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Trends in Japanese Zero Emission Systems that Lead the World
— Creation of Recycling Systems Centering on Materials Industries —

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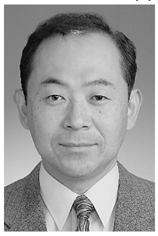
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1 Introduction

"Zero emission" has been a key concept in converting a variety of technological systems in an effort to create a sound material-cycle society. This particular concept, first proposed by the United Nations University in 1994, was put into practice as part of the program to "reconstruct socioeconomic systems toward sustainable development." There, "zero emission" is defined as an "effort to create recycling-based industrial systems producing no waste, by restructuring the production processes of all industries and developing new industrial clusters in which all waste is recycled as materials."

In other words, "zero emission" is a system design concept that enables the recycling of waste among various processes, plants, businesses and areas. It organically links the "veins" (waste stream) with the "arteries" (material stream for production), creating new industrial clusters. At the same time, waste from certain industries is used as materials by other industries in a cascade manner to minimize the generation of waste. Properly speaking, "zero emission" does not refer to the total elimination of waste, but to the minimization of waste. Meanwhile, investments have been made in the creation of zero-emission systems and their business models in Japan, which in turn are producing a variety of recycling frameworks, ranging from small-scale regional systems to large-scale nationwide systems. In particular, systems primarily implemented by materials industries (e.g., the steel, cement and non-ferrous metal smelting industries) are worth noting; they have developed into unique recycling systems.

"The Qualitative Assessment and Analysis of the Contribution of Science and Technology to the National Economy, Society and Life[1]," a survey jointly conducted by the National Institute of Science and Technology Policy (NISTEP) and Mitsubishi Research Institute, Inc. (MRI), suggests that waste-disposal and recycling technologies have a significant impact on the economy and public life. In fact, the public and private sectors have been engaged in joint research programs to develop waste-recycling systems, which have significantly contributed to creating today's technological systems of Japan. Of recycling systems that center on materials industries and individual element technologies, the gasification melting technology has made rapid headway, with the industrial sector playing a leading role in its design and development. The adoption of new environmental regulations and other regulatory measures have also served as an incentive. For example, increasingly stringent regulations on dioxin emissions have prompted the development of gasification melting technology, while government subsidies to municipalities have encouraged the introduction of expensive processes. Support measures including subsidies have thus made an indirect contribution to technological development by plant manufacturers. The gasification melting technology, which was originally imported from abroad, can be considered a technology[2] that has made a great leap forward in Japan[1].

2 Status of zero emission initiatives at home and abroad

Terms referring to "zero emission business models" vary from country to country. The "Eco Industrial Park (EIP)" is one. The President's Council for Sustainable Development (PCSD) of the U.S. defines EIP as follows:

"EIP is a community composed of companies in the manufacturing and service industries, each of which pursue common interests and maximize its individual profits by jointly managing resources such as the environment, energy, water and other materials. EIP is designed to improve the economic performance of its member companies, while minimizing their environmental load." With PCSD established, the US government decided to promote EIP projects on nationwide scale, designating four EIP demonstration sites. In addition, an initiative for eco-friendly regional development is underway in more than 10 sites across the country[3]. Table 1 shows frequently quoted examples of overseas EIP projects. An overview of the Kalundborg project, a typical EIP project, is shown in Figure 1.

