

# Progress in the Technical Development and Dissemination of the Recycling of Waste Plastics

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## 1 Introduction

The recycling of solid wastes is the core challenge in establishing a sustainable society. Waste plastics, almost 10 million tons of which generates in Japan every year, decrease landfill capacity, and impose a burden on the environment, such as the emission of carbon dioxide as a result of incineration.

In response to this, over the 10 years since the Basic Act on Establishing a Sound Material-Cycle Society entered into force in 2000, a great deal of effort has been put in various fields such as containers and packaging, household electrical appliances, and motor vehicles to increase the recycling rates, based on the recycling law for each products. The Ministry of the Environment introduced resource recycling initiatives and outcomes in its White Paper, *“Annual Report on the Environment, the Sound Material-Cycle Society and the Biodiversity in Japan 2010,”* which involves a new chapter entitled *“The Socioeconomic System Driven by the Environmental Industry.”* The White Paper shows that the Japanese technologies for *“solid waste treatment”* leads the developed world, this chapter describes Japan’s new policy on the transfer of environmental technologies to other Asian countries facing solid wastes problems due to solid wastes to the rapid economic growth. Moreover, at the Asian 3R Promotion Forum, which was established in 2009, the overseas expansion of *“venous industries”* is being promoted.<sup>[1,2]</sup> In discussions by the Industrial Structure Council of the Ministry of Economy, Trade and Industry (METI), the advanced resource recycling systems of solid wastes in Japan was highlighted as one of the promising social infrastructures of worth exporting to developing countries because of the comparative advantages.<sup>[3]</sup> Those Japanese technologies have reached the stage at which we aim

to expand *“resource recycling industry”* to overseas through the technology innovations in some fields such as resource recycling of E-wastes and ELV.

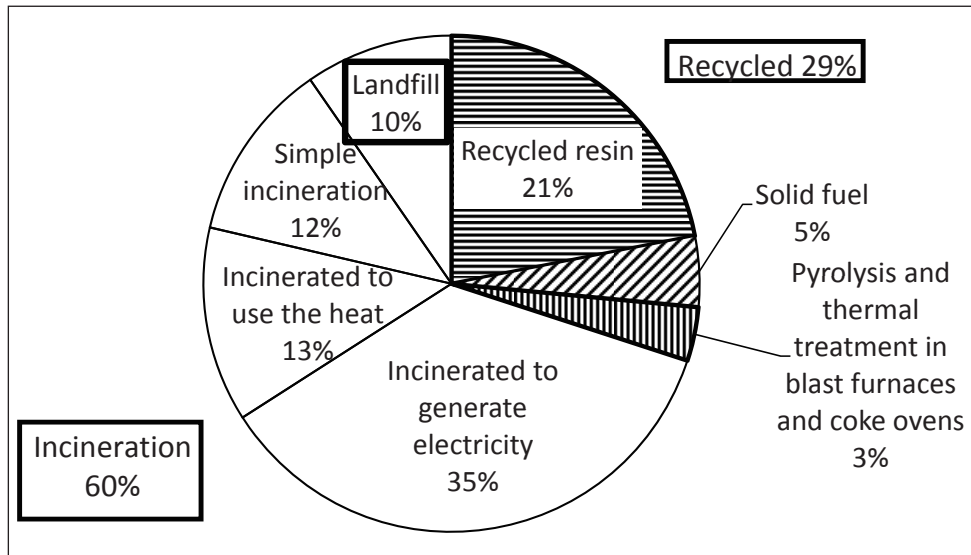
Amidst the growth in the recycling of various waste materials, the recycling of the most waste plastics is not economically feasible due to the complex composition and the high processing costs in comparison with those of metal and glass wastes. However, in the last 2 or 3 years, a upsurge in crude oil and material prices drives us to have the interest in waste plastics recycling. In particular, many companies focus on waste plastics as an important recycling business, similar to rare metals and scrap iron.

In *Science and Technology Trends*, the topics of the current status of recycling being undertaken by the materials industry<sup>[4]</sup> and technology for the recycling of resources from solid wastes<sup>[5]</sup> have been reviewed before. This article focuses on the recycling of waste plastics, which draw increasing interests in particular, due to the rise in material prices in recent years, and discusses the current situation, challenges and measures for achieving technical and social improvements.

## 2 The Current Status of Waste Plastics

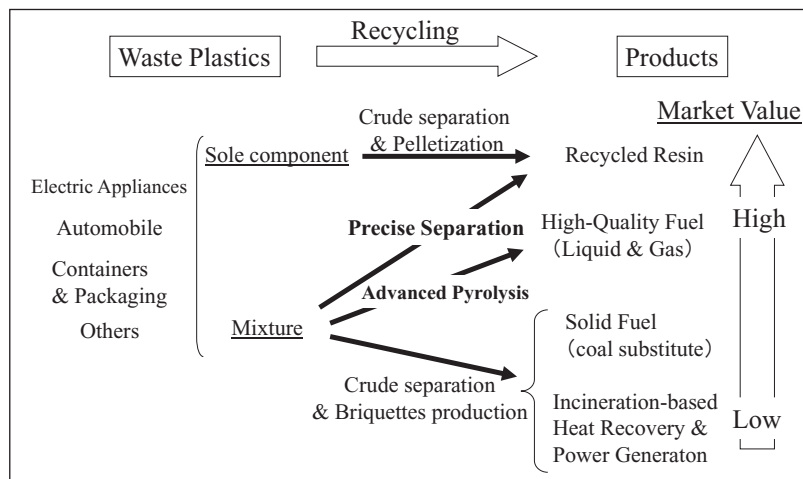
### 2-1 The Current Status of Waste Treatment and Recycling of Plastics

Around 10 million tons of waste plastics generate each year. About half of them is general waste arising from households and small-scale business sectors, and the other half is industrial waste. Based on the polluter pays principle, local governments are responsible for the treatment of general waste, while each company or facility has responsibility for the suitable treatment of the industrial waste by itself or a waste management



**Figure 1:** The Proportion of Waste Plastics Disposed and Recycled Using Each Method (2009)

Source: Plastic Waste Management Institute



**Figure 2:** The Selection of Waste Plastic Recycling Methods

Depicted by the STFC

company under contract. Figure 1 summarizes the proportions of waste plastic disposed or recycled using each method.<sup>[6]</sup> In this diagram, pyrolysis refers to gasification or conversion into oil.

