FLOW ANALYSIS OF METALS IN A MUNICIPAL SOLID WASTE (MSW) MANAGEMENT SYSTEM

C.H. JUNG[a], T. MATSUTO[a*], N. TANAKA[a]

[a]Lab of Solid Waste Disposal Engineering, Graduate School of Engineering
Hokkaido University, Kita 13 Nishi 8, Kita-ku, Sapporo, 060-8628, Japan

***Corresponding author. Tel. & Fax +81-11-706-6827**
E-mail address: matsuto@eng.hokudai.ac.jp (T.Matsuto)

Abstract

This study aimed to identify the metal flow in a municipal solid waste (MSW) management system. Outputs of resource recovery facility, refuse derived fuel (RDF) production facility, carbonization facility, plastics liquefaction facility, composting facility, and bio-gasification facility were analyzed for metal content and leaching concentration. In terms of metal content, bulky and incombustible waste had the highest values. Char from a carbonization facility which treats household waste had higher metal content than MSW incinerator bottom ash. A leaching test revealed that Cd and Pb in char and Pb in RDF production residue exceeded the Japanese regulatory criteria for landfilling, so special attention should be paid to final disposal of these substances. By multiplying metal content and the generation rate of outputs, the metal content of input waste to each facility was estimated. For most metals except Cr, the total contribution ratio of paper/textile/plastics, bulky waste, and incombustible waste was over 80%. Approximately 30 % of Cr originated from plastic packaging. Finally, several MSW management scenarios showed that most metals are transferred to landfills and the leaching potential of metals to the environment is quite small.

Key words: metal flow analysis, municipal solid waste (MSW) management, metal content, leaching concentration

1. Introduction

In Japan, “The Basic Law for Establishing a Recycling-based Society” was enacted in 2000 (The Japan Ministry of the Environment), and a number of laws and guidelines related to recycling have been enacted. The main goal of these laws is to minimize environmental damage and natural resource consumption. In this context, metals should be given a high priority since they can be hazardous properties to human health, and some of them are exhaustible resources due to limited reserves or low accessibility. The solid waste management system is a critical stage to determine whether metals are recovered, deposited in a landfill, or dispersed to the environment. This paper therefore aimed to identify the metal flow in the municipal solid waste (MSW) management system.

In the past, various studies have been performed on the mass flow of metals in society. Obernosterer and Brunner (2001) investigated the flow of Pb in an urban region, Vienna, with regard to environmental impact and resource recovery. Bergback et al. (2001) studied material flow of several metals such as Cd and Cr in Stockholm, Sweden. The flow of Cu in Europe was investigated by several studies through a lifecycle from extracting ore, through processing and manufacturing, to solid waste management or recycling (Graedel et al., 2002; Spatari et al., 2002; Bertram et al., 2002). Eriksson et al.(2002) developed a computer-based model, ORWARE (Organic Waste Research), to calculate metal flows, environmental impacts, and cost of waste management. However, most studies have focused on incineration and/or landfill in the MSW management system. Since there are many processes for pretreatment and recycling, data should be collected for every alternative option to identify the metal flow in an MSW management system.

This study includes all MSW management processes commonly used in Japan. Thermal treatment processes (incineration, ash-melting, gasification-melting) and material recovery

process for bulky waste have been examined in previous studies. For incineration, nineteen stoker incinerators, which were selected to have a variety of furnace types, furnace temperatures, and input waste, were investigated to identify the controlling factors on metal concentrations and distribution in fly ash and bottom ash (Jung et al., 2004). In ash-melting and MSW gasification-melting facilities, the production rate of melting furnace fly ash (MFA), metal distribution between MFA and molten slag, and metal concentration in MFA were studied (Jung et al., 2005). Matsuto et al.(2004) estimated metal mass balances in a material recovery facility (shredding facility) for household bulky waste.

This study investigated other recycling facilities. The metal balance in each facility was estimated as well as metal flows in the entire MSW management system. Finally, scenario evaluation was performed to find an optimal strategy for an MSW management system minimizing environmental impacts by metals.

2. Experimental

2.1. Surveyed MSW management facilities and input waste

Table 1 shows general information on MSW management facilities surveyed in this work. A resource recovery facility (*RR*), a RDF (refuse derived fuel) production facility (*RF*), a carbonization facility (*CB*), a plastics liquefaction facility (*LQ*), a composting facility (*CP*), and a bio-gasification facility (*BG*) were investigated. (In the following sections, facilities are identified by symbols). The operating temperature in liquefaction and carbonization processes is ranged from 400℃ to 500℃.Sampling of outputs from these facilities was conducted once (n=1) or twice (n=2), in 2002 and/or 2004. In the case of n=2, an average value was used for the amount of input, output, and water content. Water content in output was measured as received except for composting facilities, which was provided by facility

operators.

The composition of input waste to the surveyed facilities is shown in Table 2. In Japan, most municipalities collect PET bottles, glass bottles, and steel/aluminum cans in accordance with the Container and Packaging Recycling Law. Plastics and paper packaging are the other targets specified by the law. Plastic packaging was collected in 40 percent of municipalities, while only 8 percent collected paper packaging in 2003 (The Japan Containers and Packaging Recycling Association).

2.2. Sampling and sample preparation

On a sampling day, 3～10 kg of each output in the facilities shown in Table 1 was taken three times a day. Solid components were dried at 105℃ for 24hrs, and shredded to a size under 1mm using a cutting mill or ball mill. A composite sample was prepared for metal content analysis and leaching test. Residues and rejects, which contained various materials, were sorted according to composition (such as plastics or glass), shredded separately, and then mixed. Plastic bags in the *RR*, recovered ferrous/non-ferrous metals in the *CB*, and product oil in the *LQ* were not analyzed since they are supposed not to contain hazardous metals. Recovered materials in the *RR* were not sampled but metal contents will be estimated from those in the other residues. Rejects from pre-treatment in the *LQ* could not be sampled.