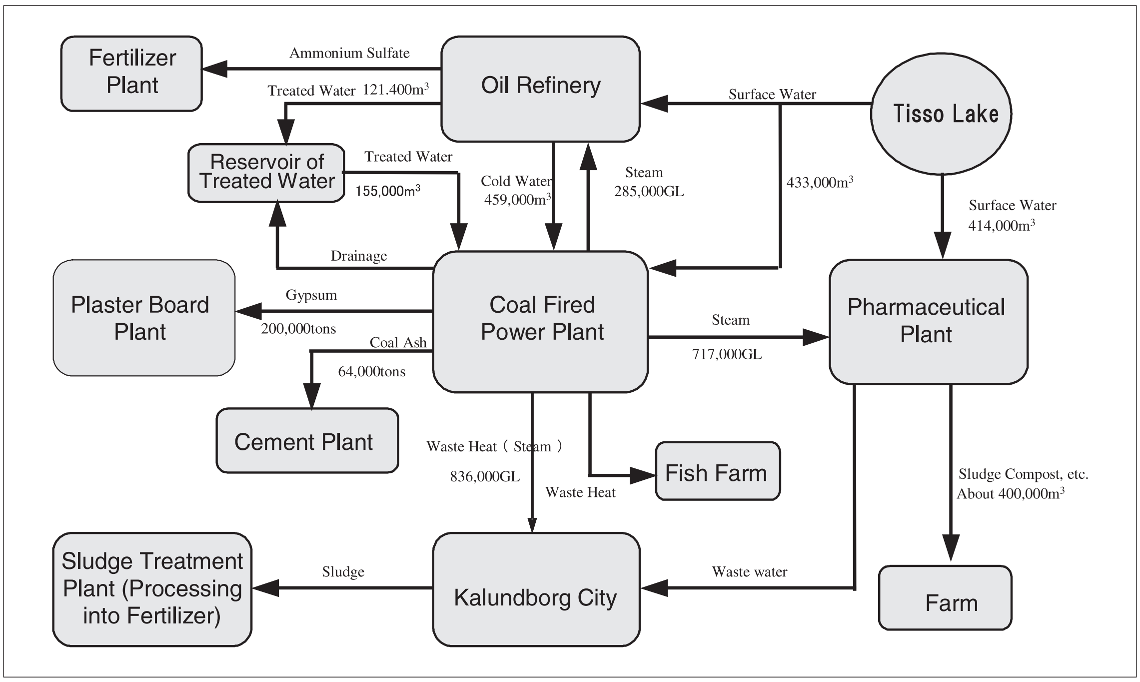
In line with the "zero emission" concept, meanwhile, several zero emission industrial parks have already been set up in Japan, with more awaiting development. The government subsidizes the construction of zero emission facilities in a total of 18 "eco towns" designated as of April 2003[4]. Figure 2[5] shows the areas

Table 1 : Overseas zero emission systems

Location	Overview
Kalundborg (Denmark)	A municipality and five major companies in the fields of power generation, plaster board, pharmaceuticals, oil refining and soil improvement form a network, through which each member company utilizes waste generated by other companies. The system was launched about 30 years ago, and 19 projects are currently underway.
Fairfield Ecological Business Park (US)	Industrial and municipal waste is recycled within the region, e.g., sludge from sewage treatment plants is processed into compost, parts from scrapped cars are recycled, and food residual is processed into feed.
Gulf of Mexico (Mexico)	A total of 21 companies are discussing the reciprocal trade of their byproducts, e.g., the recycling of steel slag as cement materials and the reuse of auto shredder residual by steel plants.
Montreal (Canada)	A total of 15 companies are discussing the reciprocal trade of their byproducts, e.g., the reuse of caustic soda and sodium sulfate by paper mills.

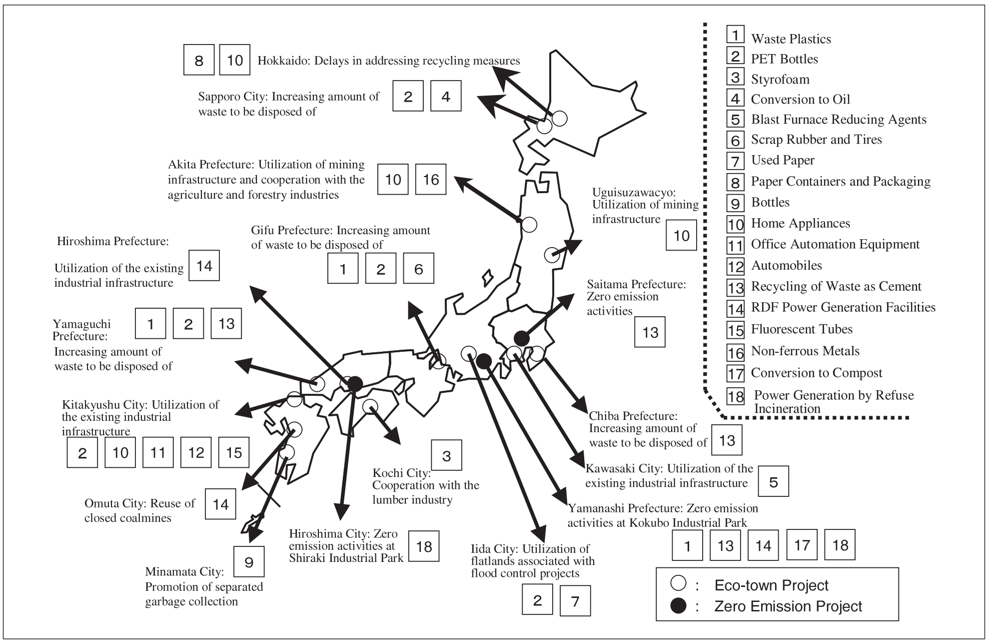
Source: Website of each project, etc.

