An Introduction to Plastic Recycling

Plastic Waste Management Institute

Introduction

The problem of waste is now a global one, and one that must be addressed in order to solve the world's resource and energy problems. Plastics are made from limited resources such as petroleum. Like other resources, therefore, large advances are being made in the development of technologies to recycle plastic waste. Methods of mechanical recycling to make plastic products and feedstock recycling to use as a raw material in the chemical industry have grown widespread, and awareness has also grown recently of the importance of energy recovery as a means of using plastics as an energy source to save petroleum resources.

With the aim of achieving sustainable development, Japan is pursuing measures to create a recycling-oriented society. Since 2000, a number of recycling-related laws, such as the Basic Law for Promoting the Creation of a Recycling-oriented Society, have been enacted and amended, and the legislative framework for recycling was largely completed with the enactment of the Automobile Recycling Law in 2002. Based on this framework, action to promote the "three Rs"—i.e. reduction and reuse as well as recycling of waste—has been strengthened to ensure more effective use of resources.

Meanwhile, in order to reduce the impact of incineration of waste on the environment, controls to curb dioxin emissions were tightened in December 2002. This has resulted in the decommissioning of existing incineration facilities and introduction of new facilities to comply with tighter standards. The trend toward use of waste as a new energy source, through incineration to generate electricity in order to combat global warming rather than simply burning or burying, is thus gathering pace.

In this publication, we consider the question of waste from a number of different angles, and look at the current state of processing and recycling of plastic waste—such an important element of the waste equation—based on up-to-data. Waste and environmental issues are tied up with all sorts of factors, and a scientific, multifaceted approach is essential to their solution. The reader, we hope, will find that *An Introduction to Plastic Recycling* sheds light on waste issues, and in particular on the issue of plastic waste.

Plastic Waste Management Institute
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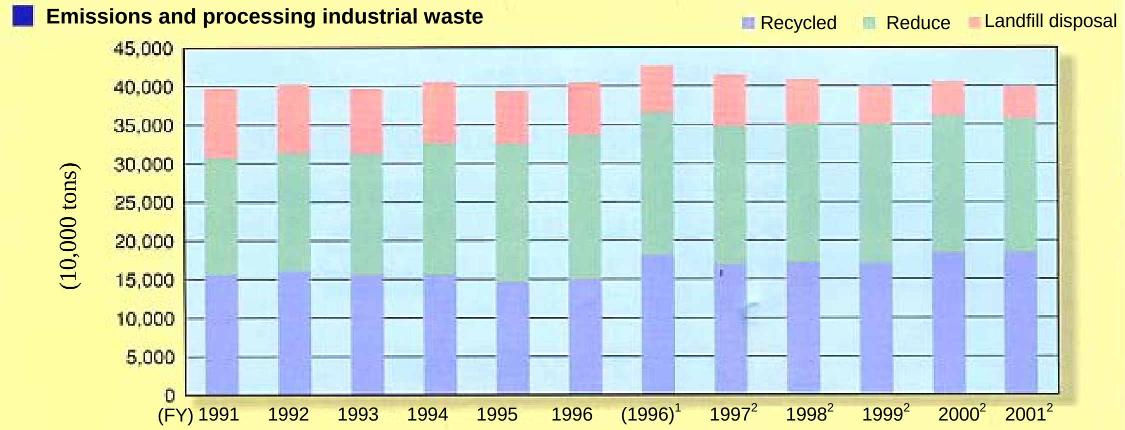
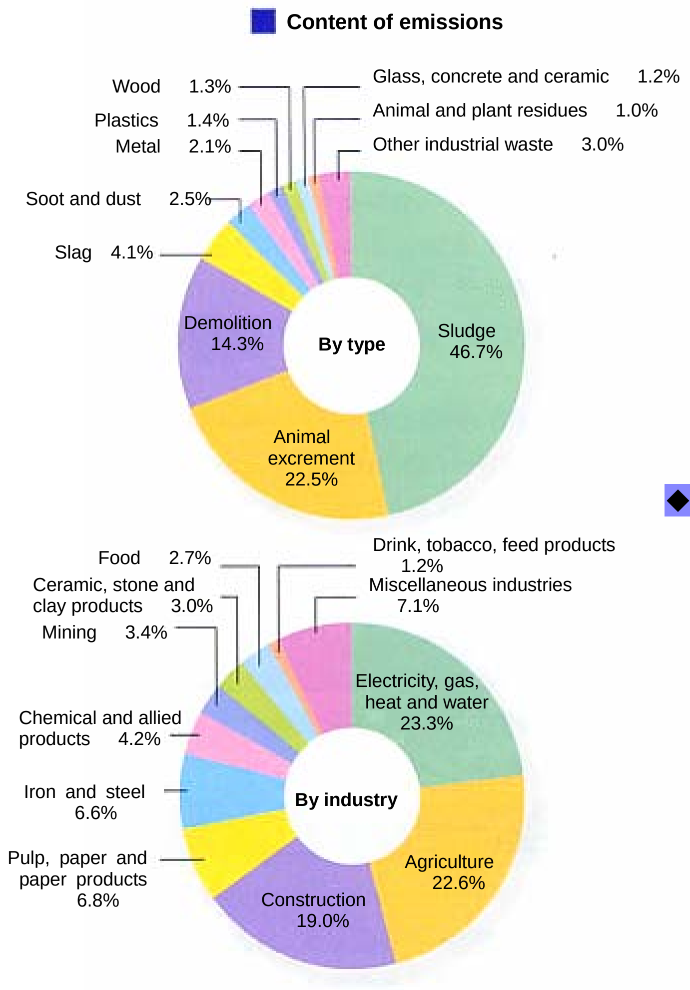
1 Waste emissions

Emissions of industrial waste level off

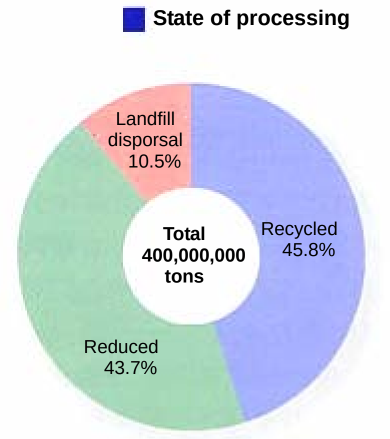


1. Figures for FY1996 are from “Targets for Reduction of Volume of Waste” (adopted by the government on September 28, 1999).
2. Emissions for FY1996 onward are calculated bv the same method as 1.

Source: Ministry of the Environment, *Emissions and Processing of Industrial Waste, FY2001*



Source: Ministry of the Environment, *Emissions and Processing of Industrial Waste, FY2001*



◆ Approximately 10% disposed of by landfill

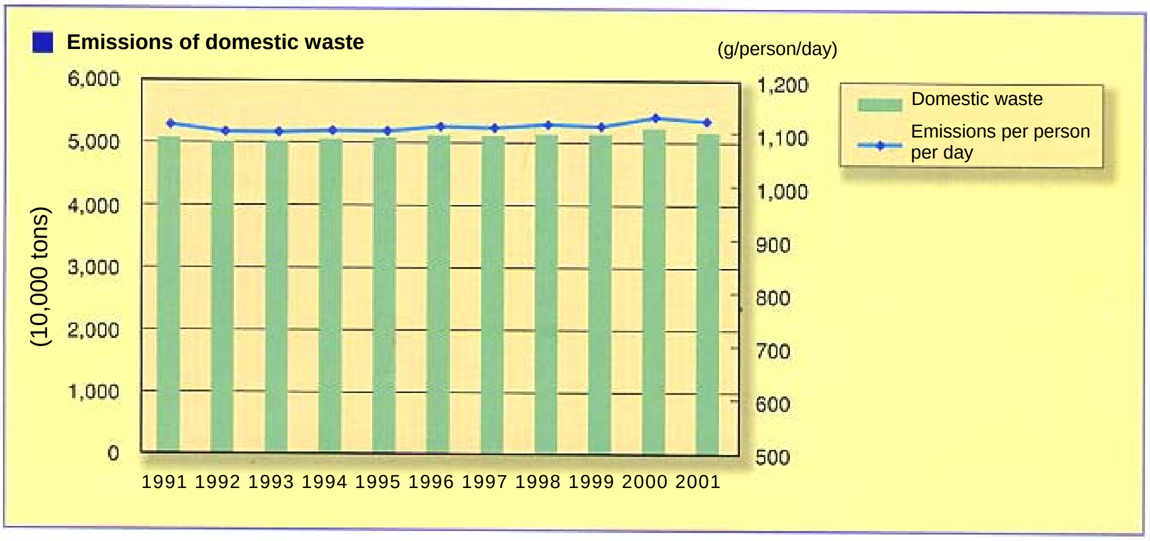
Industrial waste is waste emitted as a result of business activities at factories and other business-related establishments. Japan produces approximately 400 million tons of industrial waste per year, and this figure has remained largely unchanged for the past 10 years.

A breakdown reveals almost half the total to be sludge, followed by animal excrement and demolition waste. These three categories account for over 80% of the total.

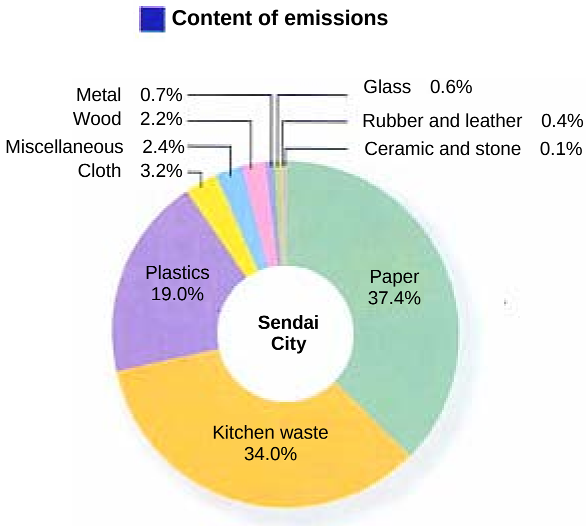
Broken down by industry, three industries produce around 60% of the total. These are the urban infrastructure industry (i.e. electricity, gas, heat service and water utilities), agricultural industry and construction industry.

While the proportion of waste processed by recycling and reducing is rising, 10% is also disposed of by landfilling. As a result, the national average remaining capacity of landfill sites is only around 4.3 years, and the situation is particularly severe in major urban areas; in the metropolitan area, for example, remaining capacity is just 1.1 years.

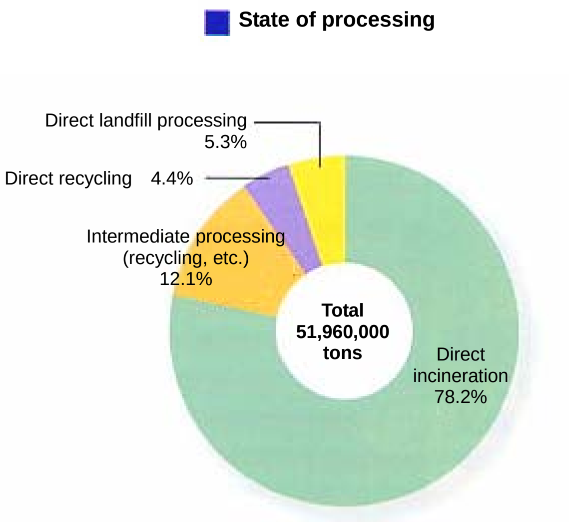
Nearly 50 million tons of emission of domestic waste



Source: Ministry of the Environment, *Emissions and Processing of Domestic waste, FY2001*



Source: Sendai City Environmental Bureau, *Annual Inspection Report, FY2001, No. 27* (unit: Under wet condition).



Source: Ministry of the Environment, *Emission and Processing of Domestic Waste, FY2001*

◆ Majority disposed of by incineration

Domestic waste consists mainly of waste emitted by households. However, it also includes some business waste produced by restaurants and other business establishments. Processing is the responsibility of the local municipality.

Japan produces around 50 million tons of domestic waste per year, and this figure has remained largely unchanged over the past 10 years. Emissions per person have also stayed at around 1.1kg per day, and there has been no major change.

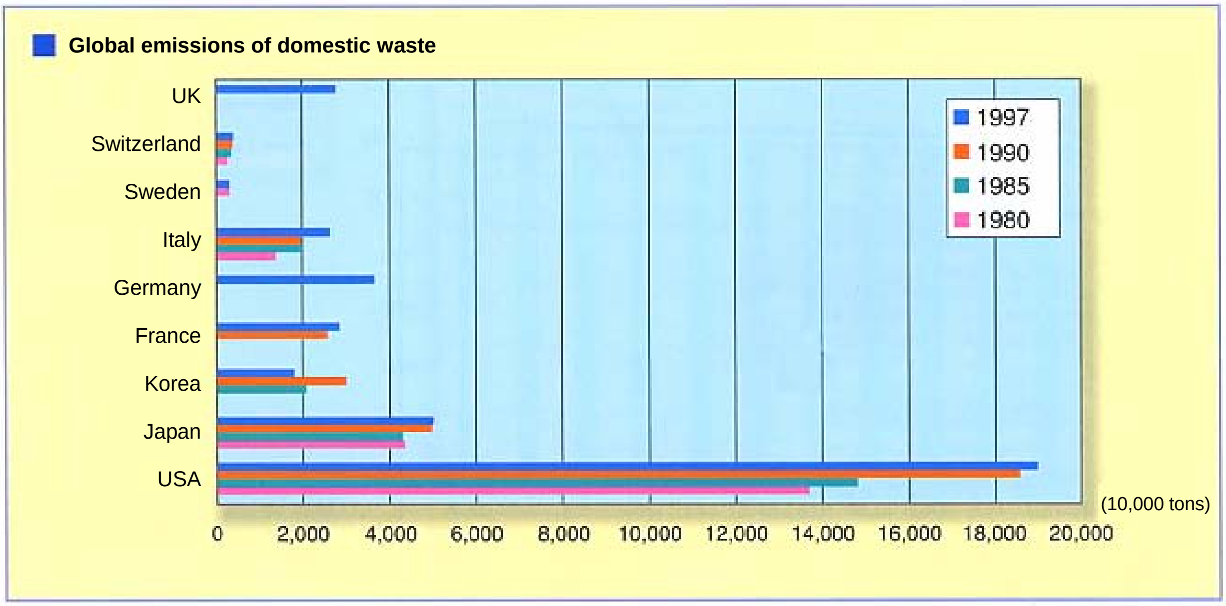
A breakdown shows most domestic waste to be made up of paper, kitchen and plastic waste.

The majority of domestic waste is disposed of by incineration. While remaining landfill site capacity is in short supply (a national average of 12.5 years), the national average has risen 4.3 years compared with 10 years ago due to increased recycling activities.

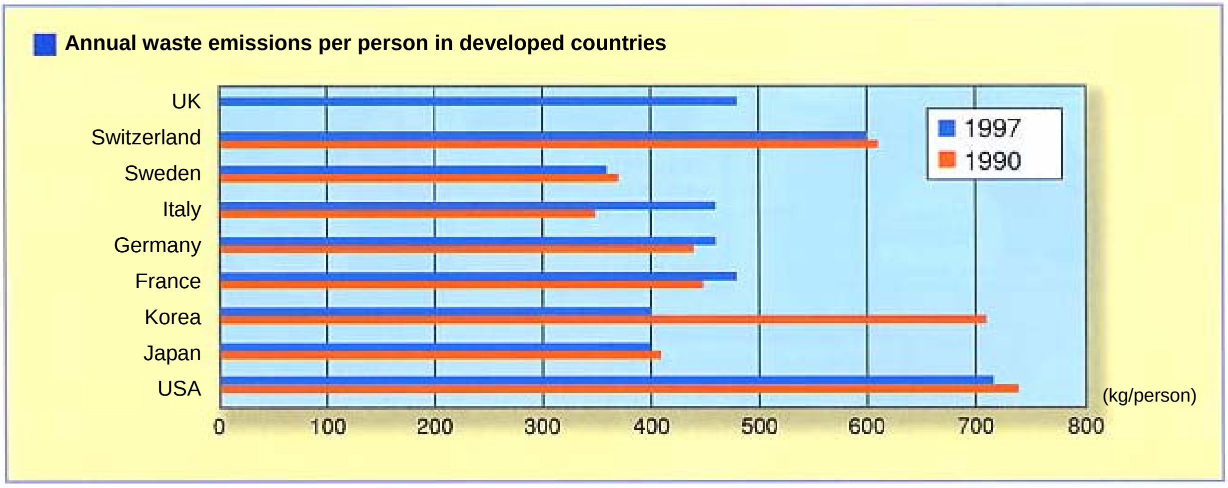
Securing landfill space is a major problem considering Japan's small size. It is therefore important to follow the three Rs (reduce, reuse and recycle) in order to reduce the quantity of landfill disposal.

