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WORLD TRENDS IN MUNICIPAL SOLID WASTE MANAGEMENT

S. Sakai,[a] S. E. Sawell,[b] A. J. Chandler,[c] T. T. Eighmy,[d] D. S. Kosson,[e] J. Vehlow,[f] H. A. van der Sloot,[g] J. Hartlén[h] and O. Hjelmar[j]

[a]*Environmental Preservation Center, Kyoto University, Kyoto 606-01, Japan*
[b]*Compass Environmental Inc., 2253 Belmont Court, Burlington, Ontario, Canada, L7P 3N3*
[c]*A. J. Chandler and Associates Ltd, 12 Urbandale Avenue, Willowdale, Ontario, Canada, M2M 2H1*
[d]*Environmental Research Group Hall, University of New Hampshire, Durham, NH 03824, U.S.A.*
[e]*Department of Chemical and Biochemical Engineering, Rutgers-The State University of New Jersey, P.O. Box 909, Piscataway, NJ 08855-0909, U.S.A.*
[f]*Forschungszentrum Karlsruhe, Institute fur Technische Chemie, Bereich Thermische, Abfallbehandlung, Germany*
[g]*Soil & Waste Research, Netherlands Energy Research Foundation, P.O. Box 1, 1755 ZG Petten, The Netherlands*
[h]*Swedish Geotechnical Institute, Linkoping, Sweden*
[j]*VKI Water Quality Institute, Agern Alle 11, DK-2970 Horsholm, Denmark*

INTRODUCTION

The philosophy of the "Waste Management Hierarchy" (prevention/minimisation, materials recovery, incineration and landfill) has been adopted by most industrialised nations as the menu for developing municipal solid waste (MSW) management strategies. The extent to which any one option is used within a given country (or region) varies depending on a large number of factors, including topography, population density, transportation infrastructures, socioeconomics and environmental regulations. Moreover, comparing national waste statistics is not a simple task. Consideration must first be given to the widely different administrative definitions applied to MSW. In addition, compositional classifications and the manner in which the data are collected also differ. Collectively, these factors can have a significant influence on the cited data.

Recognising these differences, the International Ash Working Group (IAWG) compiled available waste data from Canada, Denmark, Germany, Japan, the Netherlands, Sweden and the United States of America, for presentation at the "Seminar on Cycle and Stabilisation Technologies of MSW Incineration Residues" held in March 1996. The seminar was held at the Kyoto Research Park in Japan and was jointly sponsored by the Japan Waste Research Foundation and the IAWG. This paper summarises the information presented during the session on "National Waste Management Overviews".[1–7]

BACKGROUND

The concept of waste prevention is focused mainly on the product manufacturing sector. In most cases, the drive to avoid producing waste is provided by government or industry policies, with the major aim focussed on avoiding the costs associated with handling or managing wastes. For example, industries are very conscious of optimising production and reducing resource consumption to make themselves more competitive in today's global market economy. This includes adopting more efficient manufacturing methods in order to minimise raw material requirements (hence generating less waste), and minimising the weight and volume of packaging while maintaining product integrity during shipping. Waste prevention measures are also aimed at changing the public's attitude towards consumption, where improved product quality, durability and "environmental friendliness" are being emphasised.

The reuse of materials or products is another option which avoids the generation of waste, although it should be noted that these materials must still be handled, transported and managed. In some instances, the terms reuse and recycling are used interchangeably, however recycling is better defined as the use of a waste material as a raw material for the manufacture of a new or similar type of product. The concept has been promoted as a means to conserve resources and prevent material from entering the waste stream, thus reducing the environmental impacts associated with extracting raw materials and managing the waste.

Although recycling has had a positive effect on public attitudes towards generating waste and has been successful in diverting a fraction of the waste stream from ultimate disposal, its impact has been limited. Many recycling schemes have had difficulty sustaining themselves due to widely fluctuating markets for waste materials. Moreover, the push to recycle higher percentages of the waste stream have resulted in problems with maintaining the quality of the recycled waste materials and hence the sustainability of subsequent secondary product manufacturing. Consequently, the benefits of implementing recycling strategies should be maximised by accounting for the limitations and tempering target recycling rates.

