# An Introduction to Plastic Recycling


Plastic Waste Management Institute

# INTRODUCTION

The year 2015 turned out to be an historic turning point for the global environment. First and foremost, it marked the adoption of the Paris Agreement that set long-term goals and obligated all countries to submit and update their reduction targets for greenhouse gas emissions every five years. It also marked a consensus achieved on the 2030 Agenda for Sustainable Development centered about new and comprehensive Sustainable Development Goals (SDGs) for the entire world.

The marine litter problem including drifting plastic and micro-plastics is coming to be recognized throughout the world as a threat on a global scale. The G7 Summit 2015 held in Schloss Elmau, Germany saw the world's seven largest advanced economies agree upon a "G7 Action Plan to Combat Marine Litter," and a commitment to combat this marine litter problem was reaffirmed at the G7 Toyama Environment Ministers' Meeting 2016 in Japan and G7 Bologna Environment Ministers' Meeting 2017 in Italy. Then, at the G7 Charlevoix Summit 2018 in Canada, the leaders of Canada and various EU countries approved a "G7 Ocean Plastics Charter" that included numerical targets. Japan declined to approve this charter together with the United States, but based on the "4th Fundamental Plan for Establishing a Sound Material-Cycle Society" as decided by the Japanese cabinet in June 2018, the government formulated a "Resource Circulation Strategy for Plastics" in May 2019 to comprehensively support the recycling of plastics as a resource.

Furthermore, given the recognition that the need to take appropriate countermeasures to the problem of marine litter is not just the responsibility of advanced countries but also of all countries including Asian countries, the Group of Twenty agreed upon an "Action Plan on Marine Litter" at the 2017 G20 Hamburg Summit in Germany, and the ASEAN+3 (Japan-China-Republic of Korea) Summit Meeting held in November 2018 selected the "Marine Plastic Debris Cooperation Action Initiative" proposed by Japan. Based on these developments, G20 leaders at the G20 Osaka Summit held in June 2019 declared agreement on "Osaka Blue Ocean Vision" that aims to reduce additional pollution by marine plastic litter to zero by 2050.

Turning now to domestic plastic waste, Japan has been exporting approximately 1,500 kt of plastic waste annually to overseas destinations as a resource with most going to China, but at the end of December 2017, China banned the import of non-industrial plastic waste followed by a ban on industrial waste at the end of December 2018. Although countries such as Thailand and Vietnam have been alternatives to China, they and other Southeast Asia countries are looking to introduce import bans on plastic waste going forward. Furthermore, in May 2019, it was decided at the Conference of the Parties to the Basel Convention held in Geneva, Switzerland that any export of plastic waste would require consent of the other party as part of the control regime governing contaminated plastic waste from 2021.

As can be seen from the above, conditions surrounding plastic are becoming increasingly severe every year, but on the other hand, plastic has become something that we cannot live without—it cannot be denied that modern society would become infeasible without plastic. When discussing plastic, sufficient attention must also be given to its positive aspects instead of simply taking up its negative aspects.

To achieve a sustainable society and pass on a rich environment to the next generation, studies must be performed with regard to plastics too from the viewpoint of exhaustive resource cycling over an entire lifecycle including efficient energy recovery from waste material. At the same time, a wide range of issues must be dealt with including resource/waste restrictions, countermeasures to marine litter, and policies to combat global warming while taking into account economic issues and technical possibilities.

Plastics mainly originate in finite resources such as petroleum. It is precisely because they are finite that the reuse of plastic waste as a resource, if made possible, can contribute to the finding of solutions in terms of both resource securing and waste processing. In fact, progress has been made over many years in the development of recycling technologies for post-use plastic, and techniques such as mechanical recycling and feedstock recycling for reusing plastic waste as raw material in plastic products and as chemical raw material, respectively, have been established and have found widespread use. In addition, plastics not suitable for mechanical and feedstock recycling are being effectively used through energy recovery. For 2017, all of the above measures brought Japan's effective plastic utilization rate up to 86%. This high value can be ranked as top-class even by world standards reflecting Japan's high regard for recycling.

In this publication we consider the question of waste from a number of angles and present the very latest data on processing of waste plastic and its use as a raw material. Environmental and waste issues are composed of a great number of factors, which makes a scientific, multifaceted approach essential to their solution. The reader, we hope, will find that "An Introduction to Plastic Recycling" throws light on waste problems and in particular on the issue of plastic waste.

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An Introduction to Plastic Recycling

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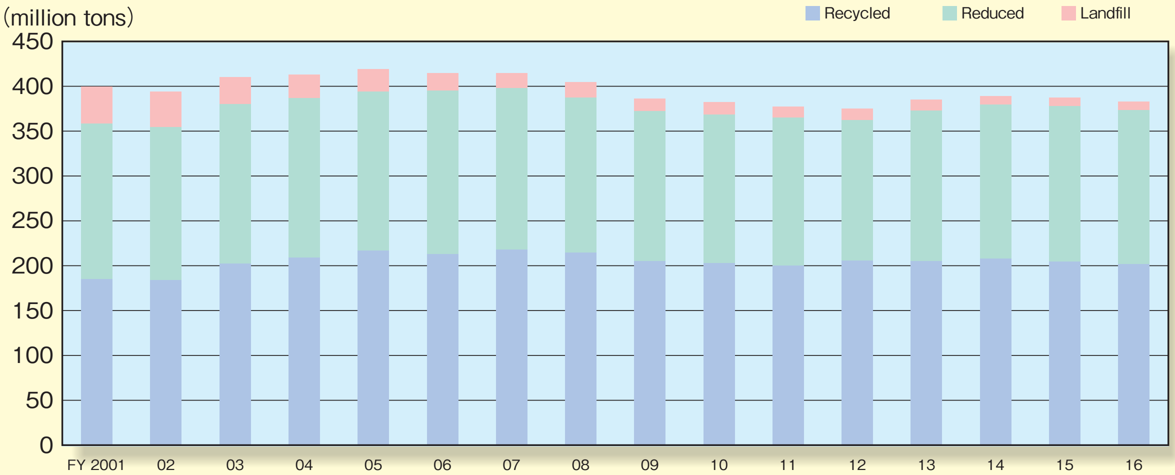
# 1 Waste emissions

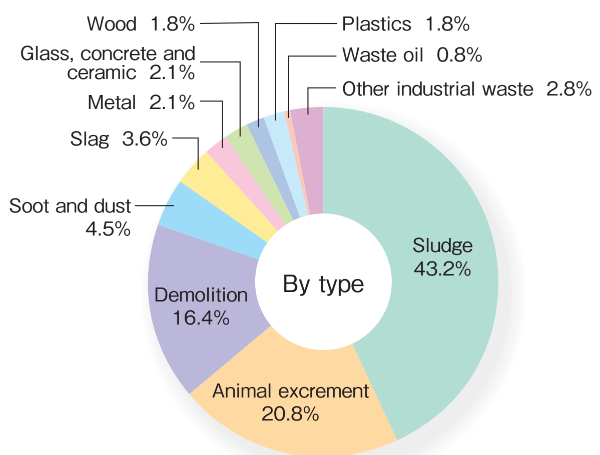
## Industrial waste emissions level off

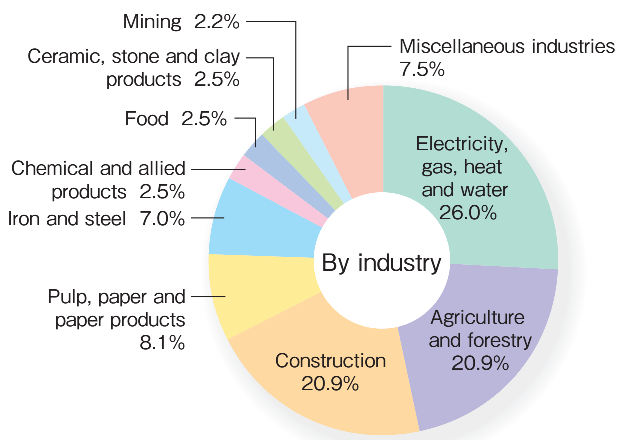
### Emissions and recycling of industrial waste




Source : Ministry of the Environment, Emissions and Processing of Industrial Waste FY 2016

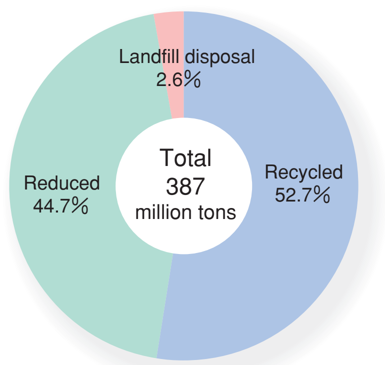
### Content of emissions




Source : Ministry of the Environment, Emissions and Processing of Industrial Waste FY 2016

### State of processing




### ◆ Approximately 3% disposed of by landfill

Industrial waste is waste emitted as a result of business activities at construction sites, livestock farms, factories, and other business-related establishments. Japan produces a little less than 400 mil1ion tons of industrial waste per year, and a breakdown reveals a little more than 40% of the total to be sludge, followed by animal excrement and demolition waste. These three categories account for around 80% of the total. In contrast, waste plastics account for very little.

Urban infrastructure industries (i.e. electricity, gas, heating and water utilities), construction produce and agriculture/forestry almost 70% of the total. Kanto region produces 26%, Chubu region produces 16%, Kinki and Kyushu region produce 14%, respectively.

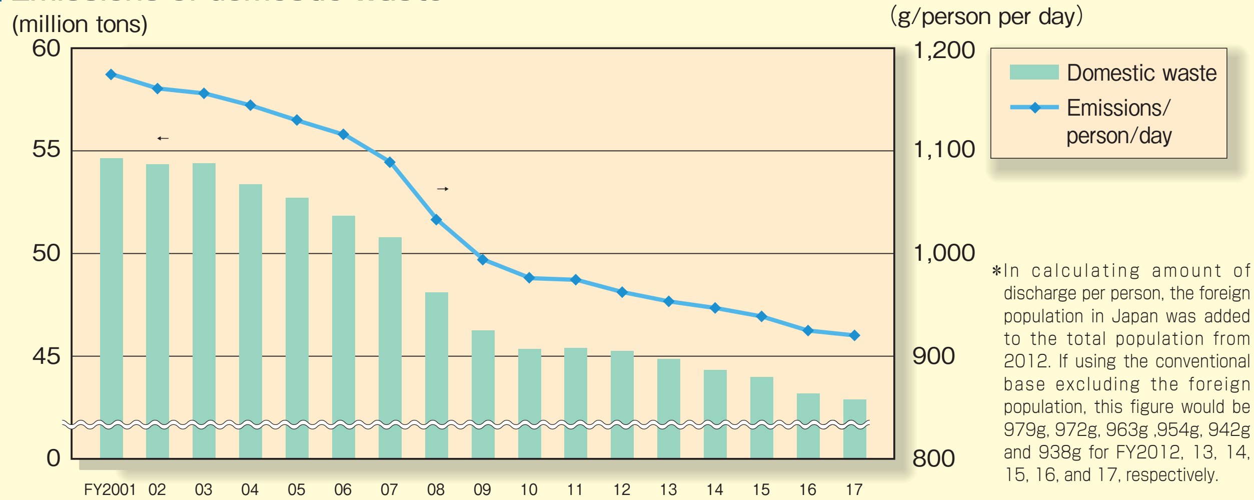
We can see from the State of processing graph that the total decreased by 4.15 million tons, and the breakdown reveals the amount of recycling decreased by 3.51 million tons, the amount of reducing decreased by 0.45 million tons and the amount of waste disposed of in landfill decreased 0.19 million tons, respectively. Although the tendency for the amount of landfill disposal to decrease and that for the amount of recycling to increase continued up to FY 2008, this decrease in the amount of landfill disposal has since weakened while the amount of recycling has leveled off.

The final disposal remaining capacity for industrial waste is a little less than 170 million $m^3$, and 17.0 years across the entire nation, especially 5.6 years in the Tokyo metropolitan area, so the landfill situation is particular1y severe.

(Source :Ministry of the Environment, Emissions and Processing of Industrial Waste, 1 April 2017)

# Decrease in domestic waste emissions bottom out

## Emissions of domestic waste




*In calculating amount of discharge per person, the foreign population in Japan was added to the total population from 2012. If using the conventional base excluding the foreign population, this figure would be 979g, 972g, 963g ,954g, 942g and 938g for FY2012, 13, 14, 15, 16, and 17, respectively.

Source : Ministry of the Environment, Emissions and Processing of Domestic Waste FY 2017

## Majority disposed of by incineration

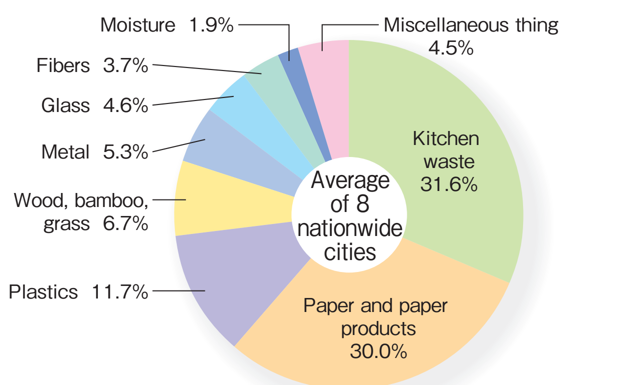
The amount of domestic waste discharged in Japan in FY 2017 was 42,890 kt (thousand tons), which is about 12,000 kt less than the peak value reached in FY 2000. This value equates to 920g of discharged waste per person*, which represents a drop of about 20% over the same period. Although the amount of domestic waste has been steadily decreasing since FY 2000, there are troubling signs that this trend is beginning to bottom out. Breaking down domestic waste reveals 29,880 kt (included 2,170 kt of garbage from group collections) of everyday garbage, 13,010 kt of business garbage, with household garbage making up 70% of all domestic waste.

On examining the composition of garbage, FY2018 of a survey conducted by the Ministry of the Environment found that kitchen waste and paper made up 32% and 30%, respectively, followed by plastics at 12% and wood/bamboo/grass, metal, glass and fiber at 7-4% in terms of percentage wet weight. Since kitchen waste makes up about 30% of garbage, it can be assumed that water makes up much of the weight of this type of waste.

The total amount of domestic waste processed in FY 2017came to 40,850 kt, but as shown by the State of Processing graph, most of this waste (80%) was processed by incineration. In addition, final disposal was 3,860 kt (420 kt direct + 3,440 kt after intermediate treatment), which means that about 83 g of waste per person per day ended up as landfill. There are 1,651 final disposal sites (landfills) in Japan with a remaining capacity of 103 million m³, which equates to a national average of 21.8 remaining years**. In addition, the number of remaining years for landfill disposal in the Tokyo metropolitan area and Kinki region became 25.1 (2.8 years more than the previous year) and 20.0 (0.2 years more than the previous year), respectively. There are also 297 municipalities (cities, towns, and villages) with no landfills of their own, and around 17% of municipalities in Japan consign final disposal of domestic waste to private landfills. Domestic waste carried outside prefectural and city governments to which local governments belong for the purpose of final disposal came to about 260 kt (6.7% of the total amount of final disposal), most of which was from the Kanto and Chubu regions. To secure final disposal sites and extend the number of remaining years of landfill, it is therefore important the three Rs (reduce, reuse, recycle) in order to reduce the quantity of landfill disposal.

** In June 2018, the Japanese cabinet approved a “Waste Treatment Facility Development Plan”(FY 2018–2022) that, with regard to the number of remaining years of final disposal sites for domestic waste, will “aim to appropriately dispose of waste still remaining after garbage recycling and reduction without hindering the preservation of the living environment by promoting the preparation of final disposal sites for domestic waste through the establishment or upgrading of final disposal sites, volume reduction of landfill waste, etc.” so as to maintain the FY2017 level (20 remaining years).

## Composition of garbage discharged at garbage stations (percentage wet weight)

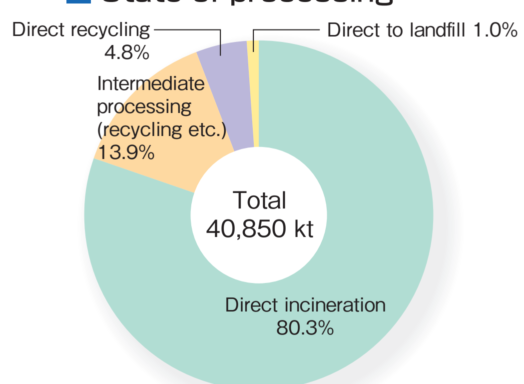



Survey target : For each of 8 cities (Tohoku: 1, Kanto: 4, Chubu: 1, Kansai: 1, Kyushu: 1), household garbage was discharged in 3 types of districts having the following characteristics. District A: relatively old residential district of detached houses; District B: recently developed residential district of detached houses; District C: apartments.

Survey period : August 2018 - December 2018

Source : Ministry of the Environment, Use, discharge fact-finding of waste containers and packaging discharged (FY 2018)

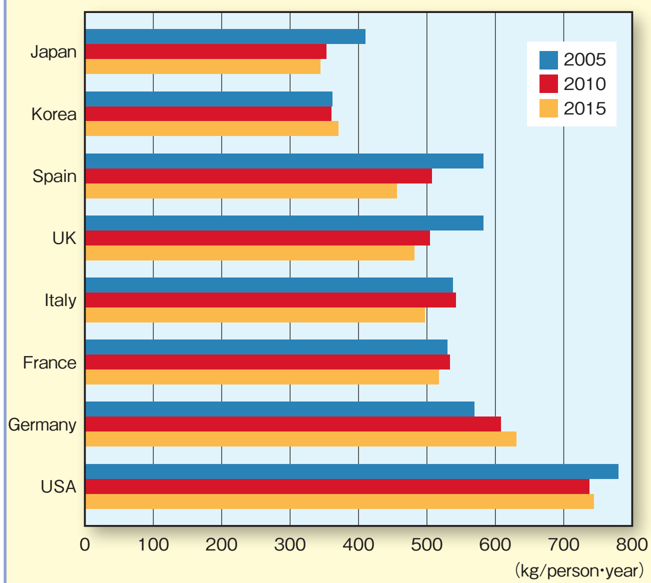
## State of processing




Source : Ministry of the Environment, Emissions and Processing of Domestic Waste (FY 2018)

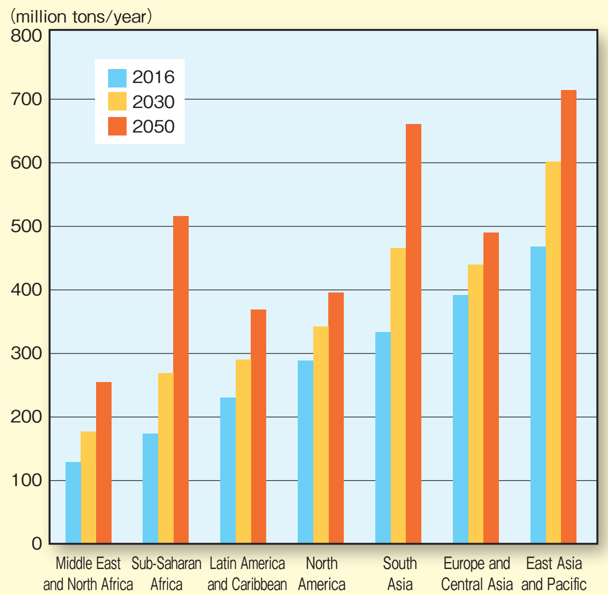
# State of global domestic waste emissions

## Annual waste emissions per person in major countries




Source : OECD.Stat

## Projected Waste Generation by Region




Source : The World Bank, What a Waste 2.0 2018

### Garbage discharge in major OECD member countries around the world

The volume of discharge of domestic waste by member countries of the Organization for Economic Cooperation and Development (OECD) came to 670,000 kt annually as of 2015. In particular, the volume of domestic waste discharged by the United States came to 240,000 kt, which equates to 744 kg of discharged garbage per person, a figure far greater than that of other countries (OECD member countries average: 523 kg). Japan's small volume of garbage discharged per person per year (344 kg) stands out among these figures (source: OECD.Stat).