The types of plastic and content of rejects, which are the substances unsuited to recycling, in the solid wastes vary greatly depending on the types of wastes such as Electrical and Electric Waste (E-wastes), End of Life Vehicles Directive (ELV), and other wastes from factories, logistics and consumers. The recycled plastics are used as inexpensive household commodities, industrial materials, and textile goods such as bedding. Moreover, solid fuel called RPF, which is a substitute for coal, can be prepared from waste plastics mixed with wood or paper, solidified. This is mainly used in coal boilers as a heat source in paper factories. In addition, waste plastics are also

recycled by means of pyrolysis, which is generally called feedstock recycling, or chemical recycling in Japan. Pyrolysis is thermal conversion of waste plastics into other types of compounds. Depending on the chemical properties and combustibility, the products are utilized as coal substitutes in coke ovens and blast furnaces at steel plants, synthetic gas production, and fuel oil production as petroleum substitutes.

In order to improve the recycling rate of waste plastics only around 30% at present, it is vital to adopt a new technological approach to mixed waste plastics. Moreover, with regard to the recycled products that currently manufactured, new technologies are also required to increase their market values.

## 2-2 The Selection of Waste Plastic Recycling Methods

Figure 2 summarizes the approach to the selection of processing and recycling methods for solid wastes containing plastics. The typical products derived from waste plastics are recycled resin and fuel. As long as there are no legal constraints on the wastes, the recycling method is selected on the basis of the properties of the waste plastic to be processed, the degree of difficulty of the recycling operation and the market value of the product (number of users or sale price). Even if there are legal constraints, the recycling method must be chosen carefully, with the aim of achieving a low environmental impact and a high recycling rate.

Recycling is feasible only when a solid waste contains enough amounts of valuable components, which can be converted into a suitable recycled product that has a market value. When the wastes contain different types of plastics that have low compatibility, the manufacturers of recycled products cannot accept those plastics as raw materials for recycling. In this case, fuel production can be the main option.

Recently, precise separation techniques for some types of plastics have been developed for commercial use, using electrostatic separation of mixed waste plastics, such as those in wastes of household electrical appliances, and the more waste plastic can be used as high-quality recycled resin by the new technique. The technological reliability of converting waste plastics into fuels in solid, liquid and gaseous forms has also been verified; in particular, the solid fuel is now popular as a boiler fuel, as a substitute for coal, primarily in the paper industry.

## 2-3 Problems in Recycling

### 2-3-1 The High Recycling Cost of Waste Plastics

Only 30% of waste plastics is recycled as shown in Figure 1. The typical reasons is no economic advantages in recycling for waste generators and waste management sectors. The other reason is higher recycling cost, while incineration and landfill are still conducted by local authorities and industrial waste processing businesses at the lower costs.

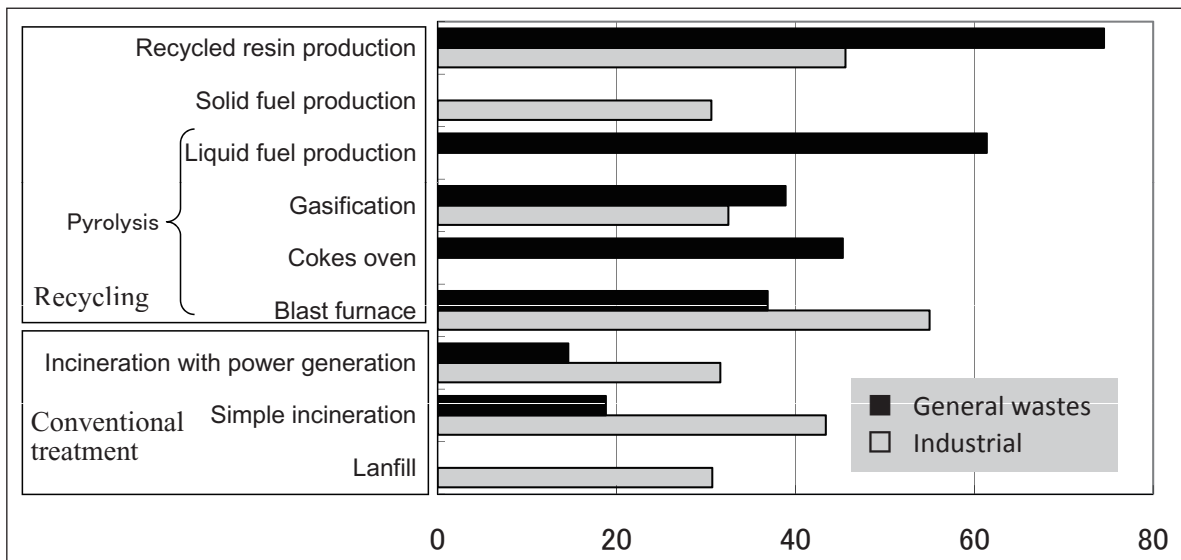
The Containers and Packaging Law prescribes the recycling of containers and packaging materials in household wastes, including PET plastic bottles, plastics other than PET (mixed plastics), glass bottles

and paper packaging. Of the 1,800 local authorities across Japan, 1,308 local authorities engage in the separated collection of plastic containers and packaging; of these, 1,017 have entrusted recycling to the Japan Containers and Packaging Recycling Association (JCPRA), a designated corporation stipulated in the Containers and Packaging Law, and the total quantity of mixed plastics has reached 600,000 tons (fiscal 2008). This means that a commensurate degree of resource and energy conservation has been steadily taking place each year.

The cost of the recycling consigned to recycling businesses by the JCPRA is as much as ¥41 billion annually (fiscal 2009), which is the total for mixed plastics, PET plastic bottles, glass bottles and paper packaging. Based on the principle of extended producer responsibility, as well as the polluter pays principle, these costs are borne by the companies involved with commercial products that use those materials, in other words, the various businesses involved in the manufacture of containers and packaging, and those involved in the manufacture and sale of commercial products that use containers and packaging, so ultimately the consumer bears those costs. In the total recycling costs of the JCPRA, mixed plastics accounts for 94%. Thus, the cost reduction of, especially, mixed plastics recycling is the major challenge and concerning the recycling law. Consumers and businesses involved with plastic goods have a strong desire for low-cost recycling techniques.