At a special cabinet meeting on dioxin issues held in September 1999, the government adopted the target of halving landfill processing of both industrial waste and domestic waste by 2010 compared with 1996.

Global increase in waste emissions



Source: OECD ENVIRONMENTAL DATA COMPENDIUM 1999



Source: OECD ENVIRONMENTAL DATA COMPENDIUM 1999

◆ 640kg per person in 2020

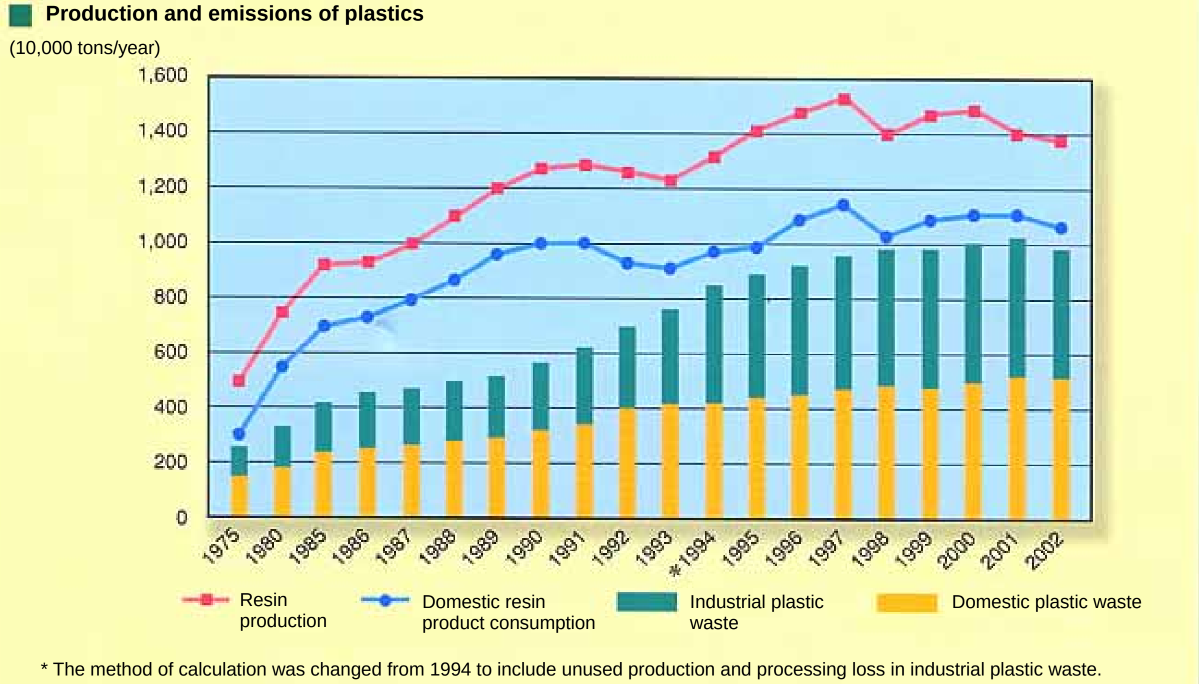
Economic expansion and the spread of patterns of mass production, mass consumption and mass processing have led to a steady increase in emissions of domestic waste throughout the world over the past 20 years. Annual waste emissions of OECD members in 1997, for example, came to 540 million tons in total and around 500kg per person, an increase of approximately 40% overall and 22% per person compared with 1980. In the OECD, emissions are projected to rise a further 43% by 2020 to an annual total of 770 million tons and 640kg per person.

◆ Recycling efforts at the national level

Steps are being taken to curb waste emissions by countries around the world. In Germany for example, which is a world leader in the recycling field, a company called Duales System Deutschland AG (DSD) has been commissioned by the federal government to process containers and packaging, including recovery and recycling, since 1991. Under this system, companies apply to DSD for a license, in exchange for a fee, to display a green dot—the "Grüne Punkt"—on their containers and packaging, which is then recovered and processed by DSD. As a result, container and packaging waste has been reduced by 12%, and in 1997 that it had achieved a recovery rate of 89% and recycling rate of 86%, according to DSD announcement.

2 Processing and recycling of plastic waste

Major progress in effective utilization of plastic waste



Source: Plastic Waste Management Institute

Trends in quantity and rate of effective utilization of plastic waste

Year	1990	1995	1996	1997	1998	1999	2000	2001	2002
Effective utilization (10,000 tons)	144	221	358	399	435	452	494	535	542
Effective utilization (%)	26	25	39	42	44	46	50	53	55

* Detailed data on production, waste emissions, recycling, processing and processing of plastic products can be found at the PWMI website.

Source: Plastic Waste Management Institute

◆ Plastic waste emissions level off

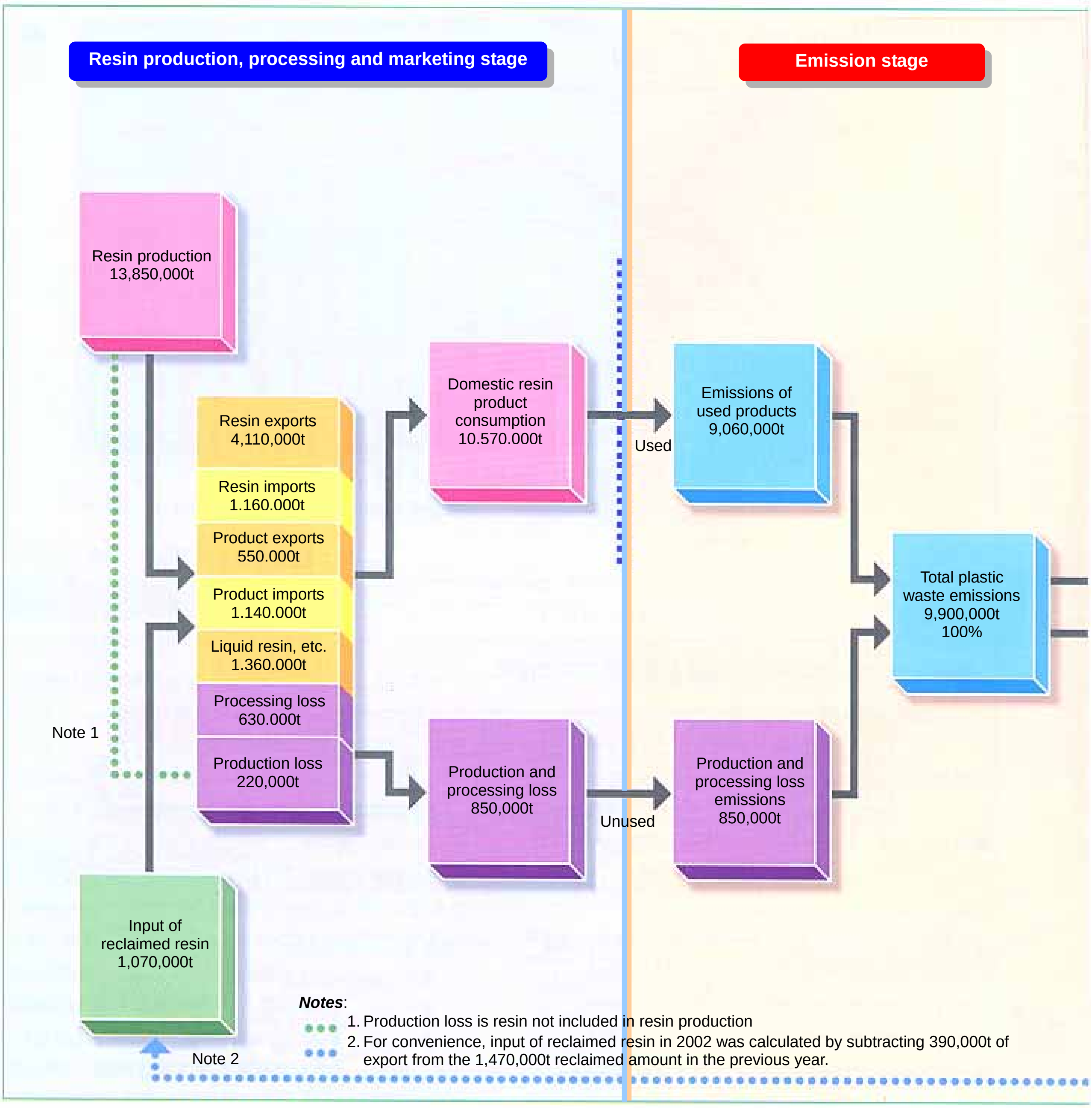
Domestic plastic production peaked at 15.21 million tons in 1997, but has since decreased and leveled of for the past few years and came to 13.85 million tons in 2002. Total emissions of plastic waste have also held steady over the past few years, and fell 260,000 tons from the previous year to 9.90 million tons in 2002.

◆ Effective reutilization more than doubles in seven years

Five point four two million tons of plastic waste were effectively reutilized in 2002, an increase of 60,000 tons from the previous year despite a decline in total waste emissions. The effective utilization rate is also steadily increasing, rising 2 points from the previous year to 55% in 2002.

This is due to an increase in use of mechanical recycling and feedstock recycling of plastic waste as blast furnace feedstock. It is also important not to overlook the growth in energy recovery by local governments, such as the generation of electricity through waste incineration, and use of plastic waste as materials and fuels at cement works.

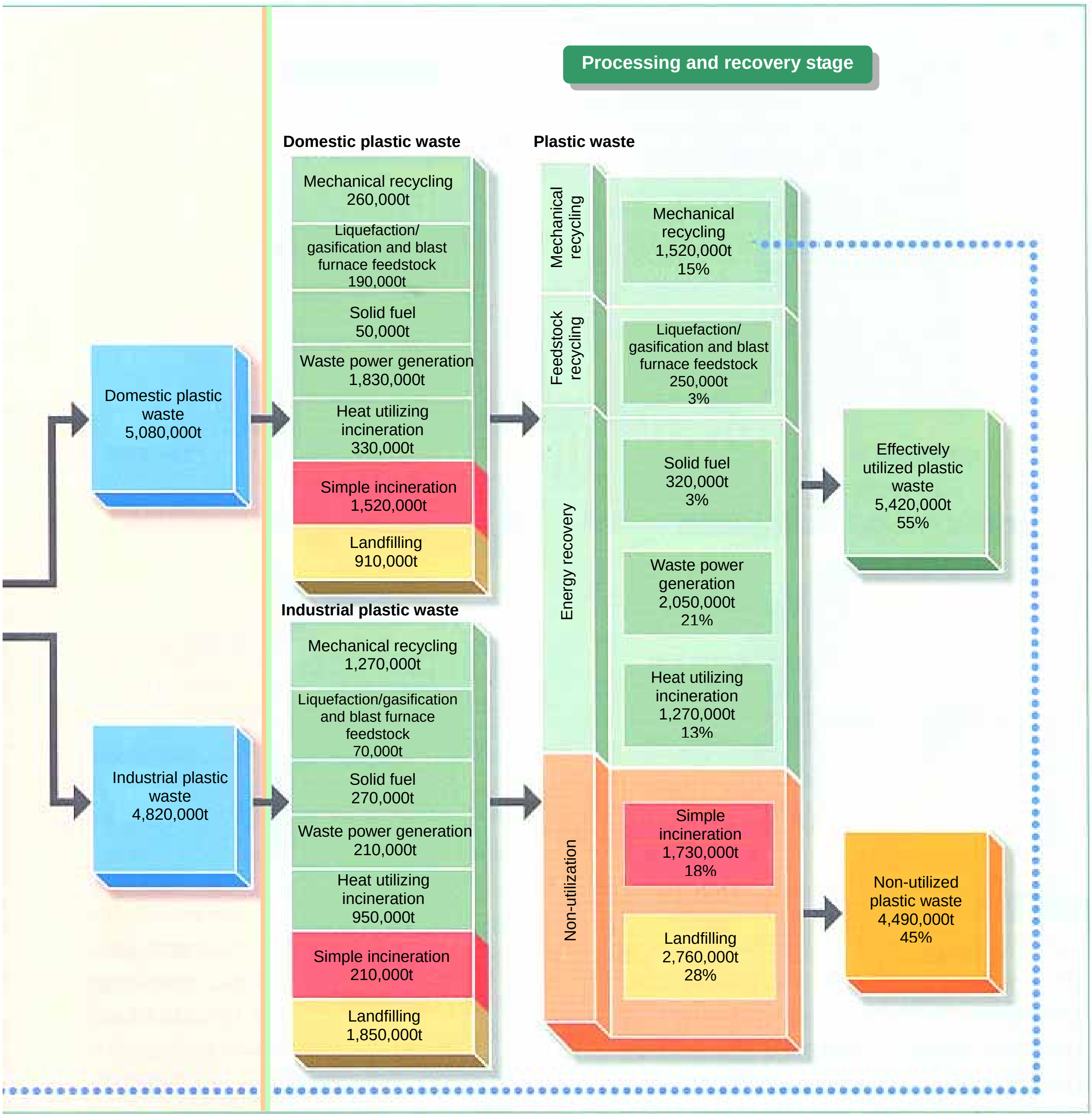
Flow of plastic products, waste and recycling (2002)



◆ Effective utilization of plastic waste rises to 55%

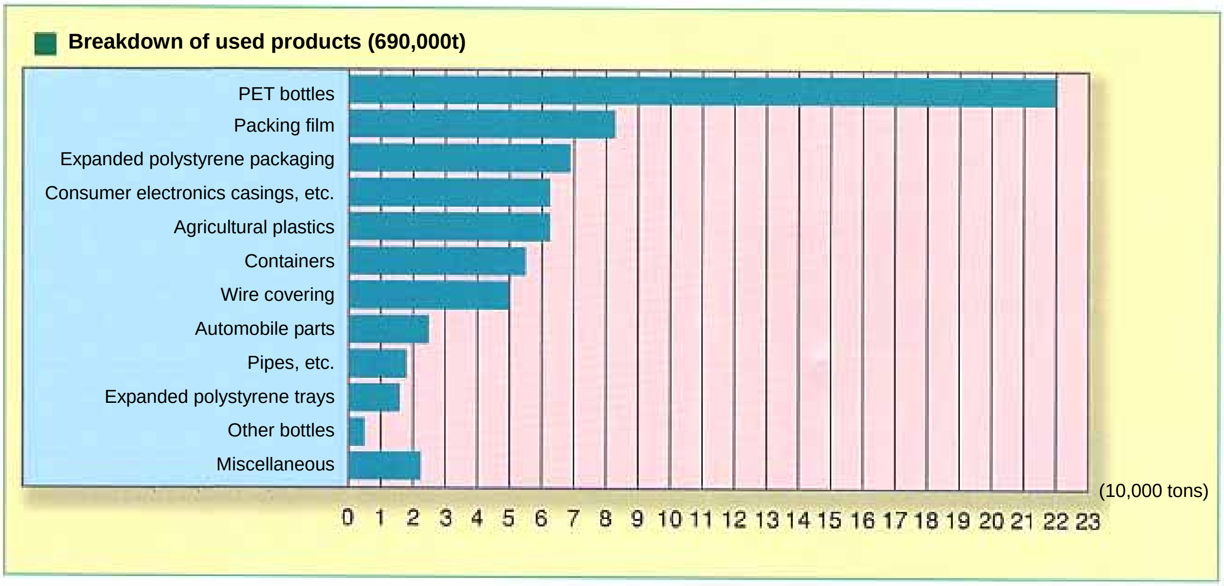
In order to curb consumption of natural resources and reduce the burden on the environment, implementation of the three Rs (reduce, reuse, recycle) of waste is important.

Companies too are increasingly designing their products with the three Rs in mind. In the plastics industry, resin manufacturers, processors, consumer electronics and automobile manufacturers and others are working together to facilitate recycling by, for example, making PET bottles and plastic carrier bags thinner and adopting unified grades of plastics for products such as consumer electronics parts and automobile bumpers. As a result of such efforts, effective utilization of plastic waste has been steadily risen 60,000 tons and the overall effective utilization rate increased to 55% in 2002, despite a decline in emissions of 260,000 tons from the previous year.

