

Waste Recycling Technologies Required by a Sound Material-Cycle Society

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1 Introduction

Realization of a recycling based society in harmony with the environment is stated as one key policy issue in Japan's Third Science and Technology Basic Plan. There is a close and inseparable relationship between the waste problem, which has attracted considerable interest in recent years, and a sound material-cycle society.

Accompanying the flow of material in diverse social activities and everyday life, large quantities of waste are generated. Efficient removal and treatment/disposal of this waste is an essential urban service in the modern age. With changing times, the main purpose of these activities has also changed to securing public sanitation, protecting the environment, and forming a recycling based society. From Japan's annual material balance (fiscal year 2004), it is estimated that approximately half of the country's material input, which exceed 1.9 billion tons, is accumulated as buildings and infrastructure facilities.^[1] Buildings, urban structures, and the like, which form this type of stock, all eventually become waste.

Reducing the generation of waste, which is the first priority in the concept of the 3Rs (Reduce, Reuse, Recycle), is a response at the so-called upstream side of the material flow, and is the basis of waste countermeasures. On the other hand, on the downstream side, a response that satisfies both treatment of the wastes discharged each day in the course of everyday life and production activities and, simultaneously, recycling of materials and energy, is also important for the formation of a recycling society. Thus, an approach which involves both reducing the generation of wastes

and, in parallel, reuse and recycling would appear to be realistic.

Furthermore, today, as global warming countermeasures are being accelerated in all fields, reduction of carbon dioxide (CO₂) emissions by actively utilizing biomass, etc. is an urgent matter. Because much of the biomass in Japan is waste-type biomass, efforts related to waste treatment are demanded. In addition, circulating use of resources also plays a major role in reducing consumption of virgin natural resources.

Based on the conditions outlined above, this paper describes directions for the development of waste treatment when given the mission of forming/realizing a sound material-cycle society, and considers waste recycling technologies for the near future and related problems by examining actual examples.

2 Trends in waste and waste treatment technologies

2-1 Quantitative and qualitative changes

(1) What is waste?

Waste can be defined as unnecessary substances or impurities. Concretely, however, it is a byproduct of industrial and agricultural products, and as such, is a material. The quantity and quality of waste change in response to the economic conditions of the times, human lifestyles, the introduction of new products, and similar factors. Figure 1 shows the changes in the amount of discharges of general waste (municipal solid waste: MSW) and industrial waste resulting from the totality of these factors. Quantitatively, MSW has shown little change since 1995, but has increased approximately 20% since 1975. The amount of

waste discharged per person (unit discharge) was around 1,000g/person-day before 1985, then increased to around 1,100g/person-day after 1990, and has declined since 2001. (Between 1985 and 2000, the increase in waste discharged was greater than the increase in population.) Here, it should be noted that unit discharge includes commercial and general household waste; the unit waste discharged purely by households is roughly 700-800g/person-day. On the other hand, industrial waste increased substantially between 1985 and 1990,

but showed no large changes thereafter. Currently, approximately a half of annual discharge amount of 400 million tons is utilized after recycling.

As one index expressing the qualitative features of waste, Figure 2 shows the trend in the heating value of waste (MSW). Although the heating value of waste shows different values depending on the local government treating the waste, it increases consistently over time. This seems to be attributable to increased use of paper, plastic materials in packaging, and similar factors.

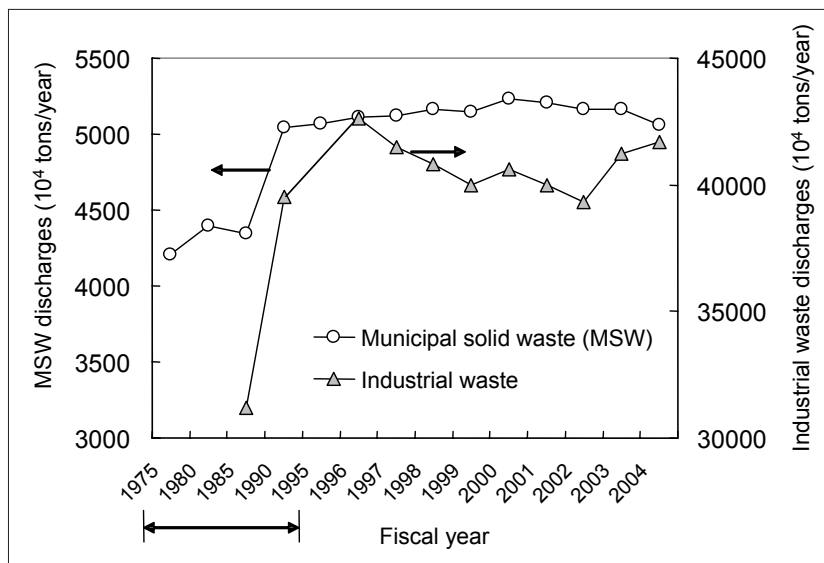


Figure 1 : Change over time in amounts of municipal solid waste (MSW) and industrial waste (Data for 1975-1995 are for 5 year intervals).

Prepared by the STFC based on Reference [1]

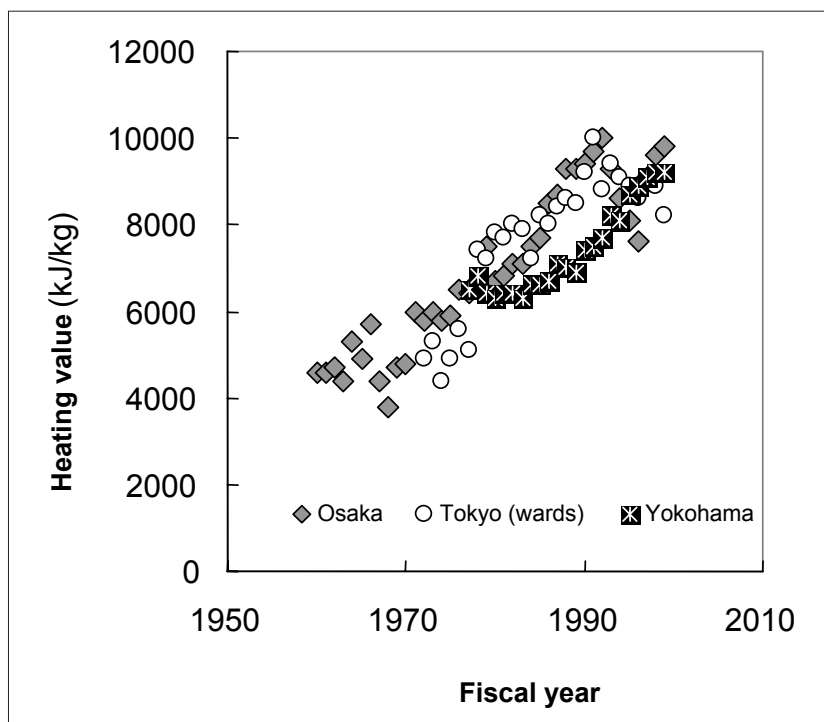


Figure 2 : Change over time in heating value of waste (lower heating value)

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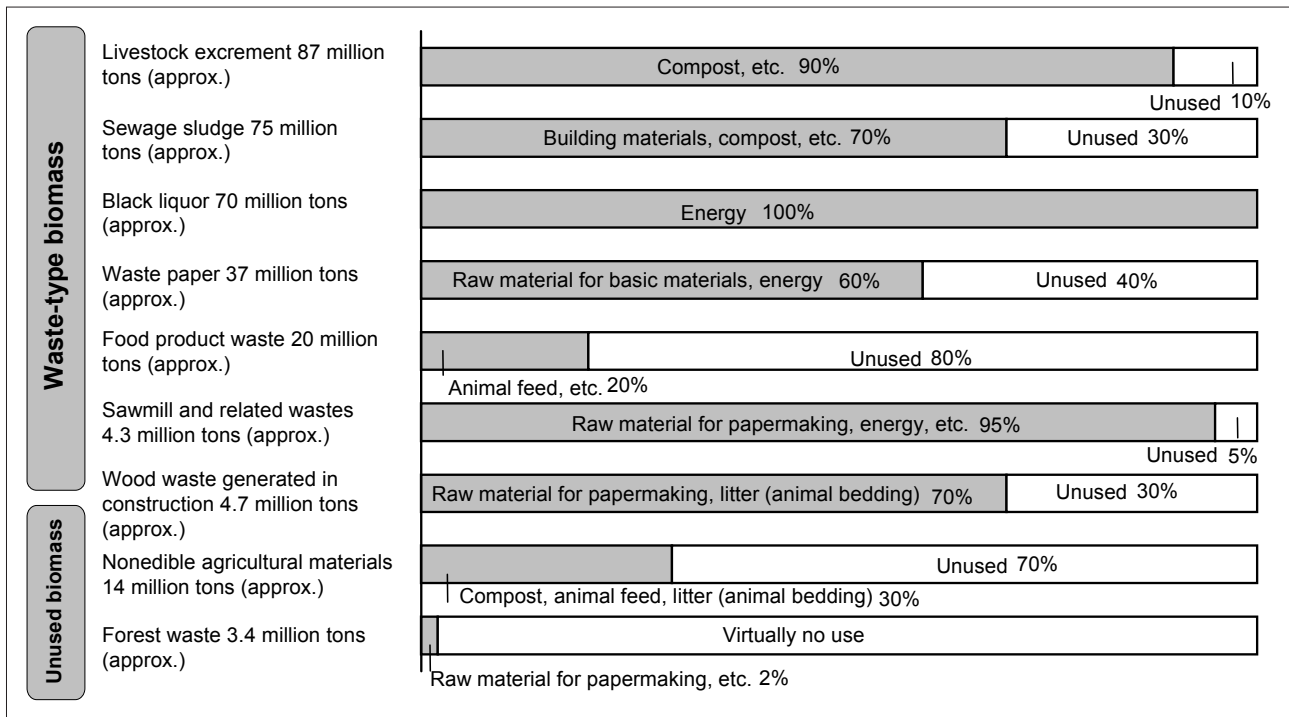