Incombustible waste, which was separated at the source and directly landfilled, was sampled twice in 2002 and 2004 at a shredding facility. Twelve kilograms samples of oversize (>10cm) and 23kg of undersize (<10cm) material were taken three times a day. The samples were sorted by component, shredded separately, and then mixed well.

The leaching test used fly ash and bottom ash from incineration, fly ash and molten slag from gasification-melting, and bulky waste, which were obtained during previous studies (Jung et al., 2004, 2005; Matsuto et al., 2004).

2.3. Metal analysis

Target metals were selected based on their scarcity and toxicity as noted in the previous report (Jung et al., 2004). Metal content was determined by atomic absorption spectrometry (AAS, Hitachi A-2000 and Z-8200) after microwave-assisted digestion (Jung et al., 2004). Bi, Cd, Cr, Pb, Sb, and Zn were analyzed by flame AAS, and As and Se were measured by graphite furnace AAS.

The leachability of metals was examined by Japanese leaching test No. 13 (Environmental Agency of Japan 1973). Ten grams of sample were added to a glass flask containing 100mL of distilled water adjusted to pH 5.8~6.3, to reach an L/S ratio of 10. After shaking horizontally for 6 hrs at 200 oscillations per minute, the leachate was filtered through a glass-fiber filter (1μm) and acidified below pH 2 by HNO_3. Metal concentration was measured by ICP-AES (Shimadzu ICPS-7500). As and Se were determined by graphite furnace AAS.

3. Material balance of metal in MSW management facilities

3.1. Composition of outputs of MSW management facilities

The composition of outputs from MSW management facilities is shown in Table 3. In the *RR*, residues were collected as either incombustibles or combustibles. The largest component of incombustible residues from the *RR-N* and *RR-K* was broken glass, which constituted up to 97%. Combustible residue consisted of rejects, which were inappropriate materials for recycling, and plastic bags for waste collection. The reject percentage in combustible residue was about 50% in the *RR-K* but was not known in the *RR-N*. Since the residue removed as

plastic bags mostly consisted of plastics, its composition was not shown in Table 3. In the *CP-M*, most residue was wood chips while about 40% of residue from the *CP-I* was bone and tableware. The residue of the *LQ* was carbon.

Incombustible waste was shredded and then classified into oversize and undersize material with a 10 cm vibrating screen, after recovery of ferrous metals and aluminum. Table 4 shows the composition for the oversize fraction, which was approximately 65% of total weight. The largest component was plastics (about 24%). The undersize fraction was mostly fine particles so it was impossible to sort this into components by manual separation. The quantities of recovered ferrous metal and aluminum were 10% and 0.6%, respectively.

3.2. Metal content in outputs of MSW management facilities

Metal content in outputs of MSW management facilities and incombustible waste are summarized in Table 5. Bulky waste (Matsuto et al., 2004) is also shown for reference. A high variability was found for Cr, especially in the residue of the *LQ*, which treats plastic packaging. In the analysis of metals in plastic packaging, Cr content was extremely high in plastic shopping bags, whose contribution ratio to Cr in plastic packaging was about 80% (Jung, 2005). Variable composition in plastic packaging waste might have caused the variability of Cr content. The variability of Cr and Pb in incombustible residues can be attributed to variable content of fine particles and electric circuit boards in samples (Jung, 2005). As for Bi and Se, detected values were close to the detection limit, so the variability was not high. The influence of data variability on metal flow on MSW management system will be discussed in section 4.2. Metal contents in RDF, compost, and undersize fraction (<5cm) of shredded bulky waste from literature are provided in Table 6. Most metals in Table 5 are in the range of metal contents from literature except for As, Cd, Sb, and Se in RDF.

To make comparison easier, metal content was normalized by the content of MSW incinerator bottom ash, as shown in Figure 1. The average value for each sample in Table 5 was used. Outputs were classified into two groups, i.e. products and residues. The RDF of the *RF*, the char of the *CB*, and the compost of the *CP* were defined as products and the others were grouped as residues. For most metals, char (carbonization residue), bulky waste, and incombustible waste were higher than bottom ash. In particular, levels of Cd, Pb and Zn in char were considerably higher than those in bottom ash. Pb in the residue of the *RF* and the incombustible residue of the *RR-N* was higher than in other outputs excluding char, bulky waste, and incombustible waste. Cr and Se were contained in most outputs although most of them were lower than in bottom ash. Zn in compost was much lower than the regulatory criteria of compost product as organic fertilizer, 1,800mg/kg.

3.3. Leaching potential of metals

Figure 2 provides the result of the leaching test. The acceptance criteria for landfilling are indicated by a dotted line. The results for an incineration and gasification-melting facility are also presented for comparison. All values that were higher than the detection limit were plotted in Figure 2.

Pb and Cd in char and Pb in RDF production residue exceeded the Japanese regulatory criteria for landfilling (Pb 0.3 mg/L, Cd 0.3 mg/L), so special attention should be paid to disposal of these substances, and especially to RDF production residue which is directly landfilled without any pretreatment. Se were leached from most residues and products, but below landfilling criteria, 0.3 mg/L. Bulky waste and incombustible waste showed a high metal concentration as explained in 3.2, but their leaching potential was quite low.

3.4. Estimated metal content in input waste

Metal contents in input waste were estimated by multiplying metal contents (Table 5) and the generation amount of outputs (Table 1). In this calculation, the average value for metal content was used. Figure 3 shows the estimated contents of Cr, Pb, Sb, and Zn in input wastes on a wet weight basis. For the *CP*, metal contents in food waste were calculated by assuming that sawdust and wood chips do not contain metals.