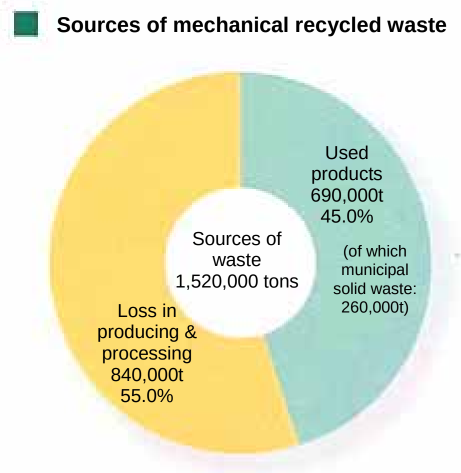


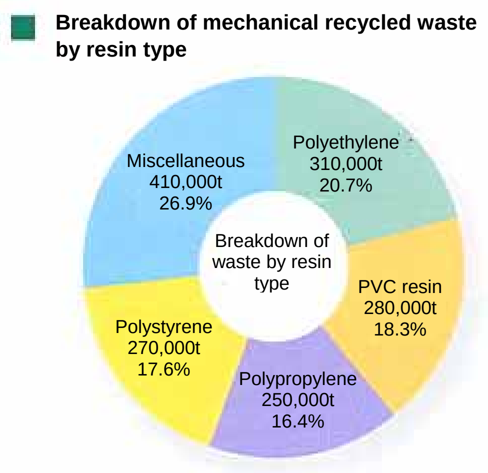
Source: Plastic Waste Management Institute.

Recovery systems supporting mechanical recycling



Source: Plastic Waste Management Institute





◆ 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) increased 50,000 tons from the previous year to 1,520,000 tons in 2002. Of this amount, 260,000 tons was accounted for by domestic plastic waste (5.1% of domestic plastic waste). In contrast, five times this amount of industrial plastic waste (1,270,000 tons, or 26.3% 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 a 90,000 ton increase from the previous year in recycling of used products to 690,000 tons. This is a result of the Container and Packaging Recycling Law coming fully into effect in April 2000, resulting in the coverage for the first time of paper and plastic containers and packaging, and the consequent steady increase in recycling in 2002.

This 690,000 tons of used products consists of 220,000 tons of PET bottles (up 42,000 tons from the previous year), and 85,000 tons of expanded polystyrene including trays (up 6,000 tons), showing that recovery and mechanical recycling of plastic waste consisting of a single type of material is increasing, reflecting the recycling system of companies and associations in these industries going well.

Breakdown of plastic waste

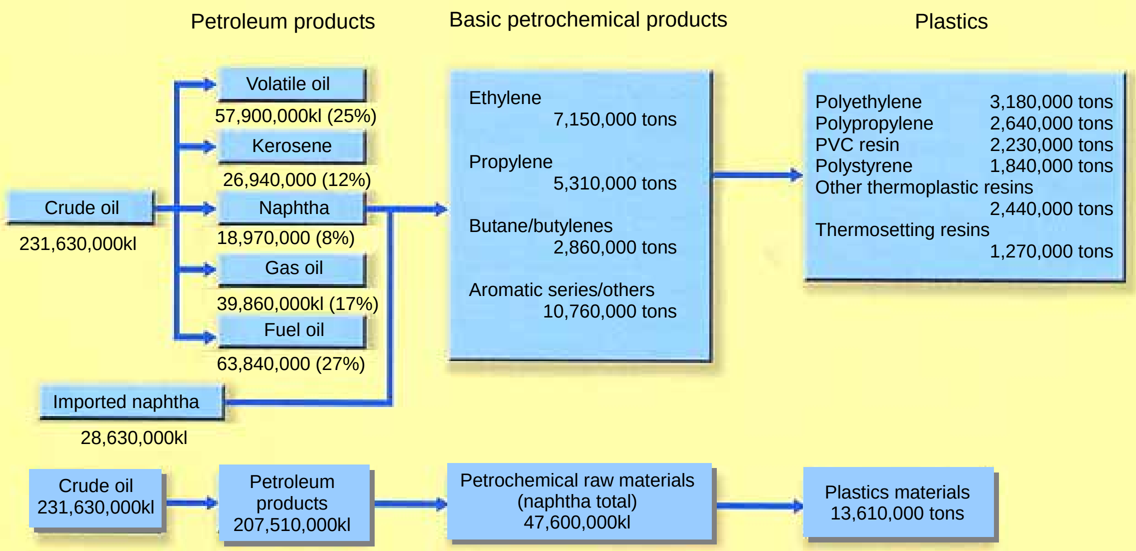
	Shape		Use and contents	Type of resin	
Bottles and tubes	Beverage bottles	Soft drinks	Juice, cola, drinking water, tea, alcoholic beverages	PET	
		Lactic acid beverages	Yogurt	Polystyrene	
	Food and condiment bottles		Tempura and salad oil, soy sauce, *mirin* , sauce	PET, polyethylene, polypropylene	
	Condiment tubes		Mayonnaise, ketchup, dressings, *wasabi* and mustard paste	Polyethylene, polypropylene	
	Bottles and tubes for daily necessities		Toiletries, gardening supplies, car supplies, liquid detergent, fabric softener, toothpaste, cosmetics, shampoo, hair conditioner, bleach, body shampoo	PET, composite material, polyethylene, polypropylene	
Packs and cups	Food packs (EPS and non-EPS packs)		Margarine, *tofu* , *natto* , fruit, vegetables, processed foods, prepared foods, packed lunches	EPS	Polystyrene
				Non-EPS	Polystyrene, polypropylene, PET
	Food cups (EPS and non-EPS cups)		*Miso* , steamed egg custard, *miso* soup, yogurt, *ramen* , *yakisoba* , jelly, custard pudding, desserts	EPS	Polystyrene
				Non-EPS	Polystyrene, PET, polypropylene, Polyethylene
	Cup and pack lids			Polystyrene, PET, polypropylene, Polyethylene	
Trays and blister packs	EPS and non-EPS Trays		Meat, fish, *sashimi* , 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	
	Carrier bags			Polyethylene	
	Rubbish bags			Polyethylene	
	Small bags		Quail's eggs, ginger, pickles, condiments, *ramen* stock, Japanese confectionery, candy, wafers, chocolate	Polypropylene, polyethylene, composite material	
Caps and stoppers			Beverages, foods, daily necessities, other plastic bottles	Polypropylene, polyethylene	
Cellophane and film	Cellophane			Polyvinylidene chloride resin, PVC resin, Polyethylene	
	Film		*Tofu* , curry roux, plastic food decorations, Japanese confectionery, cheese, frozen foods, cod roe, sausages, frozen noodles	Polypropylene, Polyethylene, composite material	
	Labels		Bottles, caps	Polystyrene, polyethylene, PET, polypropylene	
Boxes and cases			Detergent boxes and 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, multipacks, sieves, replanting pots	Polyethylene, PET, polypropylene, PVC resin, polystyrene	

Note: The types of resin indicated in the table are those mainly used.
Source: Plastic Waste Management Institute, Basic Survey for Recycling of Municipal solid waste, (March 1999).

3 Information about plastics

Manufacture of plastics from petroleum

Crude oil use and production by product type (2002)



(The difference in resin production compared with p. 6 is due to the aggregation of data for different months.)

Source: Japan Petrochemical Industry Association, *Present State of the Chemical Industry, 2003*

◆ Plastics are made from naphtha

Plastics are mainly high polymer compounds consisting of carbon and hydrogen, and are 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.

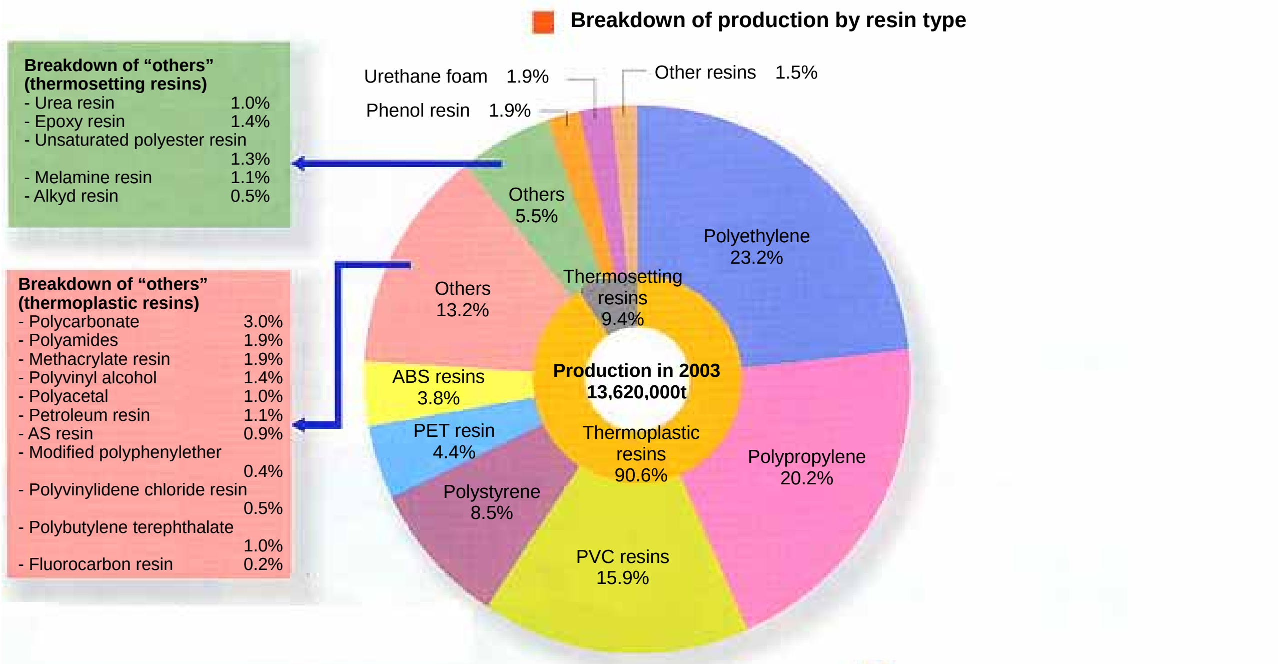
Naphtha produced by distilling crude oil is first heated and cracked to extract substances of a simpler structure (i.e. compounds with a low molecular weight) such as ethylene and propylene. The molecules thus obtained are then chemically coupled (polymerized) to form a substance with new properties. These are substances 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, it is first melted, an added additive to make it easier to process, and formed into pellets. (It is from this stage that it is normally called plastic.) It is then shipped to the molding plant to be manufactured into plastic products.

◆ Plastics account for 6% of total petroleum consumption

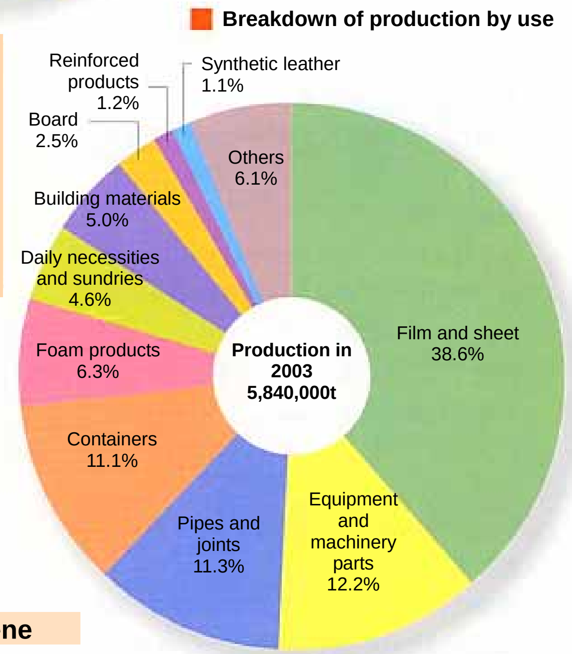
Japan presently uses around 230 million kiloliters of crude oil a year. In 2002, 18.97 million kiloliters of naphtha was produced from 231.63 million kiloliters of crude oil. Combined with imported naphtha, 47.60 million kiloliters of naphtha was used as the raw material for basic petrochemical products such as ehtylene. This is approximately 16% of the total amount of crude oil and imported naphtha used per year. The quantity used to produce plastic products accounts for around 6% of combined crude oil and imported naphtha used per year.

While plastics are thus made from crude oil through a number of chemical reactions, their production appears to require less resource and energy than iron and steel, aluminum and glass.

Breakdown of plastic production by resin type and use



Notes: The large difference between resin production (13.62 million tons) and production by use (5.84 million tons) 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 40 or more workers were included.
(3) Secondary processed products, paints, adhesives, wiring and cables, synthetic fibers and urethane foam, etc. were excluded.



Source: Compiled by the Japan Plastics Industry Federation from monthly statistics released by the Research and Statistics Department of the Minister's Secretariat in the Ministry of Economy, Trade and Industry

◆ Half of production is polyethylene and polypropylene

Plastics of different types have different characteristics, and are put to different uses according to these characteristics.

A large proportion of production is of polyethylene and polypropylene, and these 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, for which purpose polyethylene and polypropylene are well suited.

◆ Chocolate type and biscuit type

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

- **Thermoplastic plastics ("chocolate" type)**
  As chocolate melts when heated, it can be shaped into heart shapes or used to form lettering on cakes. If reheated, it will again soften. Similarly, thermoplastic plastics soften and melt when heated, and harden when cooled.
- **Thermosetting plastics ("biscuit" type)**
  Baked biscuits do not soften when reheated. Similarly, thermosetting plastics do not soften if heated again after they have hardened.

Plastics as the foundations of industry and modern lifestyles

◆ Advantages of plastics

- **Light and robust**
  Unlike metals and ceramics, plastics can be used to make light yet strong products.
- **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 are highly transparent and can be easily colored, making it possible to create bright, attractive products.
- **Mass producible**
  As there are many types that can be molded and processed by a variety of methods,products can be mass-produced efficiently in complex shapes, helping to bring down costs.
- **Excellent electrical and electronic properties**
  Because of their outstanding insulation properties and dimensional stability, they are used in components electrical and electronics products.
- **High heat-insulation efficiency**
  Plastics conduct heat poorly, and foam is a particularly good heat-insulating material.
- **Hygienic and highly gas-barrier**
  Plastics are clean and impermeable to oxygen and water, and so effectively protect foods from contamination by microorganisms.

◆ Drawbacks of plastics

- **Susceptible to heat**
  Some types of plastics deform if placed near a flame or heat source.
- **Susceptible to scratches and dirt**
  As plastics have a soft surface compared with metal and glass, they are easily scratched. They are also susceptible to static electricity and attract dust.
- **Vulnerable to petroleum benzine and thinner**
  Some types melt or discolor if exposed to petroleum benzine, thinner or alcohol.

In the home

Most electrical products' bodies and parts as well as video and cassette tapes, CDs and DVDs are largely made from plastics.

Foods could not be properly heated or defrosted in a microwave oven without cling film. Fluorocarbon resins are used to coat frying pans so that they burn less easily.

Under floors and behind walls, foam plastics are used as heat-insulation to protect the home from cold, heat and condensation, and so help save

When shopping

At the supermarket, fish, meat and vegetables are arranged in plastic trays, keeping products fresh as well as protecting them from damage during transit. Most foods oxidize and are spoiled by bacteria if exposed to oxygen and water. Plastic packaging shuts these out and improves products' shelf life. Freshness preserving film that absorbs ethylene gas (which accelerates the maturation, i.e. aging, of fruit and vegetables) and freshness preserving sheets that act to adjust water content when the tissue of fish and meat is destroyed during refrigeration and defrosting have also entered practical use.

Other uses

The majority of adhesives are synthetic resins. Instant adhesives that are so strong that two 5-centimeter square plates glued together can support the weight of a suspended car have been developed, and these are used in the assembly of machinery parts.

In the office

The parts of circuitry of semiconductors, the heart of PCs, are all made possible by plastics. Photocopiers and fax machines capable of printing on ordinary paper are becoming increasingly widespread, and these make use of microscopic particles of plastic containing carbon that are thermally deposited on the paper.

In hospitals

At hospitals, most equipment such as fluid infusion, blood transfusion and injection devices are disposable plastic devices to prevent the risk of infection. The kidney machines used by artificial dialysis patients, intraocular implants for cataract patients, dentures and artificial joints were also all developed taking advantage of the characteristics of plastics. During operations, too, plastic thread that is naturally absorbed by human tissue is used for sutures, rendering it unnecessary for stitches to be later removed.

In vehicles

Bumpers, seat cushions and numerous other automobile parts are also made from plastics. The proportion of plastic products used is increasing every year, and an ordinary vehicle contains around 75kg of plastics. Some models are now 8% in plastic in weight. Plastics serve to make vehicles lighter and improves fuel

In sport

Tennis racquets are made from carbon-fiber-reinforced plastics, and the strings are made from nylon. Skis and ski stocks are also plastic, so they no longer break. Surfboards are made from polyethylene, FRP (fiber-reinforced plastic) and polyurethane. In the Olympics, the poles used by pole-vaulters are now also made from FRP, resulting in new records being set year after year.