### Increase of waste on a global scale

The amount of discharged waste is increasing on a global scale. This trend has become only stronger on entering the 21st century. According to a World Bank report, the amount of globally discharged waste, which stood at 1,300,000 kt in 2012 increasing to 2,000,000 kt in 2016, is forecast to increase to 3,400,000 kt by 2050 at a speed exceeding the population growth rate (doubling).

Examining this discharge of waste on a regional basis, we have, for 2016 in descending order, East Asia and Oceania (470,000 kt), Europe and Central Asia (390,000 kt), South Asia (330,000 kt), and North America (290,000 kt). However, for 2050, while East Asia and Oceania (710,000 kt) will maintain their top position, the forecast is for South Asia to double (660,000 kt) and for Sub-Saharan Africa to triple (510,000 kt) their waste discharge putting them in second place and third place, respectively. To put this in perspective, South Asia and Sub-Saharan Africa are expected to experience explosive population growth, vigorous economic development, and rapid economic growth in the coming years. In contrast, Europe and Central Asia (490,000 kt) and North America (400,000 kt) with many advanced economies are expected to experience very moderate growth of 1.3 – 1.4 times (The World Bank: What a Waste 2.0 2018).

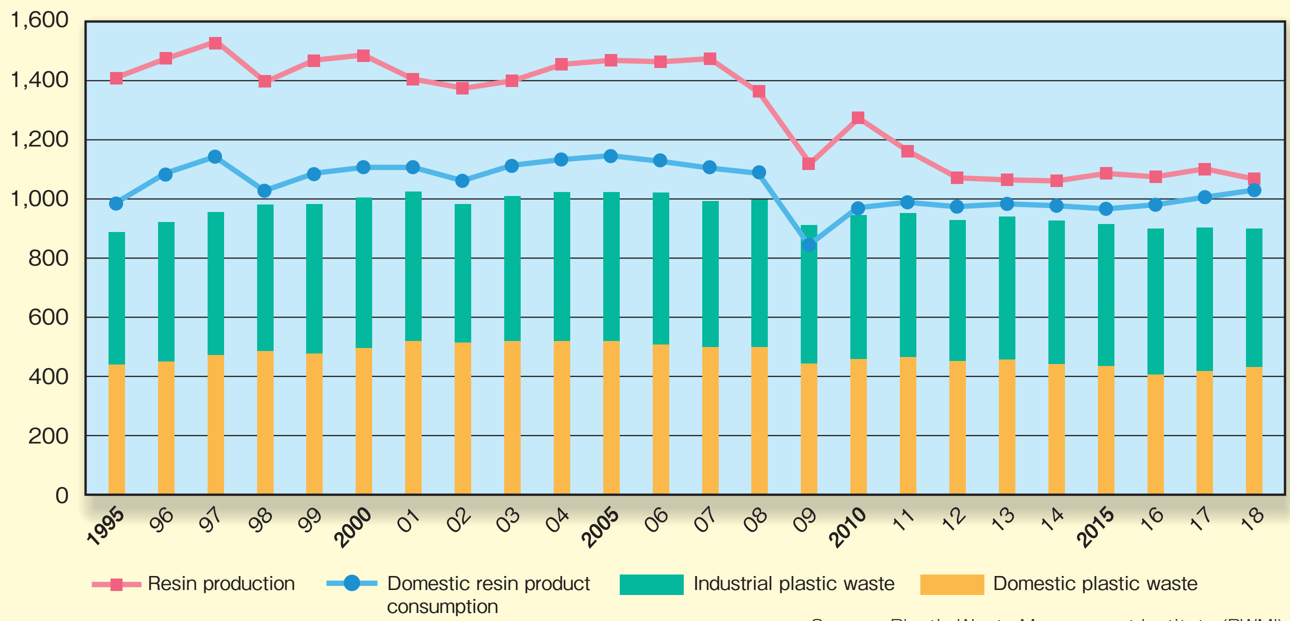
Along with economic development and economic growth, even developing countries can be expected to quickly enter an era of mass production, mass consumption, and mass discharge of waste. There is also concern that movement of people to cities and rapid urbanization will occur in a very short period of time. Most of these countries are weak in terms of the infrastructure, information, education, and funding required for waste processing, so finding a means of processing such a huge volume of generated waste is becoming a major issue. Failure to do so may create a variety of problems on a global scale such as the pollution of soil, air, oceans, and rivers, global warming, destruction of nature and ecosystems, and depletion of finite resources.

Today, this ever-growing problem of waste is not something that can be solved by one country, one region, or one individual. Collaboration on a global scale is needed more than ever to appropriately manage waste, control the generation of waste, and promote the reuse and recycling of waste.

# 2 Processing and recycling of plastic waste

## Effective use of plastic waste increases steadily

### Production and emission of plastics




Source : Plastic Waste Management Institute (PWMI)

### Trends in quantity and rate of effective utilization of plastic waste

(10 kt)

| Year | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total waste plastic emissions | | 1,006 | 1,005 | 994 | 998 | 912 | 945 | 952 | 929 | 940 | 926 | 915 | 899 | 903 | 891 |
| Effective utilization | Mechanical recycling | 185 | 204 | 213 | 214 | 200 | 217 | 212 | 204 | 203 | 199 | 205 | 206 | 211 | 208 |
| | Feedstock recycling | 29 | 28 | 29 | 25 | 32 | 42 | 36 | 38 | 30 | 34 | 36 | 36 | 40 | 39 |
| | Thermal recycling | 368 | 457 | 449 | 494 | 456 | 465 | 496 | 502 | 535 | 534 | 521 | 517 | 524 | 502 |
| | Total | 582 | 688 | 692 | 733 | 689 | 723 | 744 | 744 | 767 | 768 | 763 | 759 | 775 | 750 |
| Effective utilization (%) | | 58 | 69 | 69 | 73 | 75 | 77 | 78 | 80 | 82 | 83 | 83 | 84 | 86 | 84 |

Source : Plastic Waste Management Institute (PWMI)

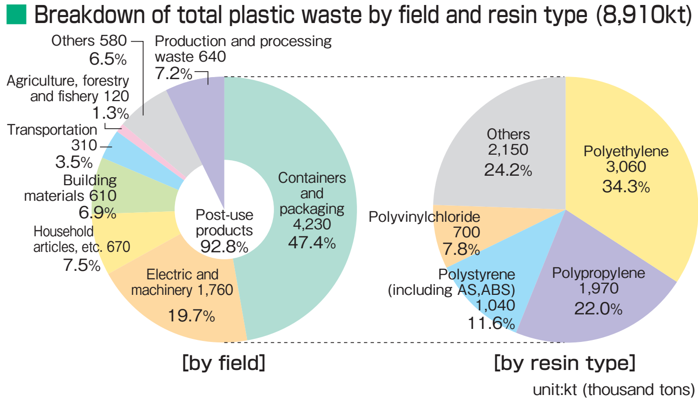
### 2018 Highlights

① For 2018, resin production and domestic plastics products consumption were 10,670 kt and 10,290 kt, respectively.

② Total plastic waste discharge was 8,910 kt.

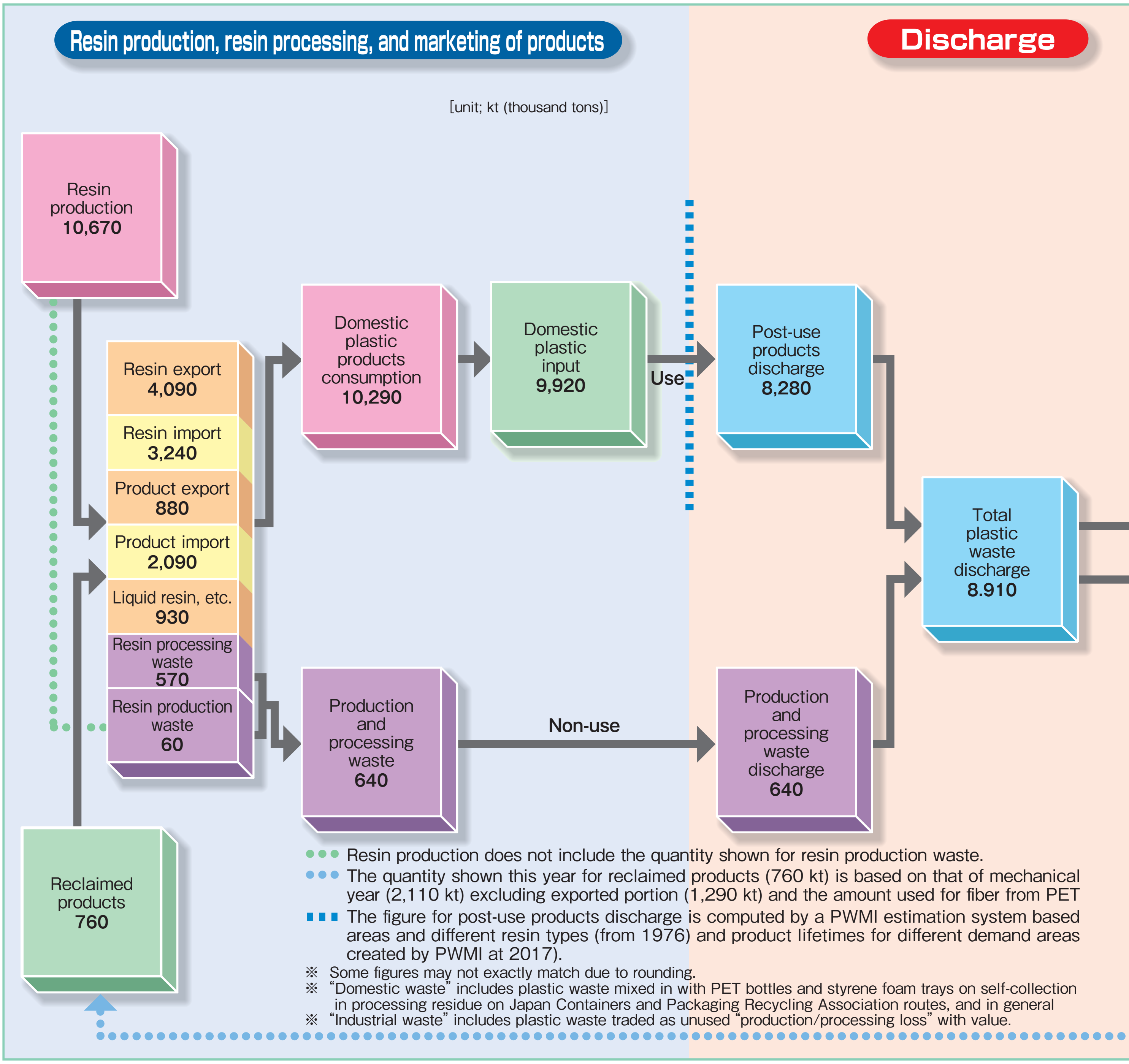
③ Effectively used plastic waste was 7,500 kt making for an effective plastic utilization rate of 84%.

### Breakdown of total plastic waste by field and resin type (8,910kt)




Source : Plastic Waste Management Institute (PWMI)

# Flowchart of plastic products, plastic waste and resource




## ◆ Effective utilization of plastic waste was 84%

Resin production for 2018 decreased from the previous year to 10, 670 kt (-350 kt relative to 2017; -31%).

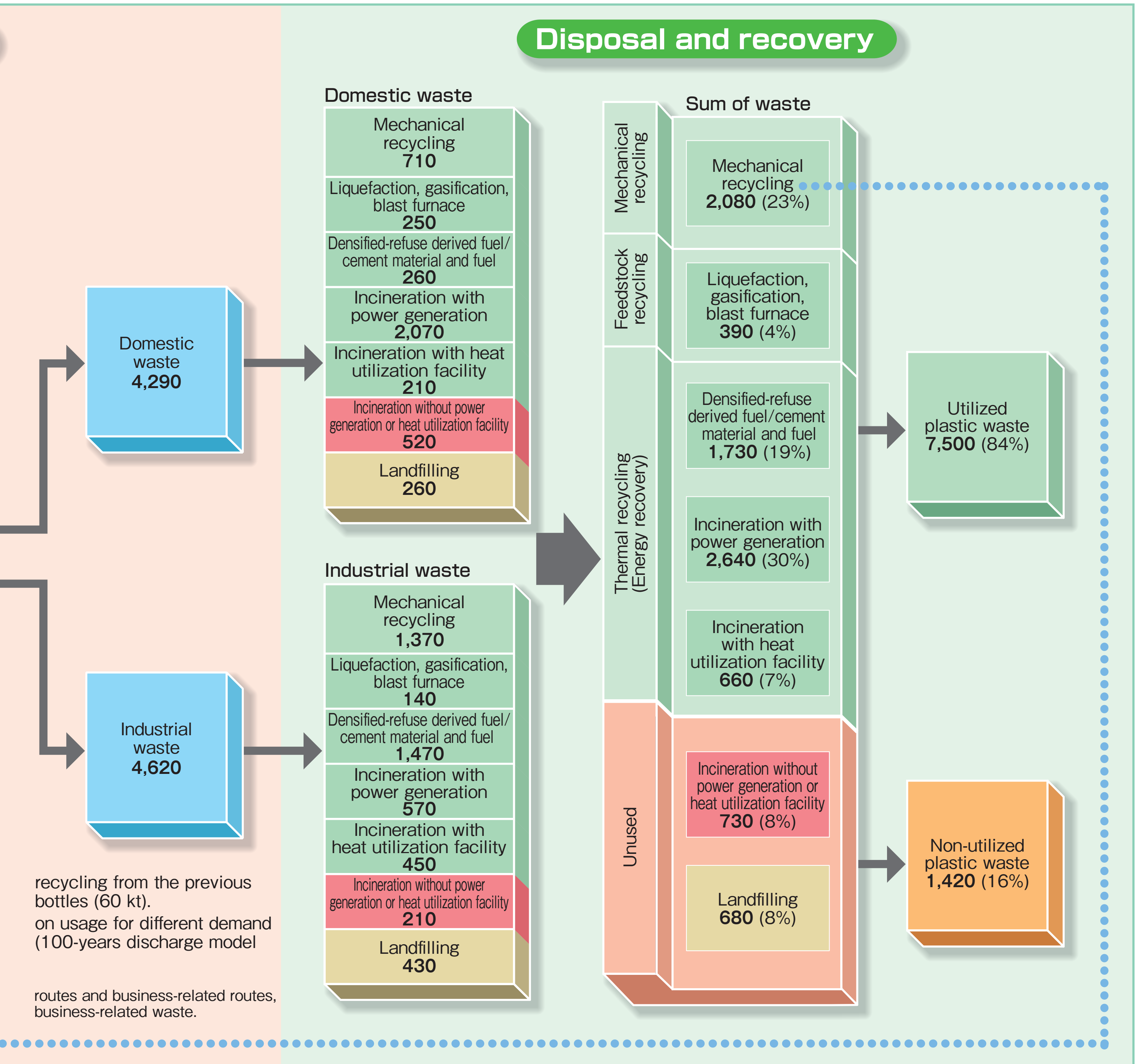
In addition, resin export, resin import, product export, and product import increased to 4,090 kt (+30 kt; +0.7%), 3,240 kt (+330 kt; +11.1%), 880 kt (+50 kt; +5.4%), and 2,090 kt (+90 kt; +4.3%), respectively.

As a result, domestic plastics products consumption increased to 10,290 kt (+170 kt; +1.7%).

Total plastic waste discharge decreased to 8,910 kt (-120 kt, -1.3%). On breaking down total plastic waste discharge, domestic (general) plastic waste increased to 4,290 kt (+110 kt, +2.7%) , and industrial plastic waste, on the other hand, decreased to 4,620 kt (-230 kt, -4.8%).

In terms of disposal and recovery methods, mechanical recycling decreased to 2,080 kt (-30 kt; -1.4%), feedstock

# e recovery 2018




Source : Plastic Waste Management Institute (PWMI)

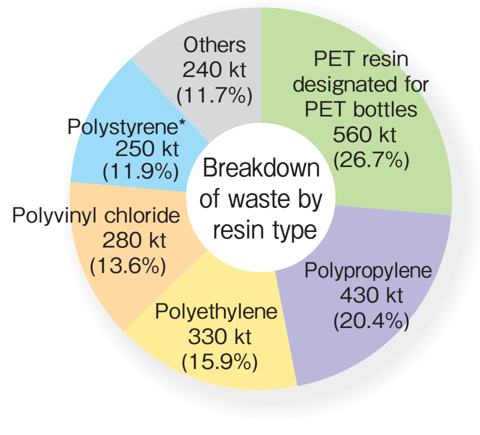
recycling*1 decreased to 390 kt (-10 kt; -2.2%), and energy recovery*2 decreased in total to 5,020 kt (-210 kt; -4.1%).

As a result, effective plastic utilization decreased to 7,500 kt (-250 kt; -3.3%) from the previous year. The non-utilized plastic waste by simple incineration or by landfilling increased to 1,420 kt (+140 kt, +10.5%). The percentage contributions to the effective plastic utilization rate by mechanical recycling, feedstock recycling, and energy recovery were 23%, 4%, and 56%, respectively, resulting in a two-point drop from the previous year to 84%.

*1. feedstock recycling = blast/coke furnaces + gasification + liquefaction
*2. energy recovery = densified-refuse derived fuel and cement material/fuel + incineration with power generation + incineration with heat utilization facility

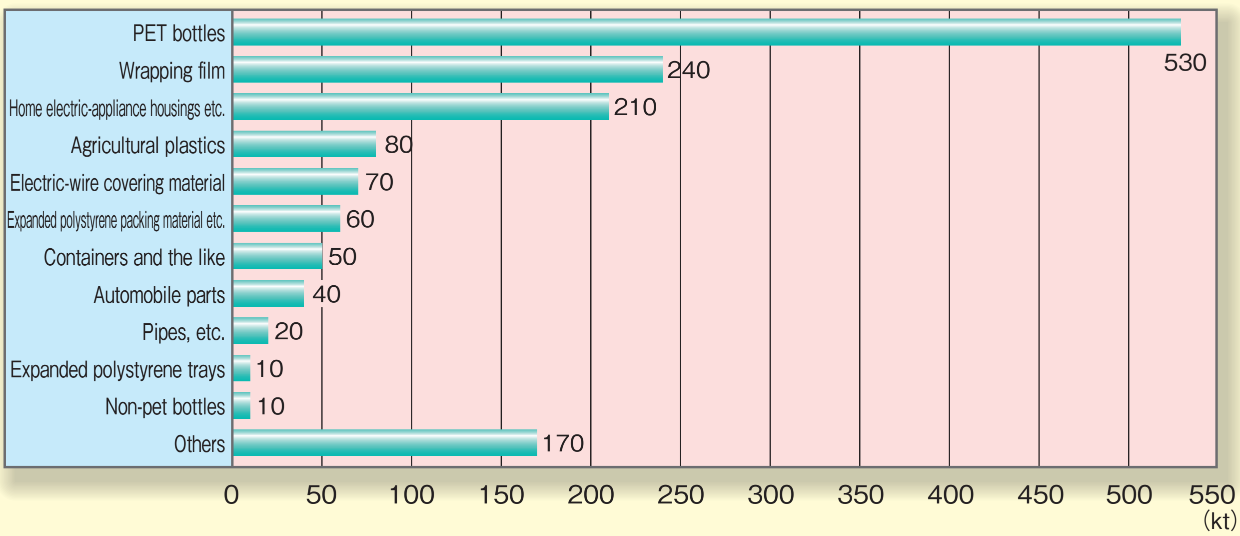
# Recovery systems supporting mechanical recycling

■ Breakdown of mechanical recycling (2,080 kt／page 7)


* Includes AS, ABS resin

■ Breakdown of post-use products for mechanical recycling (1,470 kt)




Source : Plastic Waste Management Institute (PWMI)

## ◆ Easily usable industrial plastic waste

The quantity of plastic waste used in mechanical recycling (i.e. the production of new plastic products using plastic waste as a raw material) was 2,080 kt (kt = thousand tons) in 2018. Of this amount, 710 kt was accounted for by domestic plastic waste (17% of domestic plastic waste). In contrast, about 2 times this amount of industrial plastic waste (1,370 kt or 30% of the total) was mechanically recycled. This is because a large proportion of industrial plastic waste is suitable for mechanical recycling due to its quality and comparative stability of supply.