The contents in bulky waste and incombustible waste were notably high compared to other input wastes. The high content of Pb in carbonized waste was undoubtedly caused by treating bulky and incombustible waste as well as combustible waste in the *CB*. Food waste is a source of Zn because outputs in the *CP* and *BG* contained Zn. However, Zn content was relatively low in the *BG* and *CP-M*, so the high content of Zn in input waste to the *RF* was probably derived from paper/textile/plastics. And, there was no difference in Zn content between the *CP-M* and *BG*. Thus, the Zn in wood chips added to control water content in the *CP-M* may be negligible. Plastic packaging contained a high amount of Cr, as shown in the *LQ*. From this, Cr in input waste to the *RF* and *RR* is thought to be largely due to plastic packaging.

In the *RR*, metals were distributed in incombustible residues, which were mostly made up of glass (Table 3). The recovered materials (PET bottles, cans, glass bottles) were 1.8-2.5 times larger in weight than incombustible residues, and glass accounted for about 30% of the recovered material. Metal content in recovered glass was assumed to be the same as that in glass of incombustible residue. Moreover, metal content except Al and Fe in PET bottles and cans, was assumed to be zero. Metals in input materials were roughly estimated to be 1.65 times ($1+\{(1.8+2.5)/2\}\times 0.3=1.65$) higher than in Figure 3

It is important to understand metal distribution between outputs, i.e. residues and

products, to assess the fate of metals. In the *RF* and *CP*, most metals were transferred to product, i.e. RDF and composts as shown in Figure 3. In the *BG*, metals remained in solid residues (dewatering residue and rejects), so they would be dispersed in the environment when the residue is composted. In the *RR*, metals were mostly found in incombustible residues. Approximately, 80% of Pb in bulky waste and incombustible waste was distributed in the undersized portion (<10cm) which is directly landfilled.

4. Estimation of Metal flow in the MSW management system

Based on the results obtained in the previous sections, various scenarios are evaluated to find a better choice of solid waste management options in terms of environmental impact caused by metals. However, discussion is limited to household waste due to a lack of data on commercial and business waste, which is the other element of municipal solid waste.

4.1. Estimation of metal content in household waste composition

Metal contents in each waste composition defined in Table 2 were estimated in the following manner using the information on input waste in Table 1.

(a) Food waste

The *CP* and *BG* in Table 1 treat food waste. All facilities receive food waste from both commercial and household areas. From these, the *CP-M* was chosen for calculating metal content in food waste because 93% of feedstock is generated from households.

(b) Plastic packaging

The result from the *LQ* was used.

(c) Recyclable waste (Cans, PET bottles, Glass bottles)

The result from the *RR-K* was used because a mass balance of outputs was obtained. Metal content in recyclable waste was estimated by multiplying metal content by 1.65 in outputs from the *RR-K* for the reason mentioned in 3.4.

(d) Paper/Textile/Plastics

This material is treated by the *RF*, the *CB*, and incineration. However, the *CB* receives both bulky and incombustible waste, and incineration facilities treat commercial waste along with household waste. Thus the *RF* was selected for the calculation of metal content in paper/textile/plastics. The *RF* treats food waste and plastic packaging as well as paper/textile/plastics as shown in Table 2. So, metal content in paper/textile/plastics was calculated by subtracting metal content in food waste and plastic packaging from metal content in the total input waste.

(e) Bulky waste

The estimated value in the previous work (Matsuto et al, 2004) was used.

(f) Incombustible waste

Data from this study were used.

Estimated metal content in the household waste composition is summarized in Table 7. The collected amount of household waste per capita-day was taken from Jung (2005). For most metal elements, bulky and incombustible waste showed the highest content. Plastic packaging had a high content of Cr.

Table 8 shows metal contents in household waste composition as recorded in literature. In comparison with Table 7, the content of Cd, Cr, Pb, and Zn varies significantly. This might be caused by different definitions of MSW and source separation/collection systems between countries.

4.2. Contribution ratio of MSW composition to metal content

By using Table 7, the relative contribution of each waste composition to metal content was calculated as shown in Table 9. Paper/textile/plastics showed the highest contribution for Bi, Sb, Se, and Zn. High amounts of As and Pb were contained in bulky waste. Incombustible waste was a large source of Cd and plastic packaging contributed greatly to Cr. As expected, the contribution ratio of food waste to metal content was very low.

The values in parenthesis are the contributions of specific components (e.g. food waste) to each metal by using the maximum content for the composition in Table 5 and average values for the other compositions. Except for Cr in plastic packaging, the contributions are not very different from the previous ones. Therefore, the variability of metal content in Table 5 is not critical for estimating the contribution of waste composition to metal content.

4.3. Evaluation of MSW management scenarios

In order to investigate the influence of a waste management options on metal flow, four typical scenarios of MSW management were assumed as follows:

- Present scenario (P): Bulky waste and incombustible waste are landfilled after shredding, and other waste components are incinerated.
- Incineration scenario (I_1): Incineration is maximized. All waste compositions are incinerated and residues are landfilled.
- Gasification-melting scenario (I_2): A gasification-melting system is used instead of the incineration process in scenario I1. Molten slag is assumed to be used for construction and for road material.
- Bio-waste recycling scenario (B): Food waste is collected and composted in scenario P.

Compost is used as organic fertilizer in land and residue is landfilled.

In all scenarios, recyclable waste is assumed to be collected and sorted in an *RR*. Generally, fly ash from MSW incineration and gasification-melting facility has to be stabilized before landfilling. In this study, however, the metal leaching potential of untreated fly ash is used for safety. The metal distribution ratio in the incineration process and the melting process were taken from previous studies (Jung et al., 2004; Jung et al., 2005).

Each scenario was evaluated using the total mass and leached mass for Cr, Pb, Sb, and Zn. The result is provided in Figures 4 and 5. The gasification-melting scenario (I_2) shows the lowest metal transfer to landfill. In particular, Cr is much lower than in the other scenarios since molten slag including a high Cr content is recycled for construction and road material. For other metals, there is no difference in distribution between scenarios, and most metals are deposited in landfills (Figure 4).