Figure 3 : Occurrence of biomass in Japan and breakdown of uses

Source: Reference [3]

(2) Biomass

Biomass is classified into three types: ① Waste-type biomass, ② unused biomass, and ③ dedicated biomass crops (crops grown specifically for use as biomass). At present, biomass occurrence quantity and its utilization (carbon equivalent) are put at 298 million tons of waste-type biomass, which has a utilization rate of 72%, and 17.4 million tons of unused biomass with 22% utilization.^[3]

Figure 3 shows rough values of the occurrence and utilization of various types of biomass. Depending on the item, waste-type biomass may be either biomass in the form of industrial waste or biomass including both MSW and industrial waste. Of these, the items with direct potential for circulating use include food product waste, waste paper, and construction-generated waste wood, all of which have comparatively high unused ratios, and sawmill waste and other scrap wood, although the latter have relatively low unused ratios. Excluding livestock excrement, which has a high moisture content and tends to be produced in limited geographical areas, and sewage sludge, which also has a high moisture content (unused amount: 22.5 million tons), the amount of unused biomass for the four above-mentioned items exceeds 32.4 million tons. However, even though some kinds of waste-type biomass are

currently used, effective and useful applications have not necessarily been developed. The annual occurrence of waste-type biomass is estimated at approximately 327 million tons on a wet-weight base and 76 million tons on a dry base. By energy conversion, this corresponds to approximately 1,270PJ (petajoule: 10¹⁵ Joule).^[4] By crude oil conversion, this is equivalent to approximately 32.8 million kiloliters, or about 5.6% of Japan’s total primary energy supply of 22,751PJ (FY 2005).

2-2 Transition of waste treatment technologies

(1) Transition of incineration treatment technologies

The direct purposes of incineration treatment are prevention of decay and stabilization by combustion treatment of waste at high temperature, and in combination with this, reduction of the weight and volume of the waste. Historically, however, the functions and roles widely required in incineration treatment have changed in response to the needs of the times, beginning with appropriate treatment for sanitation, followed by weight/volume reduction and reduction of environment impacts, and later by recycling. In recent years, the dioxin problem brought about a particularly large change. In line with the movement toward a sound

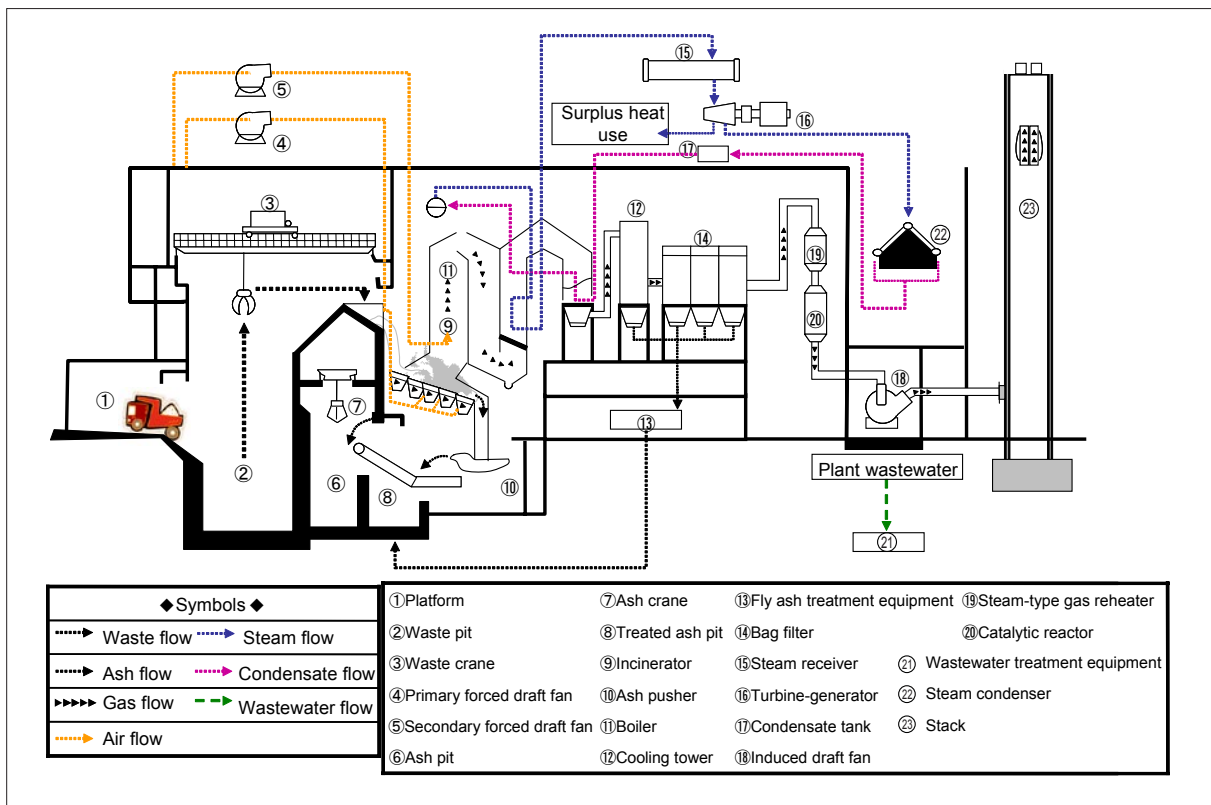


Figure 4 : Example of configuration of typical fully-continuous stoker-type incinerator

Source: Reference [5]

material-cycle society, heightened expectations were placed on resource recycling through the introduction of new methods such as the gasification and melting furnace and other technologies. The number of waste incineration facilities has gradually decreased, and was 1,320 as of the end of FY 2005 (March 31, 2006). This represented a decrease of 25% from FY 1998. However, this number is extremely large in comparison with other countries. In Japan, large-scale fully-continuous facilities like that in the example in Figure 4 account for 40% of the total number of incineration facilities and more than 80% of treatment capacity. This type of large-scale facility includes a diverse range of equipment in addition to the actual incineration furnace, such as flue gas and wastewater treatment equipment, residue (ash) handling equipment, and power generating equipment, and the number of units of equipment is larger in these facilities. Technically, complete implementation of the 3Ts of Temperature, Time (residence time), and Turbulence (adequate mixing and stirring) is promoted by a variety of technical innovations, including improvement of the secondary combustion air injection method, advanced control using artificial intelligence, etc.

Incineration is extremely effective for the purpose of treating waste. However, it is also necessary to treat the incineration ash and fly ash generated in the incineration process. These substances are equivalent to approximately 10% and 3% of the incinerated waste, respectively. In case of landfill disposal of these substances, securing landfills and chemical treatment to prevent leaching of harmful substances contained in fly ash become problems. Other issues include improving the recovery efficiency of metals, improving power generating efficiency, which is generally low at present, etc.

(2) Influence of the dioxin problem

The dioxins include the 4-8 chlorides of the polychlorinated dibenzoparadioxins (PCDDs), the 4-8 chlorides of the polychlorinated dibenzofurans (PCDFs), and among the polychlorinated biphenyl (PCBs), dioxin-like PCB, which has properties similar to the PCDDs and PCDFs. These substances are environmental pollutants having the following features: In general, these substances are characterized by long-term persistence, high accumulation, and various types of toxicity. While they have diverse environmental effects in extremely low concentrations, reliable