Figure 3 summarizes the quantity of waste plastics disposed and recycled by the cost required for each method in two categories: plastics in general waste and industrial waste. The average gate fee of industrial waste plastics is ¥40,000/ton.<sup>[7]</sup> In the case of plastics in general waste, the cost of incineration is generally low, due in part to the subsidies of the central government to incineration facilities of the local authorities. In contrast, recycled resin production from mixed plastics collected separately from households costs ¥74,500/ton, which is significantly higher than the production of recycled resin from industrial waste plastics, which uses waste plastics of the better quality as raw materials, and higher than other disposal and recycling methods.

In the consideration of the environmental effects and costs, intense debate has developed involving businesses of plastic-related products, recyclers, consumer groups, those associated with local



**Figure 3:** The Cost of Disposal and Recycling Waste Plastics According to Each Method  
No cost is shown in case of any appropriate data are not available.  
(¥1,000/ton)

Source: Prepared by the STFC based on the following sources: Recycling methods for mixed waste plastics of containers and packaging in general wastes, the Japan Containers and Packaging Recycling Association<sup>[8]</sup>; power generation from incineration and simple incineration, the Ministry of the Environment<sup>[9]</sup>; disposal and recycling methods of industrial waste, the Plastic Waste Management Institute<sup>[7]</sup>

governments and academics, concerning whether the prioritization of recycled resin production is an appropriate system, or whether it is acceptable to select a recycling method that prioritizes the cost: This debate also encompasses approaches to producer responsibility, the perspective of reducing social cost, and the expansion of business projects by companies adopting other low-cost recycling techniques.<sup>[10]</sup>

In the case of solid wastes arising from household electrical appliances and ELV, nobody is criticizing the high recycling cost comparing to that of mixed waste plastics from household containers and packaging. Waste treatment of household electrical appliances and ELV is conducted for suitable disposal of hazardous substances, processing of waste plastics, and resource recovery of valuable metal, which are relatively easy a technical and business perspective. These recyclers differ from the recyclers of containers and packaging in the cost-charging system for recycling. For the wastes of household electrical appliances and ELV, the manufacturers had been supported recycling companies and facilities equipped with suitable technologies for them. The social systems for waste collection and charging recycling fee were also implemented under the law. The limited numbers of the recycling companies in collaboration with the manufacturing companies were deployed appropriately according to the region or the generation amounts of wastes. This mechanism leads

to reduce the burden on local authorities and ensure a stable recycling business of the wastes. Moreover, the manufacturers can obtain the knowledge on the effective design of their products for resource recovery, based on the recycling experience in action under the cooperation with recycling companies.

### 2-3-2 The Difficulty of Selecting a Recycling Method

Waste plastics recycling aims to reduce the total amounts of waste plastics that are disposed by simple incineration and landfill, to utilize plastic components for the effective purposes, and to save the consumption of resources. In selecting a recycling method, rational judgments are required not only on the part of frontline waste management businesses, but also on the part of those prescribing methods in legislation, such as in the case of the recycling of plastic containers and packaging.

The relative merits of recycling methods can be judged on the basis of the quantity of recycled plastics that can be replaced as the resources consumed in society. Moreover, it is necessary to take into consideration the total energy input in the manufacturing process of those recycled products. Conventionally, this has been evaluated by means of the LCA (Life Cycle Assessment) or LCC (Life Cycle Costing) techniques.

For example, a plastic article by of virgin resin is

compared with that of recycled resin. It is easy to compare the relative merits of each manufacturing technique on the basis of the production efficiency of the manufacturing equipment, and the economic and environmental burdens of the electricity or fuel required for the production of the plastic article. However, apart from recycled plastic articles, products can be solid and liquid fuels, synthetic gas, and reducing agents for a steel manufacture. In order to compare the resource conservation effect of these different products, it is necessary to establish various calculation rules, and evaluation of each recycling method is not simple. Thus, various evaluation methods have been proposed to integrate a variety of criteria for each purpose.<sup>[11-13]</sup>

Table 1 shows the typical criteria for selecting a recycling method.<sup>[14,15]</sup> The table summarizes the ranges of the types of polymers that can be recycled, the recycling cost, the carbon dioxide emission reduction effect, and the types and prices of resources that these can replace.

In the case of the production of recycled resin, the raw materials are thermoplastics that do not contain any impurities or compounds that will spoil the color or physical strength of the resulting resin product. With regard to mixed waste plastics, it is essential to carry out high-speed, high-precision separation of foreign objects, which presents an obstacle in terms of the production efficiency and cost of recycling. In the case of waste plastics collected from specific production processes at factories, which have few impurities, the recycling cost is reduced because the process of separating foreign objects can be abbreviated. Furthermore, they have a high value, as they can be used as a substitute for expensive virgin resins.

Mixed waste plastics from household containers and packaging contain large amounts of foreign materials that cannot be separated. The recycling cost increases

and the commercial value of the recycled resin lowers as the result of the process of separating the foreign materials and generation of a large amount of the residue as a byproduct. Under the containers and packaging recycling law, the production of recycled resin from mixed waste plastics is carried out as an operational priority. Moreover, this law allows the recycling methods of processing waste plastics in coke ovens or blast furnaces, manufacturing solid fuels, gasification, and fuel oil production. The production of recycled resin and fuel oil both conserve petroleum, which are more exhaustible than coal, so one can envisage the relative merits of recycling methods that take this fact into consideration.

Solid fuel production is the recycling method to make use of the high calorific value of waste plastic with biomass of low calorific values. The calorific value of the resulting fuel is equivalent to that of coal. The recycling cost is about ¥25,000/ton. Wooden biomass has a limited end-user application because of the low calorific value. Solid fuel of waste plastics with biomass meets the demands from the more fuel consumers. Biomass combustion is not included in carbon dioxide emissions, so there is a big carbon dioxide emission reduction effect if the solid fuel users increase. The solid fuel has an economic effect as a substitute for coal. A current price of the solid fuel is about ¥3,000/ton, which is cheaper than the average coal price of ¥10,000/ton.