Figure 1 : Industrial symbiosis at Kalundborg



John R.Ehrenfeld and Marian R.Chertow 2001

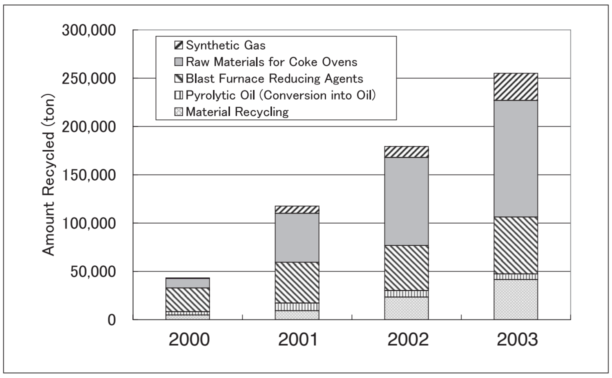
Figure 2 : "Zero emission" regional recycling projects (as of 2001)



Source: Report prepared by the National Institute for Environment Studies (The 2002 Research on the Global Environment)

designated as "eco towns" and regional zero emission projects coordinated by municipalities. In terms of relevance to the subject of this article (namely, materials industries), non-ferrous metal smelting operation in Akita Prefecture and systems that center on cement production in Saitama Prefecture, etc. merit particular attention.

Figure 3 : Amount of packaging plastics recycled[5]



3 Status of the creation zero emission systems in materials industries

3-1 The steel industry

While steel manufactures have contributed to recycling initiatives as users (electric furnace maker) of iron and steel scrap, they are now branching out into the recycling of plastic materials in response to the enforcement of the Packaging Recycling Law, an eye-opening trend. Figure 3[6] shows the amount of packaging plastics (i.e., plastics other than PET bottles, which municipalities recovered in compliance with the law) recycled as of fiscal 2003. About 70% of the packaging plastics recycled (250,000tons) in fiscal 2003 are attributable to the steel industry, which use them as fuel for coke ovens and blast furnaces. The steel industry has an annual capacity to recycle about five million tons of waste plastics[7] (the total amount of waste plastics is estimated at 10 million tons a year, almost half of which is currently disposed of).

In instituting the law, "material recycling" and the "conversion of waste plastics into oil" were prioritized over other alternatives on technological grounds. The recycling of waste plastics by the steel industry, however, turned out to be "feedstock recycling." Because of its technological credibility and capacity to recycle waste plastics, it did not take long before the steel industry took center stage in waste plastic recycling. By contrast, the conversion of waste plastics into oil, which was initially considered a promising alternative, has found limited applications to date.

Recycling packaging plastics has yet to be implemented in other countries except Germany, where they are recycled as blast furnace reducing agents in compliance with the directives relevant to packaging recycling.

3-2 The cement industry

The cement industry has been a major user of a variety of waste and byproducts (coal ash, waste oil, reclaimed oil, scrap tires, slag, byproduct gypsum, etc.), which are used as raw materials or fuel for cement production. The unit consumption of waste and byproducts in cement production increased from 295 kg/ton in 1998 to 361 kg/ton in 2002[8]; it is expected to reach 400 kg/ton in 2010. Table 2[9] shows the breakdown of waste and byproducts by source and descriptions, and Table 3[9], the actual amount of waste and byproducts recycled in recent years. As these charts suggest, large-scale cement plants have the potential to quickly change the waste stream in the areas in which they operate. The industry's recent recycling efforts include "eco cement," which uses ash from municipal waste incinerators as raw materials. The cement industry stands prepared to use other waste materials such as used pachinko machines, garbage and hazardous waste (polluted soil, specified CFCs, etc.). Indeed, a new plan is underway to use a massive amount of illegally dumped waste found on the border between Aomori Prefecture and Iwate Prefecture. Japan leads the world in the co-incineration of waste in cement kilns (in terms of the scale of operations and the proportion of received waste in its total production), a recycling effort that is attracting

Table 2 : Sources and descriptions of waste and byproducts recycled by the cement industry[8]