In agriculture and fishing industry

We can now enjoy fresh fruit and vegetables all year round thanks to plastic greenhouses. Greenhouses that adjust sunlight and curb certain pests and diseases are growing increasingly widespread. And at fishing ports, fishing nets and most fishing tackle are now made of plastics, as well as the fishing boats themselves, which are made of FRP.

Source: Data of the Japan Plastics Industry Federation and other data

Main characteristics and uses of plastics

	Resin name		Abbre-viation	Heat resistance (°C)	Acid resistance	Alkali resistance	Alcohol resistance
Thermoplastic resins	Polyethylene	Low density polyethylene	LDPE	70-90	Good	Good	Good
		High density polyethylene	HDPE	90-110	Good	Good	Good
		EVA resin	EVAC	70-90	Some products somewhat vulnerable	Some products somewhat vulnerable	Good
	Polypropylene		PP	100-120	Good	Good	Good
	Polystyrene (styrene resin)	General-purpose polystyrene	PS	70-90	Good	Good	Taste of contents changes if immersed for long period
		Expanded polystyrene	EPS	70-90	Good	Good	Taste of contents changes if immersed for long period
	AS resin		SAN	80-100	Good	Good	Repeated use renders opaque
	ABS resin		ABS	70-100	Good	Good	Swells over long period
	Polyvinyl chloride		PVC	60-80 (*2) 130	Good	Good	Good
	Polyvinylidene chloride		PVDC	(*2) 140	Good	Good	Good
	Methacrylic resin		PMMA	70-90	Good	Good	Very slight foreign odor of contents
	Methacrylic styrene (MS) resin		MS	70-90	Good	Good	Very slight change
	Polymethylpentene		PMP	160-170	Good	Good	Good
	Polyamide (nylon)		PA	80-140	Some products somewhat vulnerable	Good	Possible infiltration
	Polycarbonate		PC	120-130	Good	Some products somewhat vulnerable (e.g. detergents)	Good
	Acetal resin (polyacetal)		POM	120	Some products vulnerable	Good	Good
	Polyethylene terephthalate (PET)		PET	80-150	Good	Very slight change in some cases	Good
Thermosetting resins	Phenol resin		PF	150	Good	Good	Good
	Melamine resin		MF	110-120	Good	Good	Good
	Urea resin		UF	90	Stable or very slight change	Very slight change	Good
	Unsaturated polyester resin		UP	150	Good	Very slight change in some cases	Good
	Epoxy resin		EP	130	Good	Good	Good
	Polyurethane		PUR	90-130	Somewhat vulnerable	Somewhat vulnerable	Good

Notes: 1. "Good" indicates no problems in ordinary use.
2. According to the quality labeling guidelines for cling film established by ordinance of Tokyo Metropolitan Government.

Resistance to cooking oil	Characteristics	Main uses
Good	Lighter than water and flexible, but poor heat resistance. Good chemical resistance and electrical insulating properties.	Packaging (bags, cling film, food containers), agricultural film
Good	Opaque and rigid, but poor heat resistance. Good chemical resistance and electrical insulating properties.	Packaging (film, bags), sundries (buckets, washbowls, etc.), kerosene cans, containers, pipes
Good	Flexible and slightly opaque. Excellent rubbery elasticity and performance at low temperatures.	Construction sheeting, sandals, agricultural film
Good	Low relative density (0.90). Resembles polyethylene, but good heat resistance and glossy.	Bathroom products, sealed containers, packing string, sieves, baskets, containers, tableware, automobile parts
Vulnerable to terpene oil contained in citrus fruits	Highly transparent and easily colored. Easily scratched. Good electrical insulating properties. Dissolves in petroleum benzine and thinner.	Office appliance and TV casings, CD cases, food containers
Vulnerable to terpene oil contained in citrus fruits	Light and rigid. Good thermal insulating properties. Dissolves in petroleum benzine and thinner.	Packaging, fish boxes, food trays, *tatami* mat padding
Good	Resembles styrene resin, but good heat and shock resistance and transparent.	Tableware, disposable lighters, electrical products (fan blades, juicers)
Good	Many opaque products, outstanding shock resistance.	Travel trunks, furniture parts, PC housings, automobile parts
Good	Difficult to burn. Water and air proof. Soft and hard varieties. Sinks in water (relative density of 1.4).	Water pipes, agricultural film, cling film, corrugated plate, hoses, window sashes and other building materials
Good	Colorless, transparent, good chemical resistance, excellent gas-barrier.	Cling film, ham and sausage casing, artificial turf
Good	Colorless, transparent, glossy. Dissolves in petroleum benzine and thinner.	Automobile headlight lenses, tableware, windshields, lighting boards, water tank plates, contact lenses
Possible fine cracking	Colorless and transparent, characteristics midway between polystyrene and methacrylic resin.	Lenses, light covers, packaging (trays, lids, etc.)
Good	Colorless and transparent, chemical and heat resistant.	Microwave tableware, trays, film for food packaging, animal cages
Good	Milky white, good abrasion resistance, cold resistance and shock resistance.	Door rollers, fasteners, cogs, retort pouch packaging, automobile parts
Good	Colorless and transparent, highly resistant to acids but vulnerable to alkalis. Excellent resistance to shocks and heat.	Eating utensils, lunch boxes, feeding bottles, automobile parts, optical disks, CDs, driers, building materials
Good	White, opaque, excellent shock resistance and good abrasion resistance.	Fasteners, automobile parts
Good	Colorless and transparent, tough, good chemical resistance.	PET bottles, photography films, cassette tapes, VTR tapes, egg boxes, salad bowls
Good	Good electrical insulating properties, acid resistance, heat resistance and water resistance.	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 difficult to burn.	Buttons, caps, electrical products (wiring accessories), plywood adhesive
Good	Good electrical insulating properties, heat resistance and chemical resistance. Products reinforced with glass and carbon fiber are strong (FRP).	Bathtubs, corrugated plate, cooling towers, fishing boats, buttons, helmets, fishing rods, paint, septic tanks
Good	Excellent physical and chemical properties and electrical properties.	Electrical products (IC sealant, printed circuit boards), automobiles (tanks), paints, adhesives
Good	Hard and soft varieties. Soft variety resembles sponge.	Automobile parts (seat cushioning), cushions, mattresses, heat insulation

Source: The Japan Plastics Industry Federation, *Hello Plastics*!

4 Methods of plastic recycling

Three forms of recycling

<table>
<tr><th>Category</th><th colspan="2">Method of recycling</th><th>Term in Japan</th></tr>
<tr><td>Mechanical recycling</td><td>Recycling to make:</td><td>• Plastic raw materials
• Plastic products</td><td>Material recycling</td></tr>
<tr><td rowspan="4">Feedstock recycling</td><td colspan="2">Monomerization</td><td rowspan="4">Chemical 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
Liquefaction</td><td>Chemical feedstock</td></tr>
<tr><td rowspan="2">Energy recovery</td><td>Fuel</td><td rowspan="2">Thermal recycling (energy recovery)</td></tr>
<tr><td colspan="2">Cement kiln
Waste power generation
RDF</td></tr>
</table>

◆ The true goal of recycling

As a result of many years of technological development, plastic waste is now recycled by a great many methods. These methods may be grouped into three main categories:*

(1) Mechanical recycling
(2) Feedstock recycling (monomerization, a blast furnace reducing agent, coke oven chemical feedstock recycling, gasification, liquefaction, etc.)
(3) Energy recovery (cement kilns, waste power generation, RDF)

Recycling technology has thus advanced tremendously, and its use is spreading. However, recycling is not an end in itself. As the Basic Law for Promoting the Creation of a Recycling-oriented Society enacted in 2000 made quite 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. In promoting recycling, therefore, it is necessary to consider very carefully whether the method used reduces inputs of new resources or limits the burden on the environment (such as by means of life cycle assessment).

Regarding plastics as well, it is important to select the recycling method that imposes the least social cost as well as limiting the environmental burden given the situation of the plastic waste to be recycled.

* The methods of recycling currently recognized under the Container and Packaging Recycling Law are mechanical recycling, 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 (liquefaction and gasification)

Mechanical recycling

1) washbowl 2) road bollard 3) imitation wood post 4) pallet 5) anti-weed sheeting
6) heat/sound-insulating sheeting 7) PVC pipe 8) water-butt lid 9) colored box 10) central reservation block
11) parking block 12) duckboard 13) survey and boundary markers 14) bricks 15) cross-ties for steel products
16) video cassettes 17) weight for colored cone 18) plant pots

◆ Used for containers, benches, building materials, textiles, sheeting…

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 manufacturers around Japan.

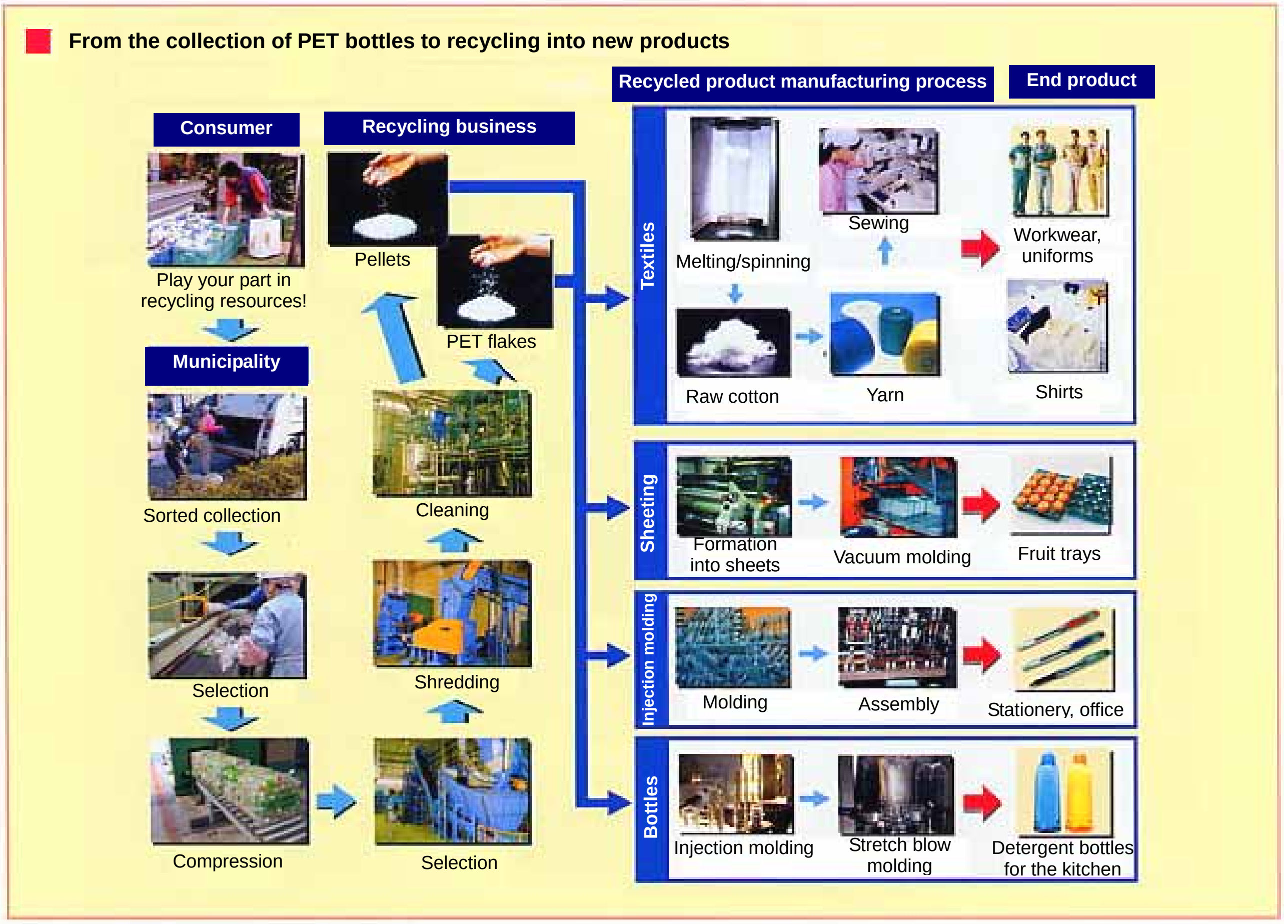
Mechanically recycled plastic waste has until now consisted largely of industrial plastic waste. The industrial plastic waste generated in the manufacture, processing, and distribution of plastic products is well suited for use as the raw material for mechanical recycling due to the clear separation of different types of resins, the low level of dirt and impurities present, and their availability in large quantities. As a result of the recent entry into effect of the Container and Packaging Recycling Law and the Home Appliance Recycling Law, the used plastics generated by households, stores and offices are also now covered by mechanical recycling.

Recycled products made from industrial plastic waste come in all kinds, including containers, benches and fences, children's play equipment, construction sheeting, and products for packaging, transportation, construction, homes, parks, roads, railways, and other goods and facilities of agriculture, forestry and fisheries.

Recycled products have a number of attractive characteristics; durable, light, easy to process and easy to cut and join just like wood, and we can expect dissemination of recycled products taking advantage of these features to use them in place of other materials, such as steel, concrete and wood.

The used plastics emitted from the home and other place, such as PET bottles and expanded polystyrene, on the other hand, is turned into textile products, packaging materials, bottles, stationery, daily necessities, video cassettes and similar products.

Mechanical recycling process



Source: Council for PET Bottle Recycling

◆ Remelted to make products

PET bottles obtained by sorted emission from households are collected, compressed and packed by municipalities for transportation to recycling plants operated by recycling business. At the recycling plant, the waste is selected to remove impurities, and the remaining PET bottles then shredded, cleaned, foreign bodies and non-resins separated, and the remainder turned into flakes and pellets (granules made of flakes thermally processed by granulator) 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.

Mechanical recycling of plastic waste other than PET bottles is performed in basically the same way.

◆ Resin molding techniques

(1) Extrusion molding
Resin is melted and continually extruded through a mold by a screw to form a molded product. Products include pipes, sheets, film and wire covering.

(2) Injection molding
Heated melted resin is injected into a mold. This solidifies to form a molded product. Products made this way range from washbowls, buckets and plastic models to larger products such as bumpers and pallets.

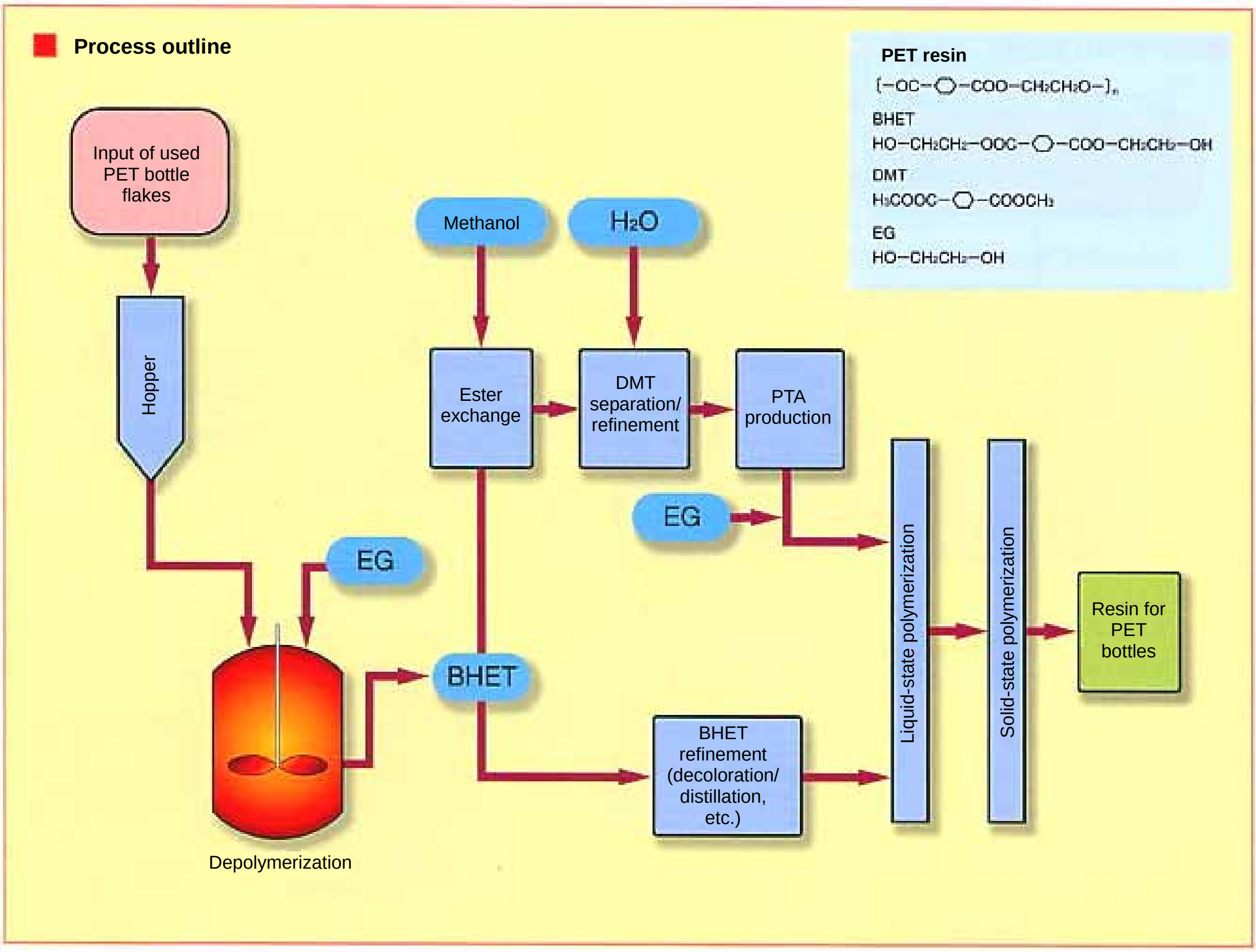
(3) Blow molding
A parison obtained by extrusion or injection molding is clanped in a mold, and inflated with air to make bottles for all kinds of uses, such as shampoo bottles. PET bottles are made by means of stretch blow molding so as to make them less likely to rupture.