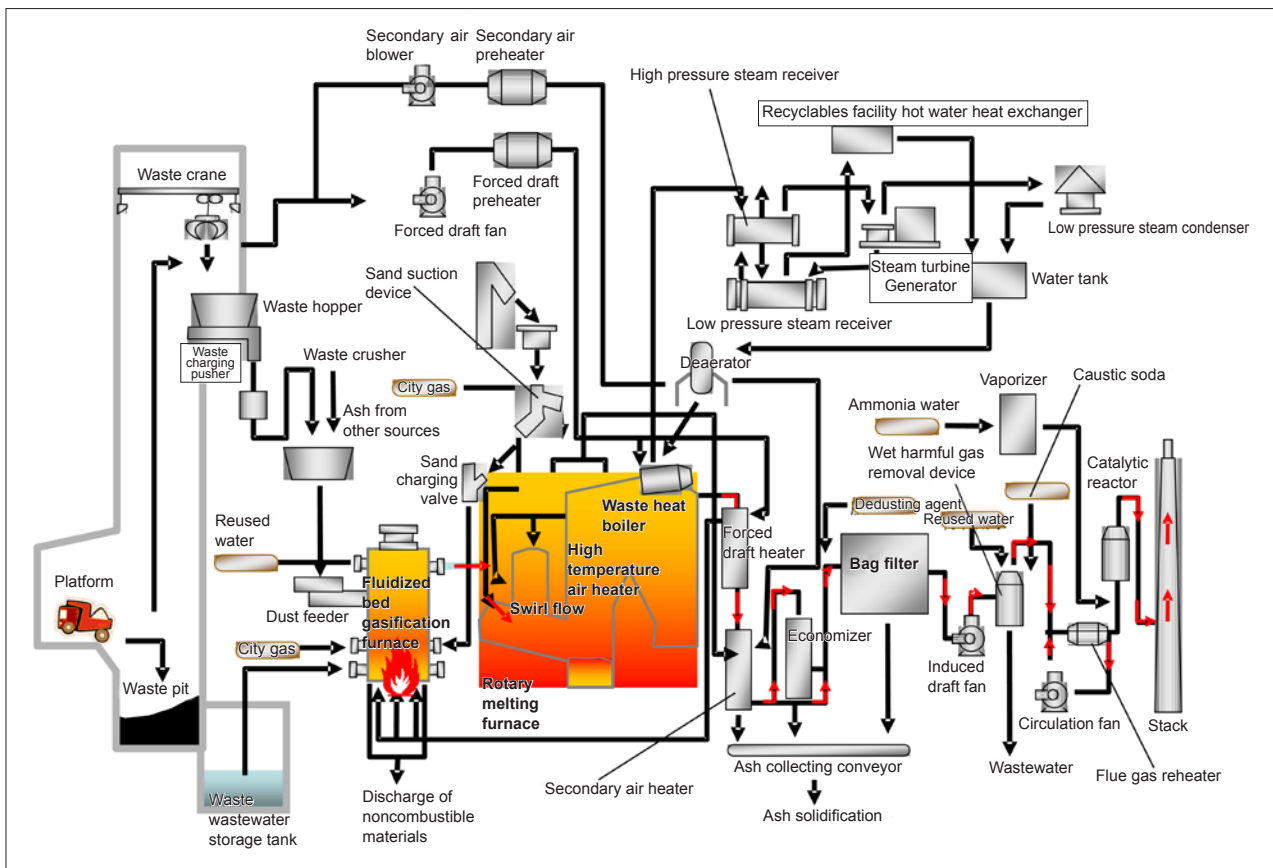


Figure 5 : Example of typical gasification and melting plant (In case of fluidized bed gasification type)

Source: Reference [5]

prediction is difficult. Because dioxins were discharged unintentionally from routine waste treatment processes, including also discharges accompanying the use of agricultural chemicals in the past, the pattern of penetration into the environment was different from that of conventional industrial pollution. The dioxins became an extremely large problem in Japan from around the mid-1990s. Subsequently, this had a direct effect on improvement of the element technologies of incineration treatment processes, including improvements in technologies, such as improvement of combustibility and higher efficiency in power generation, improvement in flue gas treatment technologies, such as changing dust collecting equipment to the bag filter, and others. This problem gave impetus to the implementation of regional waste treatment in an effort to reduce dioxins and recycle resources by regional collection and treatment of general waste in areas spanning several municipal units (cities, towns, and villages), and also led to a review of the conventional easy dependence on incineration and encouraged efforts to create a recycling society.

The following section will describe gasification and melting technology, which had a large influence.

(3) Melting treatment and the gasification and melting furnace

The aforementioned dioxin problem encouraged the development and introduction of gasification and melting furnaces (Figure 5) advanced. The features of this technology are as follows:

- ① Dioxins can be reduced by high temperature combustion at 1,300-1,400°C in the melting process, and as a result, discharges can be minimized.
- ② Because a reducing atmosphere is used in the gasification process, recovery and effective utilization of the metal content in the waste is possible.
- ③ Because the excess air ratio is low, the amount of flue gas is reduced. (The “excess air ratio” is the ratio of the actual amount of air to that theoretically necessary for combustion). As a result, compact flue gas treatment equipment and other auxiliary equipment can be used, and power generating efficiency is improved.

- ④ If the heat contained in the waste is adequate, melting can be performed using the heat of the material being treated alone, thereby eliminating the need for supplementary energy inputs from external sources. In addition, the costs of construction and maintenance control are lower than with a combination of a general stoker furnace and ash melting furnace.

The process referred to as melting in gasification and melting is one that causes perfect combustion at high temperature. Gasification and reforming is a more advanced process, in which the composition of the gas is reformed by controlling the atmosphere, etc. under high temperature in a similar manner, producing a gas, such as carbon monoxide or hydrogen, which has use value as an energy source or feedstock for chemical synthesis processes. Gasification and reforming is a stage of technology that has been applied to waste incineration facilities in a small number of cases.

2-3 *Transition to a sound material-cycle society and the flow of technology*

(1) **Formation of a sound material-cycle society**

Conventional waste treatment was performed so as to avoid environmental impacts, but was limited to a one-way type of treatment and disposal. However, in recent years, there has been a common recognition in society that reducing CO₂ emissions as a global warming countermeasure and recycling use of materials and energy are important issues. This thinking has revolutionized the conventional concept of waste treatment. As a result, improvements have been made to actively promote recycling and recovery of energy and resources in incineration treatment itself, as described in section 2-2.

On the other hand, in countermeasures for harmful substances contained in waste, technical progress has been achieved from the viewpoint of reducing the spread and the risks of chemical substance extending to the global scale, for example, in countermeasures based on the Stockholm Convention on Persistent Organic Pollutants (POPs), which took effect in May 2004. The treatment of PCB is a typical example of this. Similarly, the development and introduction of treatment/disposal technologies is also progressing. Examples include technologies for the mercury contained in batteries, fluorescent tubes, and other

products, asbestos contained in many products, beginning with building materials, and infectious waste, among others.

From the viewpoint of contributing to the 3Rs, there are technologies which aim at reducing waste by improving efficiency in the use of raw materials, etc. and extending the life of products, and technologies which aim at reuse, as seen in parts for copying machines. Where recycling is concerned, the development of design techniques which improve ease of disassembly during recycling and improve the potential for recycling of resources may be mentioned.

As a technology for recycling, in other words, recovery and use, various technologies have been developed for waste PET bottles and waste plastics, which are classified as container and packaging waste. The technologies that have been developed include material recycling, in which the waste plastic is processed again into molded products, "bottle-to-bottle" recycling, in which waste PET bottles are reused as raw material for new PET bottles, a method in which waste plastic is used as a reducing agent in the blast furnace, and a method in which waste plastic is thermally decomposed in the coke oven, producing oil and coke oven gas for use as industrial raw materials.^[1] Technologies related to these items are described in detail in the following Chapter 3. However, in recent years, the amount of waste exported to China and other countries has increased, as represented by PET bottles. Under these circumstances, there is concern not only that this trend will make it impossible to make full use of the excellent recycling technologies which Japan possesses, but also that the sound material-cycle society as a whole will suffer.

Three general indexes may be mentioned in connection with the aims in constructing sound material-cycle society systems. These are resource productivity (= GDP/Inputs of natural resources, etc.), the circulating use ratio (= Circulating use / (Circulating use + Inputs of natural resources, etc.)), and final disposal (amount of final disposal in landfills). The targets up to the FY 2010 are to increase resource productivity to approximately ¥390,000/ton, improve the circulating use ratio to approximately 14%, and reduced landfill disposal to approximately 28 million tons.^[1] The following

may be mentioned as conditions required in waste recycling technologies for the formation of a sound material-cycle society: The technology in question must ① reliably accomplish appropriate treatment of waste (effectiveness and practicality of treatment), ② be capable of efficiently producing an energy source or material as a recycled product (effectiveness and practicality of recycling process), ③ have appropriate cost and energy consumption for recycling (economy), ④ be capable of minimizing environmental loads (low environmental load), and ⑤ produce a recycled product that can be effectively utilized (utility of the recycled product). Although concrete indexing should be carried out prudently, it can be thought that an easily understood evaluation of technologies will be required.

(2) Technologies using biomass

In Japan, the Biomass Japan Comprehensive Strategy was adopted by a resolution of the Cabinet in December 2002. Internationally, the Kyoto Protocol has come into effect, making implementation of effective global warming countermeasures extremely urgent, while the rapidly rising price of crude oil has led to a deeper recognition of the necessity of reducing dependence on fossil resources. These various factors have heightened interest in biomass energy. In March 2006, the Biomass Japan Strategy was revised.^[6]

In the revised Strategy, concrete targets for the realization of “Biomass Japan” are arranged from the technical, regional, and national viewpoints.

From the technical viewpoint, the revised strategy sets targets in connection with conversion efficiency or raw material price for direct combustion and gasification plants as technologies for converting low-moisture biomass to energy, for methane fermentation and other technologies as technologies for converting high-moisture biomass to energy, and for the production of biomass-derived plastics as technologies for converting biomass to products.

Based on this, the Ministry of the Environment has made technologies in connection with bioethanol and biodiesel an object of priority technical development. The Strategic Technology Roadmap 2007 (STR) published by the Ministry of Economy, Trade and Industry (METI) includes a roadmap for the 3Rs field. Biomass-related technologies are shown under “Other main 3R technologies” other than metal resource 3Rs, as shown in Figure 6.

According to Figure 6, the main development targets for biomass utilization are fermentation technology applying the function of microorganisms, fuel conversion technology based on thermochemical principles, and higher efficiency in existing power generation. In biomass recycling technologies, the key issues are considered to be improvement of methane and ethanol fermentation technologies, development of hydrogen fermentation technology, high efficiency gasification, conversion to liquid fuels, and the like. In the following chapter, these items will be examined concretely.