Sector	Source (Industries, Facilities)	Descriptions of Waste and Byproducts	Usage in Cement Production
Private Businesses	Steel	Blast Furnace Slag (Granulated), Blast Furnace Slag (Slow Cooled), Flay Ash	Raw materials/Admixtures
	Electricity	Coal Ash, Waste Crude Oil Flue Gas Desulfurization Gypsum	Raw materials /Fuels/Admixtures Admixtures
	Non-ferrous Metal	Slag, Sludge, Foundry Sand, Gypsum	Raw materials/Admixtures
	Chemical	Waste Plastics, Gypsum, Sludge	Raw materials/Fuels/Admixtures
	Automobile	Foundry Sand, Paint Residue, Scrap Tires	Raw materials/Fuels
	Oil	Waste Clay, Waste Oil, Waste Catalysts, Sludge, Oil Coke	Raw materials /Fuels
	Construction	Waste Gypsum, Boards, Tatami Mats	Raw materials
	Construction Material	Board Chips, Sludge	Raw materials
	Paper & Pulp	Sludge, Ash	Raw materials
	Printing	Waste Plastics, Ash	Raw materials /Fuels
	Agriculture	Waste Plastics	Fuels
	Fisheries	Shells, Entrails	Raw materials /Fuels
	Food	Waste China Clay, Waste Plastics, Distilled Spirit, Deposits, Coffee Sludge, Brewer Grain, Waste Juice	Raw materials /Fuels
	Electronics & Electric	Waste Plastics, Waste Toner, Sludge, CFCs	Raw materials / Fuels /degradation processing
	Leisure	Used Pachinko Machines	Raw materials /Fuels
Municipalities	Water Treatment Plants	Sludge Derived from Water Treatment	Raw materials
	Sewage Treatment Plants	Sewage Sludge	Raw materials /Fuels
	Refuse Incineration Plants	Ash, Soot and Dust	Raw materials
	Other	Municipal Waste (Garbage), CFCs	Raw materials/Fuels Degradation processing

attention at home and abroad.

3-3 Non-ferrous metal smelting industry

The non-ferrous metal smelting industry could be another major user of waste in the future. The industry, which has been recycling car batteries, is beginning to use a variety of waste materials including metal resources, e.g., automobile shredder residue (ASR) generated in the course of car recycling, the circuit boards of used home appliances, and fly ash from municipal waste melting plants. Figure 4[10] shows the breakdown of waste materials received by 10 major waste-disposal and recycling companies; the first pie chart represents waste purchased as recyclable materials, while the other represents waste collected at cost to its producers. As these charts show, the industry is using various waste materials including metal resources to recover copper, lead, zinc, precious metals (gold, silver, platinum), etc.

A comparison with the results in fiscal 1999 reveals that the amount of recyclable materials was stable, while that of waste materials collected for intermediate treatment increased by more than 30%[10]. Specifically, ASR increased due to tightened landfill regulations for ASR (1996), and so did used home appliances (printed circuit boards, flint glass, etc.), with the Home Appliance Recycling Law in place. Sludge and contaminated soil also showed an upturn. Incidentally, a non-ferrous metal smelting plant of the "eco-town" project in Akita Prefecture is a "designated recycling plant" under the Home Appliance Recycling Law, serving as a recycling hub of waste home appliances in the Tohoku region.

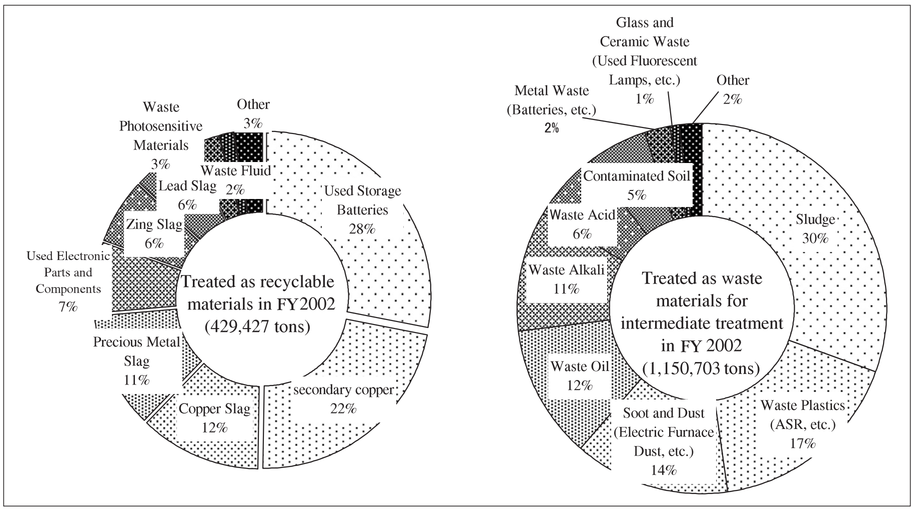
Table 3 : Amount of waste and byproducts recycled by the cement industry[8]

	FY2000	FY2001	FY2002
Blast Furnace Slug	12,162	11,915	10,474
Coal Ash	5,145	5,822	6,320
Byproduct Gypsum	2,643	2,568	2,556
Sludge	1,906	2,235	2,286
Non-ferrous Slag	1,500	1,236	1,039
Steel Making Slag	795	935	803
Burnt Residue, Soot and Dust	734	943	874
Slag Heap	675	574	522
Foundry Sand	477	492	507
Scrap Tires	323	284	253
Reclaimed Oil	239	204	252
Waste Oil	120	149	100
Waste China Clay	106	82	97
Waste Plastics	102	171	211
Other	433	450	942
Total	27,359	28,061	27,238
Total Cement Production	82,373	79,119	75,479
Unit Consumption	332	355	361

