossil fuel-derived plastics, European-style sorting centers like those described in Chapter 2 will need to be developed. Since these facilities also function as logistics centers for the collection of widely dispersed plastic carbon, several dozens of them will need to be set up around Japan.

Industry, local governments, and the national government need to work together on studying this essential initiative as soon as possible.

(7) Shift to renewable energy as soon as possible

Key facilities such as naphtha cracking furnaces and plants for the production of chemicals from methanol need to be converted to run on renewable energy in line with future carbon cycles.

Privately generated steam is also used in various processes for synthesizing resins and synthetic fiber feedstocks (Fig. 6). These kinds of processes need to be encouraged to transition to run on electric power from renewable energy sources as soon as possible.

(8) Support the business transformation of SMEs

While major chemical manufacturers are shifting to high-performance, high-value-added products, it's important to remember than many of the companies involved in the manufacture and processing of commodity plastics are small and medium-sized enterprises (SMEs). It is therefore vital to provide sufficient support measures to ensure that these SMEs can transform their businesses smoothly.

Box 3 Notable European Initiatives

● Targets for the introduction of reusable containers

The European Commission's November 2022 draft regulation on packaging and packaging waste sets the following targets for the use of reusable containers. The draft regulation is currently under consideration by the European Parliament and the European Council.

Type	Applicable containers and packaging	From Jan. 1, 2030	From Jan. 1, 2040
Food and drink packaging of hotel and catering sector	Containers for take-out drinks	20%	80%
	Containers for take-out food	10%	40%
Retail sales of food and beverages	Alcoholic beverages (excl. wine)	10%	25%
	Wine (excl. sparkling wine)	5%	15%
	Non-alcoholic beverages	10%	25%
Various packaging materials (BtoB)		10 to 90%	25 to 90%

● Targets for recycled resin use

The following regulation proposed by the European Commission has led to a race among Japanese automakers to procure recycled resin.

Draft regulation	Description
Draft regulation on sustainability requirements for automotive design and end-of-life vehicle (ELV) management	Six years after this regulation takes effect, the plastic in each vehicle to be type approved must contain a minimum of 25% recycled plastic (of which a minimum of 25% must be derived from ELVs)
Proposed regulations on packaging materials and waste	Plastic packaging is required to contain 10–35% of recycled plastic from 2030 and 50–65% from 2040 (% depends on type of plastic)

- **Taxes on plastics**

In the UK, a tax of £200 per ton on all plastic packaging containing less than 30% recycled resin content took effect in April 2022.

Since January 2021, the EU has been collecting a levy from member states based on the volume of non-recycled plastic waste. In response, Italy is planning to impose a tax of €450 per ton on packaging material made from virgin resin, with Germany and other countries considering similar measures.

Conclusion

As explained in Chapter 2, to successfully decarbonize the petrochemical industry, it is important to concurrently undertake a variety of policy and technological development initiatives, ranging from reducing production and consumption of single-use plastics, to material and chemical recycling, biomass utilization, CCU, and conversion of naphtha cracking furnaces to renewable energy sources. Trying to combine these actions in the right way and in the right proportions will be like struggling to solve a very complex set of simultaneous equations. What's more, the optimal solution to the equation will only become clear after the fact.

However, with the 1.5°C limit looming, the essential goal for now is not to arrive at a precise optimal solution, but rather to start taking action, and moving in the right direction based on a big-picture view of the challenges at hand.

If we continue to use plastics and synthetic fibers of the same quality and in the same quantity as we are doing now, the only way to decarbonize is to develop technologies such as chemical recycling, biomass, and CCUS (Carbon Capture, Utilization and Storage).

Still, decarbonization cannot be achieved through technology alone. We need to radically rethink the nature of our mass consumption society, typified by rampant use of single-use containers and packaging. Without ignoring safety and hygiene, we must be prepared to tolerate some reduction in the quality and convenience of petrochemical products. Our actions need to be principally focused on reducing production and consumption (by questioning the acceptability of single-use materials), as well as promoting material recycling, appropriately complemented by chemical recycling, as described in Chapter 2.

This requires a coordinated effort, not only by everyone involved in the petrochemical industry, but also by a wide range of other stakeholders, including the many different industries that use plastics and synthetic fibers as materials (for production of foods, daily necessities, clothing, machinery, construction, etc.), retail stores, food and beverage services, as well as the local governments and waste management industries that handle the disposal of used products, and consumers and government departments responsible for public procurement. As the Sixth Assessment Report of the IPCC states:

> **C5. Net-zero CO2 emissions from the industrial sector are challenging but possible. Reducing industry emissions will entail coordinated action throughout value chains to promote all mitigation options, including demand management, energy and materials efficiency, circular material flows, as well as abatement technologies and transformational changes in production processes.**
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> (Summary for Policymakers Headline Statements, Working Group III Report)

Pathway to Decarbonization of Petrochemicals in Japan

Shifting from Mass Consumption, Creating Carbon Circulation and Enhancing Renewable Energy Deployment

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