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MUNICIPAL SOLID WASTE MANAGEMENT IN JAPAN

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INTRODUCTION

Basic measures taken in recent years to control waste management in Japan include: (1) Pollution prevention, (2) reuse and recycling, and (3) waste incineration with air pollution control.

It is generally agreed that it is appropriate to follow the assigned priority of these options. Municipal solid waste (MSW) is the responsibility of the citizen, the local government and the business sector. The principal strategy to manage MSW is to prevent the discharge of waste and, where waste must be discharged, to recycle as much as possible to reduce the quantity. However, even if effort is made to minimize the amount of waste, a large proportion still requires treatment in view of the activities of modern society. Once waste is generated, it must be incinerated and/or buried in landfills if it cannot be recycled. Incineration plays an important role in Japan where landfill sites are difficult to secure. With these circumstances in mind, the author outlines the origin of MSW in Japan and the recycling process and the present status of thermal recycling with pollution control. Ash regulation and its treatment methods are also discussed.

REUSES AND RECYCLING IN JAPAN

Physical Composition of "Actual Municipal Solid Waste"

It is important to build up, in material recycling of MSW, social systems for sorting and separating "Latent MSW" and realize an economic demand structure for recovered resources. This is simply because, if MSW is discharged without being separated, it must be handled as a mixture of complicated physical composition, which makes it difficult to recover materials from automated recycling systems. At present, materials discharged as MSW include recyclable paper and metal. This indicates that a large proportion of "Latent MSW" is becoming "Actual MSW". Thus, the physical composition of MSW would be of significance in evaluating the effects of material recovery. Table 1 shows an example of the physical composition of MSW in representative megalopolies of Japan.[1] It is not easy to compare indiscriminately such composition because collection modes and weight percent bases, wet or dry, differ from city to city, but in terms of weight ratio on a wet basis, used paper and kitchen waste account for about 30% each of the total, plastics about 10%, glass 5% and metal 5%. Table 1 is a view of MSW in terms of weight ratio.

Another view, in terms of volumetric ratio, is equally important in considering the capacities of collection vehicles and landfill sites. Takatsuki[2] has been conducting a volume ratio-based study of the physical composition of MSW for some ten years now, in addition to a study on a small-fractionated physical composition. Figure 1 shows the results of analysis of recent volume-base MSW physical composition in Kyoto City.[3] Kitchen waste, which accounts for about 25% in terms of weight ratio, accounts for some 10% in terms of volumetric ratio. Paper, accounting for approximately 25% in terms of weight ratio, accounts for some 35% in terms of volumetric ratio. With plastics, the proportions are approximately 10% and 40%, respectively, indicating that the proportion surges in the volumetric ratio. That is to say, paper and plastics are of relatively greater significance than other ingredients of MSW from the standpoint of waste collection cost and processing landfill site capacity.

Kyoto City classifies household waste composition by purpose of use of the original materials, as shown in Fig. 2. In terms of wet weight ratio some 40% comes from foodstuff and 25% from containers and packaging material. In terms of volumetric ratio, however, containers and packaging material account

TABLE 1
Physical Composition of Japan's Municipal Solid Waste, Records of 1989*

	Paper	Kitchen waste	Fabric	Wooden waste	Plastics	Rubber, leather	Metal	Glass	Ceramic	Soil & Rubbish	Others	Remarks
Sapporo	25.2	46.6	2.4	1.7	12.5	←	3.7	7.1	←	0.8	←	Mixed collected waste Wet basis
Tokyo	44.5	31.3	3.9	6.1	7.8	0.2	1.2	1.1	0.1	←	3.8	Combustible waste Wet basis
Yokohama	40.0	9.8	4.2	5.8	14.8	←	5.7	13.2	←	6.5	←	Mixed collected waste Dry basis
Osaka	35.7	6.5	5.9	5.2	20.3	←	5.3	7.1	2.7	—	—	Mixed collected waste Dry basis, H_2O 46%

*Numerical values indicate weight percentage.

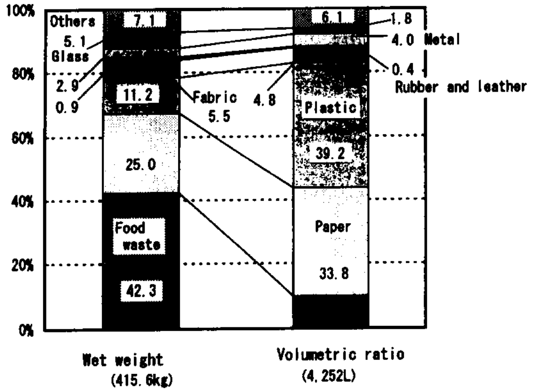


FIGURE 1. Physical composition of household wastes comparison between weight ratio and volumetric ratio.