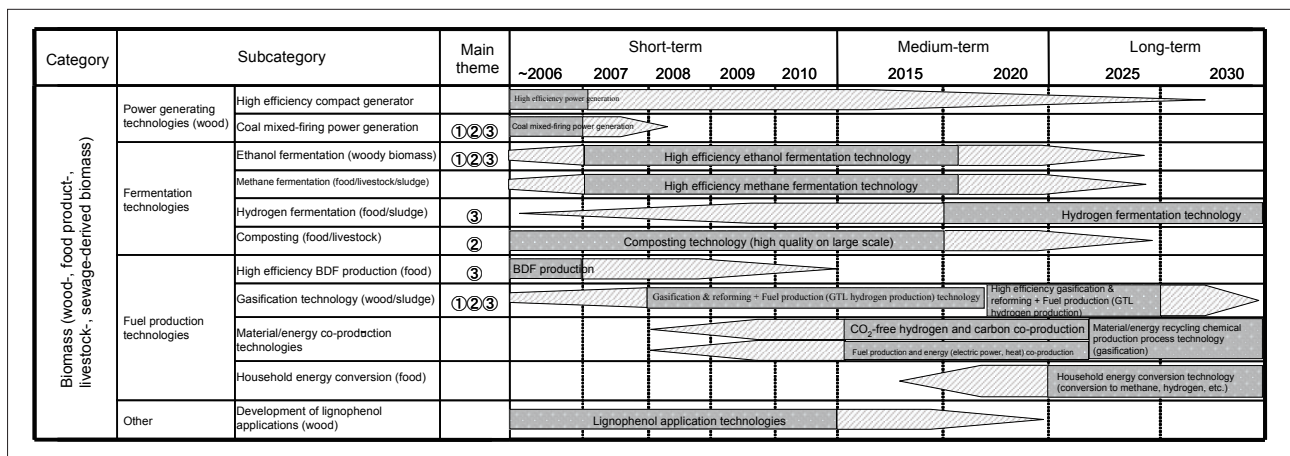


Figure 6 : Strategic Roadmap of individual biogas technologies prepared by METI

Source: Reference ^[7]

Table 1 : Comparison of waste recycling technologies

Evaluation item	Technologies using microorganisms	Gasification technologies	High temperature/high pressure fluid technologies
Main object substance	· Wet biomass, mainly foods: 20 million tons/year (approx.)	· Dry biomass, mainly wood, paper, etc.: 16 million tons/year (approx.) (general waste: 50 million tons)	· Food, animal residue, and other wet-type wastes. Application to wood-derived biomass is also studied. Applicability to toxic wastes is a feature.
Recycled product	· Biogas, mainly methane · Hydrogen · Biomass plastics	· Hydrogen, CO · Methanol · Liquid fuels	· Intermediates such as raw material for methane fermentation, etc., chemicals.
Technical principle and evaluation of system	· Hydrogen fermentation, methane fermentation, ethanol fermentation, lactic acid fermentation by biological systems · Systemization of gasification and incineration	· Pyrolysis, gas reforming (from high temperature to low temperature) · Systemization using gas engine generator, fuel cell, etc. · Systemization with ethanol production and liquid fuel production	· High speed, high efficiency reaction with special fluid. · Systemization with methane fermentation, gas reforming, etc.
Cost	· Same as conventional technology; however, advantageous if effective utilization of recovered energy is possible.	· Low temperature processes are advantageous because energy requirements are reduced. · Possible to reduce total cost by using pyrolysis char as heat source.	· Use of subcritical water is more advantageous than supercritical because required heat and energy for pressurization are lower.
Outlook for practical application and problems	· Some facilities. Because sorting is not easy, expansion to MSW treatment facilities is a problem. · Reduction of price of plastic products	· High temperature facilities exist. However, low temperature processes and systemization with liquid fuel are future developments.	· Some facilities. Problems include resistance of materials to high pressure, corrosive environment.

Prepared by the STFC.

3 Waste recycling technologies required by a sound material-cycle society

3-1 Outline and comparison of technologies

Table 1 presents an outline and comparison of the waste recycling technologies which provide the conditions desired in a recycling based society and are considering promising for the future. The respective technologies will be described in the following sections.

3-2 Technologies utilizing biofunctions (1) Biogasification

Food waste (garbage) and food product waste have become one focus as resources with comparatively low circulating use ratios. From the viewpoint of biomass-type circulating resources, food waste, wood chips, sludge, livestock excrement, etc. account for approximately half of the amount of waste generated. Because these substances have high contents of moisture and organic matter, their circulating use ratio is 16%, and the reduction ratio of weight by incineration and dewatering is limited to 53%. At present, many examples of circulating use are in the field of agriculture, where these substances are used as fertilizers and animal feed. However, there are

questions about these methods of use whether they are optimal.

Given these circumstances, methods of biogasification of food waste and waste paper by methane fermentation and recovery of methane gas are under study. Methane fermentation of thick organic waste, sewage sludge slurry, and similar wastes is a technology with a long history of use and does not involve any technical novelty. However, in application to solid wastes with relatively low moisture contents, various improvements will be necessary in the future.

In methane fermentation processes, liquid and solid residues are produced after the gas is recovered. For this reason, appropriate treatment/disposal of these substance considering the environment is desirable. The liquid residue is a highly concentrated waste liquid after fermentation, which is called digestion sludge. Because the reduction ratio of sewage sludge and similar wastes has an upper limit of 40-50% with the current technology, it is necessary to increase the decomposition ratio of the organic component and improve energy efficiency.^[8] On the other hand, where the solid residue is concerned, reduction by incineration with other combustible wastes is one direction for improving efficiency. Figure 7 shows an example of an analysis of the energy recovery effect when biogasification and incineration

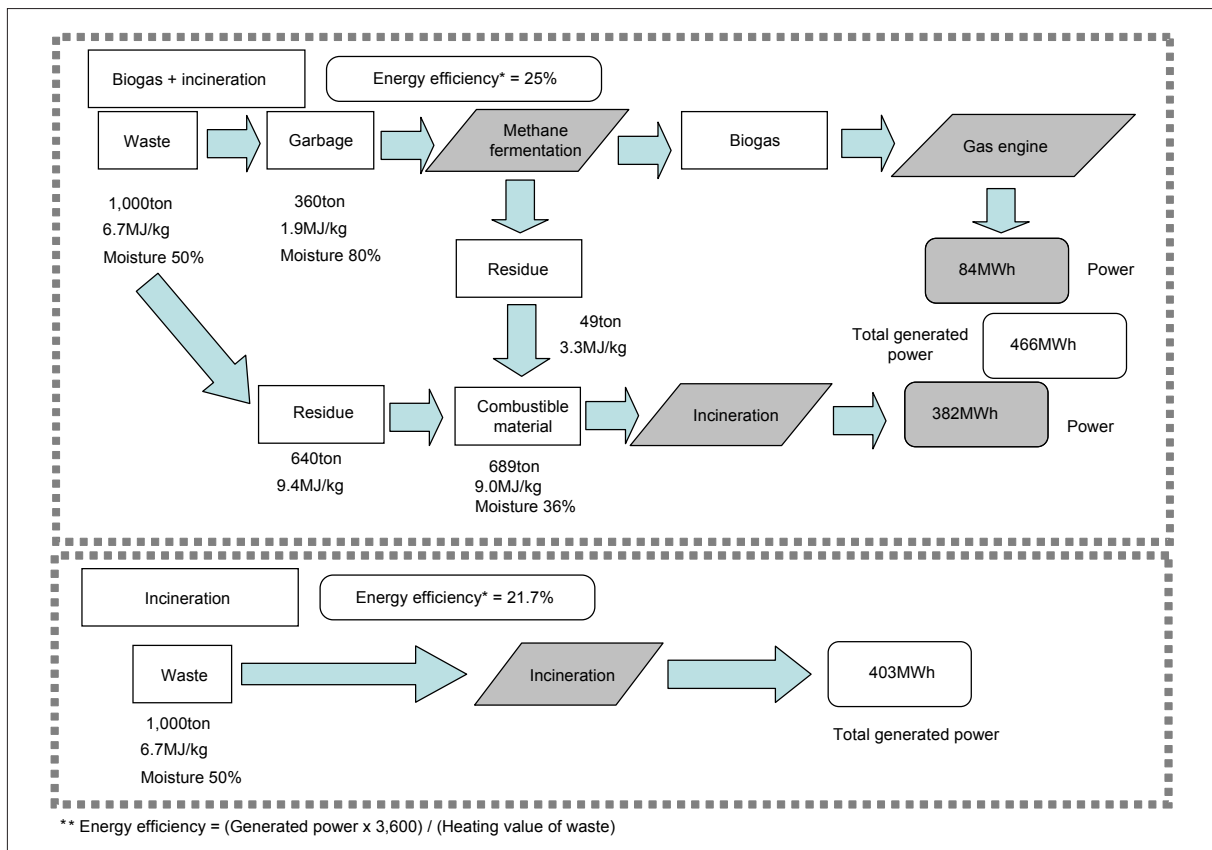


Figure 7 : Example of trial calculation of energy recovery effect by methane fermentation process

Source: Reference^[9]

are combined. Because power generation using the heat of both the biogas and incineration can be performed using advanced, high efficiency equipment in this method, energy recovery can be performed effectively by a system simply combining power generation with incineration. Examples of introduction can already been seen in private-sector waste treatment facilities. In an example in which the energy balance was calculated for the case of incineration of 100% of waste and a case in which part of the food waste was sorted and used in methane fermentation under certain conditions (assuming that the biogas is used for power generation with a gas engine), it was estimated that the amount of generated power increases by approximately 16% in the case with partial gasification.

However, where incineration is concerned, it goes without saying that adequate countermeasures for air pollutants, beginning with dioxins, must be adopted.

(2) Hydrogen fermentation and ethanol fermentation

In the Strategic Technology Roadmap in Figure

6, development of hydrogen fermentation in fermentation technologies is predicted as a mid- to long-term technology. This appears to be based on the assumption of an emerging hydrogen society.