A breakdown of the waste used for mechanical recycling reveals in recycling of used products to 1,470 kt and the loss in production and processing to 620 kt respectively. This is due to the continued smooth transition to recycling containers and packing, household appliance and cars in 2018. The success of the various recycling laws can be seen in breakdown of the 1,470 kt of used products: 530 kt of PET bottles, 240 kt of wrapping film, 210 kt of home electric-appliance housings, etc., 80 kt of agricultural plastics and 70 kt of electric-wire covering material. The efficient operation of the recycling systems of each industrial area and associated groups is striking.

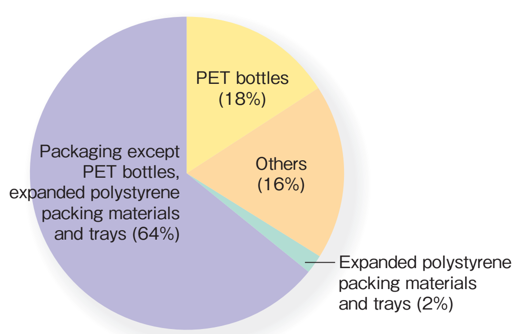
# Breakdown of plastic waste

| | Shape | | Use and Contents | Type of Resin | |
|---|---|---|---|---|---|
| Bottles and tubes | Beverage bottles | Soft drinks | Juice, cola, drinking water, tea, alcoholic beverages | PET | |
| | | Lactic acid beverage | Yogurt, milk | Polystyrene, PET, polyethylene | |
| | Food and condiment bottles | | Tempura and salad oil, soy sauce, sauce mirin (sweet sake used as seasoning) | PET, polyethylene, polypropylene | |
| | Condiment tubes | | Mayonnaise, ketchup, dressings, wasabi and mustard paste | Composite materials | |
| | Bottles and tubes for daily necessities | | Toiletries, gardening supplies, car supplies, liquid detergent, fabric softener, toothpaste, cosmetics, hair shampoo, hair conditioner, bleach and body shampoo | PET, composite materials, polyethylene, polypropylene | |
| Packs and cups | Food packs (EPS and non-EPS packs) | | Margarine, tofu, nattou (fermented soybeans), fruit, vegetables, processed foods, prepared foods, packed lunches | EPS | Polystyrene |
| | | | | Non-EPS | Polystyrene, polypropylene, PET |
| | Food cups (EPS and non-EPS packs) | | Miso (soybean paste), tamago-dofu (steamed egg custard), miso soup, yogurt, ramen, yakisoba (fried noodle), jelly, custard pudding, deserts food cups | EPS | Polystyrene |
| | | | | Non-EPS | Polystyrene, polypropylene, PET, polyethylene, composite materials |
| | Cup and pack lids | | | Polystyrene, PET, polypropylene, polyethylene, composite materials | |
| Trays and blister packs | EPS and non-EPS trays | | Meat, fish, sashimi (slices of raw fish), sliced ham, vegetables, processed foods | EPS | Polystyrene |
| | | | | Non-EPS | Polystyrene, polypropylene, PET |
| | Blister packs | | Drugs (tablets), processed meat and fish products, roast ham, bacon, curry roux, household tools, toothbrushes, cosmetics | Polyethylene, polypropylene, PET, polystyrene, PVC resin | |
| | Egg boxes | | | PET, polystyrene | |
| Bags | Large, medium and plain bags | | Rice, gardening bags, fish, fruit, confectionery, frozen foods, ramen, vacuum-packed foods, pickles, food boiled in soy, miso, bread, dried fish, cleaning | Polyethylene, polypropylene, PET, composite materials | |
| | Carrier bags | | | Polyethylene | |
| | Rubbish bags | | | Polyethylene | |
| | Small bags | | Quail's eggs, ginger, pickles, condiments, ramen stock, wagashi (Japanese confectionery), candy, wafers, chocolate | Polypropylene, polyethylene, composite materials, PET | |
| Caps and stoppers | | | Beverages, foods, daily necessities, other plastic bottles | Polypropylene, polyethylene | |
| Wrapping, packaging and labelling film | Wrapping film | | | Polyvinyl chloride resin, PVC resin, polyethylene | |
| | Packaging film | | Tofu, curry roux, plastic food decorations, wagashi, chees, frozen foods, cod roe, sausages, frozen noodles | Polypropylene, polyethylene, composite materials | |
| | Labels | | Bottles, caps | Polystyrene, polyethylene, PET, polypropylene | |
| Boxes and cases | | | Detergent boxes lids, foods, underwear, powder compacts, lotion cases, dehumidifiers, deodorizers | Polypropylene, polystyrene, polyethylene, PVC resin | |
| Protection and fixing | | | Urethane sponge, foam products, nets, air caps | Polystyrene, polyethylene | |
| Others | | | Baskets, handles, multi-packs, sieves, replanting pots | Polyethylene, PET, polypropylene, PVC resin, polystyrene | |

Note : The types of resin indicated in the table are those mainly used.

## Composition of plastic garbage (percentage)

Breakdown of plastics in the composition of garbage discharged at garbage stations (percentage wet weight) on page 3



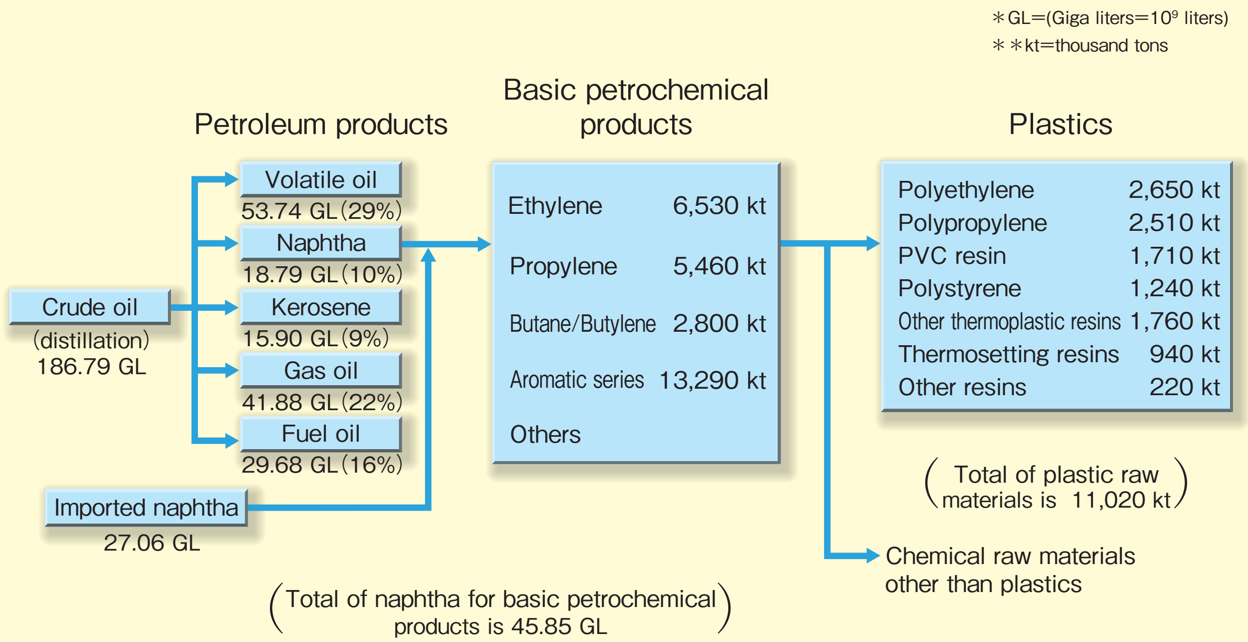

Source : Ministry of the Environment, Use discharge fact-finding of waste containers and packaging discharged(FY2018)

Recent advances in the development of high-function containers and packaging materials have led to the use of laminated film (multi-laminates) in many products. Laminated film is achieved by layering a wide variety of film-shaped resins each with different properties, which enables the advantages or disadvantages of individual films to be exploited or compensated for, respectively. For example, a layer that blocks the passage of moisture or oxygen, a layer that cuts off ultraviolet rays, and a layer with heat-resistant properties can be skillfully combined to create a film that hinders the deterioration or decay of the package content. On the other hand, to sufficiently manifest desired functions in laminated film, the constituent film-shaped resins must be closely affixed to each other, which make laminated film unsuitable for mechanical recycling. It can therefore be said that feedstock recycling or energy recovery should be promoted for the recycling of multi-laminates.

# 3 Information about plastics

## Manufacture of plastics from petroleum

### Crude oil use and production by product type (2017)




(The discrepancy with the quantity of resin produced as shown on p.6 is due to data being aggregated over different months.)
(Source : Japan Petrochemical Industry Association, Present State of the Chemical Industry 2018)

### Plastics are made from naphtha.

Plastics are mainly highly polymerized compounds consisting of carbon and hydrogen, made from substances such as petroleum and natural gas. In Japan, naphtha (crude gasoline) produced by refining crude oil is used as the raw material for making plastics. Naphtha produced by distilling crude oil is first heated and cracked to extract substances with a simpler structure (i.e. compounds with low molecular weight) such as ethylene and propylene. The molecules obtained are then chemically coupled (polymerized) to form substances with new properties, such as polyethylene and polypropylene, which are called synthetic resins and polymers. As the newly formed polyethylene and other such substances are difficult to handle in powder or lump form, they are first melted, additives added to make them easier to process, and they are formed into pellets. (It is from this stage that they are normally called plastics.) They are then shipped to the molding plant to be manufactured into plastic products.

### Plastics account for just several % of total petroleum consumption

Japan presently uses around 200 GL (Giga liters) of crude oil per year. Most crude oil is refined into gasoline, kerosene, gas oil, and fuel oil; less than 10% is turned into naphtha. In 2017, 18.79 GL of naphtha was produced from 186.79 GL of crude oil. Combined with imported naphtha (27.06 GL), 45.85 GL of naphtha was used as the raw material for basic petrochemical products such as ethylene, propylene, butane/butylene, etc. In 2017, the amount of plastic materials produced came to 11,020 kt, which is approximately 3% (weight percent) of the combined value of the amount of imported crude oil and the amount of imported naphtha after conversion to crude oil. The amount of crude oil used in plastics is around 3% of the total amount – most crude oil is burned and consumed as thermal energy.

Turning crude oil and naphtha into weight-based values requires weight conversions on the basis of density. Here, densities of 0.85 g/cm³ and 0.70 g/cm³ are used for crude oil and naphtha, respectively.

# Breakdown of plastic production by resin type and use

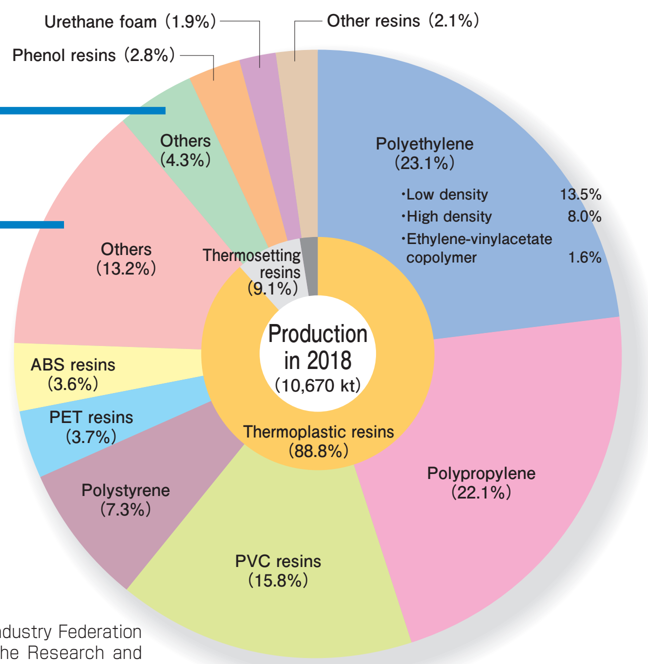
## Breakdown of production by resin type

**Breakdown of "Others" (Thermosetting resins)**

| | |
|---|---|
| ・Epoxy resins | 1.2% |
| ・Unsaturated polyester resins | 1.2% |
| ・Melamine resins | 0.8% |
| ・Alkyd resins | 0.6% |
| ・Urea resins | 0.6% |

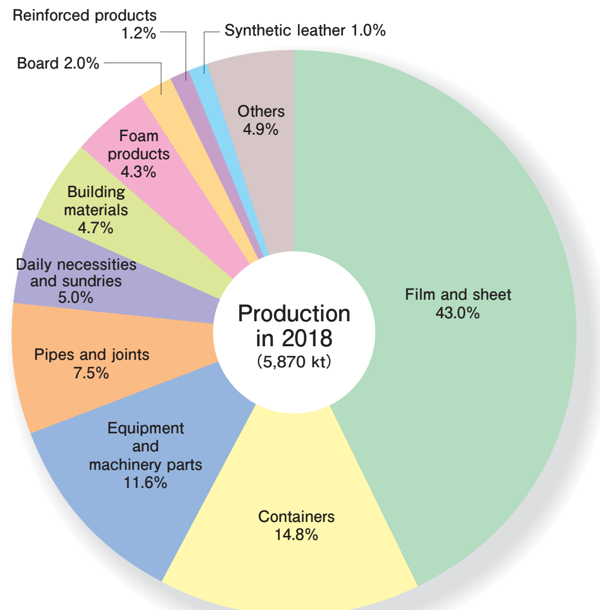
**Breakdown of "Others" (Thermoplastic resins)**

| | |
|---|---|
| ・Polycarbonate | 3.0% |
| ・Polyamides | 2.2% |
| ・Polyvinyl alcohol | 2.0% |
| ・Methacrylate resins | 1.4% |
| ・Polybutylene-terephthalate | 1.1% |
| ・Polyacetal | 1.1% |
| ・Petroleum resins | 1.0% |
| ・AS resins | 0.7% |
| ・Polyphenylene sulfide | 0.4% |
| ・Fluorocarbon resins | 0.3% |




Source : Tabulated by the Japan Plastics Industry Federation from monthly reports issued by the Research and Statistics Department, Minister's Secretariat, Ministry of Economy, Trade and Industry

## Breakdown of production by use




Note : The large difference between resin production (10,670 kt) and production by use (5,870 kt) in the graphs is because production by use was calculated according to the following parameters
(1) only primary products directly molded and processed were included
(2) only products made by business establishments with 50 or more works were included
(3) secondary processed products, plants, adhesives, wiring and cables, synthetic fibers and urethane foam, etc. were excluded.

Source : Tabulated by the Japan Plastics Industry Federation from monthly reports issued by the Research and Statistics Department, Minister's Secretariat, Ministry of Economy, Trade and Industry

### ◆ Half of production is polyethylene and polypropylene

Different plastics have different characteristics and are accordingly put to different uses.

A large proportion of production is of polyethylene and polypropylene, and these two combined account for around half of total output. This is because around 40% of plastic consumption is for bags, packaging such as cling film, and sheeting for construction and building materials, which polyethylene and polypropylene are ideally suited for.

### ◆ Thermoplastic and thermosetting plastics

Plastics are divided into two main types according to how they behave when heated : thermoplastic plastics and thermosetting plastics.

**●Thermoplastic plastics**

Thermoplastic plastics undergo strong molecular motion when heated, which causes them to soften. They harden when cooled, and repeated heating and cooling allows them to be molded into a variety of different shapes. Uses include containers and packaging material (film, sheet, bottles), daily necessities, household appliances and automobiles. The molding methods used here include injection, extrusion, blowing, vacuum, and inflation.

**●Thermosetting plastics**

Thermosetting plastics undergo relatively weak molecular motion but once softened by heat and treated they undergo a chemical reaction which causes them to form a high molecular weight 3D matrix structure. This means that once they have set they cannot be softened again by heat. Uses include food containers, circuit boards for electrical equipment, shafts for golf clubs and tennis rackets, and fiber-reinforced plastic boats. The molding methods used here include compression, injection, and transfer.

# Plastics as the foundation of industry and modern lifestyles

## ◆ Advantages of plastics

- **Light and robust**
  Plastics can be used to make light yet strong products, unlike metal and ceramics.
- **Resistant to rust and corrosion**
  Most plastics are resistant to acid, alkalis and oil and do not rust or corrode.
- **Transparent and freely colorable**
  Some types of plastics are highly transparent and can be easily colored, making it possible to create bright, attractive products.
- **Mass producible**
  Many types of plastics that can be molded and processed by a variety of methods, so products with complex shapes can be efficiently mass-produced, helping to bring down costs.
- **Excellent electrical and electronic properties**
  Their outstanding insulation properties and dimensional stability allows plastics to be used in components and electrical and electronic products.
- **High heat-insulation efficiency**
  Plastics conduct heat poorly, and foam is a particularly good heat-insulating material.
- **Hygienic with a strong gas barrier**
  Plastics are clean and impermeable to oxygen and water, effectively protecting foods from contamination by microorganisms.

## ◆ Drawbacks of plastics

- **Susceptible to heat**
  Some types of plastics deform when placed near a flame or heat source.
- **Susceptible to scratchers and dirt**
  Plastics have a soft surface compared to metal and glass and are easily scratched. They are also susceptible to static electricity and stains are highly visible.
- **Vulnerable to petroleum benzine and thinner**
  Some plastics melt or discolor if exposed to petroleum benzine, thinner or alcohol.

### 1. Household appliances : LCD televisions

Liquid crystal display (LCD) televisions with their vivid and detailed high picture quality wide angle screens are made up of a number of plastics layered together: polarizing film, phase contrast film and a diffuser panel for the backlight. Plastics are also used in electrical components, circuits and housings.

Photo : Japan Polyethylene Corporation

### 2. Automobiles: Gasoline tanks

Four different resins are applied in six layers to prevent fuel from permeating through the tank, which can be molded in a single stage into a complex shape that frees up space inside the car. Plastic tanks are lighter and also compatible with biofuels, which are expected to come into widespread use. They meet the US safety standards for use over 15 years or 150,000 miles (286,000km).

## 3. Food containers and packaging: pouches, refillable packs, cups

There is a food container for every need, from heat sterilization to frozen storage. Plastic containers are light and can be formed into retort pouches, sealed and re-sealable containers, or lined with aluminum or a barrier resin to keep out oxygen and UV radiation and extend the shelf life of food.