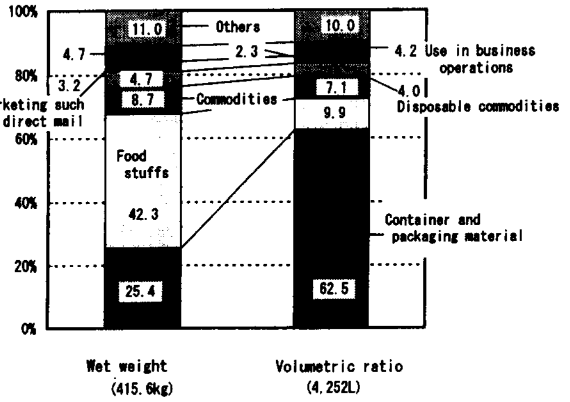


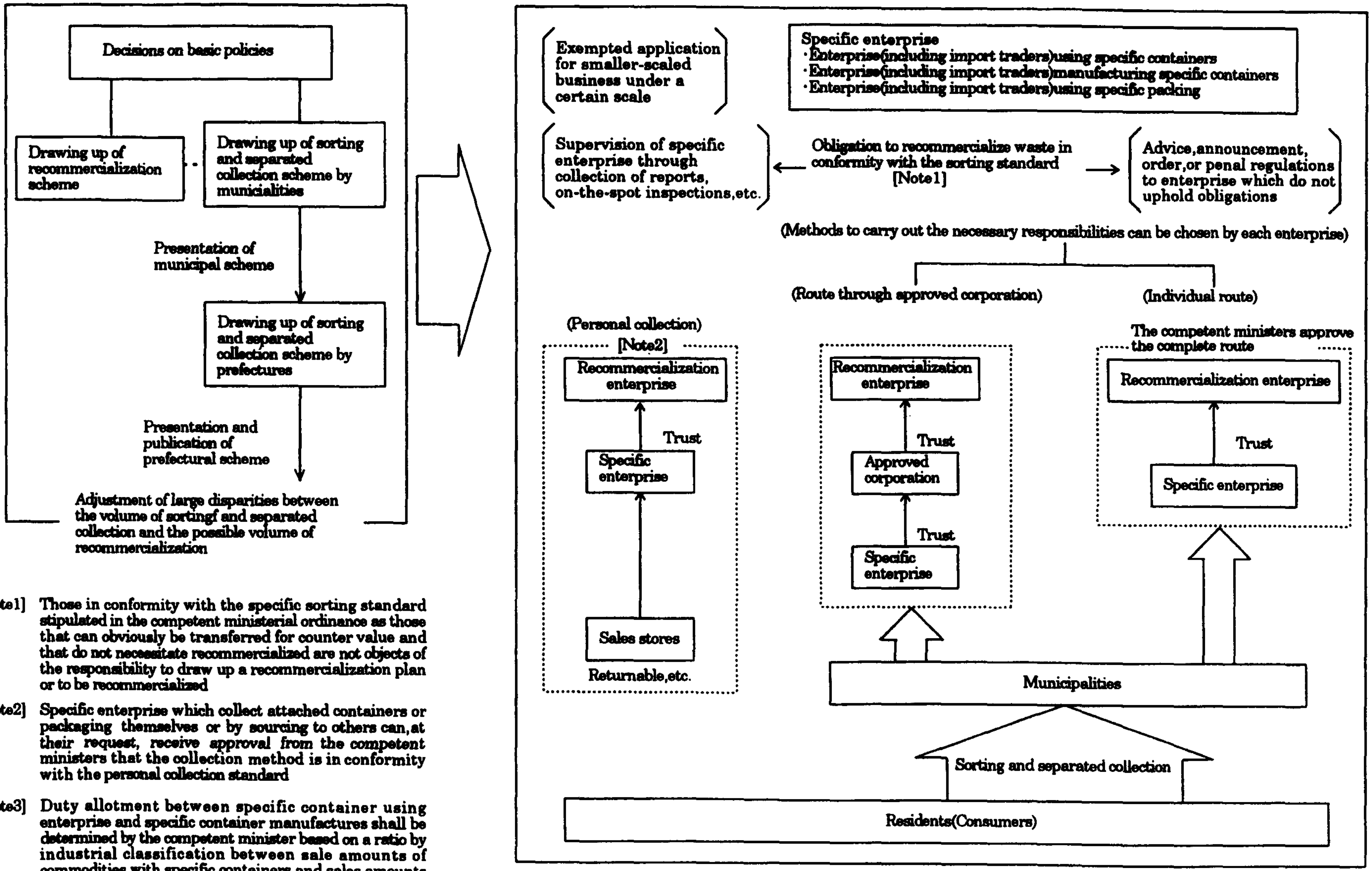
FIGURE 2. Physical composition of household wastes by origin.

for more than 60% of the total. Understanding MSW on the basis of weight, volumetric and original material is very important in considering approaches to MSW reduction and verifying the effects of avoidance and recycling measures taken, as well as in furthering material recovery from "Latent MSW" and understanding the effects of recycling. It will be required in future to establish an organization to gather information on the physical composition of MSW from a wider range of sources, for process into even more accurate statistical values than today.