Using pyrolysis, it is possible to obtain a liquid fuel that can be used as a substitute for heavy or light oil, as well as a gaseous fuel that can be used as a substitute for natural gas and LPG. Liquid and gaseous fuels are widely used in local communities, and their prices are subject to sharp fluctuations. Fuel production through pyrolysis accepts the broader range of raw materials containing dirties and impurities than recycled resin production. But because of the higher investment of system installation, as well as the need to ensure

**Table 1:** Examples of Criteria for Determining the Relative Merits of Recycling Methods

Recycling Technique	Good availability of recyclable raw materials	Recycling cost	Carbon dioxide emission reduction effect	Economic advantage as a substitute (examples of prices of substitutes,yen/kg)
Manufacture of recycled resin	△	△ (Separated wastes from factories) × (Recyclable plastic containers)	○ △	◎ ○ (Polyethylene and polypropylene 100 - 150)
Manufacture of solid fuel	◎	○	◎	△ (Ordinary coal 10)
Manufacture of oil via pyrolysis	○	△	○	○ (Heavy oil and light oil 70)

Prepared by the STFC

safety, the recycling cost is high (around ¥80,000/ton). With regard to pyrolysis plant for liquid fuel, small-scale plants were developed some 30 years ago, with a capacity of around one ton a day. Large-scale plants (with a capacity of up to 40 tons/day) were also developed and went into commercial operation. But the recycling business using large-scale plants struggle to secure the requisite amounts of waste plastic as a raw material, while the small-scale plants have poor profitability. The development of inexpensive and feasible techniques of effective de-chlorination and low-energy-consuming equipment with high heat-transfer performance are crucial challenges under about 5 tons/day capacity, which is estimated as a profitable line of business.

The next chapter provides a technical overview of advanced processes of recycled resin production and new pyrolysis processes.

### 3 The Progress of Waste Plastic Recycling Technology

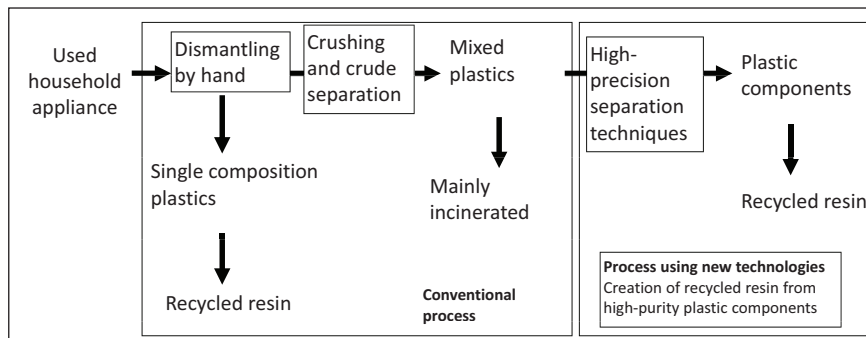
#### 3-1 Recycled Resin Production Technology That Facilitates Horizontal Recycling

Wastes of household electrical appliances are collected and recycled on the basis of the home appliances recycling law. The recycling rate is

stipulated for each item category – for example, in the case of air conditioning units, it is prescribed as at least 70% of the weight of the item – and, based on these provisions, the appliance manufacturer selects a product design and materials that make the product easy to recycle. Figure 4 provides an overview of the process for producing recycled resin from waste plastics obtained from wastes of household electrical appliances.

In the conventional recycling process of the wastes of household electrical appliances, the recycling rate prescribed by the law was achieved by means of recycling metals of a high product value and manual dismantling of waste plastics. Clean waste plastics on visual examination were then used to produce recycled resin. Moreover, the plastics that were generated in a mixed form could not be recycled, so they were disposed of by such methods as incineration. The recycling rate prescribed in the home appliances recycling law is increased as required, so in order to achieve the stipulated recycling rate, recycling companies have been engaging in ongoing efforts to achieve high-precision material collection and to expand the applications of the items collected.

To date, electrical equipment manufacturers – irrespective of whether they are manufacturers of household electrical appliances or electronic and



**Figure 4:** Schematic Processes for Producing Recycled Resin from Waste Plastics Obtained from the Wastes of Household Electrical Appliances

Prepared by the STFC

**Table 2:** Typical Separation Techniques for Waste Plastics<sup>[16,17]</sup>

Technique	Major type of equipment	Principle
Size separation	Trommel separator and vibrating screen	Crude separation by the size of wastes.
Specific gravity	Air classifier, fluidized-bed separator, and specific gravity separator	By the function of separation media such as water, sand and air, waste separation is performed by its specific gravity.
Spectroscopy	Optical separator	Waste separation by optical detection of spectroscopic difference followed by air-jet sorting.
Static electricity	Electrostatic separator	Depending on the types of plastics, positive or negative charged particles are obtained. These charged particles fly differently in an electric field to be sorted in the different storage chambers.

Prepared by the STFC

electrical instruments – have constantly striven to achieve stringent cost reductions in regard to each and every component. In particular, they are actively working on the use of waste plastics, which are not easily impacted by fluctuations in oil prices. A number of household electrical appliance manufacturers have collaborated with plant manufacturers and various recycling companies in order to develop new separation and sorting techniques for the various kinds of plastics of which mixed waste plastics are composed, and the commercial use of finely-separated recovered plastics by recycling businesses has begun to spread. Not only can the recovered plastics be used as low-performance components, where it does not matter if there are issues with their physical properties or external appearance (cascade use), but they have also opened up the way to so-called horizontal recycling, where they are used in crucial components and exterior materials where a high level of performance, such as strength, is required.

Mixed waste plastics conventionally had few applications other than heat recovery by incineration. Electric appliance manufacturers have the information on the types and amounts of materials in the wastes, and recycling companies know the effective processes of dismantling and resource recovery. Consequently, a substantial quantity of recycled resin of a certain quality level will be secured if a new separation techniques appropriate to the composition of the mixed waste plastics is developed instead of the conventional separation processes, .