Unit: 1,000 tons for waste, byproducts and cement production; kg/ton for unit consumption

Source: Cement Handbook

Figure 4 : Recycling of waste, etc. by the non-ferrous metal smelting industry (FY2002)



4 Japanese state-of-the-art zero emission systems

4-1 Economic advantages

One of the reasons that zero emission systems have developed so extensively in materials industries lies in their substantial contribution to reducing initial investment by taking advantage of existing facilities such as blast furnaces, cement kilns and non-ferrous metal smelting furnaces. The waste disposal licensing system, through which waste disposal fees can be charged, has also served as an incentive. Previously, a number of constraints (the need to obtain a license in accordance with the Waste Management Law, etc.) hampered the recycling and treatment of waste materials, sometimes forcing materials manufacturers to purchase waste as "raw materials." With the licensing system in place, however, waste disposal has become a profitable business. While the production of and demand for industrial materials are declining, materials industries appear to be shifting from being "arterial industries" that produce industrial materials to "venous industries" that recover waste materials.

In addition, government support measures including subsidies are playing a part in promoting zero emission systems. In particular, the Ministry of Health, Labor and Welfare, the Ministry of Economy, Trade and Industry, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Environment provided research and development funds to materials manufacturers in the 1990s when grave problems such as dioxin treatment and the final disposal of waste materials loomed large[1], to expand the category of waste, produce high-quality slag, and improve power generation efficiency. Recycling facilities to be set up in designated "eco-towns" are also subsidized, an arrangement that encourages the construction of new facilities.

4-2 Effects of individual recycling laws

A series of recycling laws instituted or to be instituted in response to Extended Producer Responsibility (the Packaging Recycling Law, the Home Appliance Recycling Law, the Construction material Recycling Law, the Food Recycling Law and the Automobile Recycling Law) are also essential in establishing the current zero emission systems. Of packaging plastics recovered by municipalities in accordance with the Packaging Recycling Law, a major part of "other plastics" (excluding PET bottles) is recycled as blast furnace reducing agents and coke materials. With the Home Appliance Recycling Law in place, meanwhile, an increasing amount of circuit boards and other waste materials are recycled by non-ferrous metal smelting plants, regardless of whether they are designated as "recycling plants" or not under the law. The Automobile Recycling Law and the Construction Material Recycling Law are expected to promote the recycling of ASR, with the latter recycled as wood chips for paper manufacturing. As mentioned earlier, the cement industry is no exception to this trend, recycling scrap tires and wood voluntarily, not under specific recycling laws.

The existing recycling laws mandate the recycling of waste materials, while specific laws such as the Packaging Recycling Law and the Home Appliance Recycling Law stipulate that manufacturers and waste producers bear the costs of recycling, which together constitute a system that ensures reasonable profits for those involved in the recycling business.

4-3 Technological factors: technological credibility and great potential for recycling

Both industrial materials production and waste disposal involve high-temperature processes (above 1,000 degrees Celsius), which is the reason that waste disposal has developed so extensively through the zero emission systems of materials industries. With their proven high-temperature processes and advanced emission control systems, materials industries ensure the safe disposal of waste materials with varying properties, some of which contain hazardous substances, a great advantage in waste recycling.

Another advantage is the capacity to recycle waste; they have the potential to consume a massive amount of waste materials, with their industrial processes fully utilized on a nationwide basis.

5 Direction of research and development in zero emission systems and dissemination of Japanese models

Zero emission systems centering on materials industries, however, have yet to contribute to waste disposal in other countries, although some pilot projects are underway. Japan leads the world in terms of the amount and variety of waste recycled through the systems. Indeed, Japanese zero emission systems are yielding practical results, materials industries being the driving force. This is a noteworthy trend that suggests the possibility of their being business models applicable to other countries.

In order to further develop such Japanese business models, new recycling technologies should be developed (in addition to waste recycling through existing industrial processes) by incorporating some sort of qualitative conversion processes. The following section provides two excellent examples of such processes: the waste melting process, and the process of gasifying and recycling waste plastics as chemical raw materials