Summary of Recycling Law of Containers and Packaging[4]

Until now municipal solid waste management, from its collection and transport to treatment and disposal, has been the responsibility of municipalities. Under the new packaging recycling law 1995, municipalities, consumers and enterprise will share the responsibility and cost of the recycling of waste containers and packaging. The term "containers and packaging" is defined in the law as containers and packaging of products which become unnecessary when the products are consumed or when the products are separated from containers or packaging. According to the definition, all containers and packaging which are attached to products are considered to be subject to the law. The law proposes that municipalities would carry out the separate collection of containers and packaging wastes and consumers would incorporate the sorting and separate collection of these wastes. Enterprise would recycle and recommercialize the containers and packaging wastes which the municipalities have collected. Specific enterprises would have to recommercialize the volume of waste containers and packaging which they were responsible for using or producing. Enterprises would carry this responsibility out in the following three methods, as shown in Fig. 3.

Personal collection. Containers and packaging would be exempted from the obligation to recommercialize if their method of collection is certified as fulfilling a certain recovery rate fixed by a competent ministerial ordinance, when collection is carried out by the enterprise itself or by someone contracted to collect the material. For example, when specific enterprises using returnable containers such as beer bottles receive this certification, even if a part of the container is discarded as municipal solid waste, the container would be exempted from the obligation to



[Note1] Those in conformity with the specific sorting standard stipulated in the competent ministerial ordinance as those that can obviously be transferred for counter value and that do not necessitate recommercialized are not objects of the responsibility to draw up a recommercialization plan or to be recommercialized

[Note2] Specific enterprise which collect attached containers or packaging themselves or by sourcing to others can, at their request, receive approval from the competent ministers that the collection method is in conformity with the personal collection standard

[Note3] Duty allotment between specific container using enterprise and specific container manufactures shall be determined by the competent minister based on a ratio by industrial classification between sale amounts of commodities with specific containers and sales amounts for the containers

FIGURE 3. Framework of bill on promotion of sorting, separated collection and recommercialization of containers and packaging.

recommercialize. Also, when specific enterprises collect the same kind of containers and packaging which they manufacture or use, or contract someone else to collect, the volume of the collection would be deducted from the volume of obligation to recommercialize.

Trusting to approved corporation. The corporation would receive approval from the minister to handle the recommercialization of waste for specific enterprises. Thus, these enterprises could contract out the collection to meet their obligations to the law.

Approval for recommercialization. Specific enterprises would either carry out recommercialization by themselves or could contract specially approved corporations to do it. Alternatively, it would be necessary to obtain a special approval of the competent minister in order to guarantee that they have reached certain standards.

The operation of sorting and separating collection, which is based on the municipal scheme, would be enforced within two years or, from April 1997. However, containers and packaging made mainly from paper or plastic which are specified by a government ordinance would be enforced within five years, or from the year 2000.

Present Status of Material Recycling in Japan

Used paper. The paper and pulp statistics[5] reveal that Japanese production of paper and plate paper—the paper used for manufacturing corrugated cardboard—amounted to 28.31 million tons in 1992 (26.8 million tons in 1989). This is the world's second highest production, following the 69.5 million tons in the U.S. in 1989. In terms of per capita consumption of paper, Japan is the third largest, registering 228 kg/person/year, following the 304 kg/person/year in the U.S. and the 223 kg/person/year in Sweden. The recycling rate of used paper in Japan was 51.3% in 1993 and the reuse rate was 53.1%. These levels are very high by world standards, may be the highest. Furthermore, Japan achieved the target of 55% in 1994. However, the reuse rate of normal paper represents only 25% and that of plate paper 86%. Thus, used paper is recycled and reused at a high rate, turned into plate paper which is the material for corrugated cardboard. Judging from the general recycling rate of used paper, it seems that the recycling rates of used newspaper and cardboard are better than the overall average of 50%. Thus, the recycling and reuse of used paper has long been positively promoted socially, for example in the small business exchange system. This encourages us to hold to our conventional commitment, i.e. continuation of used newspaper and corrugated cardboard collection as a central role in recycling. Materials whose recycling should be furthered in the future are fine-quality paper, such as that for printing in information processing, the probable major cause of the recent increase in the amount of MSW, and those types of paper which have a low reuse rate and a low recycling rate.

Interesting surveys on the causes of such infrequent reuse have been conducted by Kyoto City.[6] Based on the results of a questionnaire survey (reply rate: ca. 68%) on the destination of used paper waste which compared 320 enterprises and 30 public sectors. The results indicated that newspaper was sold to used paper collection businesses by approximately 66% of the organizations surveyed and corrugated cardboard was sold by 73% of the survey subjects, whereas computer continuous forms, photocopy paper and ledgers and slips were disposed by approximately 54, 69 and 69% of the businesses, respectively, indicating a low rate of recycling. One of the main reasons for a large percentage of the computer forms, photocopies and ledgers and slips not being recycled was that they were considered confidential documents. In sharp contrast are the main reasons for not recycling newspaper and cardboard; the storage space is lacking and acceptable collection businesses are not available. In the current situation, paper used for confidential documents is incinerated, together with other paper not requiring confidential attention. It is desired that greater care be taken on the side of discarders to ensure that only confidential documents are discarded. Another finding of the survey implies that the subject organizations strongly desire public sector involvement in the collection and storage of confidential documents. This is one of the aspects to be given further consideration. Fine-quality paper is recycled primarily into sanitary paper, whereas the reuse rates of low-quality and plate papers are generally held to be near their upper limits. Hence, the reuse rate of used paper in printing and information-processing must be raised to enhance paper recycling.