Biological treatment technologies (composting, anaerobic digestion, etc.) are now reemerging as commercially viable means to permanently remove the organic material fraction from the waste stream. Because the success of these technologies relies on securing a stable market for the treated product, countries are implementing regulatory measures to ensure that compost quality is commensurate with the intended application of the product. Typically, this has resulted in a move away from mixed solid waste processing to the processing of only the putrescible fraction of the waste stream (garden, kitchen and commercial food wastes).

The main objectives of MSW incineration are to sterilise the waste and reduce the volume of material requiring final disposal. The majority of new incineration facilities are also designed for energy recovery, either in the form of electricity or process steam for industry or district heating. Over the past decade, the concern over air emissions from these facilities has resulted in most countries adopting very stringent air emission control regulations which has increased the cost of constructing and operating incinerators. However, some countries are now implementing new measures to reduce the volumes of post-recycled waste destined for landfill by limiting the organic content of the material to less than 5%, thus promoting the use of incineration systems within an integrated waste management strategy.

QUANTITIES AND COMPOSITION

Before waste management strategies can be developed, there is a need to characterise the volumes and composition of the waste stream within a given region. This is particularly important when considering waste minimisation policies and specific materials for recycling, such as paper, cardboard, plastics, etc. Table 1 provides an overview of the quantities and composition of wastes in the seven countries. Despite the different definitions of MSW, it is evident that paper and organic wastes are the major components (by weight) in the waste stream. It is also evident that there are substantial efforts underway in most countries to recover and recycle waste materials, i.e. recycling rates ranging from 10 to 30%.

Waste statistics also need to be assessed on a volumetric basis, particularly for transportation and landfill capacity issues. It is also an important tool in identifying specific waste materials for recycling or waste avoidance programs. According to an example of volume-based waste statistics for Kyoto City, although food waste accounts for 40% of the total weight of the waste stream, it only accounts for about 10% of the volumetric ratio. Conversely, waste paper accounts for 25% of the weight and up to 35% of the volumetric ratio of the waste stream. Moreover, plastics make up only 10% of the weight of waste, whereas it accounts for up to 40% of the volume. The substantial difference and implication underscores the need to include this type of data collection in waste characterisation programs.

WASTE AVOIDANCE AND RECYCLING

Table 2 summarises the waste avoidance and recycling initiatives established in the seven countries. A good example of an implemented "hierarchy" is the German "Law on the Prevention and Disposal of Waste" (1986), which was then followed by the "Closed Loop Economy Law" in 1994. Other countries have followed similar approaches to waste management. For example, the United States passed the "Pollution Prevention Act" in 1990 to entrench the concept of the waste management hierarchy. The "Act" included waste minimisation initiatives via raw material substitution, product reformulation, production process design and modernisation, as well as in-plant recycling. The success of the initiative is based on government/industry collaboration and implementation of incentive programs, such as provisions for technical assistance, education and training programs.

In Denmark, the "Government Action Plan on Waste and Recycling" was established in 1993 and is based on the priorities of waste minimisation (including material substitution and adopting clean technologies), recycling, utilisation, incineration and landfill. The "Plan" set out a series of targets for management of the MSW stream by the year 2000, which includes 54% recycling rates, 25% incineration and 21% landfill.