The leaching potential of metals from molten slag is very low as explained in Figure 2. Fly ash and bottom ash show the highest leaching potential for most metals, and high amount of Zn is leached from shredded bulky and incombustible waste. The leaching risk of metals to the environment is, however, quite small in the well-designed and managed landfill because the leak of leachate is minimized by liner system and leachate is treated before discharged to the environment. Higher risk can be caused when the products such as compost are used in the environment, but the leached mass of metals is negligible as shown in Figure 5. Consequently, there was found little difference in environmental risk under all assumed scenarios.

5. Conclusion

This study quantified metal flows in MSW management systems. The main results are:

- For most metals, char, bulky waste and incombustible waste showed a higher content than bottom ash. Metal distribution analysis between outputs shows that most metals transferred to products, i.e. compost and RDF, in composting (*CP*) and RDF production facilities (*RF*) while they remained in reject and dewatering residue in bio-gasification facilities (*BG*).
- The results of the leaching test (JLT No. 13) showed that Cd and Pb in char and Pb in RDF residue were higher than the Japanese regulatory criteria for landfilling. This means that final disposal of RDF production residue and recycling of char should be given special attention.
- In the household waste flow, the total contribution ratio of paper/textile/plastics, bulky waste, and incombustible waste to metals was over 80 % except for Cr. Approximately 30 % of Cr originated from plastic packaging.
- Under all assumed scenarios, most metals were transferred to landfills and controlled well. It means that the present MSW management system does not have serious problems with regard to metals.

This study will be helpful to management of metals. But, in order to reduce environmental risk in the society, products that have high contribution to metals should be identified by more detailed analysis.

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Table 1. General information of facilities for sampling

[Wet weight basis]

Facility		Capacity	Input [ton/year]		Output [kg/t-Input]		Water content[%]	Sampling	n	Composition analysis
Resource recovery	*RR-N*	105t/8h	Recyclable waste (Glass bottles, Cans, PET bottles)	23,782	Recovered material*	601	N.A.			
					Plastic bag	102**	N.A.			
					Reject		N.A.	○	1	○
					Incombustible residue	246	1	○	2	○
	RR-K	75t/5h	Recyclable waste (Glass bottles, Cans, PET bottles)	10,503	Recovered material	567	N.A.			
					Plastic bag	28	N.A.			
					Reject	33	N.A.	○	1	○
					Incombustible residue	317	2	○	1	○
RDF production	*RF*	20t/7h	Paper/Textile	1,253	RDF	731	5	○	2	
			Food waste/Plastics		Residue	22	15	○	2	○
Carbonization	*CB*	210t/d	Paper/Textile	57,575	Char	144	0	○	1	
			Bulky waste/Incombustible waste		Ferrous metal	7	N.A.			
					Non-ferrous metal	16	N.A.			
Liquefaction	*LQ*	21t/d	Plastic packaging (Excluding PET bottle)	1,829	Oil	384	N.A.			
					Carbon residue	326	0	○	2	
					Rejects from pre-treatment	112	N.A.			
Composting	*CP-I*	3t/8h	Food waste (H:C=2.7:1)	714	Compost	287	33	○	2	
			Sawdust	72	Residue	4	8	○	2	○
	CP-M	20t/d	Food waste (H:C=9.3:0.7)	4,797	Compost	110	35	○	2	
			Wood chip	752	Residue	40	23	○	2	
Bio-gasification	*BG-F*	16t/d	Food waste (H:C=7:3)	3,700	Biogas	113,677#	N.A.			
					Plastic bag	44	21			
					Reject	85	74	○	1	
					Dewatering_residue	66	74	○	1	
					NH_4^+removal filter filtrate	1556#		○	1	
					Dewatering_filtrate	260 #		○	1	
	BG-T	50t/d	Food waste (H:C=1:3)	3,610	Biogas	117,304 #	N.A.			
					Light reject including plastic bag	180	74	○	1	
					Heavy reject	30	53	○	1	
					Dewatering_residue	33	88	○	1	
					Dewatering_filtrate	1,607 #		○	1	

H:household, C:commercial, N.A.:not analyzed, n: number of sampling work

*Recovered material: aluminum can, steel can, PET and glass bottle

**Only total amount was known.

#[L/t]

In the case of n=2, average value was used.

Table 2. Input waste composition for MSW management facilities surveyed in this work

Facility \ Input waste	Food waste	Paper /Textile	Plastics		Recyclable waste	Bulky waste#	Other wastes (Incombustible waste)
			Plastic packaging	Other plastics			
Resource recovery (*RR-N, RR-K*)					●		
RDF production (*RF*)	●	●	●	●	○*		
Liquefaction (*LQ*)			●				
Composting (*CP-I, CP-M*)	●						
Bio-gasification (*BG-F, BG-T*)	●						
Carbonization (*CB*)	●	●	●	●		●	●
Shredding						●	●

Recyclable waste: PET bottle, Glass bottle, Steel/Aluminium can
*PET bottle among recyclable waste is fed to RDF facility
#Data were taken from Matsuto et al.(2004)

Table 3. Composition of outputs in MSW management facilities

[Wet weight %]

	Resource recovery (*RR-N*)		Resource recovery (*RR-K*)		Residue of RDF (*RF*)	Residue of composting (*CP-I*)
	Incombustible residue	Rejects	Incombustible residue	Rejects		
Plastics	1.8	53.6	2.3	95.9	15.4	18.6
Paper	0.5	0.5	0.3	0.5	9.6	-
Rubber	-	-	-	-	8.2	0.4
Wood	-	-	-	-	4.1	2.2
Ferrous metal	0.1	13.0	0.1	3.7	18.3	23.6
Non-ferrous metal	0.8	2.7	0.4	-	3.5	10.8
Glass	96.8	30.2	96.9	-	-	-
Others	-	-	-	-	40.8	44.4