Used metal. The production of steel cans, combining drink and general cans, is an estimated 17 billion pieces for the year 1988, i.e. 730,000 tons a year (assuming an average can weighs 42 g), whereas aluminum cans are estimated to amount to 8 billion pieces for 1989, or 150,000 tons a year (assuming that a can weighs 18.7 g). Of the total can production (approx. 25 billion pieces) steel accounts for some 68% of the weight and aluminum 32%. The recycling rate of steel cans was 61% in 1993 (45% in 1988), whereas aluminum was 58% (43% in 1988). The target was to raise the rate to 60%. Steel cans are normally recycled through the electric furnace process. There are some restrictions[7] for recycling material: non-ferrous materials (copper, aluminum and tin, etc.), and impurities such as plastics must be removed from the material prior to being compressed into a small size (length + width + height = 180 cm max. with each side not longer than 80 cm). If these criteria are not met, the steel can and scrap is rendered valueless. Another problem is that for prices of raw iron and imported steel scrap are lower than the cost of the domestic collection of secondary materials. For aluminum cans, however, the move toward recycling is taking root owing to the advantage that only 590 kWh/ton of energy is needed to produce recycled aluminum metal, which is only 3% of the energy (21,100 kWh/ton) needed to produce virgin aluminum. It is very likely that government and industry will encourage further moves toward aluminum recycling. The share of aluminum cans in drink containers in the U.S. was 1% in 1964. This surged to 90% in 1984 and the recycling rate reached 50% or higher.[10] With reference to this, it is suggested that the upturn in the aluminum can recycling rate in Japan requires an increase in the number of collection stations and supply collection boxes, thus further improving the collection system.

Used glass. In 1990 about 2.4 million tons, or 11 billion glass bottles, were produced. In terms of weight ratio, returnable bottles accounted for about 25% and one-way bottles for about 75% of the total. In a survey by the Glass Bottle Recycling Promotion Federation, the total bottle distribution was approximately 6.3 million tons a year, amounting to around 15 billion pieces. Bottles are generally returned to liquor shops and other retailers, and then to wholesalers and bottle companies, and finally to bottlers. The recycling ratio of beer bottles was 97% in 1993 and that of rice wine bottles (1.8 l) 83%. This channel of bottle distribution, established as a product container circulation line, constitutes a social system which will encourage further administrative action toward the dissemination of returnable bottles.

The recycling system of broken glass in the form of cullet as raw material for glass manufacture belongs to the material recovery system. In addition to material collected through liquor shops and other retailers, glass cullet follows a flow from some associated group collection and public sector-involved separation, cullet-handling businesses, and finally to glass manufacturers where the cullet is recycled into bottles. The cullet use rate was 55.5% in 1993 (48% in 1990). Treatment, including removal of contaminant materials, color sorting and washing is carried out in the recycling process. Efficiency in this process is the greatest problem with glass cullet recycling.

Quality standards for glass cullet include standards for heterogeneous glass, specifying that chromite and similar minerals, and non-melting substances do not remain and that concrete, soil and stones including bricks, are 50 ppm or less in total. In addition, standards for metal such as iron should be 5 ppm or less, ceramic 20 ppm or less and plastics 100 ppm or less. Such requirements necessitate strong measures to maintain good quality in cullet manufacture. The strong tendency to seek colorless, transparent bottles in today's glass bottle manufacture incurs demand for the provision of cullet sorted by color which is a barrier to glass recycling. The fact that the price of cullet as a raw material is very often higher than that of virgin material, and that a bottle made from cullet weighs more, suggests the need for further improvement of separate collection stations and further action toward circulated use.

Used plastics. Material recovery from plastics and material recycling were launched only recently with the collection of only polyethylene phthalate PET bottles and foam trays. Such a short history does not allow the author to judge whether or not the recycling and reuse of plastics is possible in the current social system. PET resin production for bottles was at 100,000 tons a year and polystyrene foam products at 238,000 tons a year. This is because separation of plastic types is very difficult under the present conditions. Everyone knows that a wide variety of resins are discharged as waste, ranging from the polyolefine (PO) family to polystyrene (PS) to polyvinyl chloride (PVC) to polyethylene phthalate (PET). However, it is difficult to collect these separately. It is clear that, excluding PET (all of which is used for drink bottles), PO, PS and PVC plastics are applied to a very wide spectrum of products. The results of a questionnaire survey[3], asking household waste generators if they knew the differences among plastic resins, showed that only 2.4% of those replying answered "Yes" and were capable of naming such resins. When plastics are viewed as a subject of material recovery from MSW, it is therefore reasonable to think it impossible to collect resins separately under the current system, except where a single resin is used for a given range of products (e.g. PET bottles). Even if marking by type of resin continues to be promoted, there is no reason to expect waste discharge in completely sorted condition. The ideal material recovery and reuse methods for plastics should be pursued with a recognition of this defect. If society cannot choose this direction, despite recognizing the positive effect of plastics reuse, the next best measure would be to recover the oil or incinerate the material and generate power.