Photo: Vinyl Environment Council

## 5. Construction materials: PVC sash

Energy loss through windows can be reduced by 1/3 by using PVC sashes and low emissivity double glazing, as compared to aluminum sashes and normal glass windows. They can also prevent condensation and are widely used in Europe as a way to save energy. Japan is expected to adopt them for the same reason.

Photo : Hosokawa Yoko Co., medical packaging division

## 4. Infusion solution bag (containers for nutrient fluid and dialysis)

Plastic containers have good heat resistance making them suitable for heat sterilization, are light and flexible so they drain without the need for venting, and can be used in a closed system (to prevent hospital infections). Some drugs are supplied in a double-bag kit, which prevents errors in drug administration by making them easy to mix.

## Main characteristics and uses of plastics

| | | JIS abbr. | Resin name | | Standard thermal resistance (℃) | Acid resistance | Alkali resistance | Alcohol resistance |
|---|---|---|---|---|---|---|---|---|
| Themoplastic resins | Generic plastics | PE | Polyethylene | Low density polyethylene | 70—90 | Good | Good | Good |
| Themoplastic resins | Generic plastics | PE | Polyethylene | High density polyethylene | 90—110 | Good | Good | Good |
| Themoplastic resins | Generic plastics | EVAC | Polyethylene | EVA resin | 70—90 | Some products somewhat vulnerable | Some products somewhat vulnerable | Good |
| Themoplastic resins | Generic plastics | PP | Polypropylene | | 100—140 | Good | Good | Good |
| Themoplastic resins | Generic plastics | PVC | Polyvinyl chloride | | 60—80 | Good | Good | Good |
| Themoplastic resins | Generic plastics | PS | Polystyrene (styrene resin) | Polystyrene | 70—90 | Good | Good | Taste of contents changes if stored for a long time |
| Themoplastic resins | Generic plastics | PS | Polystyrene (styrene resin) | Expanded polystyrene | 70—90 | Good | Good | Taste of contents changes if stored for a long time |
| Themoplastic resins | Generic plastics | SAN | AS resin | | 80—100 | Good | Good | Repeated use renders opaque |
| Themoplastic resins | Generic plastics | ABS | ABS resin | | 70—100 | Good | Good | Swells over long period |
| Themoplastic resins | Generic plastics | PET | Polyethylene terephthalate (PET resin) | | Stretched film around 200<br>Un-stretched film around 60<br>Heat-resistant bottle around 85<br>Aseptic filling bottle around 70 | Good | Good (except strong alkali) | Good |
| Themoplastic resins | Generic plastics | PMMA | Methacrylic resin (acrylic resin) | | 70—90 | Good | Good | Gives contents a slight foreign odor |
| Themoplastic resins | Generic plastics | PVAL | Polyvinyl alcohol | | 40—80 | Softens or dissolves | Softens or dissolves | Dissolves at a low saponification point |
| Themoplastic resins | Generic plastics | PVDC | Polyvinylidene chloride | | 130—150 | Good | Good | Good |
| Themoplastic resins | Engineering plastics | PC | Polycarbonate | | 120—130 | Good | Some products somewhat vulnerable (e.g. detergents) | Good |
| Themoplastic resins | Engineering plastics | PA | Polyamide (nylon) | | 80—140 | Some products somewhat vulnerable | Good | Possible infiltration |
| Themoplastic resins | Engineering plastics | POM | Acetal resin (polyacetal) | | 80—120 | Some products somewhat vulnerable | Good | Good |
| Themoplastic resins | Engineering plastics | PBT | Polybutylene terephthalate (PBT resin) | | 60—140 | Good | Good | Good |
| Themoplastic resins | Engineering plastics | PTFE | Fluorocarbon resin | | 260 | Good | Good | Good |
| Thermosetting resins | | PF | Phenol resin | | 150 | Good | Good | Good |
| Thermosetting resins | | MF | Melamine resin | | 110—130 | Good | Good | Good |
| Thermosetting resins | | UF | Urea resin | | 90 | Stable or very slight change | Very slight change | Good |
| Thermosetting resins | | PUR | Polyurethane | | 90—130 | Somewhat vulnerable | Somewhat vulnerable | Good |
| Thermosetting resins | | EP | Epoxy resin | | 150—200 | Good | Good | Good |
| Thermosetting resins | | UP | Unsaturated polyester resin | | 130—150 | Good | Good | Good |

Standard thermal resistance (℃) is the heat resistance of each resin type in normal use. It does not apply to generic resins, engineering plastics or thermosetting resins. (Generic resins are measured in terms of short term thermal resistance, and engineering plastics and thermosetting resins in terms of long-term resistance.) The entries on this table have been arranged into standard grades to give a rough idea of their physical properties. Consult the manufacturer if you require particular physical properties for product design.

| | Resistance to cooking oil | Characteristics | Main uses |
|---|---|---|---|
| ce | | | |
| | Good | Lighter than water (relative density <0.94), excellent electrical insulation, water resistance, chemical resistance and environmental adaptability, but poor thermal resistance. Mechanically strong but soft, does not become brittle even a low temperatures. | Packaging (bags, cling, film, food containers), agricultural film, wire covering, film within milk carton |
| | Good | Slightly heavier than low-density polystyrene but still lighter than water (relative density >0.94). Excellent electrical insulation, water resistance, and chemical resistance, higher thermal resistance and more rigid than low-density polystyrene. Whitish and opaque.. | Containers and packaging (film, bags, food containers), shampoo and conditioner bottles, sundries (packets, washbowls, etc.), gasoline tanks, kerosene containers, containers, popes |
| | Good | Transparent and flexible, with rubbery elasticity that gives it excellent resistance at low temperatures. Some items have excellent adhesive properties. Poor thermal resistance. | Agricultural film, stretch film |
| | Good | Low relative density (0.9-0.91). Relatively high thermal resistance. Excellent mechanical strength. | Automobile parts, household appliance parts, wrapping film, food containers, caps, trays, containers, pallets, clothing boxes, textiles, medical instruments, daily necessities, trash containers. |
| | Good | Does not burn easily. Soft and hard varieties. Sinks in water (relative density of 1.4). excellent glossy surface shine, well suited to printing. | Over and underwater pipes, joints, guttering, corrugated sheeting, window sashes, flooring, wallpaper, synthetic leather, hoses, agricultural film, wrapping film, wire covering |
| ges | Vulnerable to some fatty oils such as terpene oil from citrus fruits and perilla oil | Comes in a transparent, rigid general purpose (GP) grade and a milky white shock-resistant high impact grade (HI). Easily colored. Good electrical insulating properties. Dissolves in petroleum benzine and thinner. | Office appliance and TV casing, CD cases, food containers. |
| ges | Vulnerable to some fatty oils such as terpene oil from citrus fruits and perilla oil | Light and rigid. Good thermal insulting properties. Dissolves in petroleum benzene thinner. | Packaging, fish boxes, food trays, cup noodle containers, tatami mat padding |
| rs | Good | Excellent transparency and thermal resistance. | Tableware, disposal lighters, electrical equipment (fan blades, juicers), food storage, containers, toys, cosmetic containers. |
| | Good | Excellent shock-resistance and glossy appearance | Office appliances, automobile parts (interior and exterior), games, consoles, building components (internal), electrical equipment (air conditioners, refrigerators). |
| | Good | Excellent transparency, rigid, excellent gas barrier properties. | Insulating material, functional optical film, electromagnetic tape, camera film, wrapping film |
| | | Excellent transparency, oil-resistant, excellent chemical resistance. | Containers for foodstuffs, food boiled in soy sauce, fruit, salad and cakes, drinks cups, clear bottles, various kinds of transparent packaging (APET). |
| | | Transparent and rigid, excellent gas barrier. | Containers for drinks, soy sauce, alcohol, tea, and drinking water (PET bottles). |
| ht | Good | Colorless, transparent, glossy. Dissolves in petroleum benzine and thinner. | Automobile headlight lenses, tableware, lighting boards, water tank plates, contact lenses. |
| t | Good | Water-soluble, film-forming, adhesive, chemically resistant, excellent gas barrier. | Vinylon fabric, films, paper coating agents, adhesives, PVC suspension stabilizing agent, automobile safety glass. |
| | Good | Colorless, transparent, good chemical resistance, excellent gas barrier. | Cling film, ham and sausage casing, film coating. |
| | Good | Colorless and transparent, highly resistant to acids but vulnerable to alkalis. Excellent resistance to shocks and heat. | DVDs and CDs, electronic part housings (e.g. mobile phones), automobile headlight lenses, camera lenses and housings, transparent roofing materials. |
| n | Good | Milky white, scratch-resistant resistant to low temperatures, good shock resistance. | Automobile parts (air inlet pipes, radiator tanks, cooling fans, etc.), food film, fishing line and monofilament, gears, fasteners. |
| | Good | White, opaque, excellent shock resistance and good abrasion resistance. | Gears (DVD player, etc.), automobile parts (fuel pumps, etc.), fasteners and clips. |
| | Good | White, opaque, good balance of electrical and other physical properties. | Electrical parts, automobile parts. |
| | Good | Milky while and thermally resistant, high chemical resistance with non-stick properties. | Frying pan coatings, insulating materials, bearings, gaskets, all kinds of packing material, filters, semiconductor industry applications, wire coverings. |
| | Good | Good electrical insulating properties, acid resistance, heat resistance and water resistance. Does not burn easily. | Printed circuit boards, iron handles, distribution board breakers, pan and kettle handles and knobs, plywood adhesive. |
| | Good | Good water resistance. Resembles ceramic. Hard surface. | Tableware, decorative laminate, plywood adhesive, paint. |
| | Good | Resembles melamine resin, but cheaper and more difficult to burn. | Buttons, caps, electrical products (wiring accessories), plywood adhesive. |
| | Good | A wide variety of physical properties can be obtained from the resin, from flexible to rigid. Excellent adhesive and scratch-resistant properties, foam also has many desirable physical properties. | Foam is mainly used for cushions, automobile seats and heat insulation. Non-foam variety is used for industrial roll packaging belts, coatings, waterproofing materials, spandex textiles. |
| | Good | Excellent physical, chemical and electrical properties. Products reinforced with carbon fiber are particularly strong. | Electrical products (IC sealant, printed circuit boards), paints, adhesives, all kinds of laminates. |
| | Good | Good electrical insulating properties, heat resistance and chemical resistance. Products reinforced with glass and carbon fiber are particularly strong | Baths, corrugated sheeting, cooling towers, fishing boat, buttons, helmets, fishing rods, coatings, septic tanks. |

Source: The Japan Plastics Industry Federation, "Hello Plastics ! "
(Partly revised by PWMI)

# 4 Methods of plastic recycling

## ● Three forms of recycling

<table>
<tr><th>Category (in Japan)</th><th colspan="2">Method of recycling</th><th>ISO 15270</th></tr>
<tr><td>Material recycling</td><td colspan="2">Recycling to make<br>・Plastic raw materials<br>・Plastic products</td><td>Mechanical recycling</td></tr>
<tr><td rowspan="4">Chemical recycling</td><td colspan="2">Monomerization</td><td rowspan="4">Feedstock recycling</td></tr>
<tr><td colspan="2">Blast furnace reducing agent</td></tr>
<tr><td colspan="2">Coke oven chemical feedstock recycling</td></tr>
<tr><td rowspan="2">Gasification<br>Liquefaction</td><td>Chemical feedstock</td></tr>
<tr><td rowspan="2">Thermal recycling</td><td>Fuel</td><td rowspan="2">Energy Recovery</td></tr>
<tr><td colspan="2">Cement kiln<br>Waste power generation<br>RPF(*1), RDF(*2)</td></tr>
</table>

*1. Refuse Paper & Plastic Fuel (high-calorie solid fuel made from waste paper & plastic)
*2. Refuse Derived Fuel (solid fuel made from burnable waste, plastic waste, etc.)

### ◆ The true goal of recycling

Many years of technological development now allow plastic waste to be recycled by a number of methods. They can be grouped into three main categories(note 1, 2).

(1) Mechanical recycling
(2) Feedstock recycling (monomerization, blast furnace reducing agent, coke oven chemical feedstock recycling, gasification, liquefaction, etc.)
(3) Thermal recycling (cement kiln, waste power generation, RPF, RDF)

Recycling technology has advanced tremendously and its use is spreading, but recycling is not an end in itself. As the Fundamental Law for Establishing a Sound Material-Cycle Society enacted in 2000 made explicit, the purpose of recycling is to curb consumption of finite natural resources such as oil and minimize the burden on the environment through the cyclical use of resources. This means it is necessary to carefully consider whether the method used reduces inputs of new resources or limits the burden on the environment when promoting recycling.

It is important to select the recycling method for plastics that imposes the least social cost as well as limiting environmental impact given the situation of the plastic waste to be recycled.

note1 : The methods of recycling currently recognized by the Containers and Packaging Recycling Law are material (mechanical) recycling, chemical (feedstock) recycling (monomerization, liquefaction, use as a blast furnace reducing agent, coke oven chemical feedstock recycling and conversion to chemical feedstock by gasification) and energy recovery (thermal recycling) (liquefaction and gasification). Under the amendment in 2006, RDF and other forms of energy recovery were added as supplementary methods, albeit with some limitations.

note2 : In classes specified by JIS Z0130 established in 2015 to incorporate environmental considerations in packaging applications, feedstock recycling is included in mechanical recycling.

JIS Z 0130 List of classes

| Category(in Japan) | JIS Z 0130 (targeting packaging) |
|---|---|
| Material recycling | Material recycling (JIS Z 0130-4*1) |
| Chemical recycling | Material recycling (JIS Z 0130-4*1) |
| Thermal recycling | Energy Recovery (JIS Z 0130-5*2) |

*1 Revising ISO18604
*2 Matching to ISO18605

# Mechanical recycling


**Main recycled products made from industrial plastic waste**

① Railway signs
② Boundary marking piles
③ Pallet
④ Two-rail fence (imitation wood)
⑤ Geo-step (Stairs for slope inspection/ management)
⑥ Manhole
⑦ Curb material for partitioning (imitation wood)
⑧ House cock box
⑨ Springboard
⑩ Step ramp
⑪ Central reservation block
⑫ Parking block
⑬ Clothes hangers
⑭ Kite-string spools
⑮ Plant pots
⑯ Stationery (Name tag case, Ballpoint pens, Paper knives, Rulers)
⑰ Duckboard
⑱ Washbowls
⑲ Bath chair

## ◆ Used for containers, building materials, sheeting, automobile engine compartments,…

Mechanical recycling is a way of making new products out of unmodified plastic waste. It was developed in the 1970s, and is now used by several hundred manufactures around Japan.

Mechanically recycled waste has until now consisted largely of industrial plastic waste. Industrial plastic waste generated in the manufacture, processing and distribution of plastic products is well suited for use as the raw material for mechanical recycling thanks to clear separation of different types of resins, a low level of dirt and impurities and availability in large quantities.

Up until now, recycled products that have used industrial plastic waste as raw material have had a few weak points such as degraded physical properties and unstable quality, but these problems have been overcome by enhancements in quality-control procedures, compounding techniques, and manufacturing/processing techniques for plastic waste used as raw material. Today, industrial plastic waste is being used for a wide range of articles and facility components such as containers, benches, fences, playground equipment, and construction sheeting in areas related to package transport, construction, homes, parks, roads, railroads, and agriculture, forestry, and fisheries. More recently, it has also come to be used for units and parts in a variety of fields requiring high performance and high functionality such as parts for automobile engine compartments, units for rainwater storage and infiltration systems, and parts for produce cultivation systems.

Recycled products have a number of attractive characteristics: they are durable, light, easy to process and easy to cut and join, just like wood. We can expect greater adoption of recycled products with these features being used in place of other materials, such as steel, concrete and wood.

Furthermore, in conformance with the Containers and Packaging Recycling Law, domestic plastic waste discharged from households, stores, and offices has also become a target of mechanical recycling thanks to improvements in sorting, quality control, compounding, and manufacturing/processing techniques for plastic waste as raw material. Centered about PET bottles, this type of waste is being turned into bottles, packaging materials, stationary, daily necessities, etc.

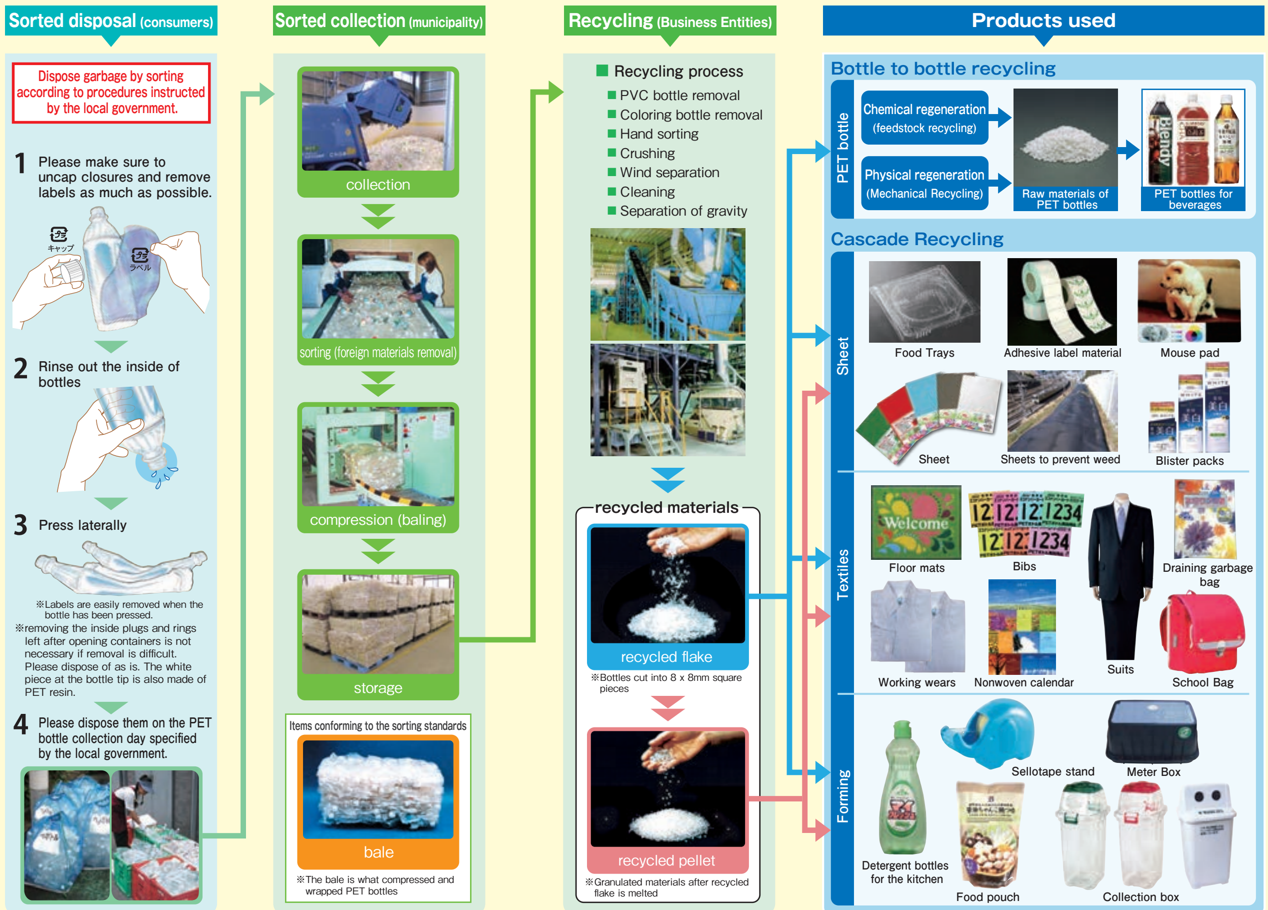

Ⓐ Radiator support opening cover
Ⓑ Front bumper extension mounting
Parts for automobile engine compartments
Photo ; ISONO Co., Ltd.