In addition to waste minimisation initiatives, there are also efforts to reduce the quantities of priority pollutants in the waste stream. These measures have included banning the disposal of household hazardous waste, automotive batteries, mercury and nickel/cadmium batteries, automobile scrap, non-degradable

TABLE 1
Overview of the Quantity and Composition of Municipal Solid Waste in Seven Countries

	Canada	Denmark	Germany	Netherlands	Sweden	USA	Japan
Area	9,980,000 km^2	43,000 km^2	357,000 km^2	42,000 km^2	450,000 km^2	9,160,000 km^2	378,000 km^2
Population	29×10^6 (1995)	5.2×10^6 (1995)	82×10^6 (1995)	15×10^6 (1995)	8.9×10^6 (1995)	263×10^6 (1995)	125×10^6 (1994)
GDP	$548 billion (1994)	$96 billion (1993)	$1,476 billion (1994)	$263 billion (1993)	$154 billion (1993)	$6,736 billion (1994)	$4,630 billion (1994)
MSW quantity	33.76×10^6 tons (1992)	2.3×10^6 tons (1993)	43.5×10^6 tons (1993)	12.0×10^6 tons (1993)	3.2×10^6 tons (1991)	207×10^6 tons (1993)	50.2×10^6 tons (1992)
	Annual increase: 7% (1988 to 1992)	Total of 9.6×10^6 tons with industrial waste					
Management methods	Composting: 1.88%	Recycling: 22% (48%)	Sorting and recovery: 13×10^6 tons (30%)	1996 » 2000	Recycling: 18%	Recycling and composting: 22%	Recycling or composting: 10.7%
	Incineration and recycling: 14.22%	Incineration with energy recovery: 58% (45%)	Incineration: 11×10^6 tons (25%)	Reuse: 22% » 56% Utilization: 0% » 5%	Composting: 2%	Incineration: 16%	Incineration: 74.3%
	Landfill: 83.9%	Landfill: 20% (7%)	Landfill: 20×10^6 tons (45%) (1993)	Incineration: 27% » 39%	Incineration: 53%	Landfill: 62%	Landfill: 14.9%
		(Target, the year 2000)		Landfill: 61% » 0%	Landfill: 27% (1994)		(1992)
MSW Composition (weight basis %)	Paper: 37.7%		Paper: 19.9%	Putrescible: 30%	Paper: 35–40%	Physical composition	Physical composition
	Organics: 28.7% Metals: 10.4%		Textile: 1.5% Plastics: 6.1%	Plastics: 4.2% Metals: 1.0%	Wood: 1% Textile, rubber, leather: 1–2%	—Paper: 37.6% —Glass: 6.6%	—Organics: 42.3% —Paper: 25.0%
	Plastics: 8.0% Glass: 4.4%		Metals: 3.9% Glass: 11.5%	Glass: 3.4% Bulk: 5.6%	Food, yard trimmings: 37–45%	—Metals: 8.3% —Plastics: 9.3%	—Plastics: 11.2% —Textile: 5.5%
	Inorganics: 0.9% Others: 9.4%		Minerals: 2.9% Putrescible: 27% Middle fraction: 15.6% Fine fraction: 8.6% Others: 3.1% (1983)	Office waste: 14.1% Paper/cardboard: 17.1% Packaging: 15.6%	Plastics: 6–8% Glass: 4–7% Metals: 2–5% Others: 4–6%	—Wood: 6.6% —Food: 6.7% —Yard trimming: 15.9% —Others: 9.0% Origin basis —Containers and packaging: 34.1%	—Glass: 2.9% —Metal: 5.1% —Rubber and leather: 0.9% —Others: 7.1% Origin basis —Containers and packaging: 25.4%
					Figures before source reduction (1993)	—Nondurable goods: 26.5%	—Food: 42.3%
						—Durable goods: 15.4% —Yard trimmings: 15.9% —Food, others: 8.1% (1993)	—Commodities: 8.7% —Disposal commodities: 4.7% —Direct mail: 3.2% —Business related: 4.7% —Others: 11.0% (1990)
Others			Special waste: 9.02×10^6 tons Sewage sludge: 5.48×10^6 tons (1993)		Industrial waste: 45×10^6 tons Hazardous waste: 0.32×10^6 tons (1991)	Tipping fees —Landfill: $29/ton ($8–75/ton) —Incineration: $48/ton ($22–80/ton)	