(4) Vacuum molding
A heat-softened sheet is sandwiched in a mold, and the space between the sheet and mold sealed and evacuated to form products such as cups and trays.

(5) Inflation method
This is a type of extrusion molding by which a melted resin is inflated into a cylinder to form a film. This method is used to make products such as shopping bags.

Monomerization

[Feedstock recycling]



Reference: Teijin and Aies pamphlets

◆ PET bottles to PET bottles

While PET bottles are recycled to make textiles and sheeting, they cannot be used to make PET drinks bottles without further processing due to the fact that used PET bottles are unsuited for use as the raw materials for soft drink, liquor and soy sauce bottles, both for reasons of hygiene and smell. However, more economic use of resources can be made if waste PET bottles are converted back to their state during synthesis instead of making PET resin right from beginning out of petroleum and naphtha. Following this line of thinking, therefore, a “bottle-to-bottle” scheme to make resin equivalent to newly made resin suitable for drinks bottles is to start in 2003.

The method used is to chemically decompose the used PET bottles into their monomers (depolymerization), from which stage they are again made into PET resin.

Even before now, Teijin Ltd. has used its own proprietary decomposition method of combining ethylene glycol (EG) and methanol to break waste PET resin down into DMT (dimethyl terephthalate) to turn it into the raw material used to make textiles and film. This technique has been built upon to break waste PET bottles down further from DMT to PTA (purified terephthalic acid) to make PET resin, and Teijin Fiber Ltd. commenced production of around 50,000 tons per year in November 2003.

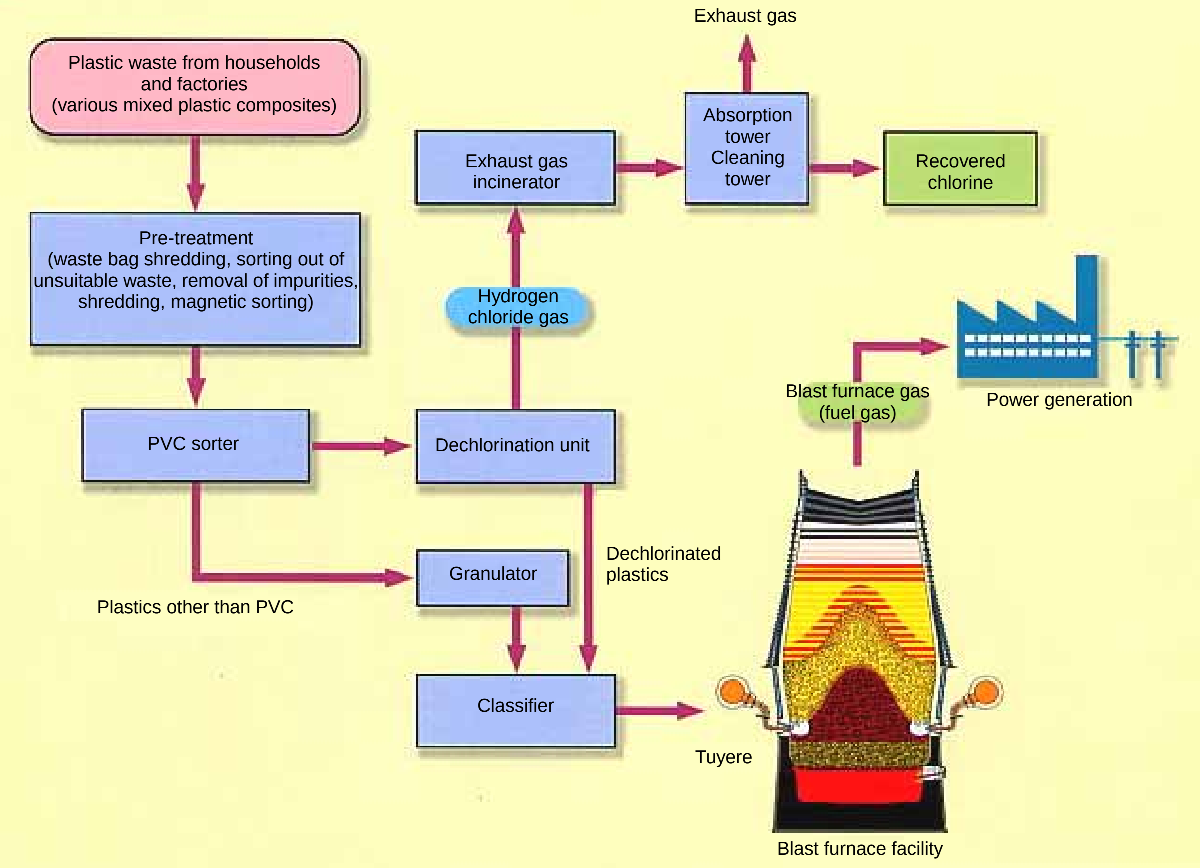
Aies Co., Ltd. has also developed a technique for manufacturing resin by breaking it down into high-purity BHET (bis-(2-hydroxyethyl) terephthalate) monomer using a new method of depolymerization using EG, and established a new company, PET Reverse Co., Ltd., which commenced production of around 23,000 tons per year in March 2004.

Applying these new technologies, PET bottle recycling is expected to grow by leaps and bounds in the years ahead.

Blast furnace feedstock recycling

[Feedstock recycling]

Blast furnace feedstock recycling process



Reference: JFE Steel Corporation. pamphlet

◆ Plastics used as reducing agent

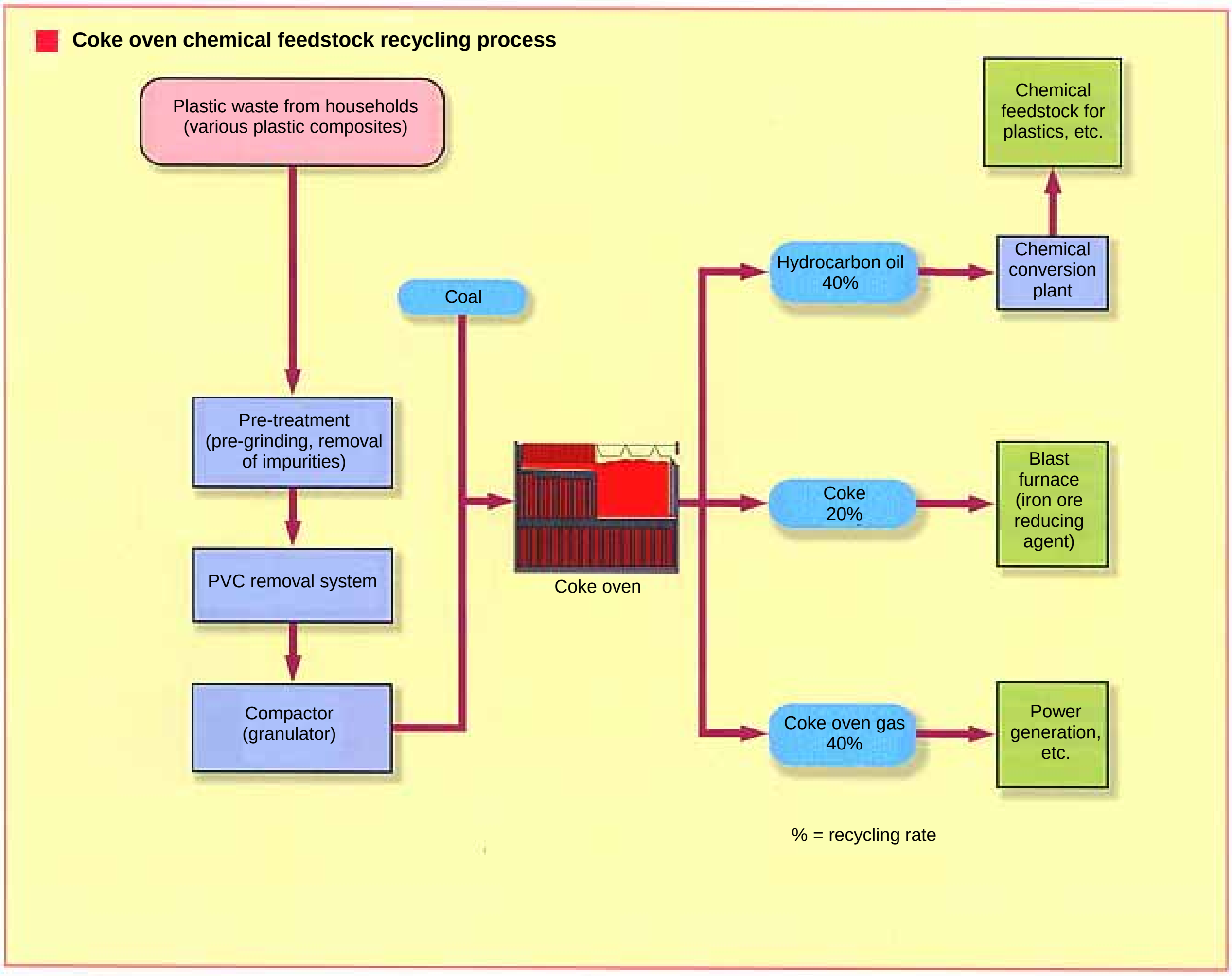
At steel mills, iron ore, coke and auxiliary raw materials are fed into a blast furnace, and the iron ore melted to produce pig iron. The coke is used as fuel to elevate the temperature in the furnace, and also acts as a reducing agent by removing the oxygen from iron oxide is one of the main constituents of iron ore. As plastics are made from petroleum and natural gas, its main constituents are carbon and hydrogen, meaning that it should be possible to devise a means of using it as a replacement for 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 homes is cleansed of non-combustible matter and other impurities such as metals, and then finely pulverized and packed to reduce its volume. Plastics that do not contain PVC are granulated, and then fed into the blast furnace with coke. Plastics that do 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 method of dehydrochlorination was developed at the request of the New Energy and Industrial Technology Development Organization (NEDO) by the Plastic Waste Management Institute, Japan PVC Environmental Affairs Council, Vinyl Environmental Council, and JFE Steel Corporatin (formerly NKK).

Coke oven chemical feedstock recycling

[Feedstock recycling]



Reference: Nippon Steel Corporation pamphlet

◆ Plastic waste rentilized in coke ovens

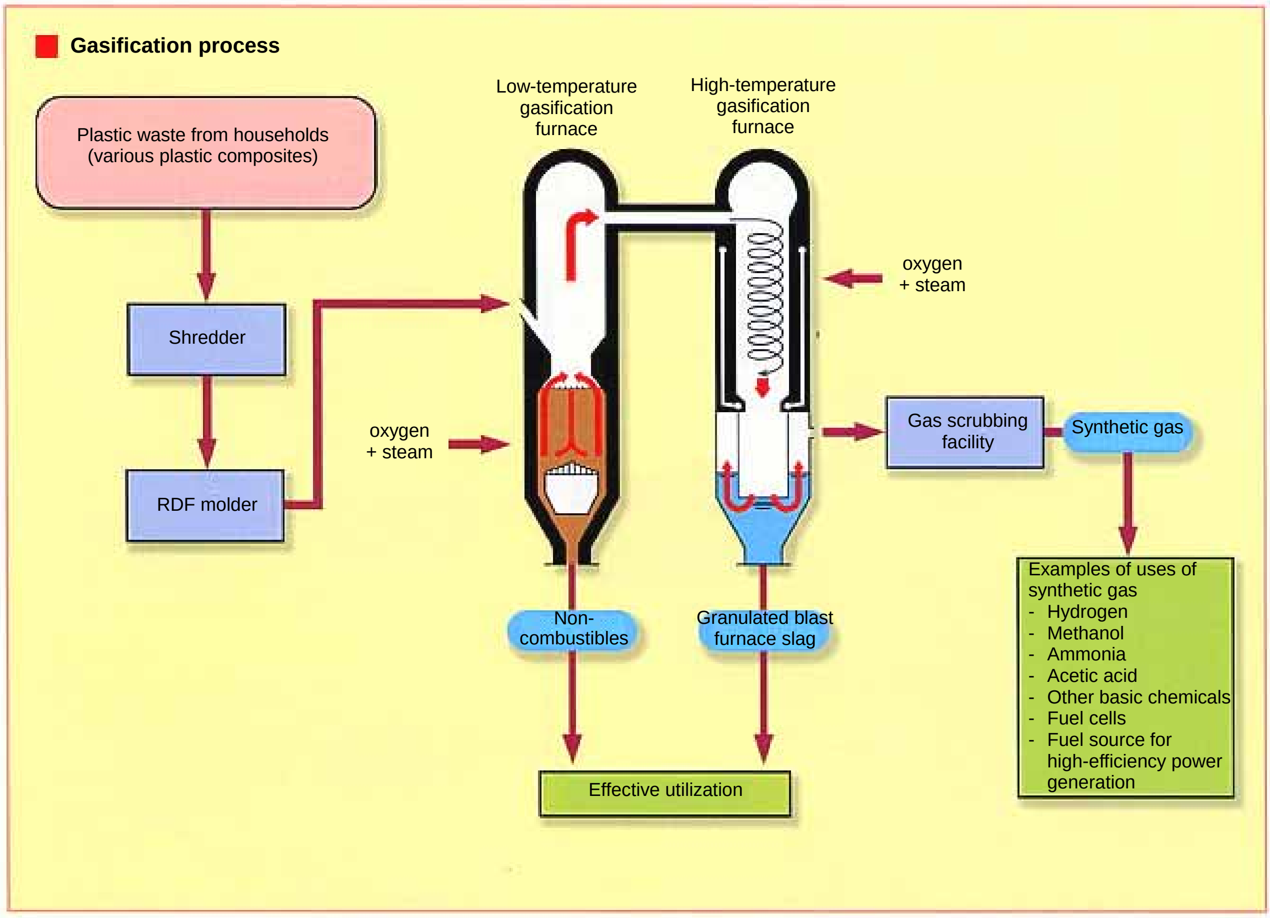
Coke is made by baking coal, and hydrocarbon oil and coke oven gas are produced from the volatile constituents generated during this process. Coke, hydrocarbon oil and coke oven gas can be similarly produced from plastic waste. At its steel mills in Nagoya, Kimitsu, Muroran and Yawata, Nippon Steel Corporation has developed facilities to use plastic waste as chemical feedstock and fuel, and these are now in operation.

At these plants, plastic waste collected from households is first shredded and impurities such as iron removed. PVC is then removed, the plastics heated to 100°C and granulated, and fed into the carbonization chamber of a coke oven mixed with coal.

The carbonization chamber is sandwiched by combustion chambers on either side, which heat the content indirectly. The plastic waste does not combust inside the chamber because of the absence of oxygen, and instead is cracked thermally at high temperature to produce coke for use as the reducing agent in coke ovens, hydrocarbon oil, which is used as chemical feedstock, and coke oven gas, which is used to generate electricity.

Gasification

[Feedstock recycling]



Source: Plastic Waste Management Institute

◆ Plastics are converted to gas for use as a raw material in the chemical industry

Plastics are composed mainly of carbon and hydrogen. Normally, therefore, it produces carbon dioxide and water when combusted. The gasification process requires oxygen and stream, which are supplied and the plastics heated. As the supply of oxygen is limited, however, much of the plastics turn into hydrocarbon, carbon monoxide and water.

More specifically, sand heated to 600~800°C is circulated inside a first-stage low-temperature gasification furnace, and plastics introduced into the furnace break down on contact with the sand to form hydrocarbon, carbon monoxide, hydrogen and char. In the case of plastics containing chlorine, hydrogen chloride is produced, while in the case of plastic products containing metals and glass, these substances are recovered as they are as non-combustible matter.