Units for rainwater storage and infiltration systems
Photo ; Joto Lyprone Co., Ltd.

Parts for produce cultivation systems
Photo ; Sunpoly Co., Ltd.

# Mechanical recycling process

## From the collection of PET bottles to recycling into new products




Source : Report 2018 of Council for PET Bottle Recycling (Partly omitted the figure by PWMI)

### ◆ Re-melted to make products

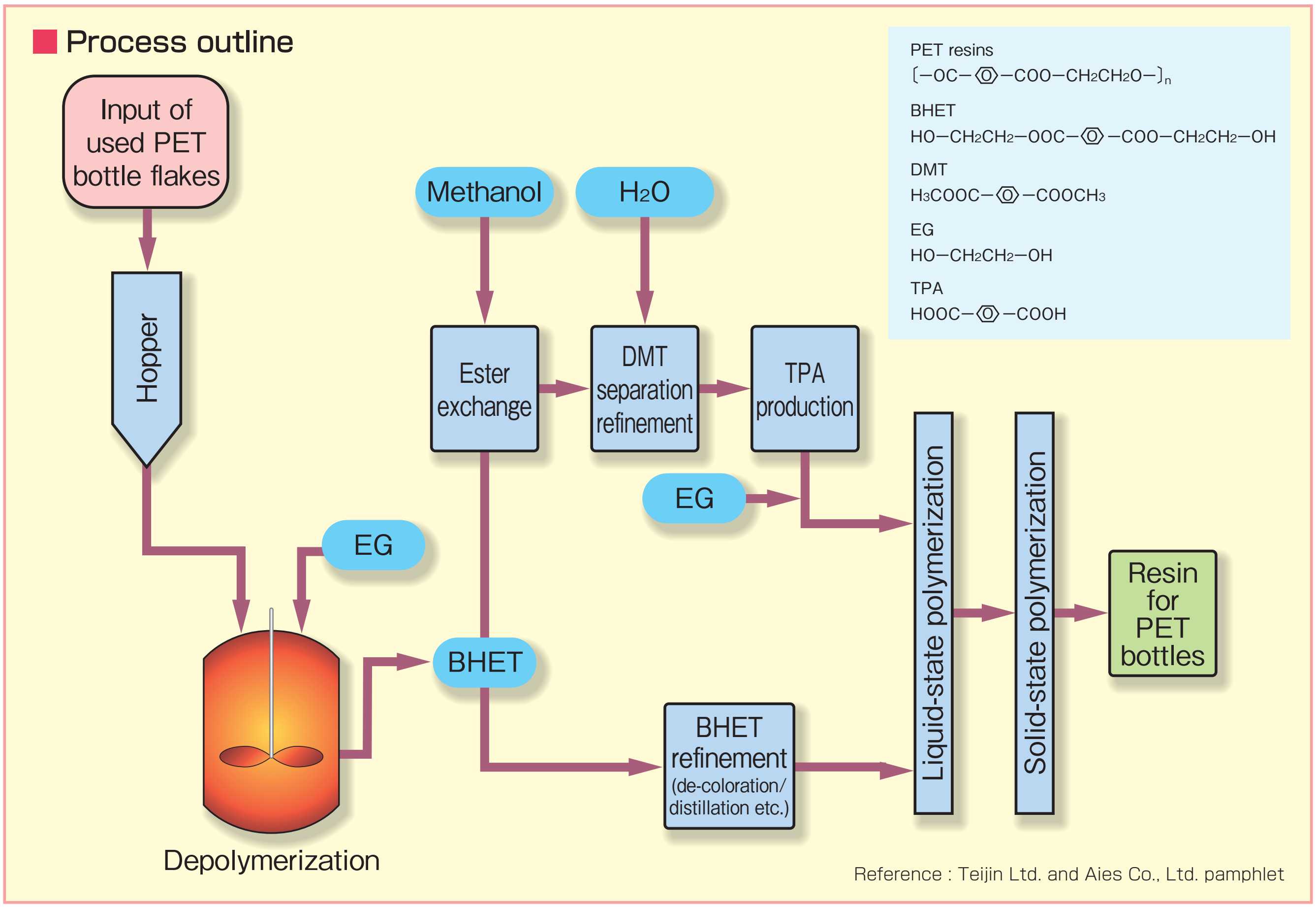
Mechanical recycling of plastic waste is generally performed as follows. After performing resin sorting and removing impurities, the waste is pulverized and washed to form flakes or the flakes so obtained are melted and formed into pellets by an extruder. These flakes or pellets are then used as raw material for making products.

PET bottles from sorted household waste are collected, compressed and packed by municipalities for transportation to plants operated by recycling businesses. At the recycling plant, the waste is sorted to remove impurities, and the remaining PET bottles then shredded and cleaned, foreign bodies and non-resins are removed and the remainder turned into flakes and pellets (made from flakes, thermally processed by an extruder) for recycling. The recycled materials are then sent to textile and sheet-making plants, where they are again melted down to make into textile and sheet products.

Up until recently, recycled raw materials were not used for PET bottles targeted for beverage use due to hygiene concerns, odor-related problems, etc. These issues, however, were solved by chemical methods, and B to B (bottle to bottle) business for making beverage-specific PET bottles from post-use PET bottles began in 2003 (see Monomerization (Feedstock Recycling) on p. 19). Additionally, B to B business for the same purpose based on a mechanical recycling method has been in operation since 2011. This method removes impurities from flakes and performs polymerization under a vacuum and high temperature using the result as raw material for beverage-specific PET bottles.

# Monomerization

〈Feedstock Recycling〉




## ◆ From PET bottles to PET bottles

While PET bottles can be recycled to make textiles and sheeting, they cannot be used to make PET drinks bottles. This is because used PET bottles are unsuitable for use as raw materials for soft drink, alcohol or soy sauce bottles for reasons of hygiene and smell. However, converting PET bottles back to an earlier state of processing is a more economic use of resources than making PET resin from scratch out of petroleum and naphtha. A "bottle to bottle (B to B)" scheme to make recycled resin equivalent to newly made resin suitable for drinks bottles started in 2003 on this basis. The method chemically decomposes the used PET bottles into their component monomers (de-polymerization), and they are made into new PET bottles from this stage.

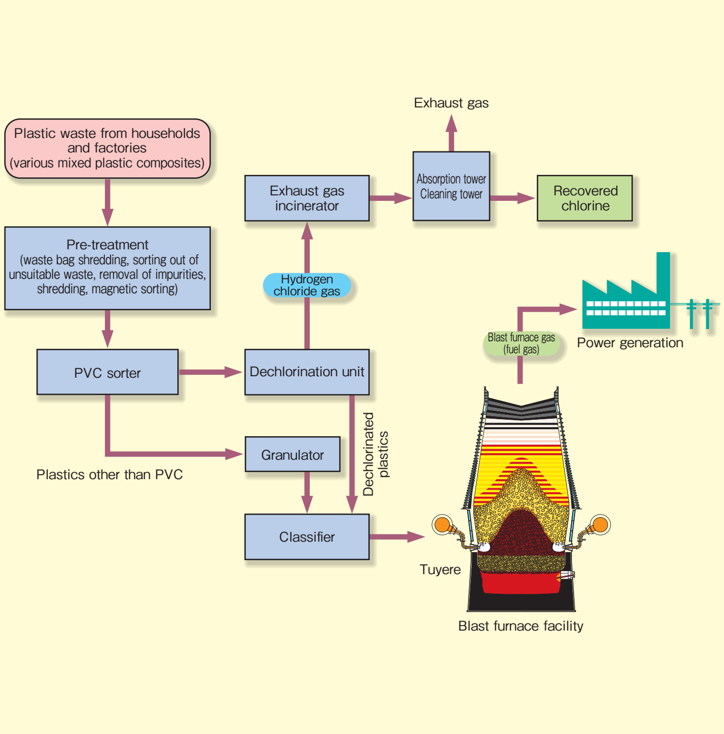
Teijin Ltd. already uses its own proprietary decomposition method, combining ethylene glycol (EG) and methanol to break waste PET resin down into DMT (dimethyl terephthalate) to turn it the raw material used to make textiles and film. This technique was improved upon to break PET bottles down further from DMT to PTA (purified terephtalic acid) to make PET resin, and Teijin Fiber Ltd. commenced operation of a facility with the capacity to process around 62 kt (*kt = thousand tons) a year in 2003. The resin produced was judged suitable for use in food containers by the Japanese Food Safety Commission in 2004, and B to B production started in April with the approval of the Ministry of Health, Labor and Welfare.

Aies Co., Ltd. has also developed a technique for manufacturing resin by breaking it down into high-purity BHET (bisydroxyethyl-terephthalate) monomer using a new method of de-polymerization using EG. It established a new company, PET Reveres Co., Ltd. in 2004 which can process around 27.5 kt per year.

However, a shortage in raw materials due to a dramatic increase in the export of waste PET bottles gave Teijin Fiber no alternative but to withdraw from B to B production. PET Reverse, meanwhile, has had to undergo a restructuring, and their B to B business is being carried on by PET Refine Technology Co., Ltd., a member of the Toyo Seikan Co. Ltd. Group. Since then, JEPLAN,INC. has inherited this business.

# Blast furnace feedstock recycling 〈Feedstock Recycling〉

## Blast furnace feedstock recycling process




(Source: JFE Steel Corporation. Pamphlet)

## Plastics used as a reducing agent

At steel mills, iron ore, coke and auxiliary raw materials are fed into a blast furnace and the iron ore melted to produce pig iron. Coke is used as fuel to elevate the temperature in the furnace, and also acts as a reducing agent by removing the oxygen from iron oxide, one of the main constituents of iron ore. As plastics are made from petroleum and natural gas, their main constituents are carbon and hydrogen. This means that it should be possible to devise a means of using them instead of coke as a reducing agent in the blast furnace process.

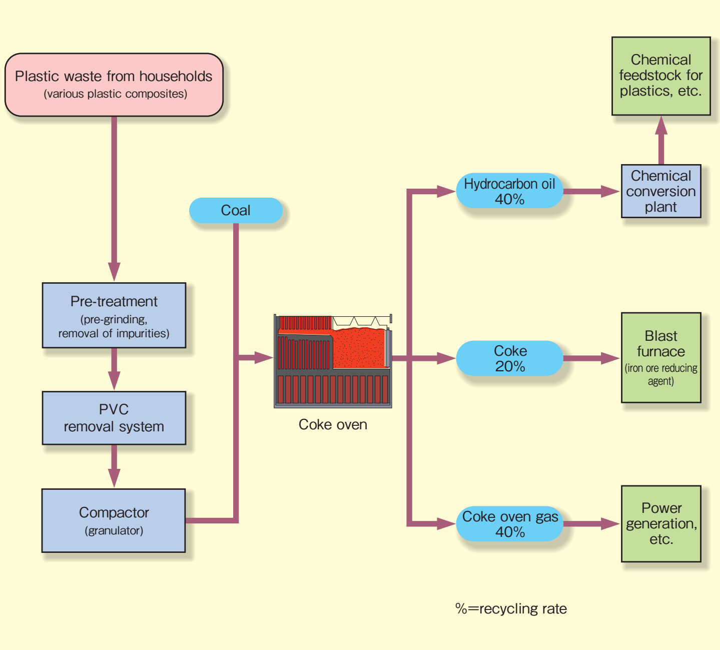
The process by which plastics are used as a reducing agent is as follows. Plastic waste collected from factories and households is cleansed of non-combustible matter and other impurities such as metals, then finely pulverized and packed to reduce its volume.

Plastics that do not contain PVC are granulated, then fed into the blast furnace with coke. Plastics that contain PVC are fed into the blast furnace after first separating the hydrogen chloride at a high temperature of around 350°C in the absence of oxygen, as the emission of hydrogen chloride can damage a furnace. The hydrogen chloride thus extracted is recovered as hydrochloric acid and put to other uses, such as acid scrubbing lines for hot rolling at steel mills.

This dehydrochlorination method was developed by the Plastic Waste Management Institute (PWMI), Japan PVC Environmental Affairs Council, Vinyl Environmental Council and JFE Steel Corporation (formerly NKK) at the request of the New Energy and Industrial Technology Development Organization (NEDO). JFE Plastic Resource Corporation (founded in November 2005) has been applying this process in full-scale operations.

# Coke oven chemical feedstock recycling 〈Feedstock Recycling〉

## Coke oven chemical feedstock recycling process




(Source : NIPPON STEEL CORPORATION Pamphlet)

## Plastic waste reused in coke ovens

Coke is made by baking coal, and the process also generates volatile compounds which produce hydrocarbon oil and coke oven gas. However, coke, hydrocarbon oil and coke oven gas can also be produced from plastic waste. NIPPON STEEL CORPORATION has developed facilities at most of its steel mills to use plastic waste as cokes, chemical feedstock and fuel, and it is now in use in its Nagoya, Kimitsu, Muroran, Yawata and Oita sites.

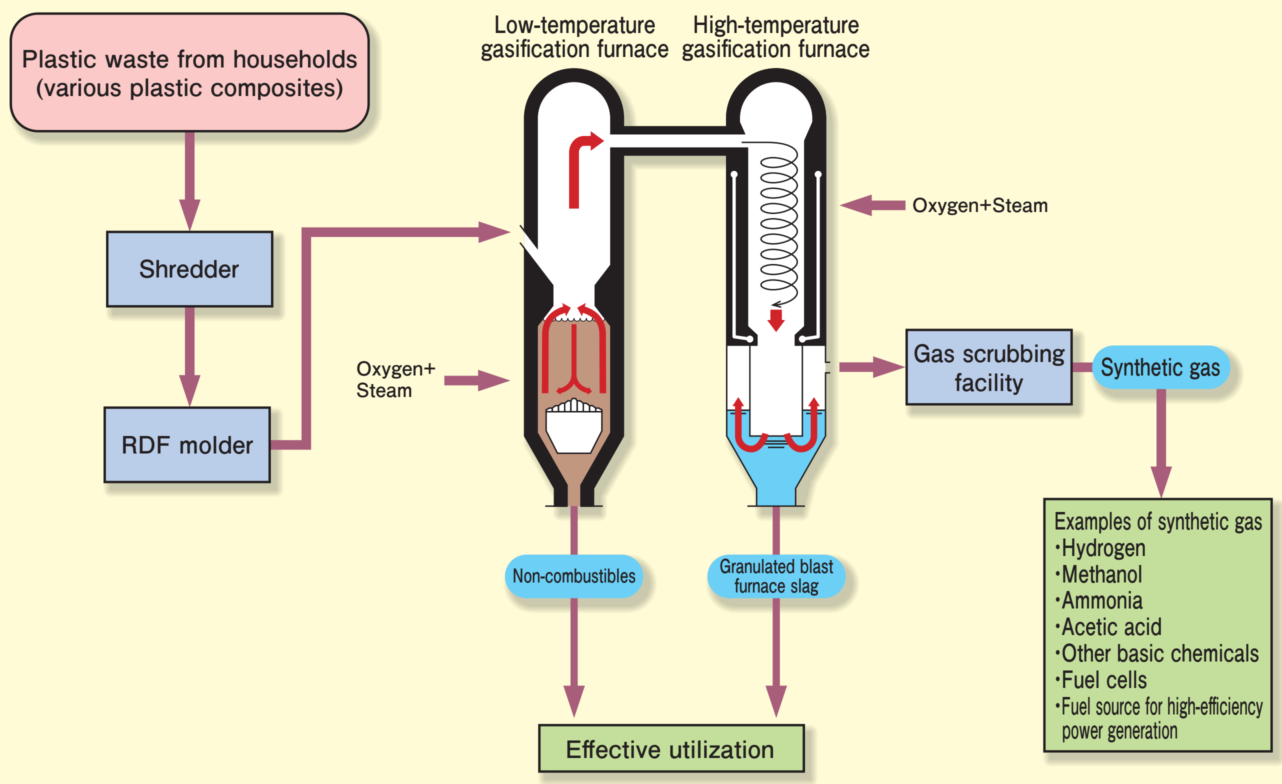
This system begins by crushing plastic waste obtained from local governments and removing iron and other impurities and PVC. It then heats the plastics to 100°C and forms it into granules, which are then mixed with crushed and granulated coal at a ratio of 1–2% before being fed to the carbonization chamber of the coke oven.

The carbonization chamber has combustion chambers on both sides which heat the content indirectly. The plastic waste does not combust inside the chamber due to lack of oxygen, but it is instead cracked thermally at a high temperature to produce coke for use as the reducing agent in coke ovens, hydrocarbon oil. This process results in 40% hydrocarbon oil for use as chemical feedstock, 20% coke for use as a blast-furnace reducing agent, and 40% coke oven gas for generating power.

# Gasification

〈Feedstock Recycling〉

## Gasification process




Source : Plastic Waste Management Institute (PWMI)

## ◆ Plastic waste converted to gas for use as a raw material in the chemical industry

Plastics are composed mainly of carbon and hydrogen and therefore normally produce carbon dioxide and water when combusted. The gasification process involves heating plastics and adding a supply of oxygen and steam. The supply of oxygen is limited, which means that much of the plastics turn into hydrocarbon, carbon monoxide and water.

Sand heated to 600-800°C is circulated inside a first-stage low-temperature gasification furnace. Plastics introduced into the furnace break down on contract with the sand to form hydrocarbon, carbon monoxide, hydrogen and char. If the plastics contain chlorine, they produce hydrogen chloride. If plastic products contain metal or glass, these are recovered as noncombustible matter.

The gas from the low-temperature gasification furnace is reacted with steam at a temperature of 1,300-1,500°C in a second-stage high-temperature gasification furnace to produce a gas composed mainly of carbon monoxide and oxygen. At the furnace outlet, the gas is rapidly cooled to 200°C or below to prevent the formation of dioxins. The granulated blast furnace slag also produced is used in civil engineering and construction materials.The gas then passes through a gas scrubber and any remaining hydrogen chloride is neutralized by alkalis and removed from the synthetic gas. This synthetic gas is used as a raw material in the chemical industry to produce chemicals such as hydrogen, methanol, ammonia and acetic acid.

The Plastic Waste Management Institute (PWMI) was commissioned by New Energy and Industrial Technology Development Organization (NEDO) to conduct trials of this technology, which were performed with the cooperation of Ebara Corporation and Ube Industries, Ltd. After verification testing, this technology was put into actual operation by EUP Co., Ltd., in 2001, but owing to the difficulty of acquiring plastic waste as raw material, this venture was closed down in May 2010.

However, Showa Denko K.K. began operation of a new facility using this technology at its Kawasaki Plant in 2003.