In processes in which organic compounds are subjected to methane fermentation under anaerobic conditions, hydrogen is generated in the acid fermentation stage. For example, in case glucose is used as the fermentation substrate, $C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 4H_2 + 2CO_2$. Representative bacteria which form hydrogen under anaerobic conditions include the Clostridium species, Enterobacter species, and others.

Because hydrogen fermentation is normally a transition process, it is unstable. To obtain a stable recovery rate, it is necessary to provide environmental conditions for culture within the optimum range. Thus, the key to development aiming at improvement and practical application of hydrogen fermentation technologies is considered to be one of the following:

- ① Achievement of long-term sustained hydrogen recovery using mixed microorganisms by optimizing its environmental conditions.
- ② Isolation of a microorganism with a high

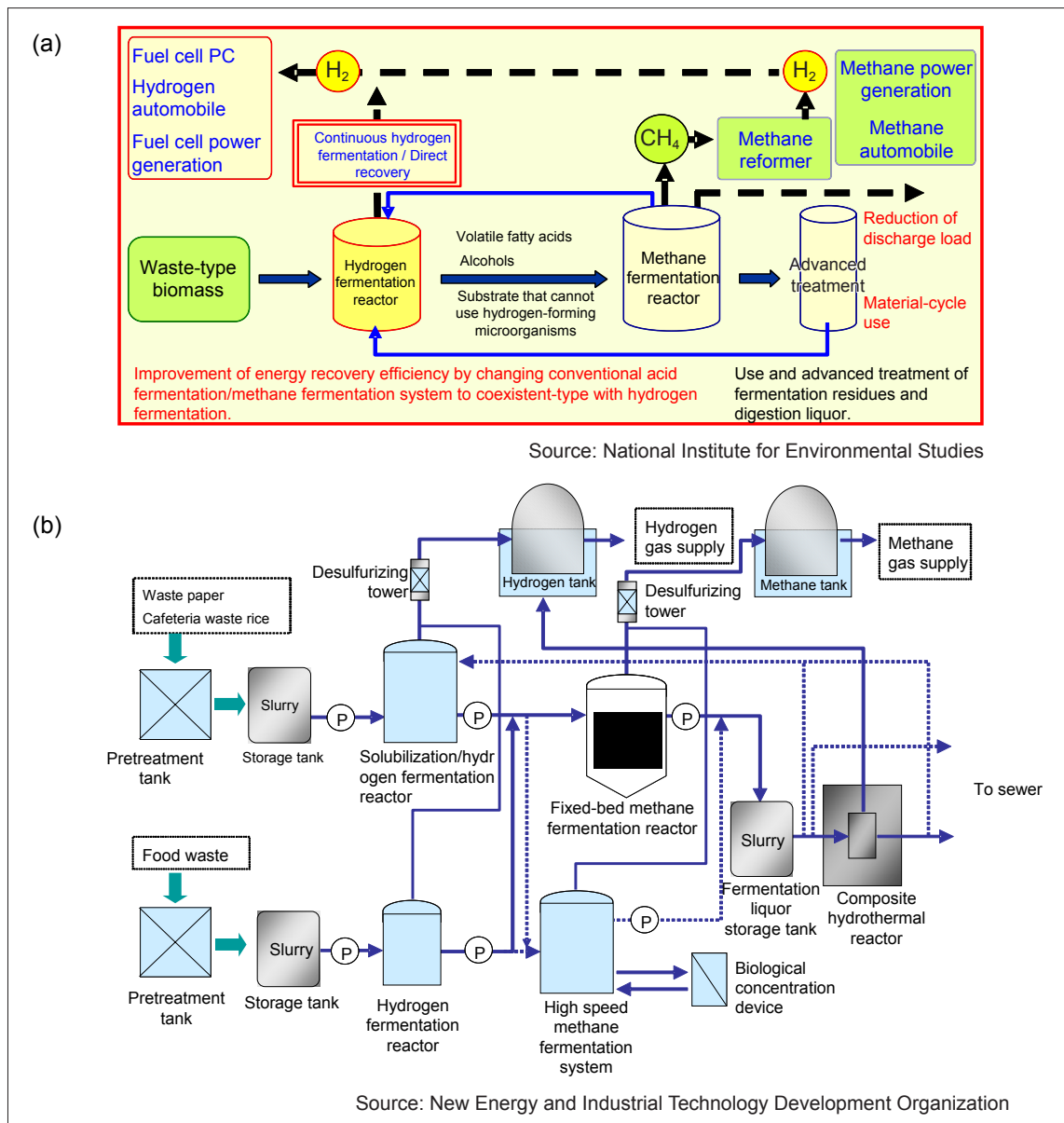


Figure 8 : Examples of the development concept of hydrogen/methane 2-stage fermentation process
 (a) Development concept proposed by NIES (b) System configuration proposed by NEDO

hydrogen fermentation capacity and effective utilization of its capacity.

Accordingly, research and development are being carried out in connection with fermentation technologies which promote hydrogen formation from mixed microorganisms with high efficiency and the related recovery processes, or the search for microorganisms with a high hydrogen-forming capacity. Examples of main large-scale research projects^[10] include “Technical development of 2-stage fermentation technology for organic wastes centering on high efficiency hydrogen/methane fermentation” (FY 2001-2005), which was carried out by private-sector companies and the National Institute of Advanced Industrial Science and Technology (AIST), under the

leadership of Japan’s New Energy and Industrial Technology Development Organization (NEDO), the “Development of Kuzumaki Town advanced use cogeneration system,” carried out under the leadership of Tohoku University, and the technical development project “Development of hydrogen production technology using bioresources/waste, etc.” (FY 2003-2007) of the National Institute for Environmental Studies (NIES). In addition to these, there are also numerous examples of research on hydrogen-forming bacteria by other research institutes and private companies.^[11,12] Figure 8 (a) and (b) show the development concept of the hydrogen/methane 2-stage fermentation process developed by NIES and the configuration of a system of 1/10-1/100 scale of actual size by

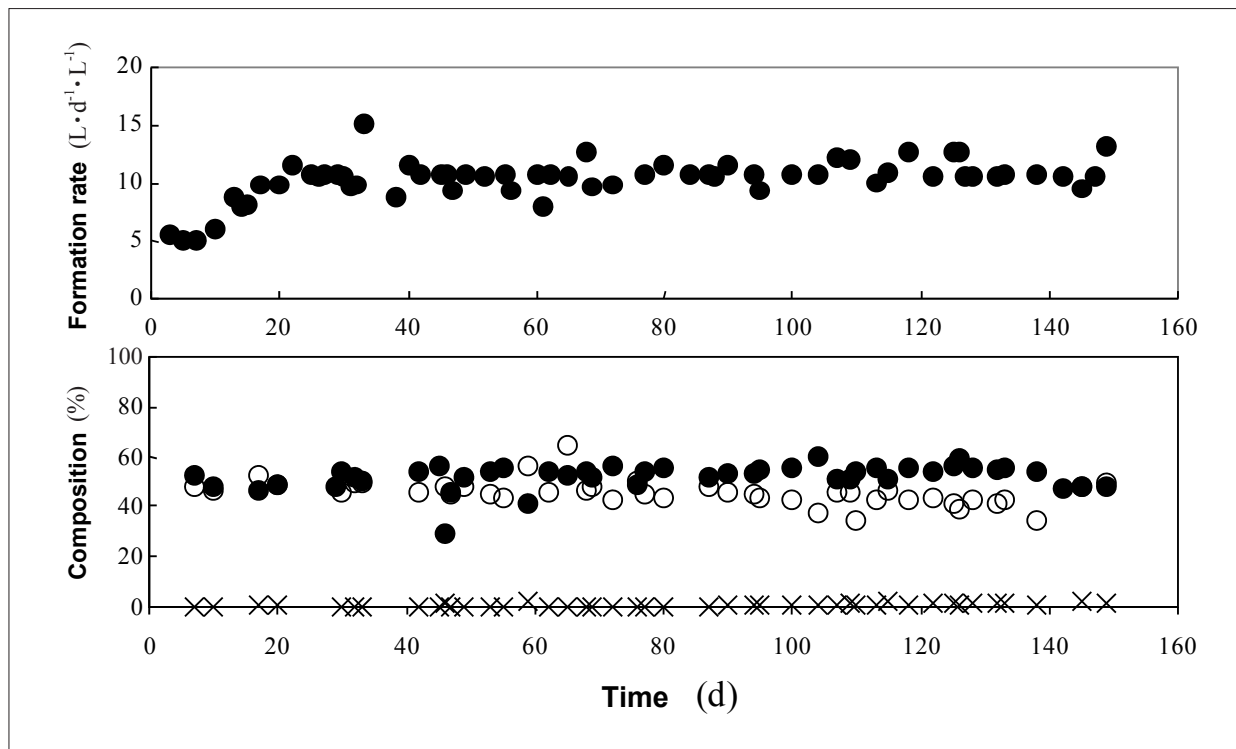


Figure 9 : Generated gas composition and hydrogen formation rate (velocity) in long-term test of hydrogen fermentation reactor (●: H₂, ×:CH₄, ○:CO₂)^[13]

Source: Reference^[13]

NEDO. As features of the technology developed by NIES, the aims include recovery of hydrogen and methane, and simultaneously, removal of the eutrophication salts such as nitrogen and phosphorus. Figure 9 shows the results of a continuous hydrogen recovery test conducted over a 150-day period using food waste from a cafeteria as the raw material. Hydrogen gas with a concentration of approximately 50vol% was obtained continuously. This test also clarified the fact that maintaining a substantially constant pH in the system by returning the digestion sludge after methane fermentation to the hydrogen fermentation reactor is an important condition.