In a second-stage high-temperature gasification furnace, the gas from the low-temperature gasification furnace is reacted with steam at a temperature of 1,300~1,500°C to produce a gas composed primarily of carbon monoxide and hydrogen. At the furnace outlet, the gas is rapidly cooled to below 200°C to prevent the formation of dioxins. The granulated blast furnace slag also produced is used in civil engineering and construction materials.

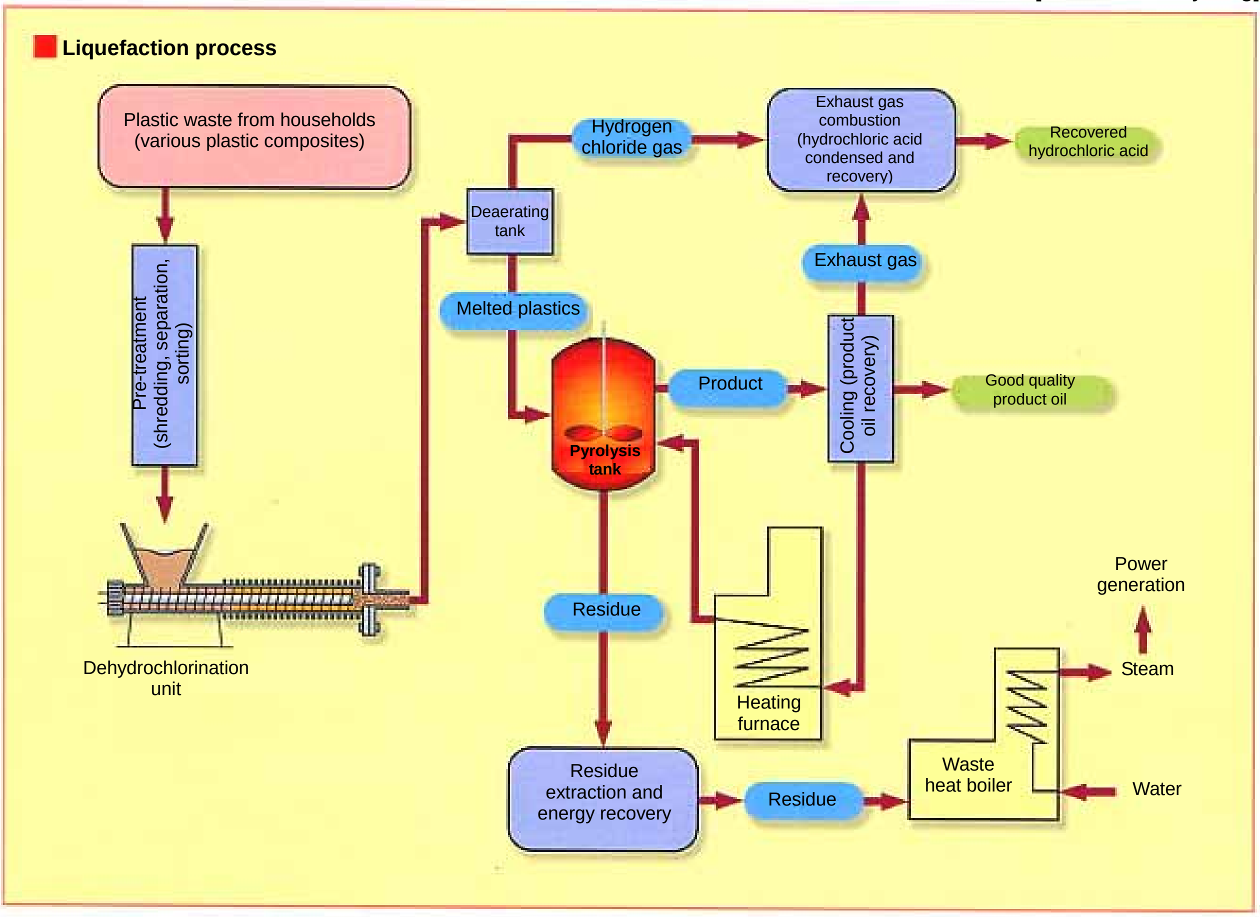
The gas then passes through a gas scrubber, and any remaining hydrogen chloride is neutralized by alkalis and removed from the synthetic gas. This synthetic gas is used as a raw material in the chemical industry to produce chemicals such as hydrogen, methanol, ammonia and acetic acid.

The Plastic Waste Management Institute was commissioned by NEDO to conduct trials of this technology, which were performed with the cooperation of Ebara Corporation and Ube Industries, Ltd. Since January 2001, EUP has had a plastic gasification plant in full operation in Ube City.

Using this technology, Showa Denko K.K. brought on stream a new facility at its Kawasaki plant in July 2003.

Liquefaction

[Feedstock recycling]



Source: Plastic Waste Management Institute

◆ Waste plastic converted back to oil

As plastics are made from petroleum, it should be possible to produce petroleum from it by reversing the process by which it is manufactured. And indeed, the Plastic Waste Management Institute has established a technique to convert plastic waste back to oil following development work initiated in the latter of 1970s.

The facilities applying this technology have until now used industrial plastic waste, as this is relatively easier to process. In recent years, however, there has been strong demand for treatment of plastic waste obtained by sorted collection from the domestic waste produced by households, creating a need to develop a method of simultaneously converting a variety of plastics containing PVC to oil.

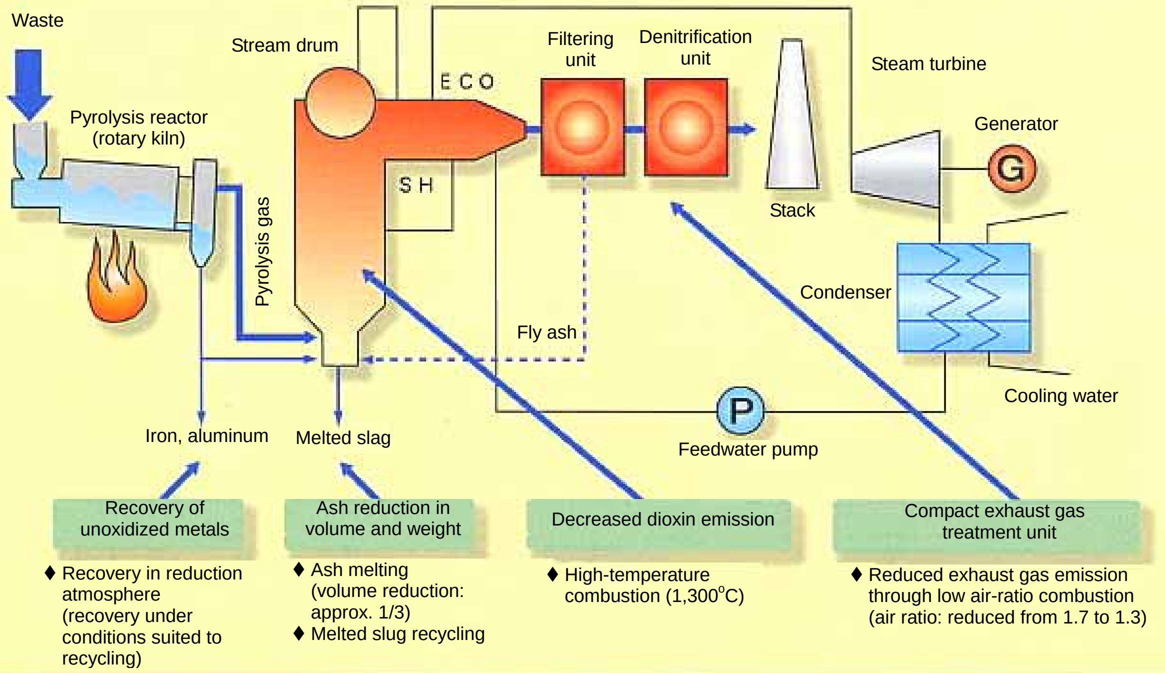
With the assistance of a grant from the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry), the Plastic Waste Management Institute undertook a successful three-year project from FY1995, called the Next-Generation Plastic Waste Liquefaction Technology Development Project, to develop a method of effectively converting to oil (i.e. liquefying) plastic waste of a variety of types.

To trial the technology, the Niigata Plastic Liquefaction Center was established in Niigata City by Rekisei Kouyu Co., Ltd. Applying the Plastic Waste Management Institute's own findings from the above project, the center entered trial operation in December 1997 and commercial operation in May 1999.

A similar large-scale facility was built by Sapporo Plastic Recycling Co., Ltd. in Sapporo, and this entered operation in April 2000. Japan Energy Corp. also commenced practical operation in April 2004 of a plant to convert recycle plastic waste oil into naphtha in Niigata and Sapporo.

Energy recovery

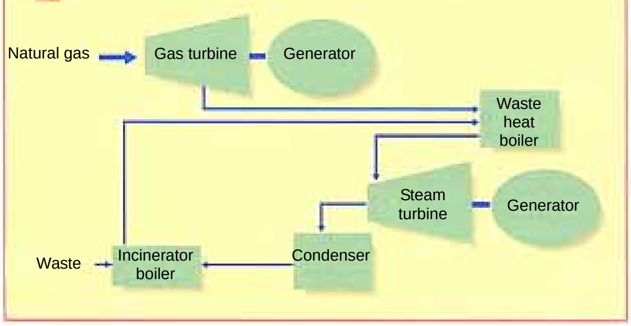
Gasification and melting furnace power generation system (rotary kiln plus combustion-melting furnace)



Source: NEDO

◆ Energy recovery as important as mechanical recycling

Re-powering generation plant



The Basic Law for Promoting the Creation of a Recycling-oriented Society, which establishes the framework for creation of a recycling-oriented society, lays down the following order of priorities for recycling and dealing with waste: (1) reduce, (2) reuse, (3) mechanical recycling and feedstock recycling, (4) energy recovery, and (5) appropriate processing of waste. energy recovery was thus seen as a second-best solution. However, the Expert Panel on a Recycling-oriented Society set up under the Council on Economic and Fiscal Policy (an advisory body to the prime minister) and Planning Group of the Industrial Structure Council recommended in 2000 that energy recovery be accorded the same status as mechanical recycling as a means of effectively recovering energy from waste.

As well as liquefaction (conversion to oil) and gasification, which are recognized under the Container and Packaging Recycling Law, other forms of energy recovery include use of heat produced by waste incineration, generation of electricity by waste incineration, conversion to fuel and feedstock for cement kilns, and refuse-derived solid fuel (RDF).

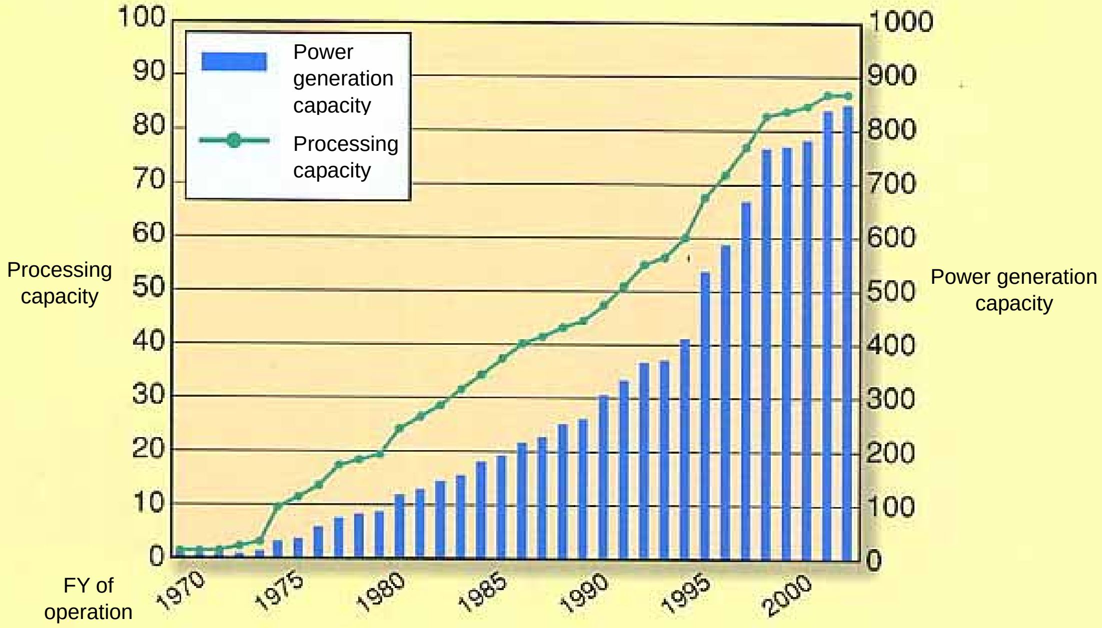
A current focus of interest is waste power generation, and stoker ovens, gasification and melting furnaces and gasification reformers are likely to become the favored means of producing electricity in this way due to their advantages in terms of their smaller burden on environment (e.g. by rendering waste harmless and reducing it in weight and volume) and effective utilization of energy.

Gasification and melting furnaces gasify waste at high temperature, and use the pyrolysis gas and char thus produced as fuel to drive a steam turbine and generate electricity, while the incineration ash is melted and solidified. Gasification reformers pyrolysize waste, add a gas containing oxygen and water vapor to the gas thus generated, recover the product as a gas containing a high concentration of carbon monoxide and hydrogen, and use this as fuel to generate electricity and as a raw material for the chemical industry. Both methods can be performed using shaft furnaces, fluidized-bed and rotary kilns.

As well as steam turbines, power can also potentially be produced by the method using gas engines, gas turbines and fuel cells, which offer highly efficient means of generating electricity.

Steady increase in waste power generation

Trend in waste power generation facility processing capacity



Source: Ministry of the Environment, Waste Management and Recycling Department

◆ Power generation capacity to supply 2.1 million households

Use of waste as an energy source is steadily increasing. Many waste incineration facilities around the country are now equipped with boilers to enable them to supply the hot water and steam generated to facilities such as local health spas, facilities for the elderly, heating system, bath houses and heated swimming pools.

Waste power generation around the world

Country	Number of facilities	Power generation capacity
USA	ca. 107	ca. 2,300,000kw
Germany	50	ca. 1,000,000kw
Japan	ca. 210	ca. 86,000kw
Holland	10	ca. 50,000kw
France	ca. 80	ca. 30,000kw

Source: NEDO, 1999

Another method of use now attracting interest is waste power generation. As of the end of 2001, the number of waste incineration facilities around Japan currently in operation or under construction equipped with power generation facilities had climed to 210.* While this number represents only around 12% of the total, the fact that the efficiency of waste power generation increases with the size of a waste processing facility means that the proportion in terms of waste processing capacity leaps to 48%. These facilities have a combined power generation capacity of 1.06 million kilowatts, which is enough to supply around 2.1 million households assuming an annual power consumption of 5,000kWh per household.

** According to the figs. of Tech. Off., Policy Planning Div., Elect. and Gas Industry Dep., Agency for Natural Resource and Energy, METI.*

Furthermore, although waste power generation has until now had a generating efficiency of only around 5~15%, progress is being made on the practical use of a method of re-powering generation that combines the use of steam generated by waste incineration with high-temperature waste heat from a gas turbine, which is used to superheat the steam to increase the output of the steam turbine, resulting in a power generation efficiency of 25% or more. Also now under development is a method of directly combusting the gas produced by a gasification- and melting furnace by means of gas engine or gas turbine to further raise the efficiency of power generation.