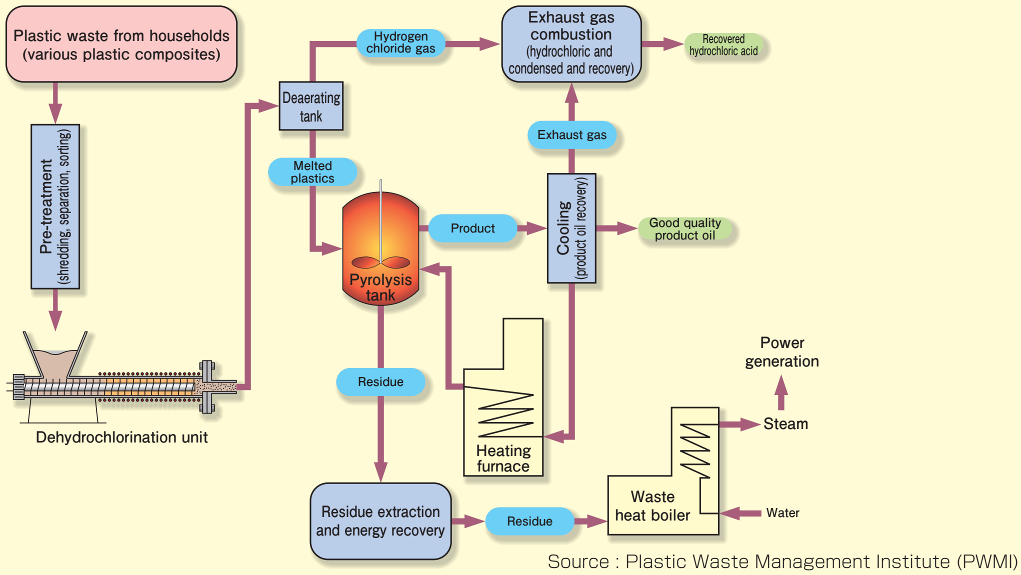
In addition, the Thermoselect process (for using plastic waste as clean fuel gas) operated by JFE KANKYO Corporation since 2000 has been inherited by J&T Recycling Corporation, which was established in 2019 through a merger with Tokyo Waterfront Recycle Power Co., Ltd.

The same process was adopted in the form of a private financial initiative (PFI) waste business by Mizushima co-works Co., Ltd in 2005 and by ORIX Environmental Resources Management Corporation in 2006.

# Liquefaction

〈Feedstock Recycling〉

## Liquefaction process




Source : Plastic Waste Management Institute (PWMI)

## Plastic waste converted back to oil

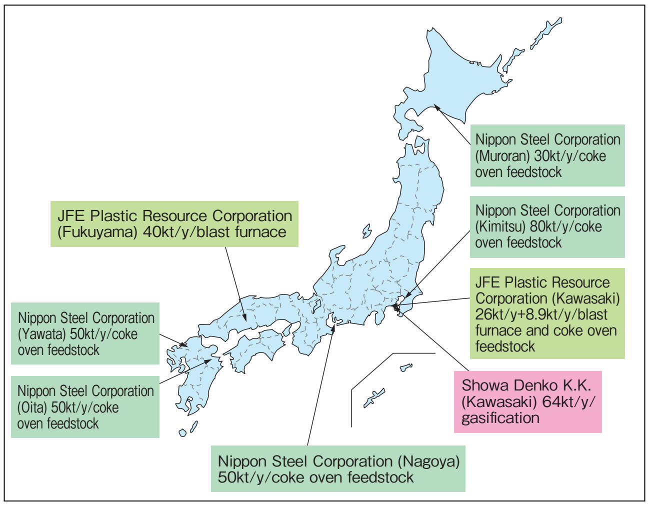
Since the raw material used to produce plastics is petroleum, it should be possible to return plastics to petroleum by reversing the production process. Development of plastic waste liquefaction technology for this purpose began in the second half of the 1970s, and today, plastic-waste liquefaction is essentially an established technology.

However, the process of returning plastic in a macromolecular state to a low-molecular state is an endothermic reaction that requires energy. It requires, In particular, extra energy for heating material up to temperatures of about 400°C (which means that some of the generated oil must be consumed as fuel or that electric power must be purchased to perform such heating). In addition, the process product in crude-oil form must again be cracked and refined to obtain commercial products, and facilities for this purpose are essential. At the same time, there is always risk of ignition or explosion in the liquefaction process and countermeasures to that risk must be taken. For the above reasons, many large-scale liquefaction facilities could not achieve profitability and were forced to withdraw from the business before the second half of the 2000s. Sapporo Plastic Recycling Co., Ltd. had been working to establish a liquefaction business with large-scale facilities, but they withdrew from the business in 2010.

The research and development of plastic-waste liquefaction technology has had some achievements, but many issues remain, such as how to achieve a scale of business that is commercially viable and how to reduce costs. At present, any new ventures in the liquefaction business face difficult conditions. The above problems and issues must be thoroughly studied by any enterprise looking to adopt this technology.

## Reference : Large scale feedstock recycling facilities (under the Containers and Packaging Recycling Law) (2019)

In Japan, there are many facilities applying the feedstock recycle technology. Figure shows that the facilities of feedstock recycle using the collected plastics under the containers and packaging recycling law. In 2019, there are 8 facilities of blast furnace feedstock recycling, coke oven chemical feedstock recycling and gasification in Japan.

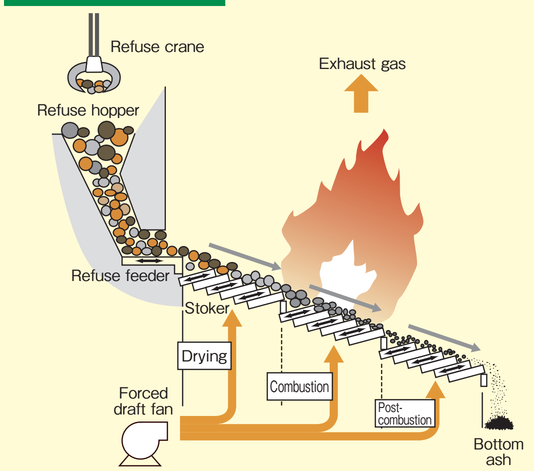



Note : The numeric shows treatment capacity (2019)　　kt = thousand tons

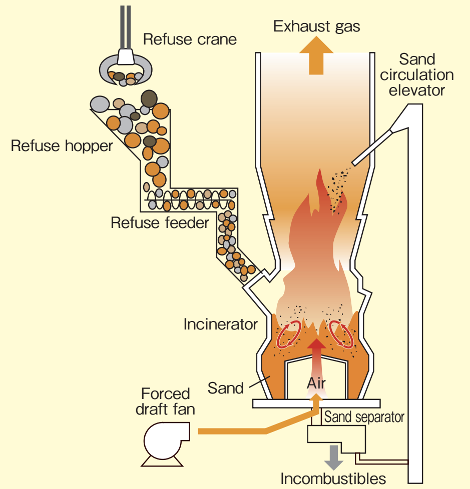
# Thermal recycling (Energy recovery)

## Incinerator mechanisms

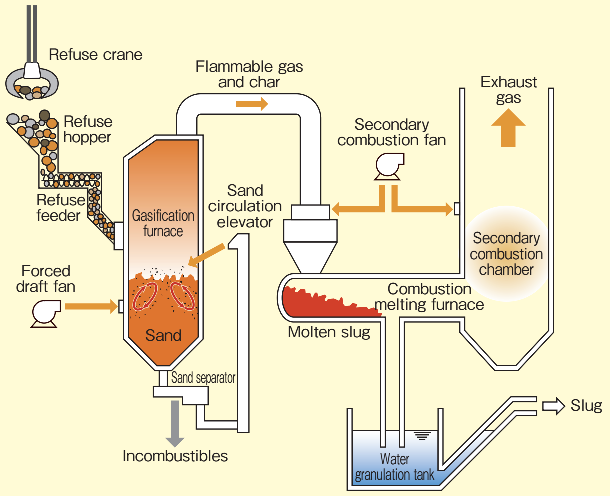
### Stoker incinerator




### Fluidized-bed incinerator




### Gasification melting furnace




Up and rite site Source : Clean Authority of TOKYO, Waste Report 23 2019 (portions of figure reconfigured by PWMI)

## From waste plastic and landfill to thermal recycling

Waste plastics are currently collected and processed differently by different municipalities, but the Ministry of the Environment is unifying the previously separate categories of waste into one ("burnable"), with an amendment to the Waste Disposal Law on May 2005 which changes its basic policy to state that "first, emission of waste plastic should be reduced, after which recycling should be promoted; any remaining waste plastic should not go to landfill as it is suitable for use in thermal recovery".

In a similar move, the Tokyo municipal area, which had since 1973 been putting household waste plastics into landfill as non-burnable garbage, set a goal in 2008 of sending zero household waste plastic to landfill and instead using it for incineration and thermal recycling by default.

As a result, data on the effective use of heat energy for FY 2017 as recorded by the Clean Association of TOKYO23 showed that total generated power came to 1,250 million kWh, electricity sold came to 760 million kWh, and supplied heat (fee-based) came to 470,000 gigajoule(GJ) , the income of electricity and heat sold came to 10.5 billion yen.

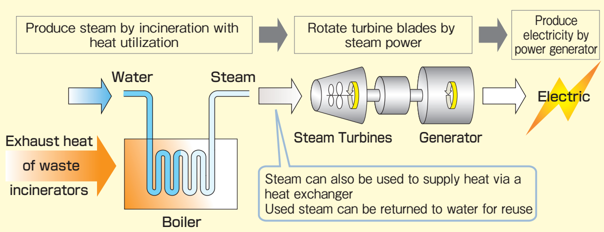
* For convenience of statistics, these figures were tabulated from March 2017 to February 2018. ** Includes sale amount of corresponding amount of electricity for new energies (environmental value)

Energy recovery techniques include incineration with heat utilization, incineration with power generation, cement material/ fuel, and refuse-derived solid fuel (RPF, RDF). Among these, incineration with power generation has recently been attracting attention again as an important source of energy.

Typical waste incineration systems in use today include stoker incinerators, fluidized-bed incinerators, and gasification melting furnaces. A stoker incinerator burns refuse while transporting it along a stoker. It consists of a drying section for evaporating moisture in the refuse, a combustion section for vigorously burning the refuse, and a post-combustion section to fully burn the refuse. A fluidized-bed incinerator, on the other hand, burns refuse by adding it to heated sand that swirls about much like boiling water by air forced in from below. A gasification melting furnace, meanwhile, decomposes refuse into gas at high temperatures and recovers the resulting pyrolysis gas and char for use as fuel to drive a steam turbine and generate electricity. The char is melted into slug at this time.

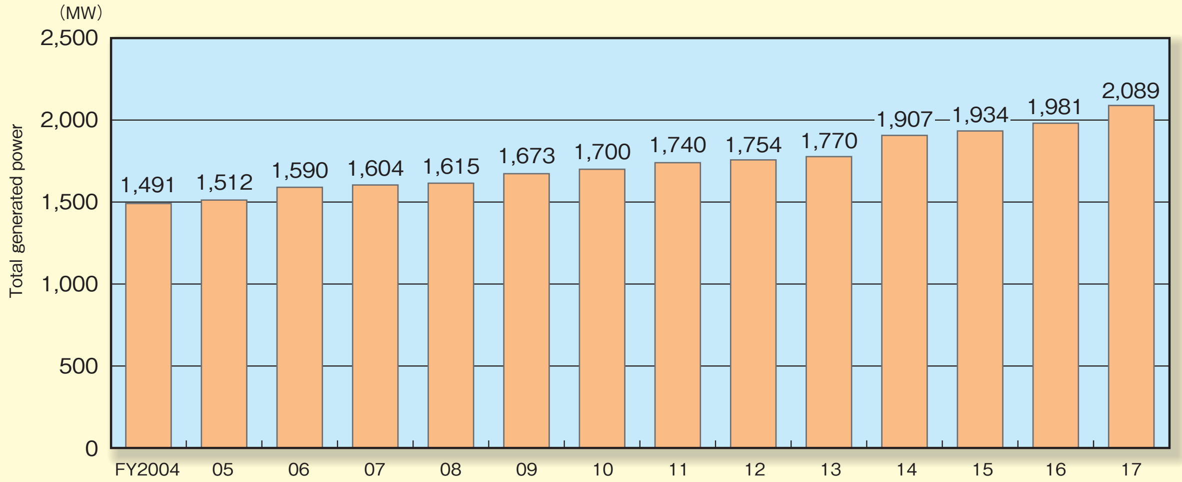
In any of the above systems, the heat and exhaust gas generated by incinerating refuse can be used as new sources of energy. Refuse can also be effectively used as a raw material for cement kilns thanks to its high calorific value and good combustibility. The demand for refuse paper and plastic fuel (RPF)—a mixture of plastic waste and used paper—has also been growing among pulp manufacturers as an alternative fuel to oil.

## Power generation and feed mechanism



# Current state of waste power generation (domestic waste)

## Change in total power generation capacity




Source : Ministry of the Environment, Survey on Disposal of General Waste, FY 2017

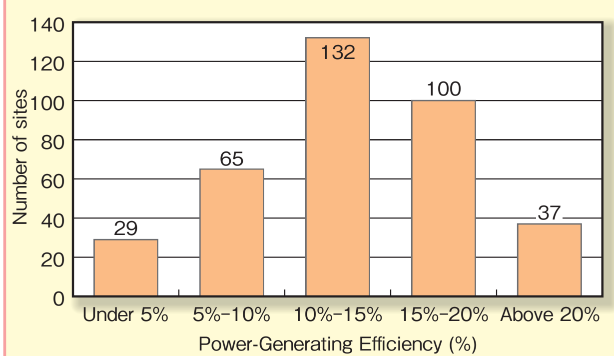
### Power generation capacity for more than 3 million households

The use of waste as a source of energy is increasing steadily. About two thirds of all waste incineration facilities (1,103) in Japan are now using residual heat in some form. For example, the hot water and steam generated by boilers at these facilities can be supplied to local health spas for general heating and for heating baths and swimming pools. Recently, however, the use of waste for generating electric power has been attracting attention, and as of FY 2017, the number of waste incineration sites equipped with power generating facilities came to 376 or about 34% of all waste incineration sites in Japan. The total power generating capacity of these sites was 2,089 MW. At 9,207 GWh in FY 2017, the total amount of power generated in this way could cover the power needs of about 3,100 thousand households (calculated on the basis of 247.8 kWh/month/household as estimated by the Federation of Electric Power Companies (FEPC), FY 2015).

However, the efficiency of waste power generation is still less than satisfactory : there are only 37 sites with a power generation efficiency of 20% or greater. Additionally, there are 240 small-scale sites with a power generating capacity less than 5,000 kW, or 64% of all sites. This figure reflects the need for improving the efficiency of waste power generation by consolidating facilities, upgrading equipment, deploying new incineration technology, etc.

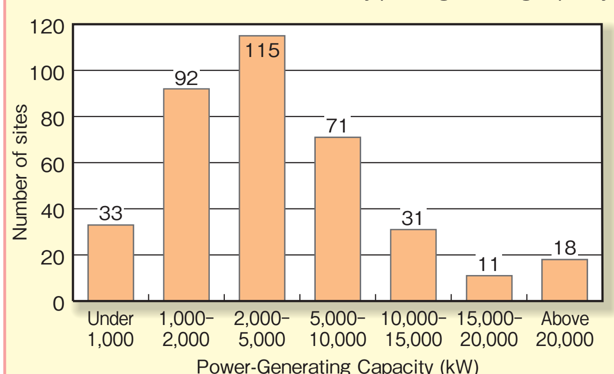
Against this background, the Japanese cabinet approved a "Waste Treatment Facility Development Plan" (FY 2018–22) in June 2016 with the aim of establishing waste treatment facilities that incorporate measures to prevent global warming and promote energy creation. This would include, for example, the promotion of large-scale facilities to secure a sufficient level of energy recovery. The plan states, in particular: "Based on the basic principle of cyclic use and disposal of garbage as specified in the Basic Act for the Promotion of the Recycling-Oriented Society and taking into account recent advances in thermal recovery technologies, thermal recovery from waste destined for incineration will be performed while securing a fixed thermal recovery rate or better to contribute to energy savings and energy creation in regional waste treatment systems." In conjunction with the above, the plan sets a specific target for improving the average power generation efficiency of garbage incineration facilities established in this period from 19% (FY2017 estimated value) to 21% (FY2022).

## Number of waste incineration sites by power-generating efficiency




Note ; For 363 (out of 376) power-generating sites responding to the survey.

## Number of waste incineration sites by power-generating capacity



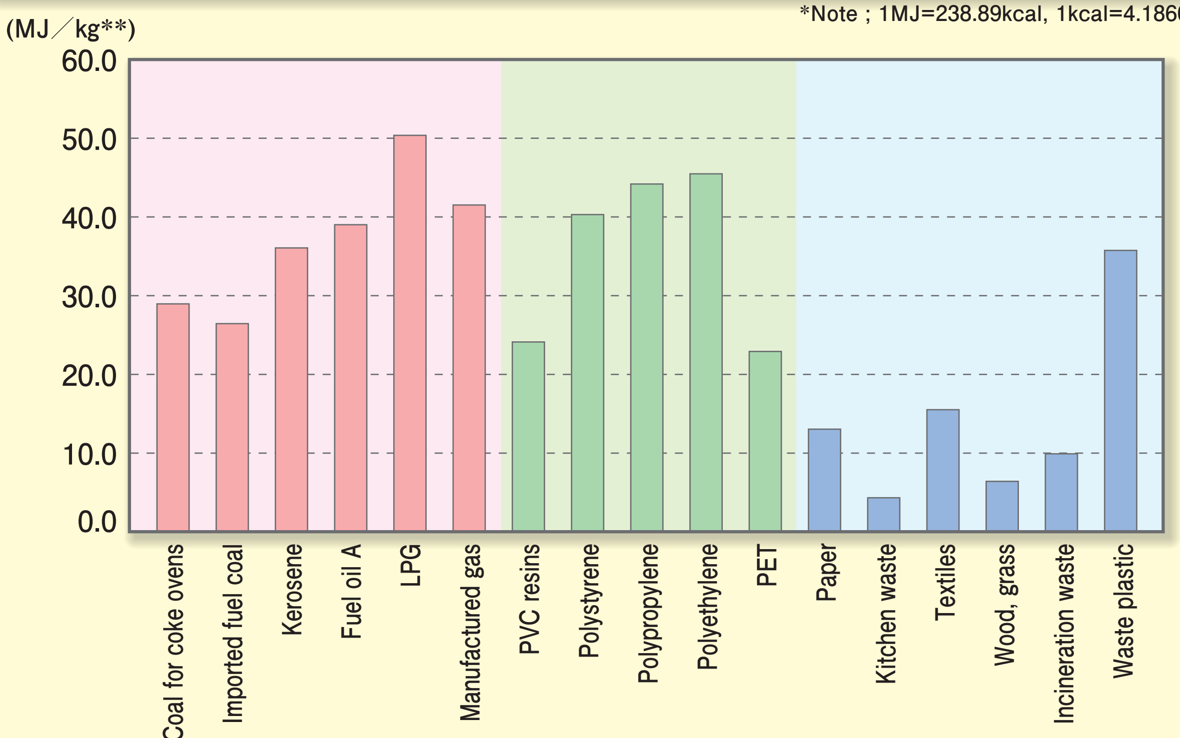

Note ; For 371 (out of 376) power-generating sites responding to the survey.
Source : Ministry of the Environment, Survey on Disposal of General Waste, FY 2017

# High calories provide a valuable energy resource

## Calorie comparison

| Group | Material | Unit | MJ | kcal | Source |
|---|---|---|---|---|---|
| Fuel | Coal for coke ovens | kg | 28.94 | 6,914 | Based on "Standard Calorific Value and Carbon Emission Factor," Agency for Natural Resources and Energy, August 2018 |
| | Imported fuel coal | kg | 25.97 | 6,203 | |
| | Kerosene | Liter | 36.49 | 8,718 | |
| | Fuel oil A | Liter | 38.90 | 9,293 | |
| | LPG | kg | 50.06 | 11,958 | |
| | Manufactured gas | $Nm^3$ | 41.21 | 9,844 | |
| Plastics | PVC resins | kg | 24.1 | 5,760 | "Ecological efficiency analysis on the processing of plastic containers and packaging" Plastic Waste Management Institute (PWMI), September 2006 |
| | Polystyrene | kg | 40.2 | 9,600 | |
| | Polypropylene | kg | 44.0 | 10,500 | |
| | Polyethylene | kg | 46.0 | 11,000 | |
| | PET | kg | 23.0 | 5,500 | |
| Waste (damp) | Paper | kg | 13.2 | 3,160 | Council for the best technology for plastic waste processing (Eds), Processing and Disposal of Plastic Waste, Nippo Co.,Ltd.1995 |
| | Kitchen waste | kg | 3.9 | 930 | |
| | Textiles | kg | 16.3 | 3,900 | |
| | Wood, grass | kg | 6.6 | 1,570 | |
| | Incineration waste | kg | 10.0 | 2,390 | |
| | Waste plastic | kg | 36.2 | 8,650 | "Ecological efficiency analysis on the processing of plastic containers and packaging", PWMI, September 2006 |

*Note ; 1MJ=238.89kcal, 1kcal=4.18605kJ




**Note : MJ/liter for kerosene and fuel oil A; MJ/$Nm^3$ for manufactured gas

## ◆ Calorie on a par with coal and oil

The waste collected at waste incineration facilities consists of a variety of materials. The graph above compares the calories of combustible waste substances, and you can see that plastic has twice the calories of paper waste and that some plastics with the highest calories, polyethylene, polypropylene and polystyrene, are on a par with coal and oil. Waste containing high calorie plastics is thus a valuable energy resource, and it is expected to be used more effectively in future.