TABLE 2
Prevention and Recycling of Municipal Solid Waste in Seven Countries

	Canada	Denmark	Germany	Netherlands	Sweden	USA	Japan
Prevention minimization	Diversion from landfill	Government action plan on waste and recycling for 1993–1997	Closed cycle economy act—a strict hierarchy	Ordinance of waste prevention and recycling: target for the year 2000	Producer responsibility	Pollution prevention act (1990) – a hierarchy	Hierarchy under waste management law (1991)
	—15–19%: recycling —2%: composting	1. Minimization 2. Recycling, utilization	1. Prevention 2. Material recovery		—Packaging —Waste paper (journals and magazines)	1. Source reduction 2. In process recycling	1. Prevention 2. Reuse and recycling
	(1992)	3. Incineration	3. Energy recovery		—Tires		3. Waste management with pollution control
	50% division by the year 2000 is the national objective	4. Controllled landfill	Production integrated environment protection (1994)		—Nickel-cadmium batteries		
Packaging waste	National packaging Protocol: a target of 50% reduction in packaging	Waste tax	Packaging ordinance		The producer ensures		Recycling law of containers and packaging (1995) Steel or aluminium, glass: by 1997 Paper, plastics: by 2000
Recycling		—Waste to be incinerated: \$30/ton —Waste to be landfilled: \$37/ton —Recycled or utilized: no tax	—Final target: 80% of collection and recovery —Dual system Germany —1.6 Mio tons (1995): 45% (metals, glass, wood), 55% (plastics)		1. A collection system 2. Reusing or recycling by 1 January 1997		
		—One-way packaging —Disposable tableware —CFCs and halons	—3 methods of recovery 1. Material recovery 2. Thermolysis 3. Blast furnace				
Composting	Composting: 413,000 tons (7% of organic waste)	Yard waste: 304,000 tons (1994)	3 Mio tons/a in 300 composting facilities	Disposal ban of organic matter in landfill, as of 1997	6 central separation and composting plants: 60,000 tons, of which 20,000 tons finds a market, Reactor based technology	MSW: 17 facilities Yard waste: 3,202 facilities	
	—Central facilities: 315,000 tons —Backyard: 98,000 tons		Problem on heavy metal and PCDD/PCDF pollution	Separation/composting of putricibles			
Toxic reduction	WASTE program	Voluntary agreements		Reduction on use of Cd	Waste assessment project to present classification rules	Toxic reduction in MSW packaging (16 States, 1993) Pb, Cd, Hg, Cr(VI)	
Others	—Vancouver EFW facility —Sources and fate of trace metals —Putrescible organic fraction contributes a significant portion	—A reduction of the use of PVC —Taking back nickel/cadmium batteries, used car tires Disposal ban (from 1997) —Combustible waste with exceptions of PVC and tree stumps		Disposal ban for several wastes by 1997	Waste tax is under discussion	Disposal ban (virtually all states) 1. Household hazardous waste 2. Vehicle batteries 3. Tires 4. Yard materials 5. Motor oil 6. White goods	

grocery bags, glass, metals and motor oil in landfills. In addition, sixteen States within the US passed toxicities reduction legislation in 1993 based on guidelines proposed by the Source Reduction Council of the Coalition of Northeast Governors. The regulations include a phase out of lead, cadmium, mercury and hexavalent chromium in packaging. It is believed that the use of these trace metals in inks, dyes, pigments, adhesives and stabilisers contravenes the principles of pollution prevention. However, banning trace metals has also been considered at the international level and the results are different. For example, in 1994, a proposal to ban the use of lead in manufacturing was the subject of an OECD Workshop. Although there was consensus that a phase out of lead-based compounds in gasoline and cosmetics was justified, the outright ban of lead as a raw material in manufacturing was not justified. It was concluded that in view of the ability of modern waste management practices to limit human exposure to waste emissions, the use of the trace metal in applications requiring its special properties was reasonable.