Table 2 shows the typical separation techniques for waste plastics. Air classification is an effective crude separation technique for separating waste plastics from mixed waste of different sizes and shapes. By separating and recovering specific types of plastics from the mixed wastes, it is possible to obtain high-value recycled resin. And wet specific gravity separation and spectroscopy have been used.

A new technique using electrostatic separation for powdered plastics has now been developed. This makes it possible to separate some types of plastic materials more precisely.

When a charged plastic powder is put into an electrical field, it flies to different directions depending on the type of plastics, thereby making it possible to separate them. The electrostatic separator was developed using this principle (Figure 5).

This equipment consists of the following three

functional areas:

- 1.Area I: Plastics were crushed less than 10mm and separated into up to two types using specific gravity separation. The resulting plastic power undergoes triboelectric charging followed by a constant feeding to the rotating drum.
- 2.Area II: In an electrostatic field charged with high-voltage direct current, the electrically charged plastic particles are separated by type.
- 3.Area III: The separated plastic particles enter separate containers.

Separation of polystyrene and ABS is a typical example of this technique. Waste plastic from household electrical appliances firstly undergoes air classification and specific gravity separation; then, the polystyrene separated from the mixture of ABS resin and polystyrene with a recovery rate of 88% and a purity level of 99%. Moreover, with regard to the recovery of ABS from more complex waste plastic mixtures, combining the conventional specific gravity separation with electrostatic separation leads to give ABS with a purity level of around 99%. This result means that the recovered resin can be used for the similar applications as virgin ABS resin.<sup>[18]</sup>

From 2011, Mitsubishi Electric Co. has announced that will increase the consumption of recycled resins for their products from the current level of 6% to 70% of annual generation amounts, 10,000 tons, of the waste plastics. The company introduced this technology in a new recycling factory, and it opened in June 2010, with a primary focus on recycling plastics from the wastes of household electrical appliances.<sup>[19,20]</sup>

### 3-2 Conversion into Solid Fuel

Converting waste plastics into fuel is a recycling technique that can be used with mixtures that cannot be used as recycled resin. The key properties required of the fuel are a high calorific value and clean exhaust gas. Solid fuel is easy to produce from combustibles such as wood and plastics that does not contain chlorine or nitrogen. In order to reduce carbon dioxide emissions, the use of biomass as fuel is being promoted. However, wood-based biomass only has about half of the calorific value of plastic by weight. By mixing it with waste plastics and solidifying the resulting mixture, it is possible to create a solid fuel that has a calorific value equivalent to that of coal,

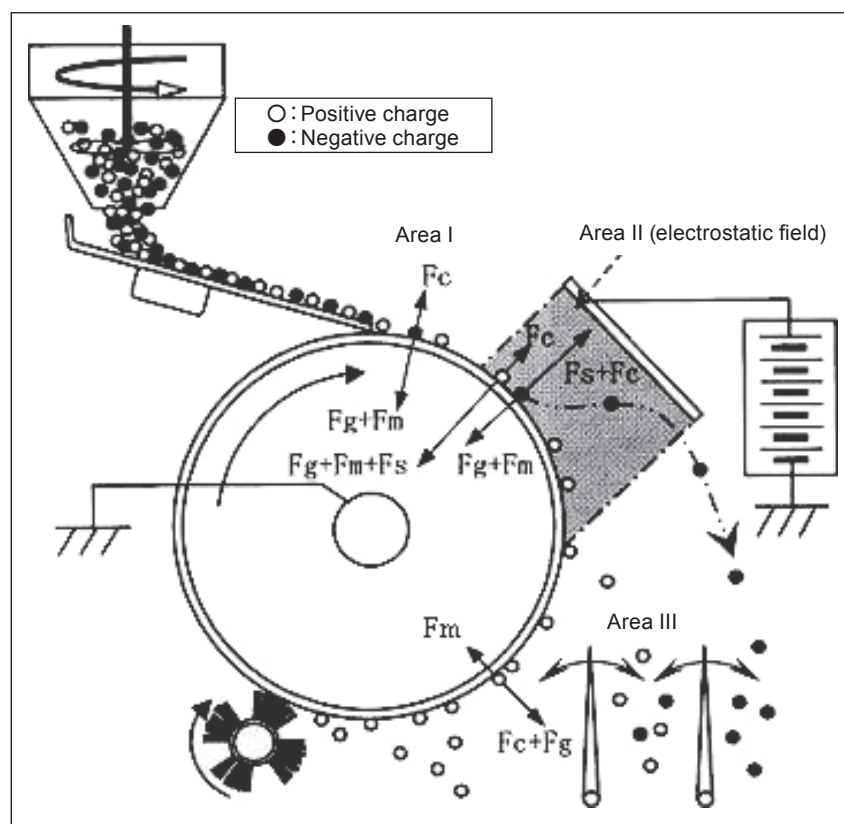
so its use has become popular among large-scale fuel users, such as paper factories that require a large quantity of low-priced fuel. Unlike heat recovery by incineration, fuel production provides the convenience to heat users in the points of transportation and heat supply at any time. However, depending on the composition of the raw material, boilers undergo corrosion or the exhaust gas at combustion contains hazardous substances. Consequently, at present, its use is limited to coal boilers equipped with exhaust gas cleaning systems.

### 3-3 Pyrolysis for Manufacturing High-Quality Fuel

In terms of their calorific value by weight, liquid or gaseous fuels obtained through the pyrolysis of waste plastic are of the higher value than solid fuels. The typical important task in the development of new pyrolysis technologies is the removal of the waste components yielding hazardous exhaust gas, such as chlorine, during the pyrolysis process with respects to the production of high-quality fuels. In particular, in the case of the waste plastics generated by households, plastics containing chlorine are often mixed in with

other plastics. The technical measures to remove it is a typical reason for the rise in the cost of fuel oil production. Chlorine contamination in the feedstock in fuel oil production causes the formation of hydrogen chloride when heated, which corrodes equipment, and they combine with coexistent olefinic hydrocarbons yielding organochlorine compounds. Dioxins will be generated upon combustion of such fuel. Rigid articles of polyvinyl chloride can be separated comparatively easily by means of specific gravity separation or optical sorting (spectroscopic method). However, in practical terms, it is difficult to remove chlorine-containing plastics because of the cost problems like introducing separation equipment, and difficulty in the effective separation of wrapping film containing chlorine (mainly polyvinylidene chloride).