Where ethanol production from biogas is concerned, because the target for introduction of so-called eco-fuels has been set at 500,000kl by crude oil conversion (equivalent to approximately 0.6% of all fuels used in transportation in Japan), active technical study of bioethanol, biodiesel fuel (BDF), liquefied biomass fuel (biomass-to-liquid: BTL), and other fuels is underway. Japan is also targeting production from waste-type biomass. An ethanol production plant using waste wood from the building industry as the raw material began operation at a scale of 1,400kl/year in Osaka Prefecture in January 2007. In this process,

waste wood which has been collected from the neighboring area is crushed, followed by hydrolytic degradation by dilute sulfuric acid under pressure. As a particular feature, the process utilizes a bacterium which enables use of hemicellulose together with cellulose, which is a sugar (hemicellulose is a type of short-chain sugar).^[14] In Okayama Prefecture, a pilot test is being conducted on ethanol fermentation using a special yeast with unused waste wood from sawmills, etc. as the raw material, production of anhydrous ethanol using a separation membrane, and E3, which is a mixed fuel containing 3vol% of ethanol. Ethanol production is 250kg/day.^[10]

(3) Biomass plastic

The material that has attracted the highest expectations as a biomass plastic is poly-L-lactic acid (PLLA), which is produced by fermenting multiple vegetable-derived sugars. Because PLLA is more easily decomposed by processes such as hydrolytic degradation than petroleum-derived plastics, conversion to L-lactic acid and similar raw material substances is comparatively easy. PLLA is not simply only a plastic which is easily biodegradable in the environment, but can also be considered a recyclable plastic material,^[15] and is

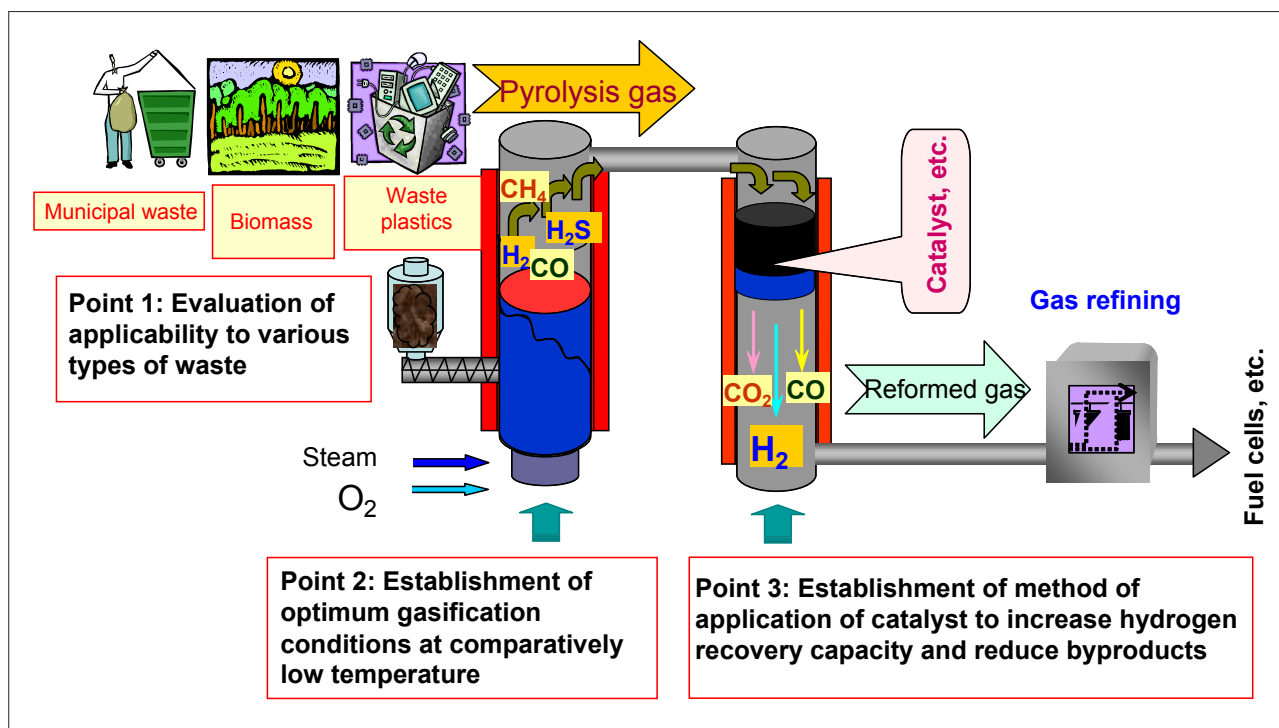


Figure 10 : Development concept of gasification and reforming system

Source: Reference [10]

therefore an attractive object for material recycling.

One important issue for producing PLLA from biomass is reduction of the cost of the refining process, for example, by a distillation process which produces high purity lactic acid from the lactic acid fermentation broth.^[16] In order to obtain products which are competitive with low-cost petroleum-derived plastic products, the above-mentioned recycling from PLLA is one useful method for development of a low-cost production process.

3-3 Improvement of gasification technology

Effective utilization of waste was already a priority in Japan in the 1970s. The former Agency of Industrial Science and Technology, Ministry of International Trade and Industry (MITI; the corresponding organizations are the new AIST, which was mentioned previously, and the Ministry of Economy, Trade and Industry, METI) carried out a comprehensive research and development project called “Stardust 80” in connection with “Resource recycling and use technology systems” from FY 1973 to FY 1982. As part of this project, a pilot plant with a municipal waste treatment capacity of 100 tons/day was constructed in Yokohama. The plant comprised a total of six subsystems, including pretreatment for sorting and

crushing municipal waste, high speed composting for garbage, pulp recycling from waste paper, pyrolysis and gasification for conversion of waste paper and waste plastic to oil and gas, and others. The targets were to recycle municipal solid wastes with a miscellaneous composition as material resources or energy resources, and to achieve high compatibility with social systems by minimizing secondary pollution, etc. Nevertheless, a number of problems remained to be solved with the gasification technology, including the fact that both the equipment cost and running cost were extremely high, treatment of acidic tarry substances was not possible, etc.^[17] As a result, it would be difficult to call the project a success.

However, with progressive introduction of gasification and melting technologies following this project, as described previously, substantial improvements were made in the gasification technology, melting technology, and other elements. Moreover, because expectations were also placed on resource recycling and hydrogen energy, gasification technology became the focus of renewed interest. For example, there was a case in which a system for synthesizing hydrogen using waste plastics as the raw material (Ebara Ube Process: EUP) was applied commercially to the production of hydrogen for use in ammonia

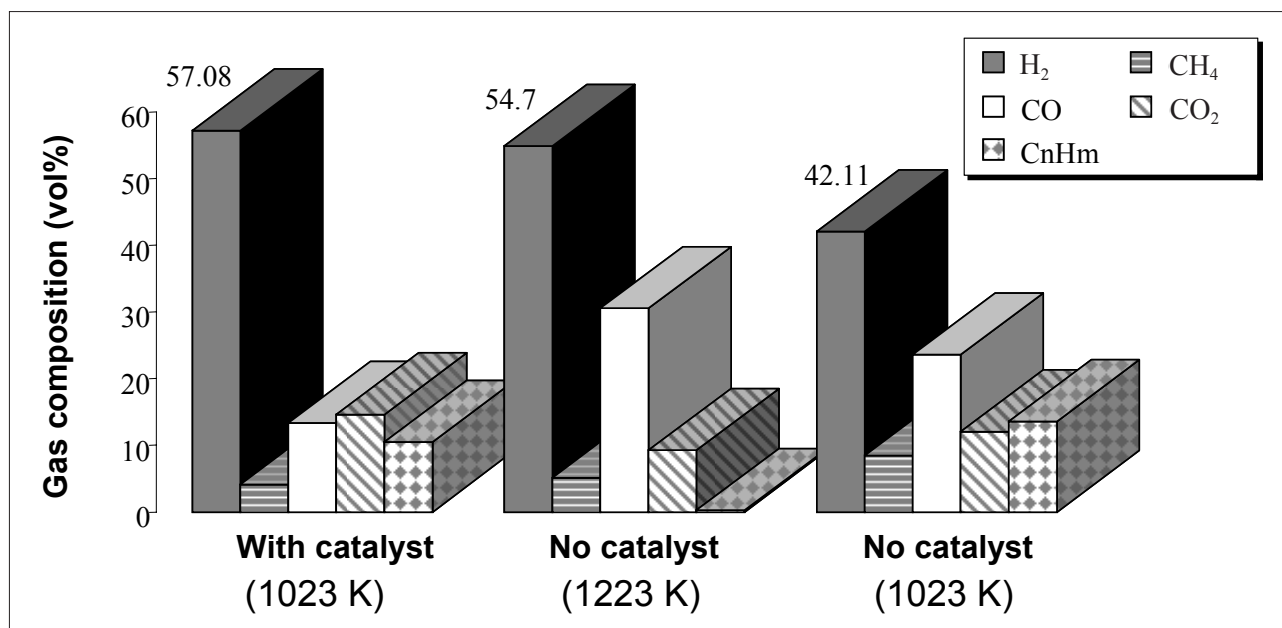


Figure 11 : Difference in formed gas composition depending on application of catalyst
(Numbers in parentheses on the x-axis show temperature. C_nH_m means hydrocarbon species.)