Moreover, in 1991, Environment Canada, the US Environmental Protection Agency and the International Lead Zinc Research Organization sponsored the WASTE Program study which was conducted in Vancouver, British Columbia. The main objective of the study was to determine the physical composition of the waste stream and quantify the trace metal composition of various waste fractions. Although a summary of the trace metal indicates that batteries and other wastes can contain measurable quantities of trace metals, the putrescible organic waste fraction (yard/garden/food waste) was also shown to contribute significant loadings of certain trace metals to the overall waste stream. Thus, while toxicities reduction programs may help to reduce overall trace metal loadings in waste, they are unlikely to eliminate the presence of trace metals in waste due to natural background contamination levels.

RECYCLING OF PACKAGING

There are several initiatives in different countries to reduce the volumes of waste being generated by emphasising recycling of specific materials, such as waste paper, glass, plastics, steel and aluminum. Most of these are focussed on the producers of packaging materials. For example, Germany adopted the "Law on the Prevention and Disposal of Waste" in 1986, which was followed up in 1991 with a "Packaging Ordinance". The Ordinance stipulated that packaging materials should be manufactured from environmentally compatible materials to facilitate recycling or reuse. Much of the responsibility was placed on the producers of consumer products, which in turn led to the establishment of the "Duales System Germany" (DSD). The DSD program operated on a cradle to grave approach to managing packaging. All packaging was labelled with a "green dot" and was identified for separate collection and management. Paper, glass and plastics were the main materials targeted for collection, with aluminum and steel comprising a small proportion of the overall stream collected.

To further modify these initiatives, Germany developed the "Closed Cycle Economy Law" in 1994, which will come into force in October 1996. The new law embodies a different philosophy towards waste management than that in previous laws. Although recovery, as direct reuse, material recycling and chemical recycling, was part of the earlier initiatives, the new law recognises energy recovery as one of the methods to help meet the new targets of 80% source separated recovery and 80% reutilisation. For example, under the new law, waste plastics collected for use as an alternative source of energy in iron manufacturing are considered as an acceptable recycling option.

Sweden has also legislated producer responsibility regarding packaging materials. Paper is one material targeted for recycling, with a goal of recycling 75% of paper packaging material by the year 2000. Targets also exist for other wastes, such as tires, where 60% must be diverted from landfill by 1996 and 80% by 1998. Voluntary collection targets have also been set for nickel/cadmium batteries, i.e. 60% in year one and 90% in year two of the scheme.

In contrast, Japan, through its new Package Recycling legislation, stipulates that producers and consumers must share the responsibility of ensuring that materials are recycled using public waste collection systems. Recycling targets for all types of paper and plastic containers and packaging have been set, as well as glass, steel and aluminum containers. Denmark has taken another approach to providing incentives to recycle by imposing taxes on specific types of one-way packaging, disposable tableware, CFCs and selected raw materials. Moreover, wastes which are recycled or reused are exempt from taxes, whereas waste processed through incinerators or sent to landfill are taxed, i.e. 160 DKK/ton for incinerated waste and 190 DKK/ton for landfilled waste. These taxes are scheduled to increase in January 1997, when waste will be taxed as follows: — processed at incinerator facilities with energy recovery = 160 DKK/ton — processed at incinerator facilities = 210 DKK/ton — sent to landfill = 285 DKK/ton.

To assist recycling schemes and clean technology projects, the Danish government also provides subsidies and funding under their Finance Act.

ENERGY RECOVERY

Recognising that waste minimisation initiatives and recycling schemes are only capable of managing a portion of the waste stream effectively, other management options are required to process the residual waste. Although landfill has historically been relied upon as the ultimate disposal option, incineration has also been used to reduce the volume and weight of society's waste, in addition to protecting human health by preventing the spread of disease. Most modern incinerator facilities are designed with the capacity to recover a substantial portion of the energy inherent in the residual waste and thus supplement or replace traditional fossil fuel powered systems.