# Waste incineration and pollutants

## Changes in the type and amount of dioxins emitted by waste processing facilities

| Year | Total quantity | Domestic waste incineration facilities | Industrial waste incineration facilities |
|---|---|---|---|
| 1997 | 6500 | 5000 | 1500 |
| 1999 | 2040 | 1350 | 690 |
| 2001 | 1345 | 812 | 533 |
| 2003 | 145 | 71 | 74 |
| 2005 | 135 | 62 | 73 |
| 2007 | 110 | 52 | 58 |
| 2009 | 68 | 36 | 33 |
| 2011 | 59 | 32 | 27 |
| 2013 | 49 | 30 | 19 |
| 2015 | 43 | 24 | 19 |
| 2017 | 37 | 22 | 15 |

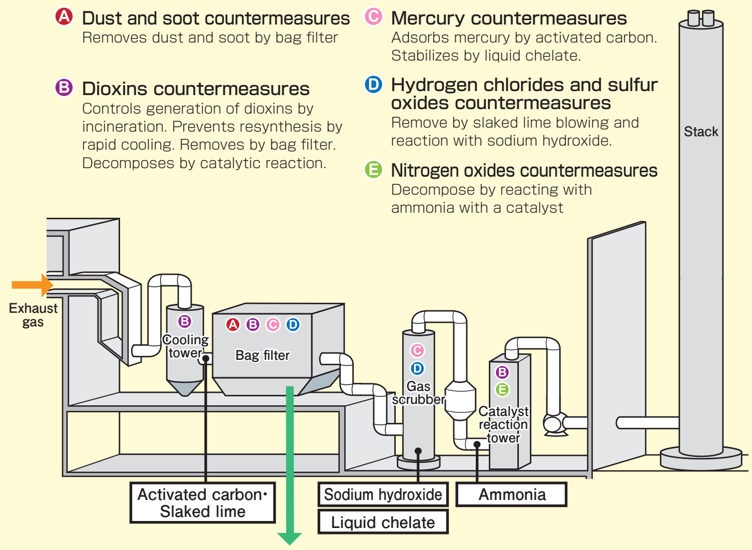
Unit : g-TEQ/year

## Dioxin concentration standards

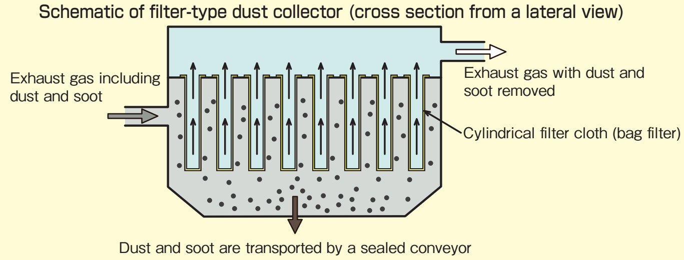
| Combustion chamber processing capacity | New facilities | Existing facilities |
|---|---|---|
| 4 tons/hour or more | 0.1ng-TEQ/m$^3$N | 1ng-TEQ／m$^3$N |
| 2-4tons/hour | 1ng-TEQ/m$^3$N | 5ng-TEQ／m$^3$N |
| Under 2 tons/hour | 5ng-TEQ/m$^3$N | 10ng-TEQ／m$^3$N |

Note : Dioxins concentration is converted to toxicity equivalent (TEQ. m$^3$N is at 0℃ and atmosphere of pressure.)
TEQ means the power of dioxin toxicity.
Source : Ministry of the Environment

## Control of exhaust from waste processing facilities
(Clean Authority of TOKYO)




Schematic of filter-type dust collector (cross section from a lateral view)




Source : Clean Authority of TOKYO, Waste Report "GOMIREPO 23 2019" (Partly revised by PWMI)

## ◆ Sharp decrease in dioxins

Incinerators used for burning municipal waste emit gases containing pollutants, but under Japan's strict standards, efforts have been made to suppress these emissions by upgrading incineration facilities and implementing new technologies. As a result, emission of pollutants has been brought well under the values specified by the relevant regulations and standards.

**(Dioxins)** ; Standards to limit the emissions of dioxins were introduced in 1997, and the Law Concerning Special Measures against Dioxins was introduced in January 2000, tightening controls on emissions from existing as well as new facilities. This law lays down standards concerning the tolerable daily intake of dioxins, environmental standards and regulations concerning exhaust gas and water emissions. Emission standards are provided for waste incinerators of a total incineration capacity of at least 50kg/hour or a total hearth area of at least 0.5m$^2$. In 2001, the Waste Management Law was amended to require that waste be incinerated using incinerators designed in accordance with the enforcement regulations for the Waste Management Law and by a method determined by the Minister of the Environment. According to the Ministry of the Environment, estimated total dioxin emissions from waste incineration facilities in 2017 was 37g (Domestic waste incineration facilities 22g, Domestic waste incineration facilities 15g), which represents a fall to almost 1/176 th of the amount emitted in 1997.

**(Particulate matter)** : Emissions of particulate matter are regulated in Japan by the Air Pollution Control Law. Some local governments also have their own stricter standards. Methods of eliminating of pollutants include physical collection systems such as bag filters and electrical dust collectors, effective against NOx, SOx, HCL, dust and soot; and chemical reaction systems using substances such as ammonia, caustic soda and calcium hydroxide.

# Reference ; Marine debris and marine plastic litter


Litter covering river bank (Tokyo)
Photo: All Japan River Litter Network http://kawagomi.jp


Litter washed ashore (Nagasaki)
Photo: Japan Environmental Action Network (JEAN) http://www.jean.jp

The problem of marine debris and marine plastic litter in particular is becoming a global problem. It has been taken up frequently in recent years at United Nations meetings and G7 Environment Ministers' Meetings, and in Japan, it is recognized as a problem that has to be dealt with as reflected by the Basic Environment Plan and other policy measures.

Plastic has come to be used in many products that surround us in daily life thanks to its superb functionality and properties, and it would be no exaggeration to say that plastic has become something that modern society cannot do without. On the other hand, plastic has low degradability in the natural environment, so once it is removed from the flow of resource recycling and released into the natural world, its collection and processing becomes difficult. Regions around the world have reported the washing ashore of plastic products and resulting loss of scenery.

As of 2010, about 4,800 kt to 12,700 kt of plastic has leaked into the ocean, originating for the most part from China and Southeast Asia where rapid economic growth has been taking place. It has been scientifically inferred that much of this leakage comes particularly from rivers. There is therefore a need in these regions for infrastructure projects targeting waste processing and for greater public awareness.

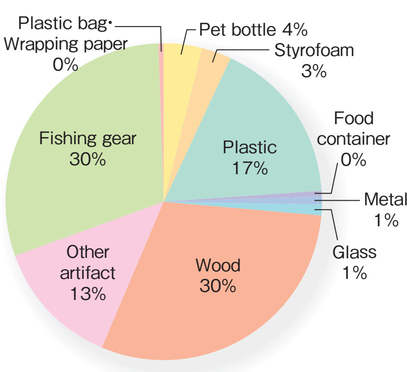
In addition, research is progressing on the impact on ecosystems of microplastics, which are small plastic pieces less than five millimeters long formed from marine plastic litter under the influence of ultraviolet rays, ocean currents, etc. and of microbeads, which are extremely small micro-scale balls used in facial cleansers, abrasives, etc.

Movements toward solving the marine plastic litter problem are taking off on a global basis. Following the agreement reached on a “G7 Action Plan to Combat Marine Litter” at the Schloss Elmau Summit in 2015, the marine plastic litter problem was discussed at many international conferences and meetings such as the G7 2016 Ise-Shima Summit and the 2017 United Nations Ocean Conference, while the “G7 Ocean Plastics Charter” that included numerical targets was approved by Canada and various EU countries at the G7 2018 Charlevoix Summit. In addition, G20 leaders at the 2019 G20 Osaka Summit declared that measures for dealing with marine debris and marine plastic litter and microplastics in particular should be taken by all countries both nationally and internationally under cooperation with all stakeholders, that each country should resolve to take appropriate and swift national actions to control and significantly reduce leakage of debris into the oceans, and that the “Osaka Blue Ocean Vision” (that aims to reduce additional pollution by marine plastic litter to zero by 2050 through improved waste management and innovative solutions while recognizing the important role of plastic in society) should be shared as a global vision as anticipated by existing actions already taken by some countries.

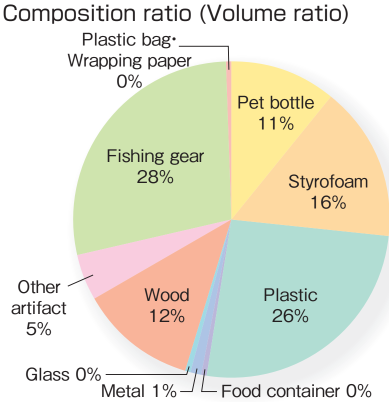
## Configuration of artificial material washed ashore along Japan’s coast

| Items | Pet bottle | Styrofoam | Plastic | Food container | Metal | Glass | Wood | Other artifact | Fishing gear | Plastic bag・Wrapping paper | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Weight (kg) | 77.0 | 65.4 | 323.9 | 4.9 | 19.6 | 25.7 | 575.9 | 249.8 | 580.8 | 4.7 | 1,927.6 |
| Volume (ℓ) | 1,333 | 1,982 | 3,143 | 53 | 141 | 37 | 1,517 | 564 | 3,428 | 27 | 12,223 |
| Number | 1,181 | 121 | 707 | 203 | 200 | 139 | 363 | 213 | 1,062 | 19 | 4,208 |

Composition ratio (Weight ratio)




Composition ratio (Volume ratio)




Survey target: 10 spots along the Japan's coast (Hokkaido 3, Yamagata 1, Wakayama 1, Oita 1, Nagasaki 2, Kagoshima 2)
Survey method: Survey a 50 m (meters) stretch of beach
Measurement method: Volume figures take a 90 L (liters) garbage bag as standard
Survey target of size of artificial material: Not less than 2.5cm (centimeters)

Source: Ministry of the Environment, FY 2016 Report on comprehensive Study on Measures against Marine Debris Washed Ashore (complied by PWMI)

# 5 Life Cycle Assessment

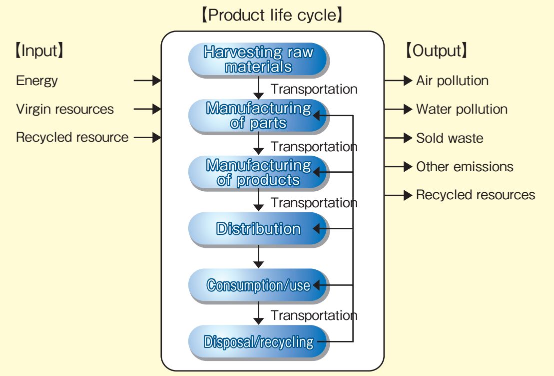
## What is life cycle assessment

Life cycle assessment (LCA) is a technique for scientifically, quantitatively, and qualitatively assessing the overall environmental burden of a product across all related processes (life cycle) from the gathering of resources to the manufacture of raw materials, processing of those materials, assembly of components, product use, and disposal.

LCA is performed in four stages: (1) establishment of goals and scope of survey (2) calculation of environment data ($CO_2$, energy consumption, etc.) at each step of the product's life cycle, (3) environmental impact assessment (inventory analysis) for various items (resource reduction effect, etc.), and (4) measurement of impact on the environment. These four LCA stages can be used to consider policies on reducing environmental load in a stepwise manner.

In addition to tangible products, LCA can also be applied to services, systems, and other intangible items. Furthermore, the application of LCA to even organizations has recently come to be studied.

### Life cycle and environmental burden




Source : Diagram of the cycle and environmental burden from the Ministry of the Environment

### History of LCA

LCA is said to have begun in 1969 with research conducted by a beverage company in the United States on techniques for assessing the environmental load of returnable bottles and beverage cans. In Japan, full-scale LCA activities began with the founding of the Life Cycle Assessment Society of Japan in 1995, and the establishment of LCA techniques and the construction, expansion, and spread of LCA databases were promoted by two LCA national projects overseen by the Ministry of Economy, Trade and Industry (METI). Then, in 2004, The Institute of Life Cycle Assessment, Japan was founded, and collaborative relationships in LCA from an academic viewpoint have since been formed and strengthened as a result.

### LCA mechanism and approach

LCA is a technique for scientifically, quantitatively, and qualitatively assessing the overall environmental load of a product (or service, system, etc.) across all related processes (life cycle), from the gathering of resources for product manufacture all the way to product disposal. Taking a plastic product for example, we consider that crude oil—the ultimate source of such a product—will be extracted from the Earth, transported to a port via a pipeline, and carried to Japan on a tanker. Then, once in Japan, this crude oil will be turned into a variety of petroleum products at oil-company rectification plants, and among these products, naphtha will be turned into polyethylene (PE), polypropylene (PP), polystyrene (PS) and other types of plastics through cracking and polymerization. Such plastics will serve as the raw material for manufacturing the plastic product. Next, the manufactured plastic product will be transported to market, used by a consumer, and disposed of as waste when it no longer serves its purpose. Finally, the disposed plastic product will be recycled, incinerated, or buried in a landfill. This is the life cycle of a plastic product, which can be represented by the flow chart shown below.

**Extraction of crude oil → (Transport) → Refining of oil → (Transport) → Manufacture of plastic raw material (pellets) → (Transport) → Manufacture of plastic product (processing of plastic raw material) → (Transport) → Use and disposal of plastic product → (Transport) → Final disposal (recycling, incineration, or landfill)**

### LCA and LCI analysis

METI and New Energy and Industrial Technology Development Organization (NEDO) have constructed an LCA database and released the results of this work. At the same time, diverse types of data have come to be provided by various organizations and research institutions, and PWMI itself has released the results of a number of inventory surveys related to plastics. These various types of data can be used to perform life cycle inventory (LCI) analysis.

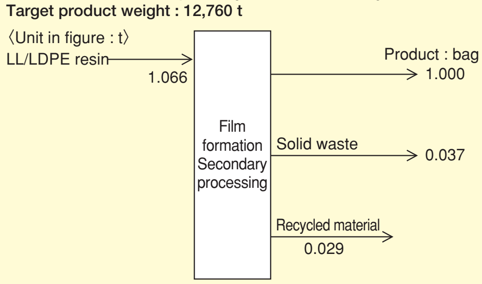
Unit : resin t

| | Process energy (MJ) | Resource energy (MJ) | $CO_2$ (kg-$CO_2$) | SOx (kg) | NOx (kg) |
|---|---|---|---|---|---|
| LDPE | 26,132 | 46,103 | 1,518 | 3.286 | 3.321 |
| HDPE | 22,324 | 46,194 | 1,326 | 3.118 | 3.015 |
| PP | 25,091 | 45,817 | 1,483 | 3.245 | 3.220 |
| PS | 28,188 | 45,626 | 1,920 | 3.330 | 3.577 |
| EPS | 29,957 | 45,537 | 1,939 | 3.441 | 3.627 |
| PVC | 24,790 | 21,273 | 1,449 | 2.174 | 2.432 |
| BPET | 28,120 | 34,772 | 1,578 | 3.549 | 3.023 |
| PMMA | 60,902 | 49,372 | 4,073 | 4.718 | 5.618 |

Note : The figures give for resource energy are the thermal values for the fossil resources used as raw materials

(PWMI : LCI Data Survey Report on Petrochemical Products, March 2009).

**Product name : LDPE bags manufactured by inflation**
**Name of public information sheet: Same as above**
**Data properties : Weighted average values based on 2009 or FY 2009 results of member companies of the Japan Polyolefin Film Industry Trade Association**
**Target product weight : 12,760 t**




**Consumed energy/resources** Unit: MJ/product t

| | | |
|---|---|---|
| Resource energy (originating in resin raw material and additives) | | 49,151 |
| Process energy (originating in resin raw material and additives) | | 27,861 |
| Process energy (of that process) | Manufacturing process | 7,417 |
| | Recycling process | 0 |
| | Common services | 279 |
| Total | | 84,709 |

(PWMI : Inventory Data Survey Report on Resin Processing, December 2011).

For example, the amount of energy/resources used in the manufacturing of one ton of bags by inflation molding using LDPE can be calculated as follows.

(1) Resource energy (originating in resin raw material and additives) 46,103 MJ/t × 1.066 (basic unit) = 49,151 MJ/t
(2) Process energy (originating in resin raw material and additives) 26,132 MJ/t × 1.066 (basic unit) = 27,861 MJ/t
(3) Process energy (of that process) = 7,696 MJ/t
(1) + (2) + (3) = 84,709 MJ/t

In general, (1) represents the total amount of heat generated by LDPE resin (pellets), (2) the amount of process-related energy from the gathering of resin raw material (crude oil) to the refining of naphtha and manufacture of LDPE resin (pellets), and (3) the amount of energy used for turning resin (LDPE) pellets into a product (manufacture of bags by inflation molding) at the bag-making company.

# Rethinking recycling with LCA

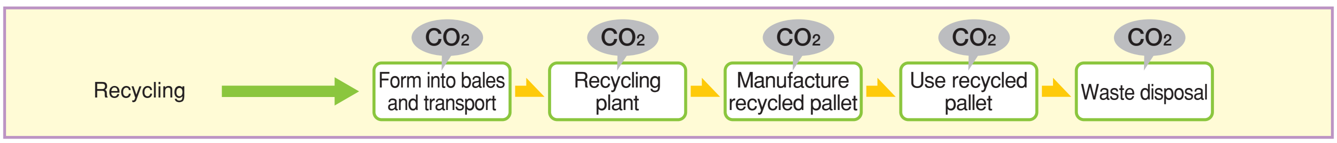
## Evaluating recycling techniques

How, then, should recycling techniques for plastic products be compared and evaluated?