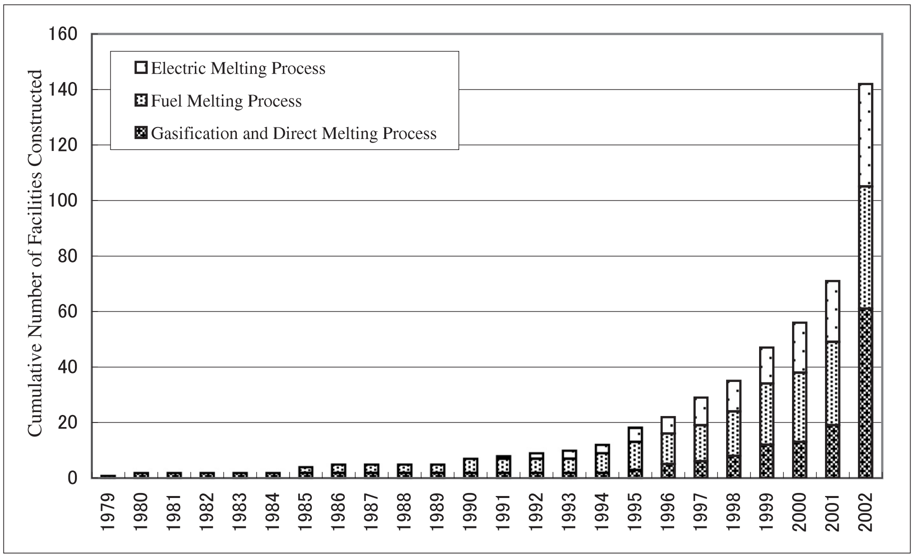
5-1 Coupling of waste melting process and non-ferrous metal smelting process[12]

The non-ferrous metal smelting industry is recycling an increasing amount of fly ash originating from municipal waste melting furnaces. The fly ash, which usually contains high concentrations of copper, lead, zinc, etc, can be recycled as quality raw materials. This coupling of materials industries and the waste melting process is unique to Japan, and hence could be a Japanese model applicable to many other countries.

Waste melting furnaces, which have contributed significantly to establishing this system, are increasing in number because of dioxin issues and a shortage of landfill space, with the Law Concerning Special Measures against Dioxins and incentives such as government subsidies playing a major role. Figure 5[11] shows the number of melting furnaces constructed in the past, which doubled year-on-year in 2002 in response to the full-scale implementation of measures against dioxins in December 2002.

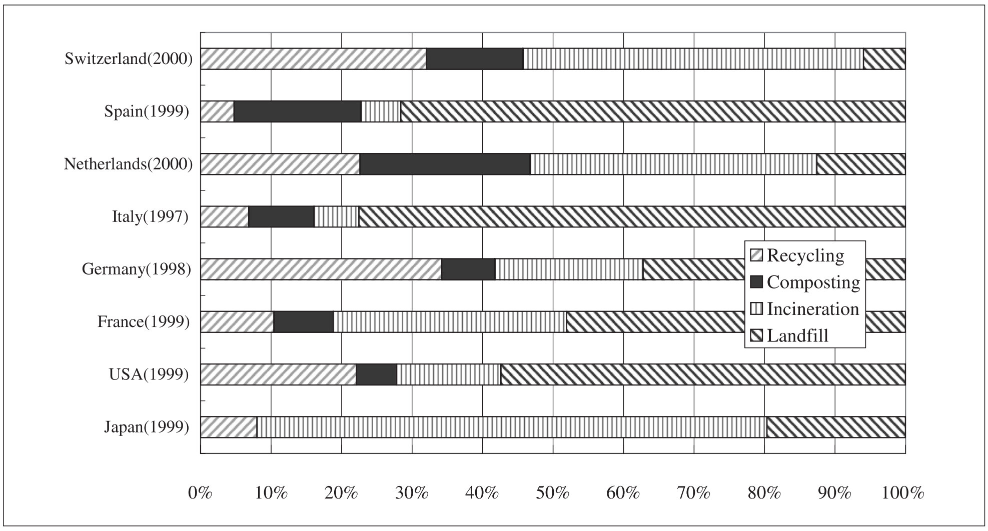
This situation is unique to Japan. Figure 6[12] shows the status of municipal waste disposal in major countries. Although the data is somewhat out of date, it shows a general trend where countries with limited land opt for incineration and recycling to minimize landfill. This is

Figure 5 : Number of melting furnaces constructed[11]