WASTE MANAGEMENT WITH POLLUTION CONTROL

The Present Status of Waste Management in Japan[9]

The amount of MSW generated in Japan in 1992 was 50.20 million tons compared to 50.77 million tons in

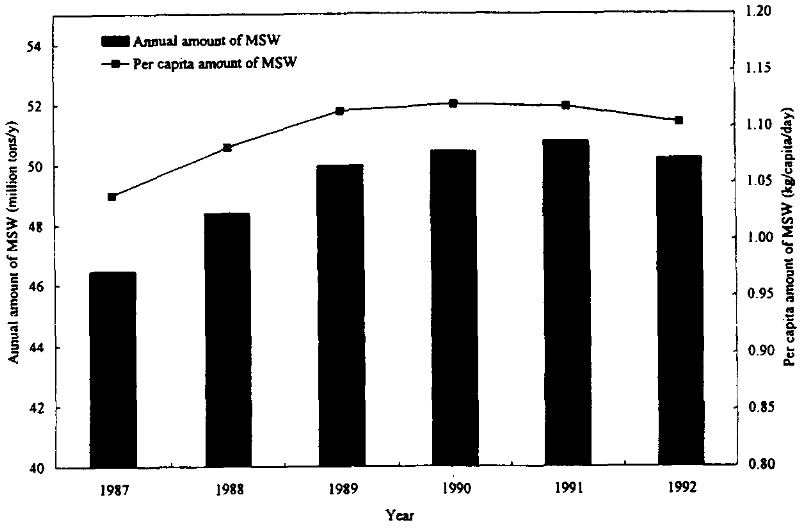


FIGURE 4. MSW amount between 1987 and 1992 in Japan.

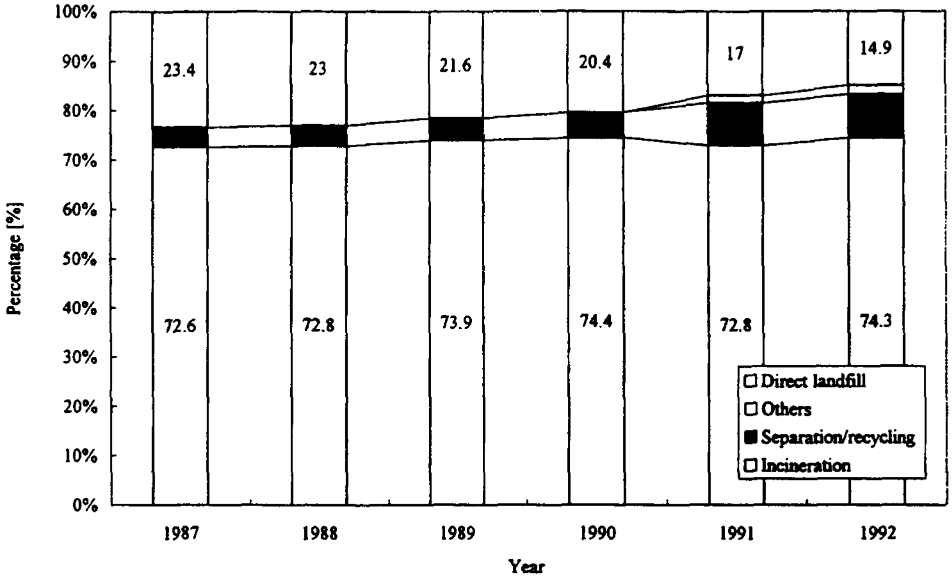


FIGURE 5. MSW management methods in Japan.

1991. The promotion of an appropriate strategy for waste reduction and an economic recession are considered to be the reasons for the 1.1% decrease. Per capita generation of MSW amounts to 1.10 kg which also decreased from the previous year (Fig. 4). The ratio of waste recycling followed by treatments such as incineration has been increasing year by year and the ratio was 85.1% in 1992 (83% in 1991). Of the total MSW generated which has been treated intermediately, the ratio of direct incineration was 74.3%, the total ratio of both MSW which has passed other methods such as crushing and separation and composting was 10.7% (Fig. 5). Conversely, the amount of MSW to be directly landfilled was 7.33 million tons in 1992 (8.46 million tons in 1991), which were equivalent to 14.9% (17.0% in 1991) of the total amount. Both the quantity and ratio have decreased significantly. The amount of resource recovery by separate collection and material separation was 1.93 million tons, the ratio of which was 3.9%. The amount of resource collected by some associated group collection was 2.16 million tons (1.41 million tons in 1992), which was also significantly increasing. In 1991, the numbers of MSW incineration and composting facilities were 1,841 and 29, respectively. The daily treatment capacity was nearly 178,000 tons in 1991. The number of landfill sites was 2,361 and their remaining capacity was 154 mio (million) m^3. The number of years remaining for landfill in the Kinki area was about 6.8 years, whereas in the Tokyo metropolitan areas the number was about 4.6 years.