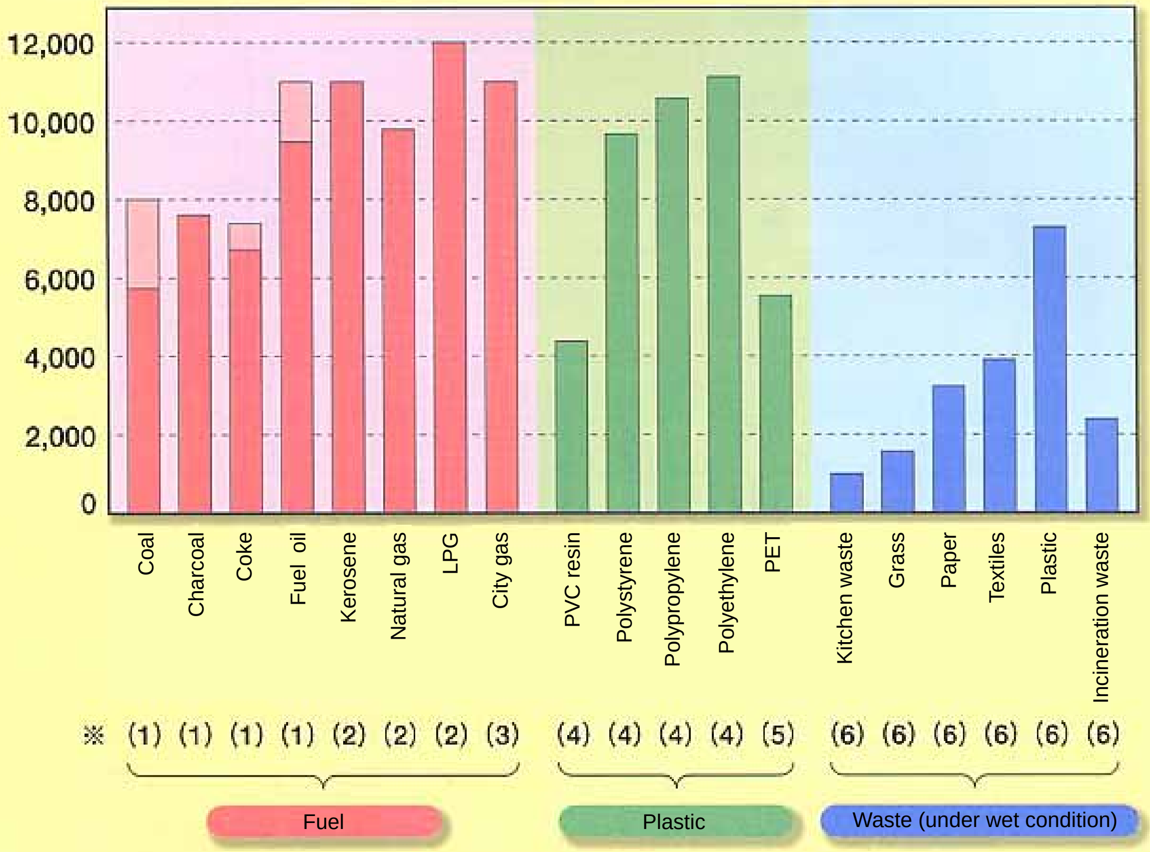
Internationally, waste power generation is rapidly gaining in popularity in industrialized countries, where power generation capacity per facility is high and further steps are being taken to improve efficiency by increasing the scale of facilities.

In Japan, the government is pursuing a policy of promoting use of renewable and sustainable energy resources. A target of a five-fold increase in capacity from 1999 to 4.17 million kilowatts in 2010 has been adopted for waste power generation, which is viewed as important a power resource as solar power, wind power and biomass power generation.

High calorie provides valuable energy resource

Comparison of calorie

kcal/kg (kcal/Nm^3 for natural gas and city gas)



Note: There is some variation in the calorie of coke and fuel oil due to their being natural products.

Sources:
(1) Fuel Society of Japan, *Fuel handbook*, 1984, Corona
(2) Agency of Natural Resources and Energy (ed.), *General Energy Statistics*, 1994, Tsusho Sangyo Kenkyusha
(3) Tokyo Gas
(4) K. Krekeler, P. M. Klimke: Kunstsoffe, 55 (10), 758, (1965)
(5) PET Bottle Association
(6) Plastic Waste Optima Processing Technology Research Council (ed.), *Processing and Disposal of Plastic Waste* (daily report)

◆ Calorie on a par with coal and oil

The waste collected at waste incineration facilities consists of a variety of things. The above graph compares the calorie of the combustible substances contained in waste.

As can be seen, plastic has twice the calorie of paper waste, and the plastic with the highest calorie, polyethylene, is on a par with coal and oil.

Waste containing high calorie plastics is thus a valuable energy resource, and increasing effective use is expected in the future.

Waste incineration and pollutants

Dioxin concentration standards

	New facilities	Existing facilities		
Combustion chamber processing capacity	(from December 1, 1997)	Up to 1 year later (December 1, 1997 to November 30, 1998)	1~5 years later (December 1, 1998 to November 30, 2002)	5 years later or more (from December 1, 2002)
4 ton/hour or more	0.1ng/Nm^3	Deferment of application of standards	80ng/Nm^3	1ng/Nm^3
2~4 ton/hour	1ng/Nm^3			5ng/Nm^3
Under 2 ton/hour	5ng/Nm^3			10ng/Nm^3

Note: Dioxin concentration is converted to toxicity equivalent (TEQ. Nm^3 is at 0^oC and 1 atmosphere of pressure).

Smoke and soot concentration limits

Category	Soot and dust		
Limit	Continuous furnaces		Others
	Up to 0.15g/Nm^3	Up to 0.5g/Nm^3	Up to 0.5g/Nm^3
Remarks	Special limit for exhaust gas emissions of 40,000m^3/n Up to 0.08Nm^3	Special limit for exhaust gas emissions of 40,000m^3/n Up to 0.15g/Nm^3	Special emission limit Up to 0.25/Nm^3

Category	SOx	HCl	NOx
Limit	Calculated at $Q = k \times 10^{-3} He^2$ Up to q(Nm^3/h)	Up to 700mg/Nm^3 O_2 = 12% equivalent Concentration equivalent up to 430ppm	250ppm O_2 = 12% equivalent
Remarks	He: effective stack height K: value determined locally		Facilities established since August 10, 1979

Note: Nm^3 means the amount of a gas occupying 1 cubic meter at a temperature of 0^oC and 1 atmospheric pressure.

Source: Ministry of the Environment

◆ Tightened regulation of dioxin emissions

Combustion of municipal solid waste results in gas emissions containing pollutants.

Dioxins:

Standards to limit 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 downs standards concerning the tolerable daily intake for dioxins, environmental standards, and regulations concerning (exhaust) gas and water emissions, and emission standards are provided for waste incinerators of a total incineration capacity of at least 50kg/hour or 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. As a result, total annual emission of dioxins from waste incineration facilities around Japan from December 2002 to November 2003 are estimated to have been approximately 635g, a 90% reduction compared with 1997.

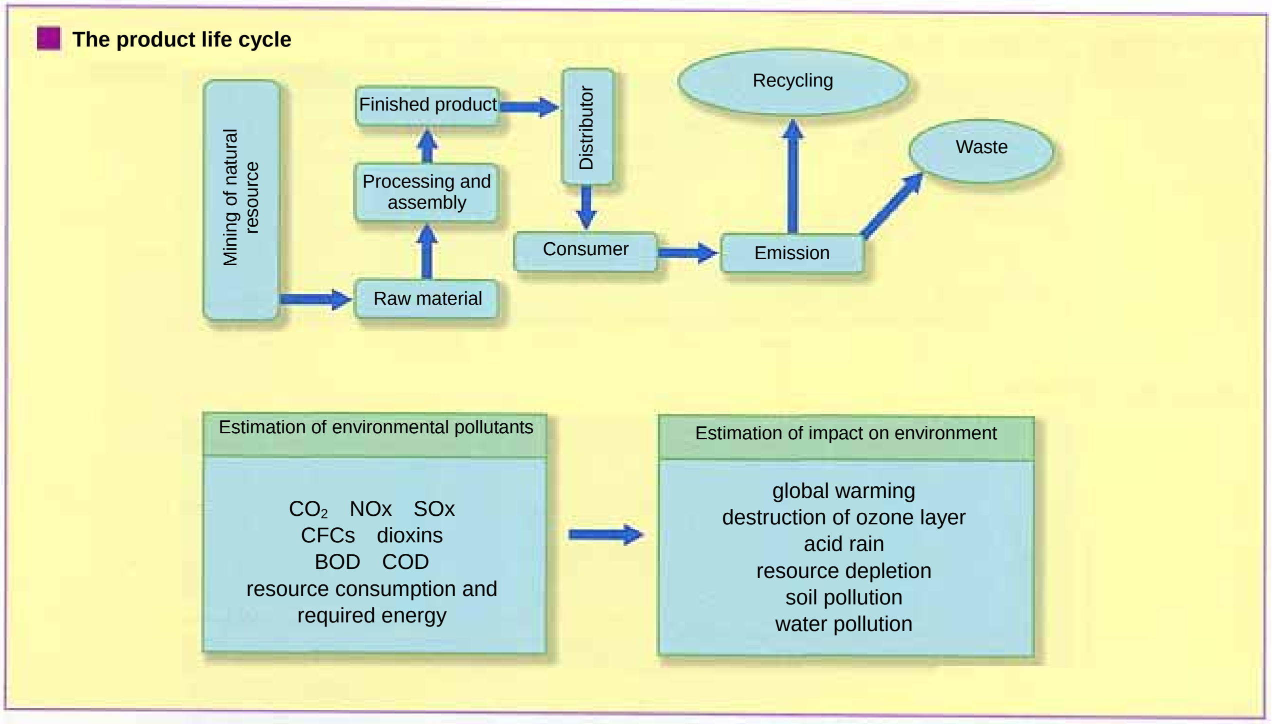
Particulate matter:

Emissions of particulate matter are regulated nationally under the Air Pollution Control Law. Some local governments also have their own stricter standards.

Methods of eliminating pollutants include physical collection systems, such as bag filters and electrical dust collectors effective for removing NOx, SOx, HCl, dust and soot, and methods of controlling emissions through chemical reaction with substances such as ammonia, caustic soda and calcium hydroxide. The most popular method of controlling NOx emissions in the past, for example, was to control furnace operation. Now, however, an increasing number of facilities are using this method in conjunction with a reactive control method involving the injection of ammonia in high-temperature areas of exhaust gas. Bag filters capable of simultaneously removing other pollutants as well as dust and soot are also growing more widespread.

5 Life Cycle Assessment

What is life cycle assessment



Source: Group "LCq"

◆ Assessment from cradle to grave

Life cycle assessment, or LCA for short, is a method of assessing the impact on the environment of products and services. In the case of a product, for example, resource consumption and emissions throughout the lifecycle—from mining of resources to use of raw materials, processing and assembly, use of the finished product and disposal—are calculated and evaluated.

In today's society, we consume large amounts of natural resources and energy, and this has a wide-ranging impact on the environment. This impact has reached the stage where it is no longer possible to deal with the problem simply by limiting emissions of harmful substances and waste. There is thus emerging a growing trend toward selecting environmentally friendlier products and production methods by assessing and comparing their impact on the environment (including use of resources), and one means of doing so that is the focus of much interest is LCA.

LCA began with a survey conducted by a leading American drinks manufacturer of the impact on the environment of returnable bottles. Considerable research has since been conducted on LCA in both the United States and Europe, and in Japan, the LCA Japan Forum was established in 1995 to examine the application of LCA in Japan.

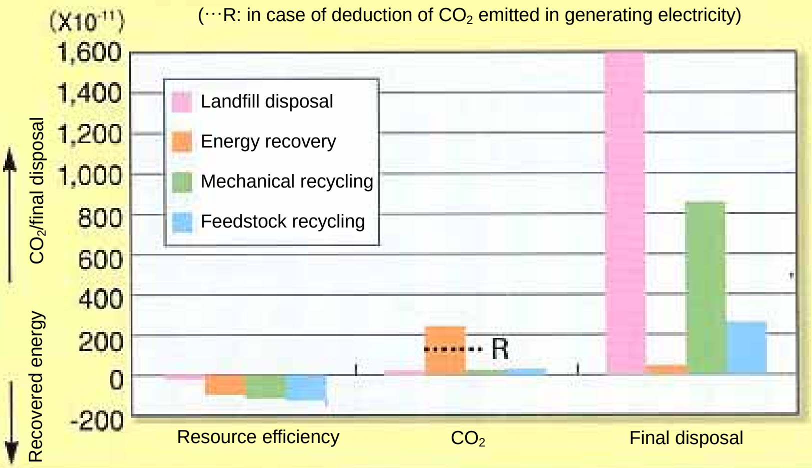
LCA in outline consists of the following steps.
(1) **Definition of goal and scope**
(2) **Inventory analysis**: A survey is conducted of data concerning the burden on environment (CO_2, required energy, etc.) of resource and energy inputs and outputs involved in the production of products. This is known as the life cycle inventory analysis (LCI).
(3) **Impact assessment**: Assessment of the various environmental impacts based on the results of inventory analysis.
(4) **Interpretation of findings**: The results of inventory analysis and impact assessment are interpreted and translated into action.

While still at the development stage, LCA has been introduced by a number of manufacturers, and has found its way into fields such as product development and improvement, strategic planning and marketing.

On the subject of LCA, the Plastic Waste Management Institute published "Life Cycle Assessment of Plastic Packaging" in 1995, followed by "An LCA Study of Municipal Plastic Waste" and "A study on Plastic Waste Treatment and Disposal by a method of LCA Technique." These were followed in 2003 by the publication of an environmental and economic-efficiency analysis of the "eco-efficiency" of plastic waste treatment and disposal systems, and this added an economic perspective to LCA. Active research by the institute into LCA continues.

Environmental and resource impact assessment of recycling methods by LCA

Fig. 1 Resource and environmental impact



The vertical axis indicates an increase in the environmental burden on the positive side, and an increase in recovered energy on the negative side.
(Improvement in resource efficiency)

Impact assessment of various factors in Japan

- Energy recovery factor
= recovered energy / total annual primary energy required in Japan*
(*Energy Economic Statistics Directory*, 2002)

- CO_2 emission factor
= CO_2 emissions / total annual CO_2 emissions in Japan*
(*Environmental Statistics*, 2002)

- Final disposal factor
= landfill disposal / total annual landfill disposal in Japan*
(*Environmental Statistics*, 2002)

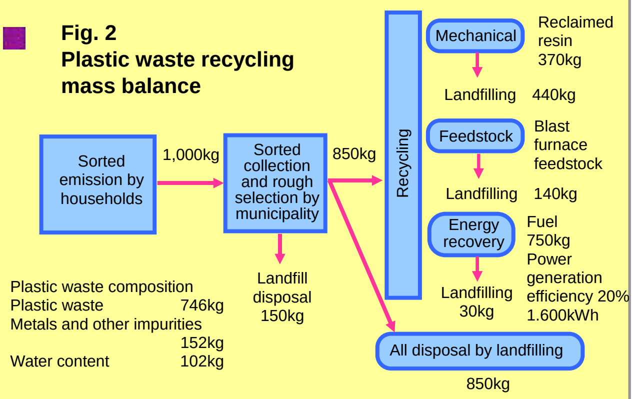
Source: Plastic Waste Management Institute

◆ Well balanced energy recovery

LCA is used to assess the impact on the environment and resources of methods of plastic waste recycling (Fig. 1). The study concerns processing of plastic containers and packaging (excluding PET bottles) as defined under the Container and Packaging Recycling Law by the following recycling methods and by landfill disposal after sorted collection by municipalities.

(1) Mechanical recycling
(2) Feedstock recycling (fed into blast furnace process as reducing agent)
(3) Energy recovery (incineration power generation at a generating efficiency of 20%)
(4) Landfill disposal

Fig. 2
Plastic waste recycling mass balance



Source: Plastic Waste Management Institute

A comparison is made of the impact on Japan in relation to the following three points:

1) CO_2 emissions burden on the environment, 2) Final disposal, 3) Efficiency of use of petroleum resources, i.e. energy recovery (important to the creation of a recycling-oriented society)*

The overall mass balances are as shown in Fig. 2. Note that the impact assessment is calculated on the basis of 850kg of plastic waste after exclusion of the amount disposed of directly by landfilling after sorted collection and rough selection by municipalities.