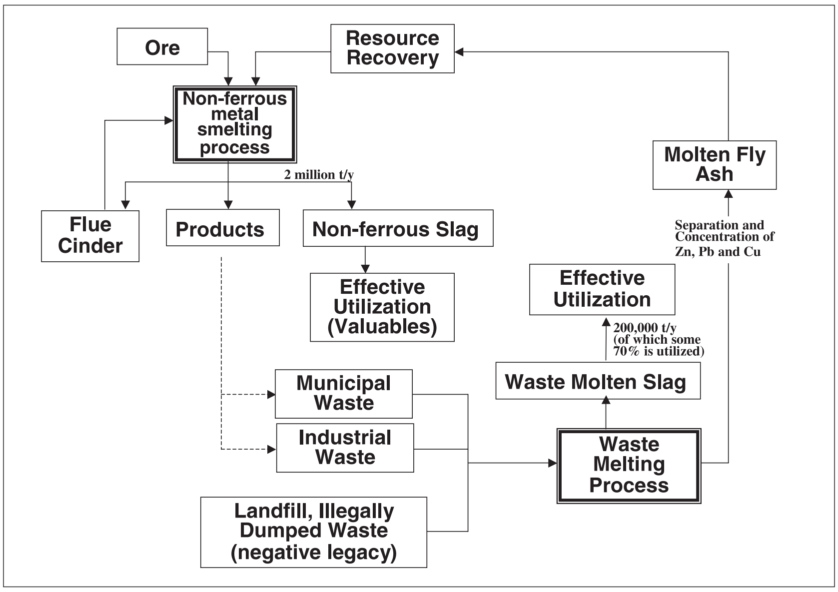
Source: A survey conducted by the National Institute for Environmental Studies in 2003

Figure6 : Municipal waste disposal in major countries



Source: OECD Environmental Data Compendium 2002

Figure 7 : Zero emission system combining the waste melting process with the non-ferrous metal smelting process



particularly true in Japan where as much as 40 million tons of waste is incinerated a year, the world's largest amount. With this situation as a backdrop, the waste melting process is increasingly popular in Japan. While many related technologies were first introduced from Europe, Japan now leads the world in the quality of its waste melting system as well as in its expertise in operating the system. Two waste melting systems are in place: an ash melting system where electric or fuel furnaces melt the ash from waste combustion, and a gasification melting system where waste is gasified for melting purposes. The development of the latter has been a subject of competition across the world, and Japan predominates in the number of gasification melting facilities in operation[13]. In fact, plant construction companies in Japan invest rather excessively in the research and development of the gasification melting process, boasting one of the best technological resources in this particular field.

Figure 7 shows the process of a system in place. The waste melting process, originally designed for waste disposal, also functions as a process for separating and concentrating metals. It is thus considered a qualitative conversion technology that establishes linkage with the non-ferrous metal smelting process. What is particularly intriguing in this chart is the way metals are recycled; buried municipal waste is recovered to extend landfill life and then fed to melting furnaces to produce slag and fly ash. The Ministry of Environment subsidizes facilities adopting this system, which is in a way an attempt to eliminate the "negative legacy of the past," promoting the recycling of metal resources in the years to come. With this system fully developed, waste landfill sites could turn into "urban mines" for the non-ferrous metal smelting industry.

A massive amount of industrial waste illegally dumped on the island of Teshima is now being recovered and disposed of at melting facilities set up on an adjacent island (Naoshima), fly ash from which is being recycled at a non-ferrous metal smelting plant located nearby. This process also deserves attention as a means to incorporate the "negative legacy" into the recycling of metal resources.

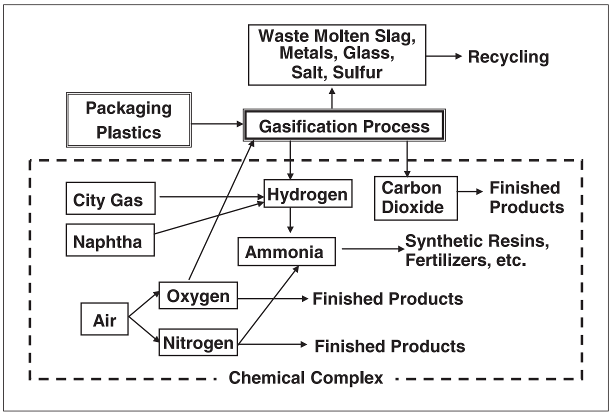
The disposal of municipal waste has a solid management base, as it is part of the public services. For municipalities, meanwhile, it makes economic sense to have the non-ferrous metal smelting industry recycle fly ash from the melting furnace, previously disposed of at landfill sites, even at their cost, which is a win-win arrangement since the industry is entitled to charge disposal fees.

In most countries, domestic waste containing a variety of materials is handled and disposed of by municipalities, many of which opt for landfill. The EU Landfill Directive, however, banned waste disposal at landfill sites, except for waste converted into inorganic forms through treatment such as incineration, a measure to extend landfill life in EU member states with limited land. While the recent movement in European countries towards recycling waste materials is irreversible, they appear to have no other options but to promote waste incineration, as is the case in Japan. The Japanese zero emission system shown in Figure 7, therefore, has the potential to be a model system that is compatible with the waste management policies of European countries.