TABLE 2
Municipal Waste Incinerators in Japan (Japan Waste Research Foundation in 1991)

Number of facilities	Stoker furnace	Fluidized bed furnace	Other types	Total
Continuous type	374	33	3	410 (24.3%)
Semi-continuous type	188	81	0	269 (16.0%)
Mechanical-batch type	812	3	0	815 (48.3%)
Fixed-grate batch type	193	0	0	193 (11.4%)
Total	1567	117	3	1687 (100%)
	(92.9%)	(6.9%)	(0.2%)	(100%)
Capacity (tons/day)	**Stoker furnace**	**Fluidized bed furnace**	**Other types**	**Total**
Continuous type	112,044	7049	700	119,793 (72.7%)
Semi-continuous type	15,364	5573	0	20,937 (12.7%)
Mechanical-batch type	22,364	95	0	22,459 (13.6%)
Fixed-grate batch type	1580	0	0	1580 (1.0%)
Total	151,352	12,717	700	164,679 (100%)
	(91.9%)	(7.7%)	(0.4%)	(100%)

Thermal Treatment with Pollution Control[10,11]
The results of a survey conducted by the Japan Waste Research Foundation on the status of municipal waste incineration are summarized in Table 2. The number of MWI in Japan is almost 1,800, out of which 1,687 facilities have answered this survey. The municipal waste incineration plants in Japan are classified as continuous, semi-continuous, mechanical batch and fixed-grate batch types. The continuous types are equipped with mechanical systems which can feed waste into the incinerator, transfer and agitate waste in the incinerator and discharge the ash continuously and easily under steady combustion control. They operate 24 hours a day. Semi-continuous types operate on the same principle but more intermittently. They generally operate 16 hours a day. Mechanical batch type facilities are not equipped with a mechanical system which can feed waste into the incinerator easily and continuously and tend to combust intermittently. They operate, in principle, eight hours a day. Part or all of the grates are power operated, and the agitation of waste and discharge of ash are carried out mechanically. Fixed-grate batch type systems are almost the same as the mechanical batch type but they operate without a grate moving system. The number of large-size continuous type incinerators which operate for 24 hours is 410, accounting for 24.3% of the whole number, and represents about 120,000 tons/day in terms of treatment capacity (72.7% of the total capacity). Continuous type incinerators are small in number but account for a large percentage of treatment capacity.

Sufficient measures must be given to environmental conservation and efforts must be made to supply electric power and hot water generated by waste heat energy through incineration to encourage energy saving. In Japan, specified control of hazardous substances such as dust, HCl, NO_x and SO_x generated during incineration are in place, but direct control over polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) has been only partly implemented at the moment. The Ministry of Health and Welfare determined guidelines for controlling dioxins and dibenzofurans in municipal waste treatment in December 1990. The countermeasures which form the nucleus of the guidelines are:

1. Measures to achieve complete combustion,
2. measures to lower temperature of flue gas into the dust collector and
3. improvement of the collection efficiency of discharged dusts.

Because formation of PCDDs/PCDFs can be suppressed by achieving complete combustion, construction designed for complete combustion and operation control are scheduled to be carried out using combustion temperature, carbon monoxide and oxygen concentrations in flue gas as indexes. Next, because PCDDs/PCDFs tend to be formed at the dust collector temperature of around 300°C, it was decided to lower the inlet temperature at the dust collector. In addition, installation of an electrostatic precipitator or fabric filter with high dust removal efficiency is planned for the completion of the PCDDs/PCDFs removal measures as well as to suppress the formation. The countermeasures based on the guidelines for controlling dioxins and dibenzofurans currently provided in Japan are expected to lower the PCDDs/PCDFs concentrations in flue gas to 0.5 ng/m^3N (2,3,7,8-TCDD toxicity equivalent concentration) in new continuous type incineration plants, and the discharge of PCDDs/PCDFs from municipal waste incineration plants throughout Japan is expected to decrease to below 1/10 of the current level. In addition, because a development of technologies to decompose slight traces of PCDDs/PCDFs contained in incineration residue is underway, effort must be made to further advance development for practical use. Further revision of dioxin guideline in Japan must include:

1. Adoption of highly efficient gas cleaning system,
2. residue destruction and recycling and
3. wide area management with sophisticated technologies and high energy recovery.

Ash Management in Japan[12,13]

The Waste Disposal and Public Cleansing Law, which concerns all aspects of waste management, was totally amended in October 1991 (hereinafter referred to as the Waste Management Law as amended). Upon establishment of the Waste Management Law, fly ash resulting from municipal waste incineration (hereinafter referred to as MWI) was designated as a domestic waste under special control, as possessing properties that can affect human health and environment. Although domestic waste is generally considered as an essentially non-hazardous waste from daily domestic activities, rather than from industrial activities, some products for domestic use contain hazardous substances even in trace amounts, and they tend to accumulate in soot and dust along with other hazardous substances produced during their incineration. This is the reason for the designation of a waste under special control. Direct landfill disposal of such soot and dust (hereinafter referred to as MWI fly ash) is banned by the new regulation. Presently MWI fly ash for landfill disposal should undergo an intermediate treatment specified by the Minister of Health and Welfare:

1. Melting and solidification,
2. solidification by cement,
3. stabilization using chemical agents, or
4. extraction with acid or other solvent.