Table 4. Composition of incombustible waste

Composition		Wet weight %
Oversize (>10cm)	Plastic film	7.5
	Plastics (rigid)	16.8
	Textile	7.4
	Wood	1.1
	Paper	2.5
	Insulating material	1.4
	Rubber	3.8
	Ferrous metals	5.5
	Aluminum	1.3
	Others	17.4
Undersize (<10cm)		24.0
Ferrous metal (recoverd)		10.3
Aluminum (recovered)		0.6

Table 5. Metal content in outputs of MSW management facilities

Facility		Sample	Content [mg/kg, dry weight basis]							
			As	Bi	Cd	Cr	Pb	Sb	Se	Zn
Resource recovery	*RR-N*	Incombustible residue (2)	9.1 / -	-	-	120 / 75	110 / 17	76 / -	1.3 / 2.3	57 / -
		Reject (1)	-	15	-	51	9.4	14	1.4	19
	RR-K	Incombustible residue (1)	-	-	-	75	-	-	1.2	-
		Reject (1)	-	40	-	38	5.6	9.3	1.2	40
RDF production	*RF*	RDF (2)	-	- / 15	-	64 / 56	350 / 17	56 / 13	- / 2.4	230 / 150
		Residue (2)	0.9 / 2.7	4.2 / 20	1.2 / -	102 / 248	98 / 40	41 / -	0.80 / 2.9	830 / 1,700
Carbonization	*CB*	Char (1)	4.5	31	44	160	6,000	190	2.8	14,000
Liquefaction	*LQ*	Residue (2)	-	-	-	1,300 / 14	18 / 17	80 / -	- / 1.2	100 / 55
Composting	*CP-I*	Compost (2)	-	- / 9.9	-	15 / -	-	36 / -	-	85 / 89
		Residue (2)	-	- / 17	-	66 / 59	- / 52	35 / -	- / 2.1	130 / 69
	CP-M	Compost (2)	-	- / 12	-	20 / 32	-	51 / -	- / 2.3	73 / 66
		Residue (2)	-	- / 7.9	-	49 / -	-	58 / -	- / 1.7	47 / 29
Biogasification	*BG-F*	Reject (1)	-	13	-	-	-	-	-	60
		Dewatering_residue (1)	-	29	-	10	-	9.1	3.0	210
		NH_4^+removal filter filtrate* (1)	0.083	0.22	-	-	-	-	0.015	-
		Dewatering filterate* (1)	0.041	0.26	-	-	-	-	0.041	0.69
	BG-T	Light reject (1)	-	-	-	-	-	-	1.8	30
		Heavy reject (1)	-	23	-	22	12	-	3.3	47
		Dewatering residue (1)	-	25	-	27	16	10	2.1	300
		Dewatering filterate* (1)	0.057	0.12	-	-	-	-	0.011	0.60
Incombustible waste		Oversize (>10cm) (2)	0.02 / -	26 / 49	22 / -	1,100 / 45	100 / 140	35 / 17	8.7 / -	1,100 / 1,600
		Undersize (<10cm) (2)	17 / 6.2	- / 59	13 / -	380 / 130	2,100 / 210	150 / 41	2.3 / 2.4	2,600 / 960
Bulky waste**		Oversize (>10cm)	1.2	13	2.7	27	130	320	0.5	640
		Undersize (<10cm)	27	12	3.5	72	2,200	520	0.7	2,200
Incinerator bottom ash#			1.3	18	5.5	110	670	98	2.0	2,400
Detection limit		[mg/kg]	0.50	6.0	0.20	2	5.0	7.0	0.50	0.5
		[mg/L]	0.005	0.06	0.002	0.02	0.05	0.07	0.005	0.005

-:Not detected

( ): Number of data

*[mg/L]

**Metal content in bulky waste was taken from Matsuto et al. (2004)

#Metal content in incinerator bottom ash was taken from Jung et al. (2004)

Table 6. Metal contents from literature

	Number of facility	Metal content [mg/kg] As	Bi	Cd	Cr	Pb	Sb	Se	Zn	Ref.
RDF	3	0.3～0.78		0.7～1.2	20～30	20～40	<0.1～0.26	<0.25	110～190	(a)
	2	0.47～1.1		1.7～8.3	30～71	35～130	2.8～7.0		98～170	(b)
Compost	1	<0.10～12.00		<0.10～0.60					138～300	(b)
	1	0.1～4.7		<0.1～1.9	1～7.8	<0.1～28			0.21～180	
Shredded bulky waste : Undersize fraction (<5cm)	2			0.13～9.5		350～2,360			2,580～4,330	(c)

Blank: Not found
(a)Kim, 1994
(b)Wasste Research foundation, 1998
(c)Sekito, 2000

Table 7. Metal contents in household waste composition

	Collected amount [g/capita/day]	Metal content [mg/kg, wet weight basis]							
		As	Bi	Cd	Cr	Pb	Sb	Se	Zn
Paper/textile/plastics	328	0.06	10	0.02	41	37	44	1.6	300
Food waste	251		0.5		2.6		2.7	0.1	6.1
Recyclable waste	64		1.8		40	0.2	0.4	0.6	1.8
Plastic packaging	72				210	5.6	13	0.2	25
Bulky waste	28	5.8	6.6	1.5	23	480	210	0.3	640
Incombustible waste	30	2.8	31	8.7	430	360	39	3.4	1300

Blank: Not detected

Table 8. Metal contents in household waste composition from literature

[mg/kg, dry weight basis]

	Cd			Cr		Pb			Zn		
	a	b	c	a	b	a	b	c	a	b	c
Paper	0.03-0.3	5.26	0.4	20-30	10.9	72-228	44.3	23	80-180	393	424
Textile	0.06-0.3	32.6	1.0	7.5-10	3160	4-12	773	35	10-20	4000	520
Organics	0.06-0.45	1.0	0.4	10-15	607	20-156	407	37	50-100	1010	241
Plastics	0.39-2.1	40.4		20-22.5	106	32-108	602		30-80	284	
Packaging plastics			0.9					109			768
Non-packaging films			1.3					219			730
Other plastic products			67.4					500			4380
Glass		1.83	1.0	22.5-30	275	8-28	628	2	10-20	75	50

a. White et al.(1999)
'Paper' includes 'carton'. 'Plastics' excludes 'PVC'.
b. Chandler et al.(1997)
c. Rotter et al.(2004)
'Paper' includes 'cardboard'. `Cr' was not analyzed.