In October 2010, a waste management company in Fukuoka Prefecture began the commercial operation of a small-scale pyrolytic oil production plant focused on separated waste plastics from households; the system has a capacity of 5 tons a day and can simultaneously dechlorinate the plastics and convert it into oil. Figure 6 provides schematic flow of the



**Figure 5:** The Principle of Electrostatic Separation Devices  
The forces working on the plastic particles,  $F_c$ ,  $F_g$ ,  $F_m$ , and  $F_s$  indicate centrifugal force, gravity, image force and electrostatic force, respectively.

Source: Reprinted with permission from materials published by Hitachi Zosen Corporation<sup>[18]</sup>



commercial plant. The thermal process was basically developed by the University of Kitakyushu. It involves the treatment of plastics in the presence of calcium hydroxide and waste FCC catalysts, which was used in oil refining.<sup>[21]</sup> Whereas typical pyrolysis takes place at 500 – 550°C, plastics undergo catalytic decomposition in the process at the comparatively low temperature of around 400°C. Moreover, it reduced the residual chlorine in the pyrolytic oil to 120ppm, which is less than 1/5.

For the efficient decomposition, FCC catalyst was used in this plant. This plant is the first commercial oil production facility to use a paddle mixer system, which has excellent mixing efficiency, comparing with a tank-shaped reactor in the conventional commercial oil production.

Moreover, by using this type of device, it has become possible to achieve the effective reaction of the hydrogen chloride generated from plastic containing chlorine with calcium hydroxide, thereby preventing the generation of organochlorine compounds in the hydrocarbon oil. In tests using a processing capacity of 10kg/h bench plant, it was possible to maintain the dechlorination rate at more than 99% where plastic used as the raw material had a chlorine content of 20%, which is far in excess of the chlorine content of plastic in separated general waste (1 – 3%). The more analytical data concerning the residual chlorine in pyrolytic oil in long-term operations are awaited.

Pyrolytic gas obtained from waste plastic is considered as a high-quality fuel comparing with solid and liquid fuels because it gives highly clean exhaust gas upon combustion. In the project of developing technologies for the detoxification of asbestos, gasification of polyethylene containing asbestos was demonstrated, and the resulting gaseous fuel was used as a fuel to melt asbestos in the demolition wastes containing asbestos. The demonstration research was carried out by using a plant of 1 ton per day capacity on the premise of commercial gasification plant with a capacity of 10 tons per day. By combining it with a melting accelerant, it was possible to melt asbestos at 750°C, which usually requires a temperature of at least 1500°C to melt.

As shown in Figure 7, the plant used in this study was an external-heating rotary kiln with a circulating bed. In this plant, asbestos in demolition wastes and the plastic sheets that generate in large quantities from asbestos removal work undergo melting treatment,

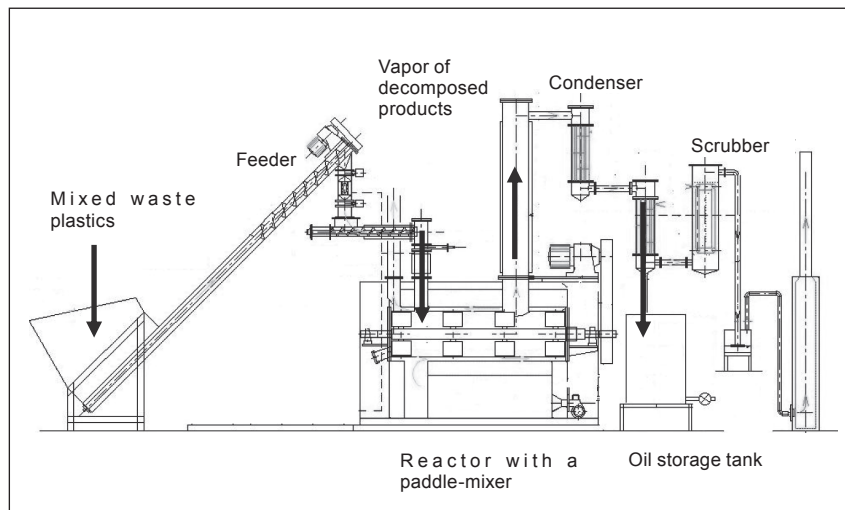
and waste plastics of mainly polyethylene are gasified effectively. Furthermore, this system uses the resulting pyrolytic gas as a fuel for melting asbestos and the gasification of plastics.

The wastes processed in this method are mixed briquettes of demolition waste containing asbestos (50% by weight), waste polyethylene (47.5% by weight) and melting accelerant (2.5% by weight). By heating the briquettes in an external-heating rotary kiln at approximately 750°C, pyrolytic gas generated from the polyethylene. This was then supplied to the rotary kiln and used as a fuel. LPG was supplied at the initial heating stage, then, after the generation of pyrolytic gas was confirmed, LPG supply was stopped.

No asbestos was detected in the solid residue, pyrolytic gas, the exhaust gas from combustion, and the pyrolytic oil that generated in small quantities as a byproduct. The combustion heat of the pyrolytic gas was in excess of the calorific value required to heat the demolition wastes and generate pyrolytic gas from waste plastic. It was clear that this system is self-sufficient in energy.