5-2 Coupling of chemical complexes and the process of gasifying waste plastics to produce chemical raw materials

Another qualitative conversion alternative concerns the coupling between chemical complexes and the process of gasifying waste plastics to produce chemical raw materials. Figure 8 shows an outline of this system, i.e., packaging plastics are gasified to recover hydrogen, which is then fed to chemical complexes to produce ammonia, etc. Chemical complexes separate oxygen and nitrogen, which are base materials for various products, from the air, using some of the oxygen for the gasification process, and the nitrogen for producing ammonia by reaction with hydrogen derived from the process. Ammonia is used to produce items such as synthetic fibers and chemical fertilizers. The byproducts of the process (slag, metals, glass, salt, sulfur, etc.) are also recycled. In this case, the gasification process functions as a qualitative conversion process that establishes a linkage with chemical complexes.

Figure 8 : Zero emission system combining the gasification process of packaging plastics with chemical complexes



Source: Brochure of Showa Denko K.K.

The gasification process developed rapidly, accounting for some 10% of the total amount of packaging materials recycled in 2002 (see Figure 3), with a waste supply and profits ensured by the Packaging Recycling Law. Subsidies for gasification facilities to be constructed in designated "eco towns" has also worked as a great incentive.

These two systems are designed to recycle mixed waste materials with complex properties at existing industrial facilities through qualitative conversion processes (based on pyrolysis gasification and melting technologies); they are expected to be the main alternatives in creating zero emission systems in the future. The process shown in Figure 8 can be applied not only to waste plastics but also to other types of mixed waste materials (biomass, etc.) that can be gasified. Indeed, commercial facilities are already in operation in Chiba Prefecture, and setting up new facilities in Mizushima is planned. While the development of the process of gasifying waste plastics to produce chemical raw materials is attracting attention worldwide, Japan has a proven record in its commercial operation[13].

The major factors in the development of the two systems are: a stable waste supply ensured by laws and regulations; disposal fees chargeable to waste producers; engagement of the public sector; subsidies for the construction of new facilities, which solidify the management bases of waste-disposal and recycling companies. The socioeconomic system supporting these systems, coupled with the technologies involved, could be a Japanese model applicable to other countries. In particular, waste management is likely to be a major concern for East Asian countries including China, whose infrastructures and materials industries are rapidly developing. The Japanese models introduced in this article have the potential to become widespread in these countries, assuming that they adopt and enforce the appropriate environmental regulations.

6 Towards the creation of Japanese zero emission systems

The original concept of "zero emission systems" is to create chains (linkages) among various industries. The Japanese zero emission systems that center on materials industries are virtually hub-based systems creating linkages between materials industries and other industries. As is the case with ecosystems, a loss of diversity may undermine these zero emission systems. In other words, the systems may fail once materials industries are unable to accept waste materials. Japanese zero emission systems, however, are expected to remain stable over the short and medium term as they are supported by legislation and have substantial economic advantages, as mentioned earlier.

In the meantime, over-emphasis on recycling efforts seems to have created blind spots in the systems. The aspect of "safety and security," namely the safety of products originating from zero emission processes is one. Specifically, the safety standards for recycled cement (produced in kilns using waste as raw materials) and byproduct slag (originating from the non-ferrous metal smelting process) could become a bottleneck when discussed on the grounds of environmental JIS and the criteria for specified goods under the Green Purchasing Law because conservative substances (heavy metals, etc.) derived from waste materials may remain or accumulate in products. In the non-ferrous metal smelting process, for example, impurities such as hazardous metals concentrate in slag as the purity of the finished product increases. Being commercial items, non-ferrous slag has been exempt from the Waste Management Law, and hence traded as general commodities, safety requirements for which are non-existent. While there has been a growing awareness of the safety of recycled products, the application of the safety standards for waste materials to recycled products could change what have been considered "products" to "waste," resulting in a situation where industrial plants can no longer recycle waste in their production processes.

A systematic concept of the safety standards for general commodities, recycled products and waste materials should thus be created immediately so that they are recognized and accepted by society, including consumers. To disseminate Japanese business models to the world, moreover, the systematization of these safety standards needs to be discussed in the context of harmonizing international standards. The topics mentioned above are the biggest challenge in establishing Japanese zero emission systems.

Whether to prioritize "reducing," "reusing" or "recycling," and whether to prioritize "recycling" or "material recycling," should also be rationally discussed, taking into account the life cycle of each practice.

Whatever the case, Japanese zero emission systems, which are linked with the hub-based processes of materials industries through the qualitative conversion of waste materials, as well as socioeconomic conditions that support the systems and their element technologies (new qualitative conversion alternatives including pyrolysis gasification and melting technologies), could be exemplary models of industrial systems, if all the challenges are properly met. It is thus recommended that the government promote research and development activities and encourage technological transfer in the field of "zero emission," focusing on the global market.

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