Table 9. Contribution of household waste composition on metals

[%]

	As	Bi	Cd	Cr	Pb	Sb	Se	Zn
Paper/textile/plastics	7 (12)	**71 (83)**	2 (4)	30 (34)	33 (40)	**63 (74)**	**74 (85)**	**62 (67)**
Food waste		3 (6)		1 (2)		3 (6)	4 (7)	1 (1)
Recyclable waste		2		6	0.03	0.1	5	0.1
Plastic packaging				**33 (67)**	1 (1)	4 (8)	2 (4)	1 (2)
Bulky waste	**61**	4	14	1	**37**	25	1	11
Incombustible waste	32 (40)	20 (27)	**84 (92)**	28 (42)	29 (41)	5 (7)	14 (23)	24 (29)
Sum	100	100	100	100	100	100	100	100

( ): Contribution ratio of specific component (e.g. food waste) to each metal by using the maximum content for the component in Table 5 and average value for other components

Figures in bold type indicate the higest contribution ratio.

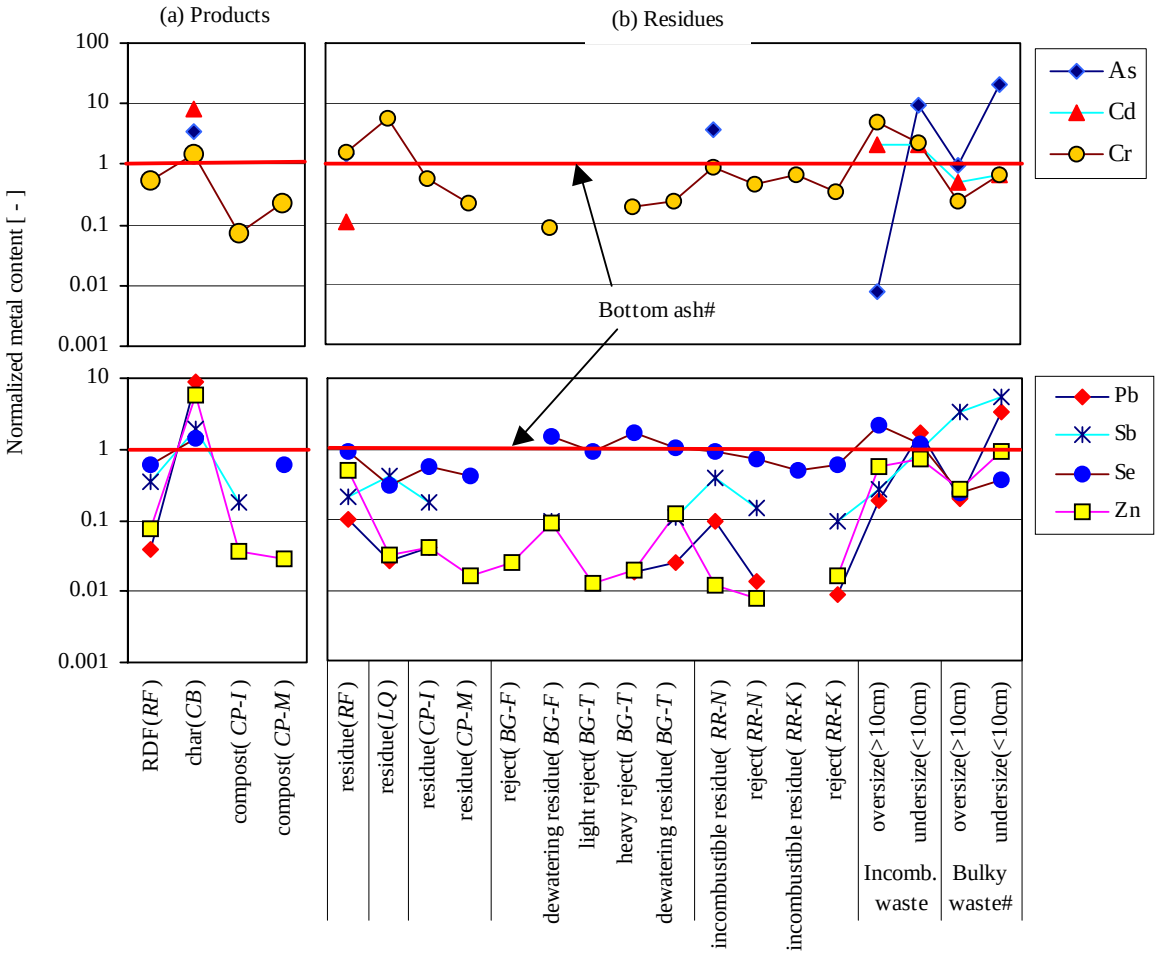

Figure 1. Normalized metal contents divided by content in MSW incinerator bottom ash [Dry weight basis]

#Metal content in bottom ash and bulky waste was taken from Jung et al.(2004) and Matsuto et al.(2004). The contents were provided in Table 5.