The total annual amounts of bottom ash and fly ash produced by MWI in Japan are calculated to be 5 million tons and 1.2 million tons, respectively (Table 3). The assumptions of this calculation are as follows. The total municipal waste in 1991 was 50.77 million tons and the ratio of the waste to be incinerated was 73%. As for the lime used in the gas treatment unit to neutralize the acidic substances in the exhaust gas, such neutralizers are collected together in fly ash. The amount of neutralizer is roughly two times the amount of MWI fly ash originating from the ash content of waste, although it varies depending on the nature of the waste, exhaust gas treatment conditions and other factors. If we assume that 100 tons of waste is incinerated, in which the waste contains 15% ash, the MWI fly ash originating from the ash in the waste accounts for 10% of the ash, and an alkali is added to the fly dust at a 2:1 ratio, then 13.5 tons of incinerated bottom ash and 4.5 tons of MWI fly ash will be produced. In the case of a stoker furnace, although 50% of the total amount of waste is treated by the lime addition process, many stoker plants adopt wet scrubbing. In 1991, 83% of total facilities disposed of fly ash with bottom ash and 13% of those treated ash using solidification processes. The Waste Disposal Law as amended requires MWI fly ash to be subjected to an intermediate treatment specified by the Ministry of Health and Welfare and to meet the criteria specified by the Environment Agency (Environment Agency Notification No. 42, July 3, 1992) before subsequent landfill disposal.

Table 4 shows the four processes of intermediate treatment specified by the Ministry of Health and Welfare (Ministry of Health and Welfare Notification No. 194). This table gives relative evaluations of the four processes by the authors. Processes (2), (3) and (4) are based on chemical reactions of MWI fly ash and chemicals for insolubilizing the heavy metals in the MWI fly ash. In process (1), MWI fly ash is exposed to a high temperature and, thus, volatilizing substances are recovered as dust (melting fly ash), the residue being recovered as rock-like slag. Because the slag is basically vitreous, the hazardous heavy metals incorporated therein are very unlikely to leach, remaining stable against leaching operation and solvent pH. There is another effect in that the dioxins in the MWI fly ash are mostly decomposed because of the high temperature atmosphere. With these features,

TABLE 3
Ash Production by Municipal Waste Incineration in Japan

	Incinerated municipal waste [10^6ton/year]	Bottom ash [10^6ton/year]	Fly ash [10^6ton/year]	Incinerated residue [10^6ton/year]
Stoker furnace	34.20	4.62	1.03	5.65
Fluidized bed furnace	2.90	0.38	0.13	0.51
Total	37.10	5.00	1.16	6.16

Note: Total municipal waste production in 1991 = 50.77 × 10^6ton/year. Incineration ratio = 73%. Number of total facilities = 1870. Unit production of fly ash* = 3% (stoker furnace), 4.5% (fluidized bed furnace). Unit production of bottom ash* = 13.5% (stoker furnace, fluidized bed furnace). *Assumption: Ash content in municipal waste = 15%. Amount of fly ash = 10% of ash content. Alkali addition = 2 times of fly ash, 50% in case of stoker furnace, 100% in case of fluidized bed furnace.

TABLE 4
Comparison of the Specified Four Methods of MWI Fly Ash Regulation in Japan.

	(1) Melting	(2) Solidification by cement	(3) Chemical treatment	(4) Acid extraction
Ministry of Health and Welfare Notification No. 194.1	Melting is followed by solidification, and the resulting sludge or fly ash is treated by method 2, 3 or 4	Fly ash is uniformly kneaded with a sufficient amount of cement to ensure chemical stabilization to prevent heavy metal leaching and appropriately granulated or shaped material is thoroughly solidified	Fly ash is uniformly kneaded with a sufficient amount of chemical agents to ensure chemical stabilization to prevent heavy metal leaching	Full leaching of heavy metals in acid or another solvent is followed by dewatering and chemical stabilization of the heavy metals in the leachate
Principle	Fly ash is melted at high temperatures of 1200 to 1500°C into stable slag and secondary fly ash. The silica in the ash gains a $Si\text{–}O_2$ network structure by melting. Heavy metals migrate into such network meshes in the slag and solidify there into a stable vitreous substance, whereby heavy metal leaching is prevented. However, measures against volatilization should be taken, since low boiling substances volatilize in the gas	During the process in which cement component minerals such as calcium silicate bind with water to set itself, forming a crystalline hydrate, hazardous substances are absorbed and/or solidified, while the strong alkalinity of cement yields sparingly soluble compounds of the hazardous substances, which are precipitated and fixed in solid	Chemicals which are expected to be effective in stabilization of heavy metals in ash include sodium sulfide and *organic chelating resins*. Organic chelating agents react with heavy metals to form strong chelate bonds, resulting in insoluble heavy metal chelate compounds	Fly ash is suspended in acidic solution or water to extract heavy metals in the ash into the solution, which are then converted into insoluble metal hydroxides by caustic soda, or converted into insoluble compounds using heavy metal stabilization agents
Present status of technical development	△	○	○	△
Cost	△	○	△	△
Volume of final disposal	○	×	△	△
Long-term stability of residue	○	×	△	△
Feasibility of resources recycling	○	×	×	○

Note: Above evaluations (○,△,×) are based on relative judgment on the present status, rather than absolute evaluations, subject to change with future developments.