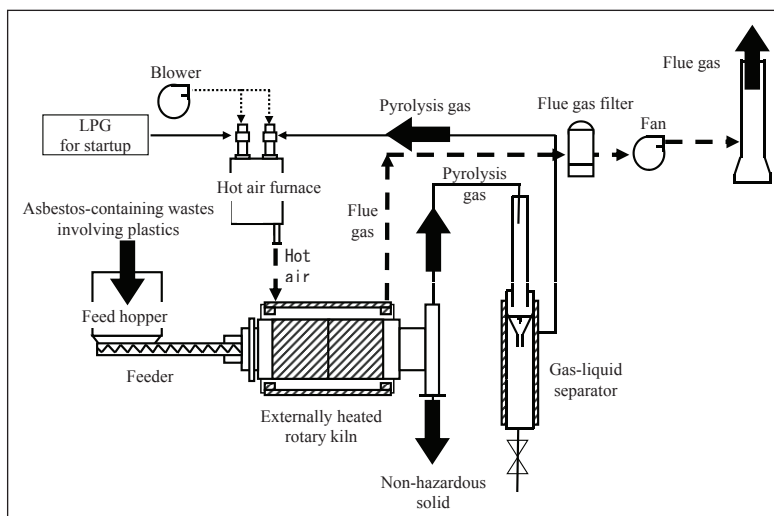
The composition of the pyrolytic gas was as follows: hydrogen 26.0, methane 25.4, ethylene 21.4, carbon monoxide 5.7, and carbon dioxide 4.7 (% per unit volume). The remaining gas that is not used to heat the plant can be stored and be used for other purposes, such as for power generation using a gas engine.

The conversion technology for producing chemical feedstock focuses on using waste plastic as a source of hydrogen or a hydrocarbon resource, rather than as a liquid or gaseous fuel.<sup>[24]</sup> The new gasification system using a rotary kiln has an advantage in the operation at the lower temperature range 700 – 800°C, compared with examples of the conventional gasification technologies, such as the production of hydrogen or methane using a gasification melting furnace,<sup>[25]</sup> and the conversion of waste plastic to a synthetic gas with hydrogen and carbon monoxide as its main constituents using a two-stage gasification furnace<sup>[26]</sup> (both of which have a reaction temperature of 1300 – 1500°C).



**Figure 6:** Schematic Diagram of the High-Efficiency Pyrolytic Oil Production System Using Waste FCC

Source: Edited from materials provided by ECR Co., Ltd.



**Figure 7:** Schematic Diagram of an Asbestos Melting Plant Using Gas Fuel from Waste Plastics

Source: Edited from materials provided by Street Design Corporation

## 4 Towards the Dissemination of Waste Plastic Recycling

### 4-1 A Technology Strategy Aimed at Expanding Recycling

The Technology Strategy Map (2010 edition)<sup>[27]</sup> details the research and development strategy of the METI. It lists a wide range of technologies, as 3R technologies for the future, including the recycling of waste plastics, environmental-friendly product designing for re-use and reduction of wastes, and the development of materials that place little impact on the environment. Figure 8 provides a summary of the development strategies for the leading recycling technologies listed in that publication. Based on the Technology Strategy Map, the future prospects of the technologies for recycling waste plastics can be

summarized as follows.

#### 1) Recycling using advanced separation processes and equipment

In the case of E-wastes and ELV, product design allowing easy dismantling and material separation should be implemented with a view to horizontal recycling, while mixed waste plastics that cannot be separated in conventional separation processes will undergo precise separation technologies to fulfill advanced resource recovery.

#### 2) Recycling using compounding technologies, such as adding an antioxidant and compatibilizing agent to improve polymer materials

Some additives are effective to increase their strength and durability, depending on the types of polymer and the degree of degradation, before undergoing horizontal recycling into high-quality

components or cascade recycling into low-grade components, according to their physical properties.

**3) Recycling using efficient pyrolysis processes and equipment**

When mixed waste plastics are not suitable to produce recycled resin, they are to be converted into liquid or gaseous products that can be used as a clean fuel or utilized as chemical feedstock.

**4-2 Innovation of Recycling Technologies According to the Properties of Waste Plastics**

Compared with other solid wastes such as paper, glass and metals, waste plastics have more differences in properties and composition depending on waste generation sources and types of applications of plastic products. Technological innovation should be oriented to recycle the wider types and compositions of waste plastics and improve the market values of recycled products. Moreover, in processing and recycling waste plastics, it is necessary to combine the reduction of the environmental impact with a decrease in the social and business costs.

In order to increase the recycling rate of waste plastics, it is important to recycle mixed waste plastics at a low cost and create products with a high market value. The high-precision separation and high-efficiency pyrolysis described in the previous chapter are effective technologies. In the case that a market value of the product commensurate with their cost cannot be obtained even if these technologies

are applied, then it is appropriate to select the option of solid fuel production or incineration for heat recovery or power generation. Mixed waste plastics from household containers and packaging are wastes containing a large amount of impurities and foreign components that are not suited to recycled resin production, such as chlorine, nitrogen or metal foil. Accordingly, new technologies that will lead to their effective use are required.

**4-2-1 Developing Advanced Separation Technologies**

As a domestic resource, recycling waste plastics will assist corporate activity by enabling it to resist soaring prices for fuel or materials, by improving the market value of recycled products and expanding the range of solid wastes that can be recycled. A great deal of high-performance plastics such as ABS and POM are contained in E-wastes and ELV, so it is important, when designing products, for manufacturing companies to give consideration on the easy separation at disposal; in addition, it is necessary for recycling companies to improve the recycling rate and to establish a closed recycling system for recovered plastics. This is a common challenge for recycling companies and manufacturing companies. Consequently, more advanced separation technology for mixed waste should be developed, and separation technology for plated items and lacquered and coated items are also important.

Technology category	Technology item	Development period			
		Short-term		Long-term	
		2010	2015	2020	2030
<b>Recycled resin</b>					
Separation and sorting technology	Separation and sorting by type of plastics from household electrical appliances and motor vehicles, etc. (horizontal recycling)	Existing resins		Adapting to new plastics	
	Removal of pigments from paint plastics				
Materials technology	Upgrading and regeneration technology for creating high-added-value products				
	Technology for detecting and restoring degradation			Self-renewal	
<b>Pyrolysis</b>					
Pyrolysis technology	Fuel conversion technology (manufacture of methane, hydrogen, etc.)				
	Technology for producing oil and chemical feedstock				
<b>Other</b>					
Containers and packaging measures	Development of advanced recycling systems				

**Figure 8: Development Strategies for Vital Recycling Technology for Waste Plastics**

Source: Compiled on the basis of the *Ministry of Economy, Trade and Industry Technology Strategy Map 2010*<sup>[27]</sup>

#### 4-2-2 Establishing Compatibilization Techniques

In contrast to precise separation techniques to obtain a sole component of polymer with the better physical properties from mixed waste plastics, compatibilization techniques is also effective. Suitable compatibilizing reagents promote to homogenize different types of polymers. If the polymers in waste plastics available cannot separate each other, adding a compatibilizing agent may satisfy the strength or other properties of the resulting recycled plastics.