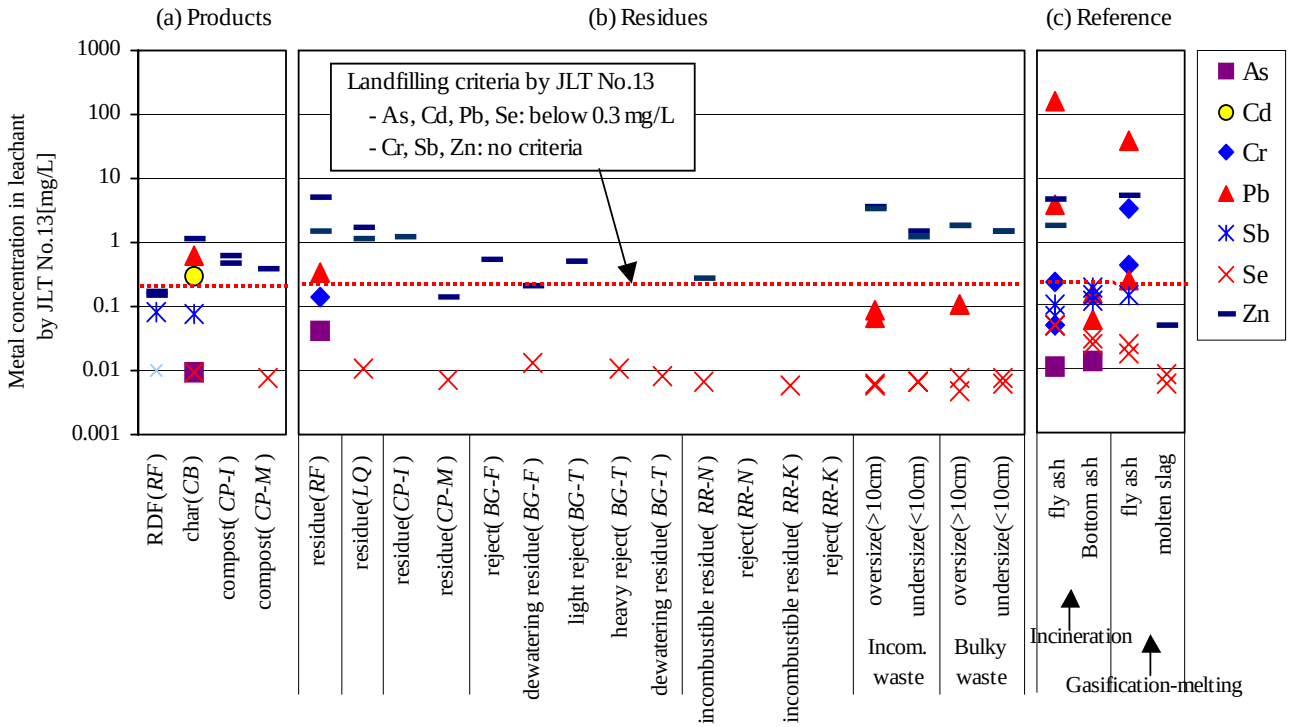

Figure 2. Metal concentration in leachant by Japanese leaching test (JLT No. 13)

All values over detection limits were plotted.

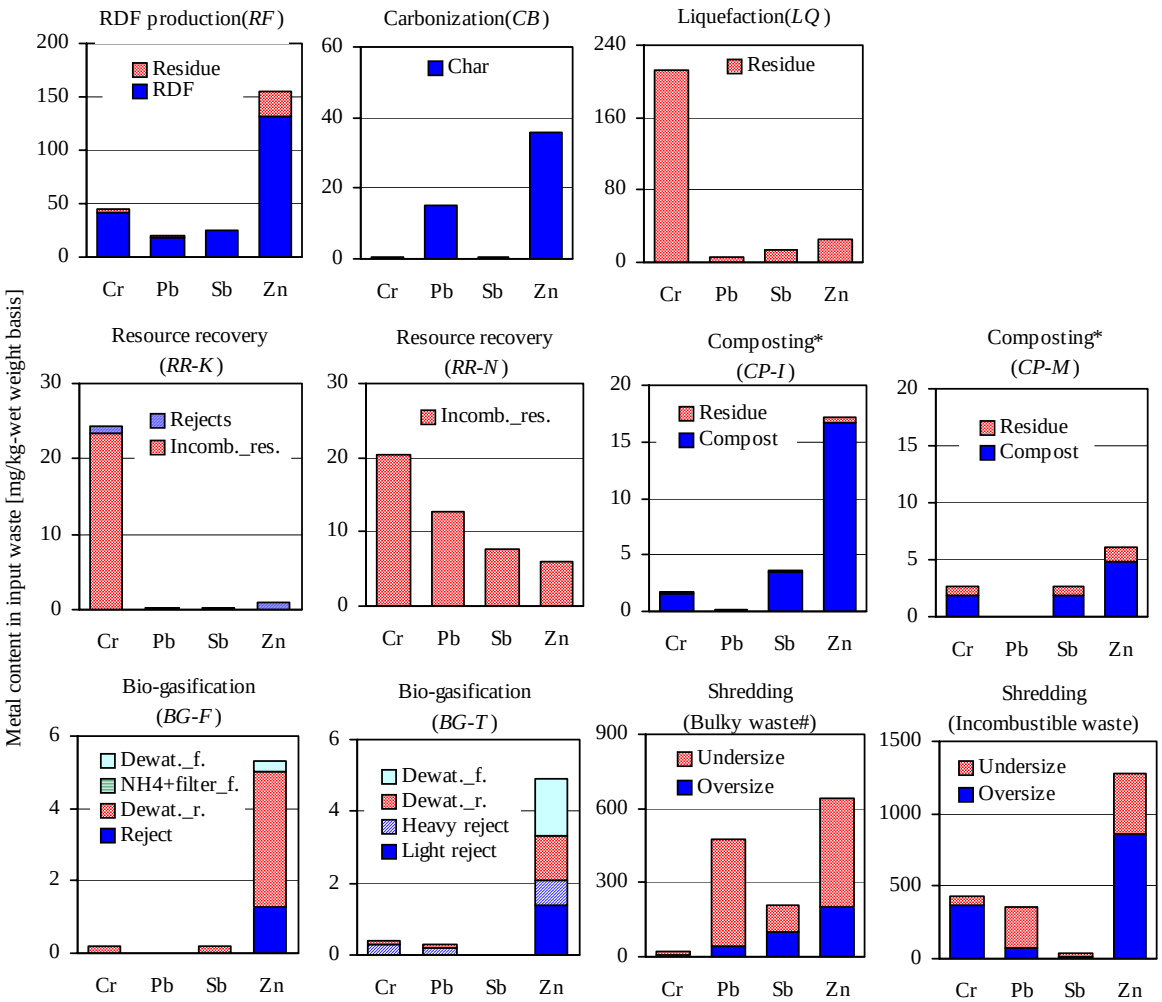

Figure 3. Estimated metal content of input waste in each facility

*Metal content in food waste was calculated by assuming that no metals are contained in sawdust and wood chip.
#Metal content in bulky waste was taken from Matsuto et al. (2004).