Source: Reference ^[10]

synthesis.^[18] The technology in this example is a pressurized 2-stage process, comprising a low temperature fluidized bed-type gasification furnace (600-800°C) directly connected to a high temperature (1300-1500°C) swirl flow combustion chamber-type gasification and melting furnace. In addition, there are also a small number of examples of application to gasification and reforming-type MSW treatment.^[19]

Although these technologies have attracted attention, it is difficult to say that application to biomass and MSW has made wide progress. As the reason for this, because a high temperature melting process is necessary, the process is subject to various restrictions, including the quantity of heat in the raw materials, cost performance, plant operability, and so on. Therefore, in order to promote utilization of biomass and expand the supply sources of hydrogen gas, technical development is underway with the aim of realizing a lower temperature process than with the developed technology, centering on the reforming process. As illustrated in Figure 10, technical development is being carried out based on the concept of compensating for the problem of reduced efficiency due to low temperature operation by applying a catalyst. A variety of issues are being studied in this development project, including the temperature when hydrogen is the main substance recovered, the steam and oxygen injection volume,

the composition of the catalyst and amount used, the method of catalyst regeneration, and the gas refining effect, among others, with the objective of discovering the optimum applicability to waste or biomass.

For example, Figure 11 shows the results when a catalyst containing 20wt% of nickel as the active ingredient and somewhat over 10wt% of calcium oxide is applied, in comparison with the results with no catalyst in operation at different temperatures. In an experiment with waste wood, when using this catalyst, a gas with the same or higher concentration of hydrogen gas as in a process at 950°C with no catalyst could be obtained at 750°C.^[10]

Similarly, as a project in connection with a biomass utilization technology in which gasification is an element technology, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Leading Project “Composite treatment and recycling project for municipal solid waste, industrial waste, and biomass” was carried out during the period FY 2003-2007.^[20] Here, development of a high efficiency process technology for recovery of energy and resources from waste was carried out as one sub-theme, and included the development of a high efficiency gasification conversion technology, development of a high efficiency gasification system technology, development of a high efficiency power generating

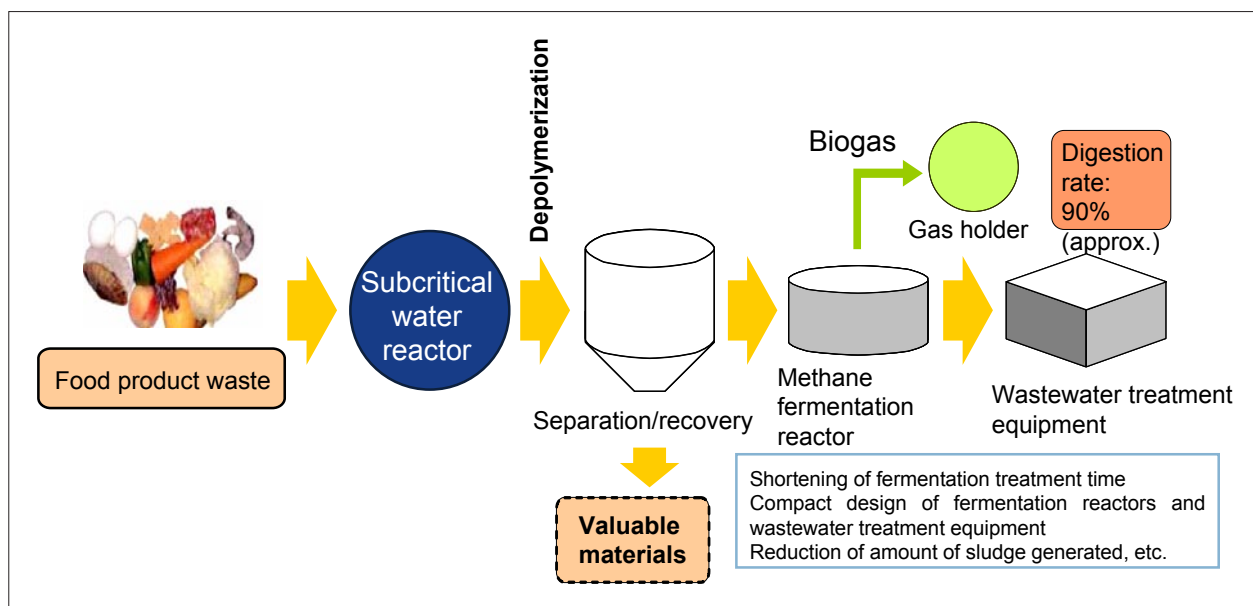


Figure 12 : Example of recycling applying subcritical process

Source: Reference [23]

technology, and development of a hydrogenation and liquid fuel synthesis technology.

In treatment technologies that use heat, environmental consideration in connection with the flue gas discharged out of the system is particularly important. Pyrolysis gasification technologies do not release flue gas directly into the open environment. However, in fuel cells, gas engine generators, and other technologies which are the use stage of the product gas, it is necessary to avoid environmental impacts related to operation, for example, due to tar and the like. Accordingly, the objects that must be considered is different from the case of incineration and other technologies which are premised on direct release into the general environment. The problems which arise here include sulfur compounds (hydrogen sulfide, etc.) which can easily damage the catalysts, polycyclic aromatic compounds, which form tar, hydrocarbons, which may cause carbon deposition, etc. Basically, it is possible to cope with refining of this kind of flue gas using conventional technologies, but from the viewpoint of optimization of the temperature conditions and the economy of the system as a whole, the optimum values will differ in each case.

3-4 Technologies applying high temperature/high pressure fluids

As high temperature, high pressure fluids, supercritical water, subcritical water, and

supercritical CO₂ are extremely distinctive fluids which make it possible to change properties from high polarity to nonpolarity, depending on the temperature and pressure conditions. A fluid in a state in which the temperature is approximately 370°C and pressure is 22MPa or higher is generally called a supercritical water. Because water in this condition is in a mixed state consisting of a liquid (reaction solvent) and gas, its strong oxidizing power can be utilized effectively, enabling application to the decomposition of hard-to-decompose substance such as organic chlorides, etc. and the detoxification of harmful chemical substances. On the other hand, subcritical water is a more moderate state than supercritical water, as its temperature/pressure are not as high as supercritical conditions. Because its ion product is larger than that of ordinary water and its reactivity is high, it can be used in reaction fields where the hydrolytic degradation reaction proceeds rapidly. Conventionally, supercritical fluids with high reactivity were the main type used in decomposition treatment of substances. However, technical studies are examining the possibility of recovering various substance by using subcritical water in this reaction field. Possible applications include reducing plastics to monomers and recovering amino acids from protein-type waste.

For example, a recycling process in which stepwise subcritical water treatment is applied to waste fish flesh has been proposed. It is possible

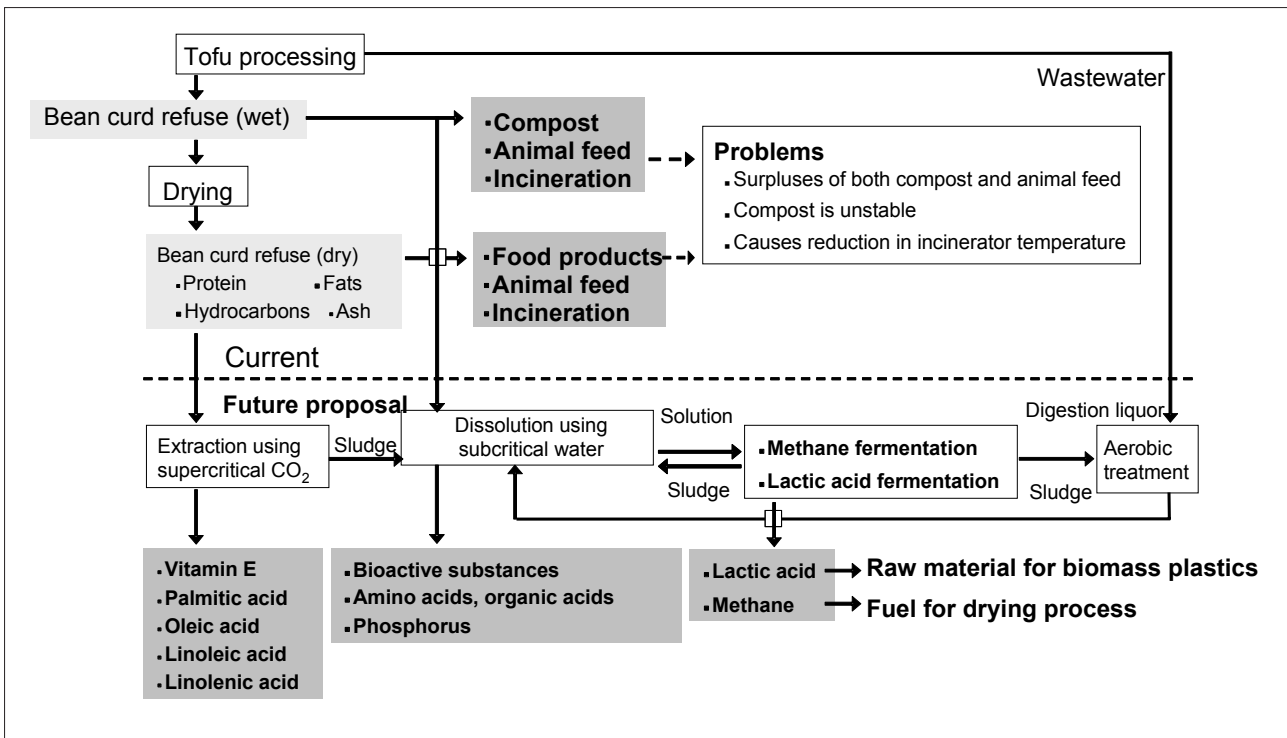


Figure 13 : Current status of treatment of bean curd lees and proposal for recycling system

Prepared by the STFC based on Reference [21]

to separate and recover pyroglutamic acid, cystine, alanine, glycine, and leucine by first refining, separating, and recovering lactic acid, phosphoric acid, and histidine in a reaction for approximately 5min under conditions of 200°C and 1.6MPa, followed by a reaction for approximately 30min at 270°C under 5.5MPa.^[21] Subcritical water can be used in the recovery of tolylene diisocyanate (TDI), which is a raw material for polyurethane, in a process in which TDI is produced based on toluenediamine recovered from the residue. Subcritical water can also be applied to a process in which sugars are obtained from cellulose with high efficiency by applying subcritical water to woody biomass and adjusting the decomposition rate, and then proceeding to ethanol fermentation.^[22] Possible applications include depolymerization as a pretreatment process, extraction of useful components, and gasification/oilification, etc.