It is important to develop compatibilization techniques for polystyrene and PET components from plastic containers and packaging, which are not soluble to polyethylene and polypropylene. There are many types of laminated plastic films used for packaging and some industrial purposes. It is necessary for plastic processing manufacturers such as compound manufacturers and converters to develop even more sophisticated compatibilization technologies.

#### 4-2-3 Developing Advanced Technologies of Pyrolysis for Producing Fuels and Chemical Feedstock

Pyrolysis is the basic technology for converting waste plastics into fuels or chemical feedstock. In the production of fuels and chemical feedstock of high quality that meet to the users' demands, a new technology for controlling plastic pyrolysis should be developed. In the previous chapter, new pyrolysis techniques were mentioned; fuel oil production under the catalytic decomposition using the reactor with a paddle mixer and the fuel gas production using the external-heating rotary kiln. The thermal conversion techniques of these two types of reactors use small-scale, low-cost equipment that handle just a few tons each day, which means that they have the prospect of being commercialized on a scale commensurate with the business scale of waste collection. Compared with pyrolysis using the conventional tank reactor, those reactors allow using a solid catalyst in structural terms. The advanced pyrolysis technology will enable the boiling range control of pyrolytic oil and the composition control of pyrogas, of which the fuel properties meet to the burners and engines of fuel users.

The production of liquid and gaseous fuels from waste plastics has been added as an accreditation category under the Japanese J-Ver credit system,<sup>[NOTE]</sup> which aims to reduce carbon dioxide emissions.<sup>[28,29]</sup>

The accreditation, will acceralate the use of high-grade fuel from waste plastics, and promote the progress of pyrolysis technologies for producing substituted fuels for petroleum, LPG and natural gas.

For chemical feedstock production from waste plastics, it is believed that waste plastics are not suited to purposes that involve the use of large quantities in mass production, such as the petrochemical industry because the amounts of generation and collection of waste plastics in local communities are limited. However, it is worth considering applications where they are used in small quantities as feedstock for functional chemicals, including paints and additives.

#### 4-3 Creating Systems for Supporting Recycling Business

Each of the central government, local authorities, and the companies involved in the manufacture and use of plastics has a responsibility and an important role to develop new technologies and expand the scope and limitation of recycling, such as high-precision separation and pyrolysis, which aims at improving recycling rates, as well as minimizing social costs of recycling through optimization of legislations and social systems considering the actual status of waste generation, technologies, the user applications of recycled products, and the economics.

For example, mixed waste plastics from household containers and packaging had been a underutilized resource, which was not recycled in the market economy. The Central government has to establish legislation and systems to implement the policy of the effective utilization of the waste resources. Selecting a recycling method involves complex issues, such as the trade-off between reducing the environmental impact and conserving resources and energy, and the social costs thereof. The promotion of the development of a resource recycling industry is also involved.

The MOE and the METI hold deliberations by stakeholders and experts, and is conducting various studies concerning the latest developments overseas, soliciting public comment from a wide range of

#### [NOTE]

The offset credit (J-VER) system was enacted in November 2008 in order to provide accreditation for the quantity of domestic greenhouse gas emissions reduced or absorbed that can be used as carbon offset credits.

people, including individuals and citizen groups to build social consensus.

The resource recovery and recycling from wastes is a system technology that combines multiple elemental technologies, while it is also an effort to organize a social infrastructure surrounding multiple stakeholders. Individual companies or local authorities have limited ability to the utilization of waste resources. The generation of waste spans all sectors, including ordinary civic life, commerce and industry, distribution, construction and demolition, and agriculture and fisheries. It is necessary for the central government to take the initiative while further promoting recycling projects in which companies, the government and local citizens collaborate. Resource recycling will progress only when the effective utilization of recycled products is encouraged across industry sectors. The authors propose that the central government, research sectors, and industry supporting organizations cultivate and support new technologies in the field of waste treatment and recycling, in the same way as they do for manufacturing technology. Furthermore, in order to promote technology dissemination of waste treatment and recycling and improve the efficiency, the government and local authorities should provide the appropriate support linked to the frontline of waste processing and recycling businesses and the communities concerned.

The processing and recycling of the waste of household electrical appliance and ELV has been established by the intensive efforts of the manufacturers, which are generally large companies and have financial ability to fulfill their social responsibilities. But there are many small and medium-sized enterprises in containers and packaging, and miscellaneous daily goods sectors, as well as overseas companies. Moreover, the waste generators and stakeholders, who is responsible for wastes recycling, are widely distributed in many business sectors and distribution and retail

businesses, and also general consumers. Unlike in large manufacturers and the associated companies in electric and electronic, and automobile industries, the development of waste processing and recycling technology for plastic containers and packaging, dairy goods, and other plastic articles is beyond the reach of the abilities of waste management businesses and recycling companies, due to the scale and financial power of the companies concerned. It is necessary for local governments and public testing laboratories to develop highly practical technologies through collaboration with plant manufacturers and waste management businesses.

Technologies for the processing and recycling of wastes of household electrical appliances and ELV were already in practical use. The related manufacturing companies readily fulfill their social responsibilities. Some technologies are even at the stage at overseas technology transfer. Many useful polymer materials have been developed in conjunction with progress in the field of organic chemistry and materials engineering, but we still rely on incineration and landfill once they become waste. Hazard data concerning new compounds are reported using material safety data sheets (MSDS). The authors would like to propose that, when developing new materials, plastic material manufacturers also devise appropriate, low-cost processing and recycling techniques that have a low environmental impact. These technologies have the potential to give rise to new business opportunities. The authors also suggest that petrochemical and plastics manufacturing companies in the upstream of the material flow of plastics, as well as academic and research institutions will take the initiatives at developing advanced technologies that will enable local authorities and companies within Japan and overseas to implement low-cost, environmentally effective recycling and utilization of the recycled products.

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