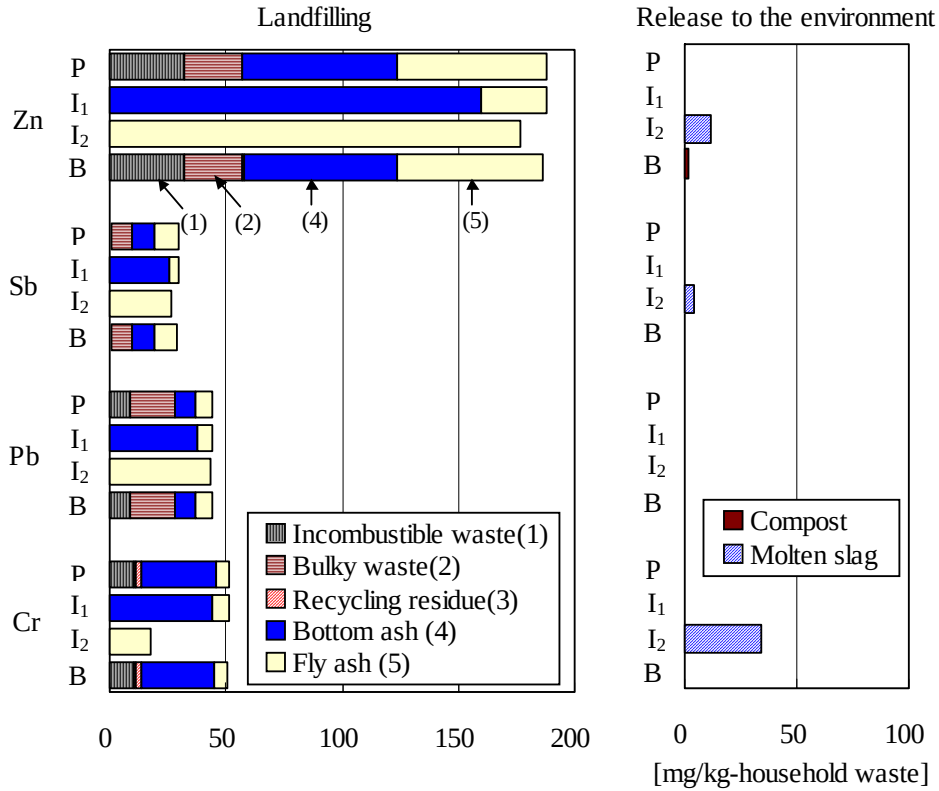

Figure 4. Fate of metals in different MSW management scenarios

P: present scenario, I_1: incineration scenario, I_2: gasification-melting scenario, B: bio-waste recycling scenario

Data of bulky waste, bottom ash, fly ash, and molten slag were taken from Matsuto et al.(2004) and Jung et al.(2004, 2005)

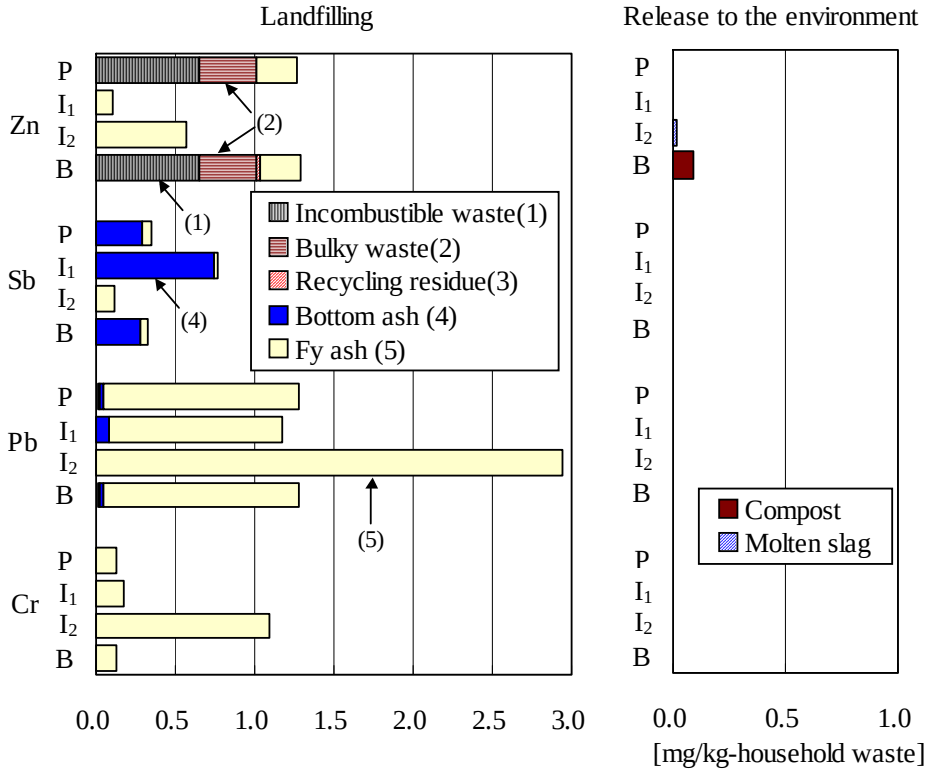

Figure 5. Leaching amount of metals in different MSW management scenarios

P: present scenario, I_1: incineration scenario, I_2: gasification-melting scenario, B: bio-waste recycling scenario