Figure 12 shows the concept of a combined system which depolymerizes high molecular weight organic compounds in food product waste utilizing subcritical water and then supplies the product to a methane fermentation process. In this example, a subcritical water process is applied, enabling rapid hydrolytic degradation, which requires time in methane fermentation, while also producing a composition which is suitable qualitatively for

methane fermentation.

The fact that these are high temperature/high pressure fluids also gives rise to various technical issues, including the durability of the reaction equipment, separation and refinement of the recovered substances, increased costs, and others. However, when the waste is in a dried condition, it is possible to recover bioactive components by supercritical CO₂ extraction. With wastes with a high moisture content, recovery of water soluble bioactive components and the like is possible by solubilizing the waste using subcritical water, and development to methane fermentation is possible after depolymerization. Thus, if the proper treatment is selected based on the moisture content of the waste, properties of the contents, etc., recycling of wastes can be maximized. Figure 13 shows the flow of recycling and use when this concept is applied to bean curd waste discharged from the tofu manufacturing process.

4 Issues and Recommendations

4-1 Issues for waste recycling technology as a total technology

The author would like to point out the following as technical issues for the recycling of wastes. First, some technologies which are applied to waste

are in fact based on unit operations which were developed or are used in conventional production technology, and a modification of this technology is used. This is not limited to wastes, but is also applied with various other environmental technologies, such as waste water and flue gas treatment. The most important point to note is that wastes are rarely homogeneous in terms of raw material composition, and there is a large possibility that the object waste will vary in both quality and quantity. There are also cases in which the composition of the waste that can be collected when actual operation begins differs substantially from that assumed in the design stage, and it is difficult to assess this accurately in advance.

Accordingly, the pretreatment process plays a crucial role in the treatment of wastes. From this viewpoint, appropriate and effective functioning of all operations is necessary. This is not limited to the fermentation reactor, gasification furnace, and other processes which are central to recycling, but also includes crushing and classification of waste in the pretreatment process, removal of mixed foreign matter, refining in the downstream stage, and similar operations.

Furthermore, as described in connection with the fermentation process, this technology is not complete in the true sense as an environmental technology if it is not a total technology which includes treatment/disposal of the various types of liquid and solid residues generated after treatment. At present, these functions are implemented as necessary treatment/disposal auxiliary to recycling. In the future, it is hoped that the research institutes, private corporations, and others conducting technical development will carry out studies and make improvement from the viewpoint of cascade use methods and effective recycling methods for residues. Moreover, the administrative agencies which evaluate technologies should also give priority to the degree of completeness as a total technology, as outlined above, as an evaluation index.

4-2 Notes on technical development

(1) System design from a comprehensive viewpoint including safety

From the viewpoint of labor accidents, for example, the average of deaths and injuries

(frequency rate) per million working hours was approximately 2 for all industries, but in contrast, this number was around 12 for facilities handling waste.^[24] In the case of biomass, it would seem that there is almost no possibility that the waste will contain hazardous materials. However, because combustible substances are recovered for use as energy sources and fuels, it is necessary to take adequate work-related safety measures against accidents due to explosion, fire, or the like, which can occur in equipment used to transport and store these substances. Those concerned must make use of examples of accidents in facilities storing refuse derived fuel (RDF)^[25] and facilities treating PCB^[26] when responding to safety needs in the future.^[27]

Accordingly, the design of systems from a total viewpoint, which heightens consideration of safety, together with excellent core technologies, are demanded as a key point in technical development. Governmental and business people who are in a position to decide the introduction of technologies must not simply focus on energy or material recovery, but must have a wide vision of the response to residue discharges, securing safety, and other matters.

(2) Consideration of efficiency of treatment and recycling

In waste recycling, there is an unfortunate tendency to make recycling an end in itself. In the Japanese government's Basic Plan for Establishing the Sound Material-Cycle Society, the circulating use ratio (Amount of circulating use / (Amount of circulating use + Inputs of natural resources, etc.; %) is used as an index, and a target value is set (approximately 14% by FY 2010). It is important to exceed this rate. Individual laws such as the Food Recycling Law (Law Concerning the Promotion of Recycling Food Cyclical Resources) set targets for the amount of recycling and related matters. However, simply comparing these numerical values does not seem appropriate. Mass consumption and mass recycling is not necessarily a desirable choice.

In other words, if the energy and new resources which are input to the recycling process are disproportionately large in comparison with the object of recycling, this is a problem which must be considered. By nature, some amount of energy

and resources must be input in artificial production and consumption. For example, where energy input into the recycling process is concerned, the following was pointed out recently in an example of recycling of PET bottles.^[28] In FY 2004, PET bottle consumption was approximately 510,000 tons. Of this, 240,000 tons were sorted and recovered, and the amount reused (estimated as the amount recycled as basic material) was 30,000 tons. Because 510,000 tons were manufactured and 240,000 tons were recycled, the remaining 270,000 tons were discarded as waste. According to a trial calculation, both the amount of petroleum for reuse of this very small 30,000 tons and the amount of waste as part of the total (including PET bottles which were discarded as waste as-is) were approximately 7 times larger than in the period (FY 1993) when there was still no recycling of PET bottles. Among the above-mentioned 270,000 tons, the amount that was sold to China and other countries was thought to be quite large. The details will be omitted, but there are points in the claims mentioned above which are partially correct. On the other hand, the assessment of the content of recycling is inadequate, and there is no comparison with the case of production from natural resources at the present point in time. In view of these and other shortcomings, it is possible to view this an argument which, as a whole, lacks accuracy.

The importance of reducing the energy, resources, and cost requirements in recycling and reducing the load of unnecessary materials discharged is self-evident. Proper guidance is necessary in the development of recycling technologies for which the determination of inputs and costs is inadequate, which tends to occur when the focus is limited to technical development.

(3) Expanded use of recycled products

In the recycling of wastes, effective utilization of the recycled products, in other words, users, is equally important as the technology for recycling. A resource circulation cycle is realized for the first time when this condition is met. For example, in energy recovery, operation in combination with a fuel cell system or power plant must be possible so as to effectively utilize the combustible gases such as hydrogen and methane produced in the recycling process. The social infrastructure for the siting of

these facilities must also be prepared in a realistic manner. This point will be particularly important in the formation of the coming fuel cell society. Because pilot tests and other related activities are already underway, a realistic study with a view to actual social introduction is necessary.

With regard to power generation from waste, the Law Concerning Promotion of the Use of New Energy (New Energy Law) opened the way to promotion of recycling-type energy by utilization of waste power generation/heat use and biomass power generation/heat use. However, in the case of waste power generation, generating efficiency is no more than an average of about 10%, and at most reaches only something more than 20%. There is still considerable room for technical development, for example, improvement of boiler efficiency. Moreover, the upper limit (2,000kW) on general high voltage power generation, which is a condition of the Electric Power Grid Inter-Connection Technical Guideline, is a restriction, and in some cases, full use of generating capacity is not possible. Accordingly, together with technical development, improvement of operational restrictions is also important.

On the other hand, as problems confronting material recycling, little progress is being made in expanding the use of recycled products, and in particular, construction-related recycled products. This applies to products such as aggregate, road base course material, and others which use slag formed in the melting furnace or gasification and melting furnace. Because use of construction-type recycled products in public places is assumed, there is a possibility of numerous, undesignated environmental safety effects. Therefore, due care with regard to safety is required, and appropriate evaluation and control are also necessary. For some recycled products, such as molten slag from general waste and sewage sludge, preparation of test methods for quality assurance and quality control in the environmental safety aspect is progressing under JIS standards and others, and the creation of a comprehensive system of testing standards is also underway.^[29] It is hoped that this kind of standardization will convey realizable quality assurance widely to users, and that this will encourage expanded use by improving the image of recycled products.

This would also seem to apply to recycled products produced by carbonizing carbon-rich materials formed in the gasification process and the use of valuable materials formed in reactions by subcritical water as products or chemical intermediates, etc. Quantitatively, these types of products are still small, and regular markets have not yet developed. However, in the future, it will be necessary to establish social systems for further promotion of the distribution and use of diverse recycled products, while continuing to give due consideration to the environmental safety aspect and other related conditions. Therefore, as a first requirement, businesses which are engaged in recycling of wastes and administrative agencies on the so-called venous side (return side) of the material cycle, and manufacturing industries that use recycled products, governmental agencies, and others on the arterial side, must share information and come to a mutual understanding on cooperation.

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