TABLE 5
Full-scale Melting Plants of MSW Incineration Residue in Japan

Municipalities	Completion	Capacity (ton/d)	Unit no.	Manufacturer	Furnace type
1. Numazu City	August 1979	20	1	Kubota	Rotating surface
2. Kashima Town	June 1981	6.5/8 h	1	Takuma	Surface melting
3. Eastern Saitama 2	March 1985	14.4	2	Takuma	Surface melting
4. Eastern Saitama 1	March 1986	15	2	Takuma	Surface melting
5. Isahaya City	March 1987	12.3	1	Kubota	Rotating surface
6. Sayama City	March 1991	15	1	Kubota	Rotating surface
7. Tokyo Ota	April 1991	250	2	Daido	Electric arc
8. Anan City	October 1991	4.8	2	Takuma	Surface melting
9. Handa City	February 1993	24	1	Ebara	Plasma
10. Omiya City	March 1993	75	1	Daida	Electric arc
11. Matsuyama City	March 1994	52	1	Ebara	Plasma
12. Sakado City	July 1994	9.6	1	Takuma	Surface melting
13. Shirane Regional Center	October 1994	7/16 h	1	Kubota	Rotating surface
14. Tokai City	March 1995	15	2	Nippon Steel	Coke bed
15. Eastern Saitama, New 1	September 1995	80	2	Daido	Electric arc
16. Kinuura Regional Center	September 1995	15	2	I.H.I.	Coke bed
17. Sayama City	March 1996	15	1	Takuma	Surface melting
18. Mima Regional Center	March 1997	5/16 h	1	Kobe Steel	Plasma
19. Hachioji City	March 1998	18	2	NKK	Electric Joule
20. Tamagawa Regional	March 1998	25	2	Daido	Electric arc
21. Kano Regional Center	March 1999	30	2	Hitachi	Plasma
22. Yokohama City	March 2001	60	1	NKK	Electric Joule

process (1) is unique against processes (2), (3) and (4) which are all based on chemical treatment, while process (1) is based on thermal treatment.

MWI fly ash can be thermally stabilized by melting and solidification. In any method, depending on the source of heating energy, fuel and electricity, inorganic materials must be melted and slagged while the temperature is kept above the melting point of the inorganics. During this process, heavy metals with low boiling points are volatilized and separated. In Japan, the sewage sludge melting process was developed in the 1980s and has been in practical operation at almost 10 full scale plants.[14,15] Some plants are being operated in which MWI fly ash, along with incineration bottom ash, is melted. Demonstrative operation and experiments for melting MWI fly ash alone are under way.[16–19] When considering ash treatment it is essential to accomplish both decomposition of persistent organic pollutants such as dioxins and the removal of heavy metals. Fly ash from MSW incineration is treated by the melting process in which dioxins in the fly ash are decomposed at temperatures of more than 1300°C in the melting furnace and heavy metals are concentrated in ash from the dust collector of the melting process.

Table 4 gives the authors' relative evaluations of the methods of chemical or thermal stabilization of fly ash. The table gives qualitative ratings of the methods as to present technical development status, treatment cost, final disposal volume, long-term stability of residue and feasibility of recycling resources. As far as the present status of technical development is concerned, solidification by cement and chemical treatment can be viewed as nearly completely established technologies. However, melting or acid extraction are now under development or improvement.

Table 5 lists MSW ash melting processes being operated commercially and under construction in Japan. Even though these melting processes are now commercialized they have technological issues to resolve and require continuous investigation to realize stable operation with minimum operation and maintenance cost. Melting, chemical treatment and acid extraction require inevitably high treatment cost in comparison with solidification by cement. Operating and Management cost of melting is between 100 US$/ton and 150 $/ton. The installation cost of each melting process is the same level, almost 1 million $/ton. However, solidification by cement increases solid volume by about 30% or more, resulting in an increased final disposal volume. Also, solidification by cement appears to be disadvantageous over other methods in long-term stability of the solidified product. With respect to metal concentration, separation and resources recycling feasibility, melting and acid extraction are thought to be better.

CONCLUSION

Material recovery from MSW is returning materials to the circulation system or commencing new circulation. To accomplish this, there is a need not only for technology to recover materials but also for building a social system, including manual separation and the establishment of new economic structures. After waste reduction and recycling, municipal waste must be incinerated and/or disposed of in landfills. Incineration plays an important role as a waste treatment method in Japan because of its high population density and limited landfill area. Of the 50 million tons of municipal waste produced in 1992, 74% was incinerated. In 1990, the Ministry of Health and Welfare promulgated guidelines for control of PCDDs/PCDFs in municipal waste treatment. In this guideline, 0.5 ng TEQ/Nm^3 is the expected value for new continuous type furnaces. According to Japan's Waste Management Law as amended in 1991, MWI fly ash cannot be allowed to be disposed of unless it is treated by one of the four methods specified by the Ministry of Health and Welfare. They are:

1. Melting
2. Solidification by cement
3. Stabilization by chemical agent
4. Acid extraction.

For ideal long-term measures against waste incineration residues, research and development priorities should be given to resource recycling, followed by stabilization and storage management. Both toxic reduction and recycling technologies are important to the cycle concept for MSW.

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