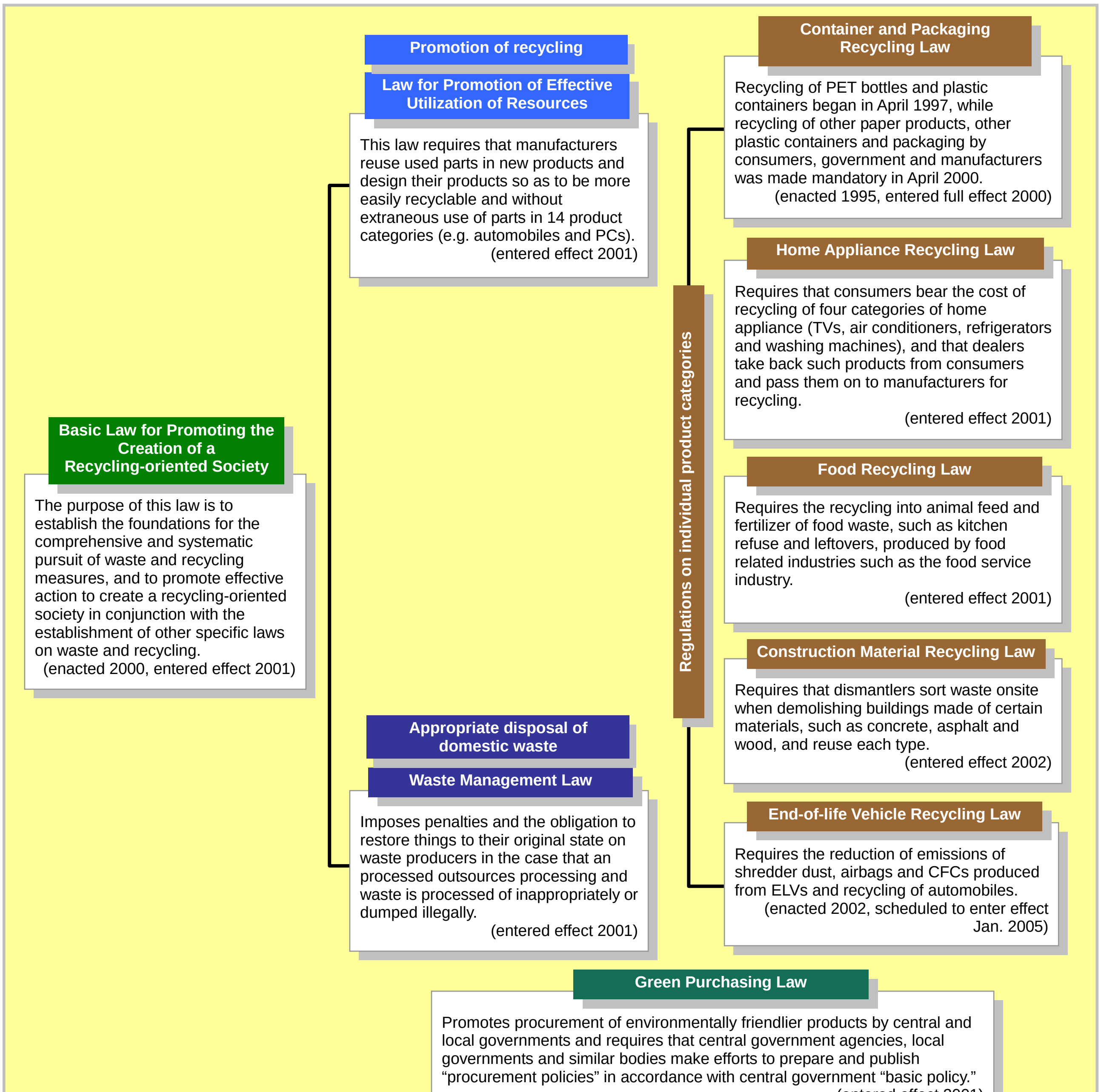
The results of the assessment are as follows.
Resource efficiency: Energy is recovered in the case of all of the recycling methods, but no energy is recovered with landfill disposal.
CO_2 emissions: With the exception of landfill disposal, all methods of processing waste results in emissions of CO_2. However, energy recovery has a comparatively large environmental burden. Nevertheless, as electricity output by thermal power plants can be reduced by an amount commensurate with the power obtained by incineration power generation, CO_2 emissions can be reduced, and this reduced amount is indicated by R in the figure.
Final disposal: While landfill disposal naturally has an environmental burden, so too does mechanical recycling. This is because the plastic containers and packaging presently collected are of poor purity and contain high levels of foreign substances. Even where mechanical recycling is used, therefore, more than 50% of waste ends up being disposed of by landfilling.

From this point-by-point assessment of the impact of various methods of processing on Japan as a whole, it can be seen that energy recovery has relatively less impact on the environment than other methods, and offers a balanced means of recycling.

* The data used in this study are drawn mainly from the LCI data contained in Plastic Waste Management Institute, "A Study on Plastic Waste Treatment and Disposal by a Method of LCA Technique 2002." Data on the composition of plastic waste for calculating CO_2 and calorie for energy recovery were calculated based on Plastic Waste Management Institute, "A Basic Survey for Recycling of Municipal Plastic Waste, 1999."

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

Basic law and recycling laws



Source: Nippo Co.Ltd. website

◆ Clarification of roles of central and local governments, businesses and consumers

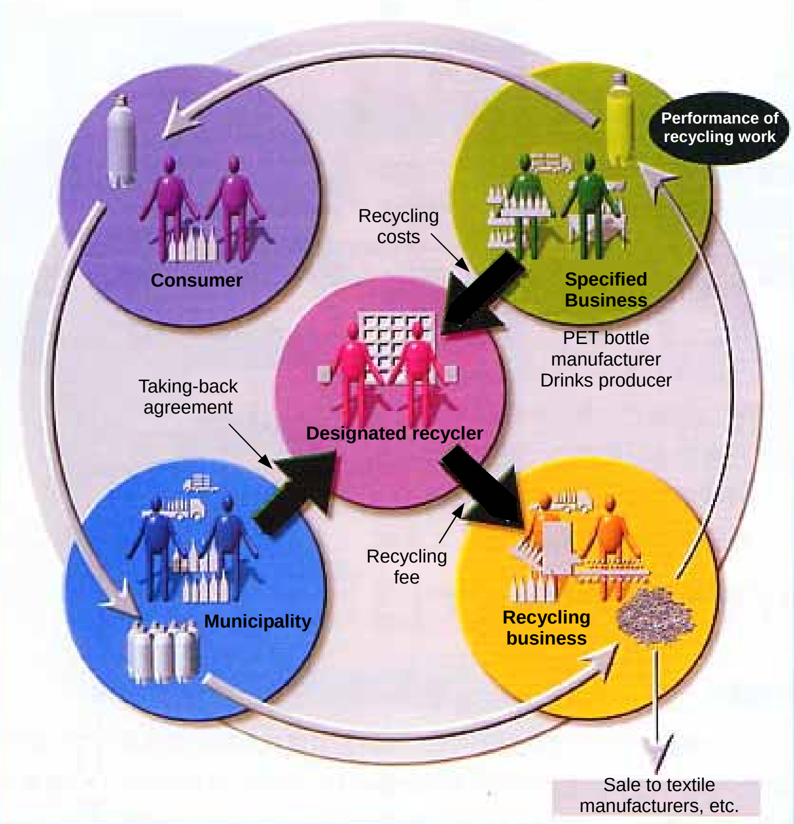
The creation of a recycling-oriented society is the biggest challenge facing Japan in the 21st century. A recycling-oriented society is defined by the Basic Law for Promoting the Creation of a Recycling-oriented Society as a society that limits consumption of natural resources and minimizes the burden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

Declaring that 2000 marked the start of the development of a recycling-oriented society, the government enacted six recycling-related laws based around the Basic Law for Promoting the Creation of a Recycling-oriented 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.

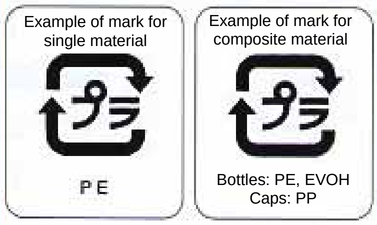
Building on the framework laid down by this law, a number of individual recycling laws, such as the Law for Promotion of Effective Utilization of Resources, were enacted, amended and strengthened. These laws provide the concrete framework in each field for effectively promoting the three Rs, i.e. reduction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

Container and Packaging Recycling Law and identification marks

Container and packaging recycling system (in the case of PET bottles)



Materials are labeled using symbols defined under JIS K 6899-12000 (ISO1043-1 1997).



Source: Ministry of Economy, Trade and Industry, *Containers and Packaging Recycling* (2001 edition)

◆ Identification marks and material labeling to assist sorted collection

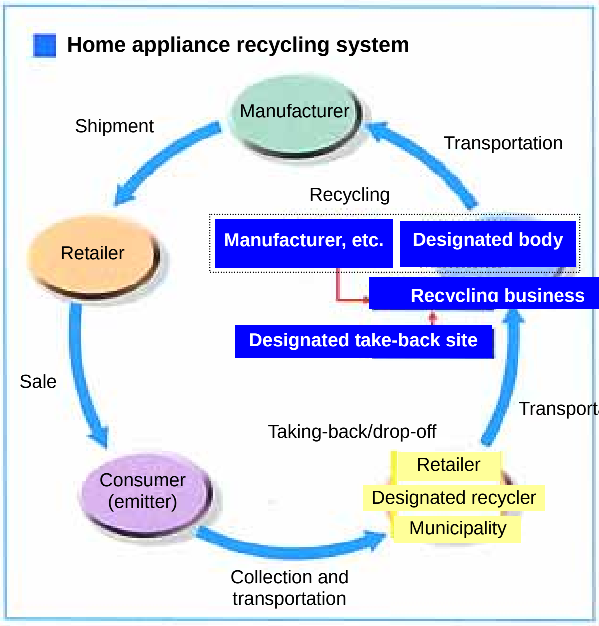
The Law for Promotion of Sorted Collection and Recycling of Containers and Packaging, known for short as the Container and Packaging Recycling Law, aims to promote recycling and reduce the amount of container and packaging waste produced by households amounting to nearly 60% in volume and 20~30% in weight, and covers glass bottles, PET bottles, and paper and plastic containers and packaging. (Plastics account for around 60% of the volume and 20% of the weight of container and packaging waste.)

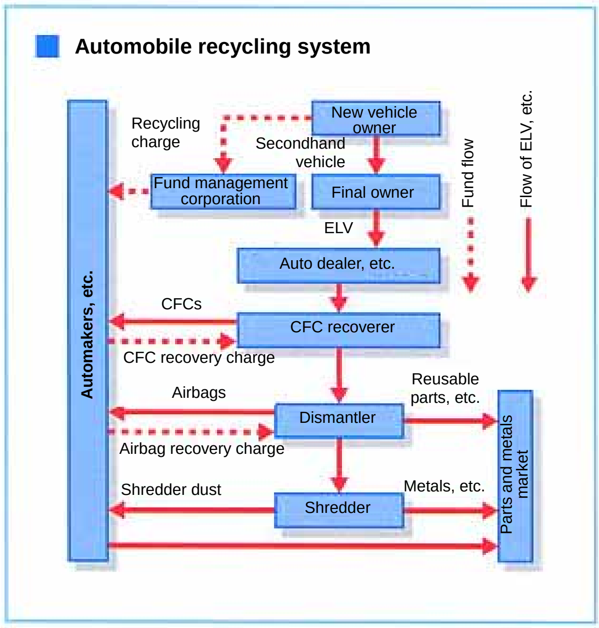
Under this law, consumers, municipalities and businesses are each required to play their role in reducing emissions and recycling of waste.

- **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 such 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 recycling 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 label" as well as identification mark.

Home Appliance Recycling Law and Automobile Recycling Law





◆ TVs, refrigerators, washing machines and air conditioners covered

The Law for Recycling of Specified Kinds of Home Appliances, known for short as the Home Appliance Recycling Law, covers the recycling of home appliances (currently television sets, refrigerators, washing machines and air conditioners), and imposes the following duties on manufacturers, importers, retailers, municipalities and consumers.

- **Manufacturers and importers**: Manufacturers or 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. This waste must also be recycled.
- **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).
- **Municipalities**: 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 Law on Recycling of End-of-Life Vehicles, popularly known as the Automobile 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).

- **Manufacturers and importers**: Businesses must take back and recycle the CFCs, airbags and shredder dust from ELVs (CFC must be resolved).
- **Handling agents**: Handling agents take ELVs back from vehicle owners and pass them on to CFC recoverers and dismantler for recycling.
- **CFC recoverers**: CFC recoverers are required to appropriately recover CFCs and pass them on to automakers. (A recovery charge may be charged for this.)
- **Dismantlers**: Dismantlers must appropriately recycle and process ELVs, and pass on airbags to automakers. (A recovery fee may be charged for this.)
- **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.

Related organizations

Organization/government agency	Activities, etc.	TEL	Homepage
Japan Hygienic Association of Vinylidene Chloride	Surveys and research on vinylidene chloride	03-3591-8126	http://www3.ocn.ne.jp/~vdkyo/
Japan PVC Environmental Affairs Council	PVC resin Recycling	03-3297-5601	http://www.pvc.or.jp/
Japan PVC Pipe & Fitting Association	Awareness raising and promotion of recycling PVC pipes and fittings	03-3470-2251	http://www.ppfa.gr.jp/
PVC Industry and Environmental Council	Surveys and research on vinyl chloride in general	03-3506-5481	http://www.vec.gr.jp/
Japan Engineering Plastic Society	Engineering plastic products	03-3592-1668	http://www.enpla.jp
Japan Reinforced Plastics Society	Fiberglass reinforced plastics (FRP), e.g. bathtubs and ship hulls	03-3543-1531	http://www.jrps.or.jp/
Clean Japan Center	Recycling in general	03-3432-6301	http://www.cjc.or.jp/
Japan Termosetting Plastics Industry Association	Surveys and research on thermosetting resins	03-3580-0881	
Food Container Mold Society	Plastic food containers and packaging	03-5256-1891	
Biodegradable Plastic Society	Surveys, research and promotion of biodegradable plastics	03-5541-2731	http://www.bpsweb.net/
Japan Petrochemical Industry Association	Petrochemical products in general	03-3297-2011	http://www.jpca.or.jp
All Japan Plastic Production Industrial Federation	Plastic processors	03-3567-4005	
Japan Environment Association	Surveys, research, promotion and awareness raising regarding environmental issues, eco-mark	03-3508-2651	http://www.jeas.or.jp/
Japan Containers and Packaging Recycling Association	Recycling under contract from businesses	03-5532-8605	http://www.jcpra.or.jp/
Japan Chemical Industry Association	Surveys and research on production, consumption and environmental safety in the chemical industry	03-3297-2550	http://www.nikkakyo.org/
Japan ABS Resin Industry Association	Surveys, research and promotion of ABS resin	03-3234-4102	
Japan Urethane Industries Association	Safety and environmental issues concerning urethane raw materials and foam products in general	03-3504-1828	http://www.urethane-jp.org/
Japan Vinyl Goods Manufacturers Association	Surveys and research on stretch film, agricultural vinyl and wallpaper, etc.	03-5413-1311	http://www.vinyl-ass.gr.jp/
Japan Plastic Industry Federation	Trends, standards and legislation regarding the plastics industry	03-3586-9761	http://www.jpif.gr.jp/
Japan Industry Union of Plastic Houseware Manufacturers	Plastic houseware manufacturers	03-3561-8778	http://www.jpm.or.jp
Nippon Plastics Effective Utilization Union	Recycled product producers	03-3297-7514	http://npy.web-tab.com/
Japan Polyolefin Film Industry Trade Association	PE and PP film related activities	03-3639-8936	http://www.pof.or.jp/
Japan Polypropylene Film Industry Association	PP film, OPP/CPP	03-3864-5060	
Japan Responsible Care Council	Self-regulation of environmental safety of chemicals	03-3297-2578	http://www.nikkakyo.org/
Japan Polystyrene Formed Industry Association	Manufacturers of expanded styrene sheet	03-3257-3334	http://www.jasfa.jp/
Japan Expanded Polystyrene Recycling Association	Recycling of expanded polystyrene (packaging, cushioning, fish boxes, fruit and vegetable boxes)	03-3861-9046	http://www.jepsra.gr.jp/
Japan Plastic Food Container Association	Sanitary management of plastic food containers	03-3561-8778	
Plastic Container and Packaging Recycling Promotion Council	Recycling and identification labeling of container and packaging plastics	03-3501-5893	http://www.pprc.gr.jp/
Association of PET Tray	Ensuring hygiene and safety of PET trays used for food, surveys and research on waste issues	03-5614-6566	http://www.pettray.jp/
Council for PET Bottle Recycling	PET bottle recycling	03-3662-7591	http://www.petbottle-rec.gr.jp/
Japan Hygienic Olefin and Styrene Plastics Association	Self-regulation of safety and hygiene of plastics used for foods	03-3297-7700	http://www.jhospa.gr.jp/
Polystyrene Paper Mold Processing Industry Association	Manufacturers of expanded polystyrene trays	03-5256-1890	
Ministry of Economy, Trade and Industry	Chemical Division, Economic and Industrial Policy Bureau	03-3501-4978	http://www.meti.go.jp/
Ministry of Economy, Trade and Industry	Recycling Promotion Division, Industrial Science and Technology Policy and Environment Bureau	03-3501-1737	http://www.meit.go.jp/
Ministry of the Environment	Minister' Secretariat Headquarters on Waste and Recycling	03-3581-3351	http://www.env.go.jp
Japanese Standards Association	Standards in general	03-3583-8005	http://www.jsa.or.jp/
Association of Plastics Manufacturers in Europe (APME),	EU plastics-related organization		http://www.apme.org
American Plastics Council (APC)	American plastics-related organization		http://www.plastics.org/

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Website: http://www.pwmi.or.jp

Environmental studies site for elementary and junior high school pupils (launched February 2004)
http://printed on recycled paper www.pwmi.or.jp/ch/index.html