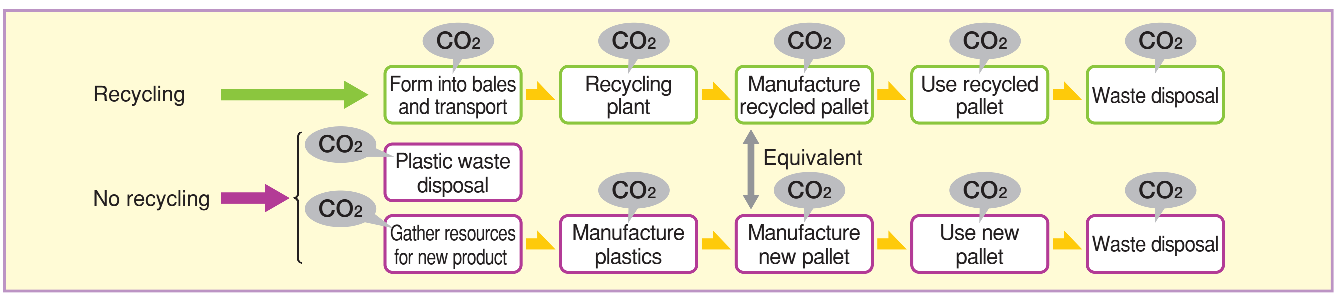
To evaluate recycling techniques, some type of criterion must first be created. For example, it is meaningless to compare the making of buckets by material recycling and the making of clothing by chemical recycling to determine which is the better recycling technique. Buckets and clothing are prepared by different processes and are used in different ways, and are thus not easy to compare. In other words, recycling techniques cannot be evaluated on the basis of the product resulting from the recycling process. On the other hand, recycling by some technique can be compared with doing no recycling at all to determine which approach reduces environmental load. For example, if 1 t of $CO_2$ emissions results from disposing waste without recycling, and if $CO_2$ emissions can be reduced to 0.5 t and 0.3 t by recycling technique A and recycling technique B, respectively, recycling technique B can be said to be the better approach.

## Using LCA to determine whether to recycle

LCA is a useful technique for calculating environmental load for the cases of recycling and no recycling. This means calculating environmental load for individual processes from the disposal of a product as plastic waste to recycling, use of the recycled product, and disposal of the product for a second time. We give the following example.



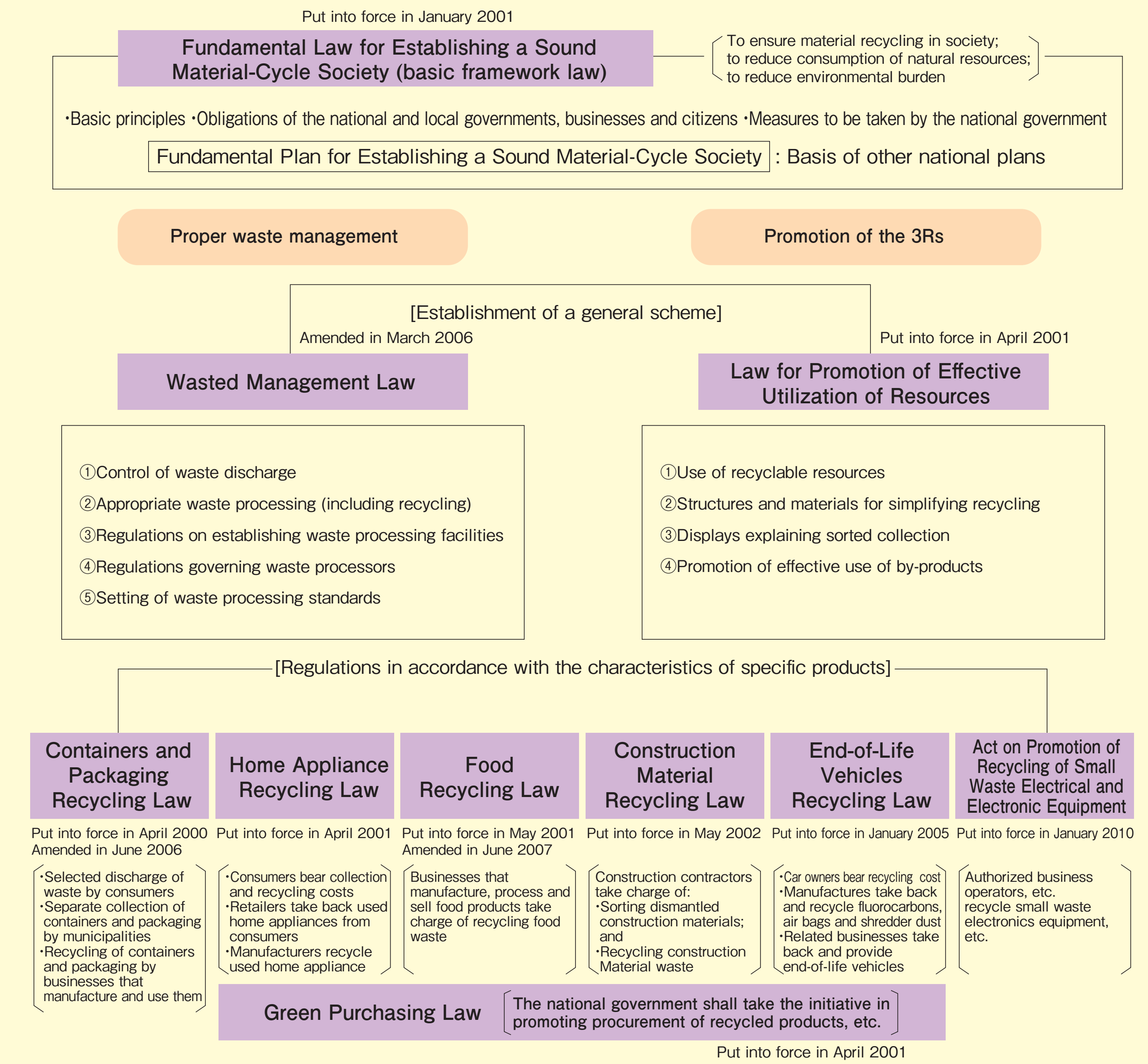

Each process results in the generation of $CO_2$ emissions, so calculating the total of these amounts gives the environmental load for recycling in terms of $CO_2$. What then do we do for the case of “no recycling?” An easy mistake to make here would be to consider the case of “no recycling” to consist only of the “waste disposal” step. If so, the amount of $CO_2$ generated for this case would be extremely small and the “no recycling” option would end up being the most “eco.” Is this really the case? In actuality, there is a huge error in this assumption. Manufacturing a recycled product means that there is no need to manufacture a new product of the same kind. In other words, disposing a product as waste without recycling means that a new product having the same function as that product made by material recycling must be manufactured.




That is to say, if choosing the “no recycling” option, the amount of $CO_2$ generated must be calculated not only for the waste-disposal process but also for the gathering of resources (crude oil) for manufacturing the new product, the refining of naphtha, the manufacturing of resin raw material (pellets), the processing of those pellets, the manufacturing of the pallet, use of the pallet, and waste disposal of the pallet. The total amount of generated $CO_2$ must be calculated in this way to determine which of “recycling” or “no recycling” is “eco.”

# 6 Legislation and arrangement for the creation of a recycling-oriented society

## ● Basic law and recycling laws




Source : Ministry of Economy, Trade and Industry, Towards a 3R-Oriented, Sustainable Society/ Legislation and Trends 2018

### ◆ Clarification of the roles of central and local government, businesses and consumers

The creation of a recycling-oriented society is the biggest challenge facing Japan in the 21st century. A recycling oriented society is defined by the Fundamental Law for Establishing a Sound Material-Cycle Society as a society that limits consumption of natural resources and minimizes the burden on the environment through ① curbing waste emissions, ② recycling resources and ③ disposing of waste appropriately.

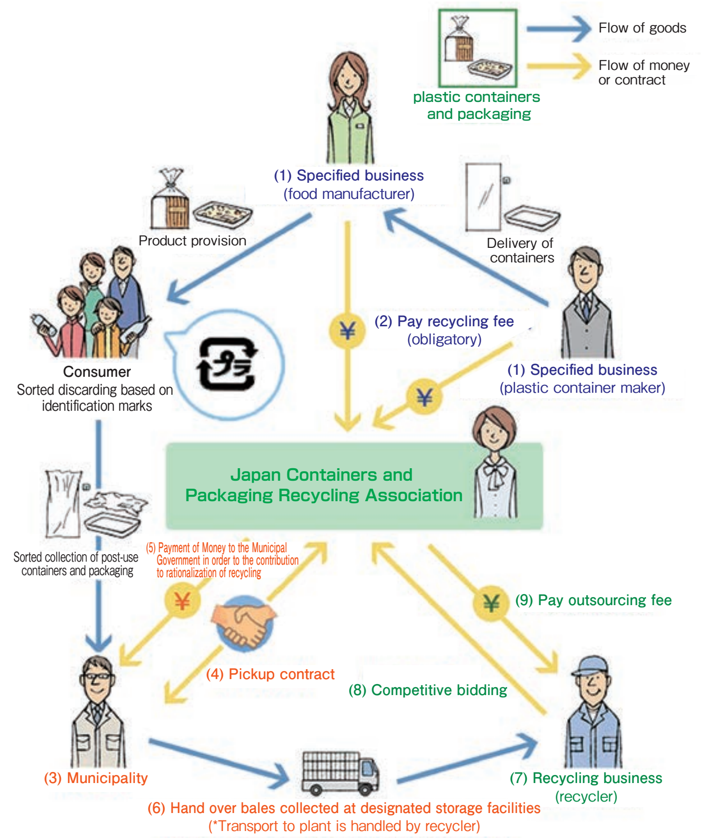
Declaring 2000 as the start of the development of a recycling oriented society, the government enacted six recycling-related laws based around the Fundamental Law for Establishing a Sound Material-Cycle Society. This basic law lays down the basic principles for the formation of a recycling-oriented society, delineates the division of roles among the government, municipalities, businesses and consumers, and specifies the measures to be taken by central government.

Building on the framework laid down by this fundamental law, a number of individual recycling laws such as the Law for Promotion of Effective Utilization of Resources, were enacted, amended and strengthened. These laws provide the concrete framework in each field for effectively promoting the three Rs, i.e. reduction and reuse as well as recycling of the waste generated by society.

In 2018, the Japanese cabinet approved the "4th Fundamental Plan for Establishing a Sound Material-Cycle Society" based on reviews performed every five years. The pillars of this plan are "Regional Circular and Ecological Sphere," "Resource Circulation Throughout the Entire Lifecycle," "Proper Waste Management and Environmental Restoration," "Disaster Waste Management Systems," and "International Resource Circulation."

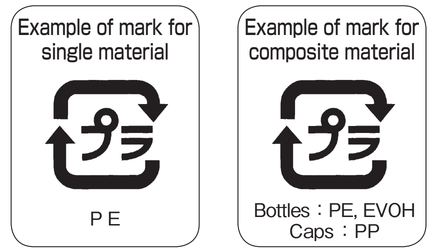
# Containers and Packaging Recycling Law and identification marks

## Recycling flow through a designated corporation (plastic containers and packaging)

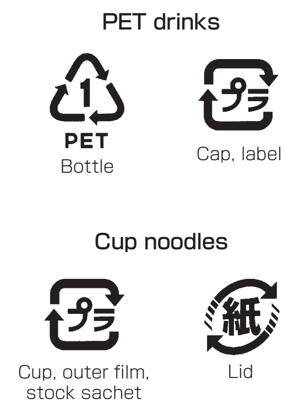



Source: Website of Japan Containers and Packaging Recycling Association

Materials are labeled using symbols defined under JIS K 6899-1 2000 (ISO 1043-1 2001)




### General product labeling




Source : "Container and Packaging Recycling FY2001" The Ministry of Economy, Trade and Industry

## Identification marks and material labeling to assist sorted collection

The Law for Promotion of Sorted Collection and Recycling of Containers and Packaging, known as the Containers and Packaging Recycling Law for short, aims to promote recycling and reduce the amount of container and packaging waste produced by households, which accounts for 60% of its volume and 20-30% of its weight.

Under this law, consumers, municipalities and businesses are each required to play their part in reducing emissions and recycling waste. Changes from the amendment in 2006 include promotion of emission reductions, high quality sorted collections (contributing funds to municipalities) and altering the PET bottle category (to include containers such as noodle broth bottles).

**● Role of consumers:**

Consumers must reduce their waste emissions through making reasonable choices of containers and packaging and sort their container and packaging waste for collection.

**● Role of businesses:**

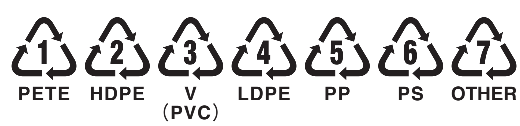
Businesses that manufacture or use products covered by the law are required to recycle those products. Businesses may also contract out recycling work for a recycling fee to the Japan Containers and Packaging Recycling Association.

**● Role of municipalities:**

Municipalities must establish sorted collection plans and take the necessary measures to collect container and packaging waste separately in their areas.

In order to assist sorted collection, containers and packaging are also required by law to be labeled with identification marks. Because of the wide variety of materials from which plastic products are made, it is recommended that such products also bear a "material mark" as well as an identification mark.

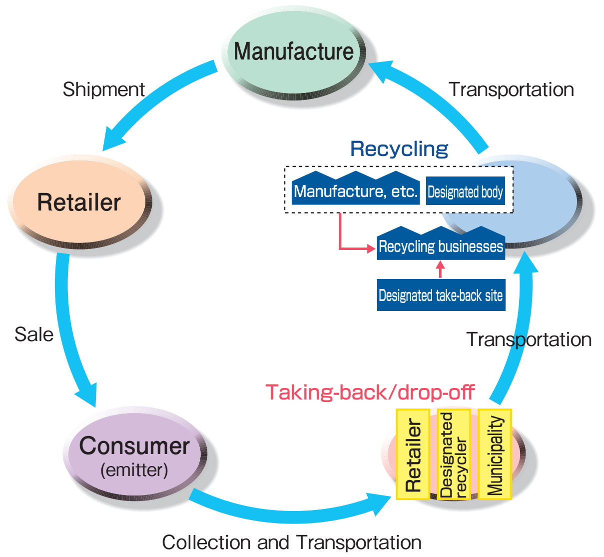
As well as the identification and material marks specified by the Containers and Packaging Recycling Law, the symbols below are sometimes seen. They are the material identification SPI codes used on containers in the USA.(*)



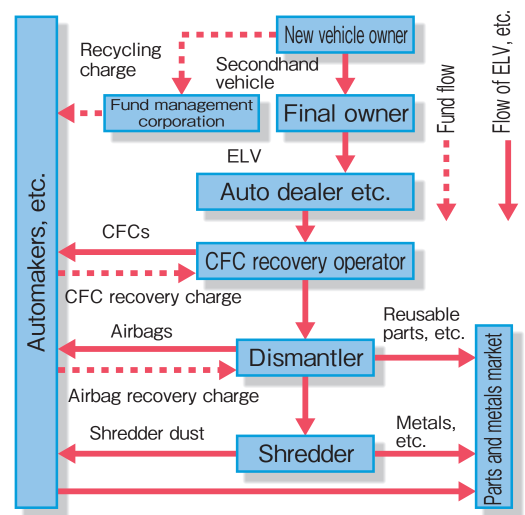

(*) Note that this display differs from the Japanese system and should be used with that in mind.

# Home Appliance Recycling Law and End-of-Life Vehicles Recycling Law

## Home appliance recycling system




## Automobile recycling system




### ◆ TVs (cathode-ray tube, liquid crystal and plasma), refrigerators/freezers, washing machines/clothes dryers and air conditioners covered

The Law for Recycling of Specified Kinds of Home Appliances, known as the Home Appliance Recycling Law for short, covsers the recycling of home appliances (TVs,refrigerators, washing machines and air conditioners), and since April 2009 it also covers LCD and plasma TVs and clothes dryers. It imposes the following duties on manufactures, importers, retailers, municipalities and consumers.

● **Manufactures and importers :**

Manufactures and importers are required to take back, if requested, products that they manufactured or imported and that are covered by the law, and to provide an appropriate location for this purpose. They must also recycle the waste from these products.

● **Retailers :**

Retailers must under certain conditions and if so requested take back products covered by the law. These products are then passed on to the manufacturer or importer (or designated recycler).

● **Municipality :**

Municipalities must drop off collected products covered by the law to the manufacturer or importer (or designated recycler) or recycle such products themselves.

● **Consumers :**

Consumers must take waste products back to the retailer and pay a charge for collection, transportation and recycling.

### ◆ CFCs, shredded waste and airbags covered

The End-of-life Vehicles Recycling Law requires that manufacturers and others recover, recycle and appropriately dispose of the CFCs in car air conditioners, shredder dust from scrapped cars and airbags from end-of-life vehicles (ELVs).

● **Manufactures and importers :**

Businesses must take back and recycle the CFCs, airbags and shredder dust from ELVs. (CFCs must be broken down.)

● **Handling agents :**

Handling agents take ELVs back from vehicle owners and pass them on to CFC recovery operators and dismantles for recycling.

● **CFC recovery operators :**

CFC recovery operators are required to appropriately recover CFCs and pass them on to automakers. (A recovery charge may be made for this service.)

● **Dismantlers :**

Dismantlers must appropriately recycle and process ELVs and pass on airbags to automakers. (A recovery charge may be made for this service.)

● **Shredders :**

Shredders must appropriately recycle and process dismantled vehicles (ELV shells) and pass on the shredder dust to automakers.

● **Owners :**

Owners must hand over used vehicles to handling agents and pay a recycling fee.

# ■ ABOUT PWMI (Business Overview)

## History :

Originally founded in December 1971 as the Plastic Management Research Association, the Plastic Waste Management Institute (PWMI) received its current name in July of the following year as operations expanded. For the last 40 years or so, PWMI has endeavored to research and develop technology for the optimal processing and effective use of plastic waste and to publicize its findings.

In addition, PWMI has changed into a general incorporated association as a result of Laws Related to the Reform of the Public-Interest Corporations System (enacted in December 2008). As a result of this change, PWMI's objectives were newly established in April 2013 as "surveying and researching the recycling of plastic waste and contributing to a reduction in environmental load by the total recycling of plastic, and helping plastic-related industries to expand their business soundly and contributing to the creation of a society capable of sustainable growth."

## Business Content :

(1) Survey and research the generation, recycling, and disposal of plastic waste and promote the appropriate use of plastic waste through various means including techniques for evaluating environmental load

(2) Support the education and study of the recycling of plastic and plastic waste and engage in related public relations activities

(3) Interface and collaborate with domestic and foreign institutions in the plastic and plastic-waste industries

## Activities :

The three core activities of PWMI are summarized below.

(1) Provision of life cycle assessment (LCA) base data and LCA evaluation of recycling & recovery (R&R) technologies

PWMI provides scientific and high-reliability data for widespread use by related industries and general citizens for application to carbon footprint systems, etc. It also works to solve technical issues so that the effective use of plastic waste can be evaluated by LCA.

(2) Preparation of the Flowchart of Plastic Products, Plastic Waste and Resource Recovery and ongoing improvements to its accuracy

PWMI strives to obtain a clear understanding of the entire lifecycle of plastic from its production stage to its disposal and R&R and to prepare and provide a highly accurate flowchart of this process.

(3) Support of environmental education

PWMI continues to hold instructor training courses and on-site classes and works to raise the level of consciousness in society regarding the usefulness of plastic. In addition to holding on-site classes on plastic R&R at primary and middle schools especially in Japan's Kanto region, PWMI will honor as much as possible requests for instructor training courses in line with new teaching guidelines and for lectures at universities specializing in environmental science.


Plastic Waste Management Institute

Kayabacho Square Bldg. 9F
3-7-6 Nihonbashi-Kayabacho, Chuo-ku, Tokyo 103-0025, Japan
Tel: +81-3-6855-9175～9177
Fax: +81-3-5643-8447
Web site: http://www.pwmi.or.jp

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