Table 3 provides a summary of MSW incineration capacities in the seven countries. The extent to which the practice is used varies widely between countries, ranging from about 6% of the overall MSW stream in Canada to over 70% in Japan. There is also a large difference in the number of incinerator facilities in the various countries, and the average size of the facilities. For example, there are about 50 facilities in Germany, 70% of which are larger than 500 tons per day in capacity. Alternatively, there are 1800 incinerators operating in Japan, of which are continuous operation type systems with about 300 tons per day capacity and many batch type systems with capacities of < 25 tons per day.

Since the early 1980s, countries have implemented increasingly stringent guidelines to address concerns over the operation and emissions of MSW incinerators. Table 4 provides a comparison of emission limits for several parameters in the seven countries. It is important to note that the actual emission limits are based on different units, and on different sampling and analytical criteria. Consequently, although the numbers may appear to differ widely, they are in fact similar to one another. For example, the new emission limit for PCDD/PCDF in the United States is 13 ng/Nm^3 at 7% O_2. This translates into about 0.14 ng TEQ/Nm^3 at 11% O_2; however, the standards for sampling (i.e. equipment and collection time, etc.) are different from the European standards. In order to meet these latest regulations, modern MSW incinerators must employ not only highly effective air pollution control systems to meet emission limits for acid gases and other contaminants (such as either Best Demonstrated Available Technology or Maximum Achievable Control Technology) but the operating conditions must also be optimised to promote highly efficient combustion conditions within the furnace.

MANAGEMENT OF MSW INCINERATOR RESIDUES

Although MSW incineration is capable of reducing the volume of waste by 90%, 20–30% of the original weight of the waste is left as ash which requires further management. There are two generic ash streams discharged from incinerators. Bottom ash is generally defined as the material collected off the incineration grates, whereas fly ash is a collective term for the finer material captured downstream of the furnace, i.e. in the heat recovery and air pollution control system. In most countries, these two streams are classified and managed differently due to the significant differences in their physical, chemical and leaching characteristics. Table 5 provides a summary of the management methods for the ash streams and the respective regulatory leach tests for the seven countries.

Although most countries have deemed bottom ash suitable for disposal in landfills or monofills, many European countries have also permitted extensive use of processed bottom ash in various construction applications. For example, Germany, Denmark and the Netherlands utilise 60–90% of the bottom ash collected in MSW incinerators as a light-weight aggregate for road construction, or as an amendment to asphalt and concrete products. Conversely, the fly ash streams, particularly the residues from air pollution control systems, are deemed to be a hazardous waste in most countries and require special handling and disposal. The most notable exception is in the United States, where both bottom and fly ash streams are combined prior to disposal in designated ash monofills with leachate collection systems.

In general, the classification of an ash stream, and determining how it needs to be managed, is based on the trace metal analytical results from regulatory leach tests compared against established regulatory limits. As indicated in Table 5, these regulatory tests and the respective limits differ significantly within the seven countries. In light of the different scenarios in which ash can be managed (and hence the environmental conditions), the IAWG has recommended that the assessment of ash management options be based on examination of the intrinsic properties of the ash rather than on the results from a single type of regulatory leach test. This recommended approach includes conducting tests to determine the chemical, physical and leaching properties of the ash stream. In addition, more than one type of leaching test should be employed to evaluate leachability over a wide range of leaching conditions.

Different strategies have been implemented in several countries for ash management. For example, waste destined for landfills must be "inert" (i.e. TOC $< 1\%$) and cannot contain substantial concentrations of salts. Moreover, LAGO, a board of German State Ministers, set the limits with respect to the utilization such as road construction. Concentrations of trace metals such as Pb, Cd and Zn must be below the stringent limits of 0.05 mg/L, 0.005 mg/L and 0.3 mg/L respectively. Other countries, such as Denmark

TABLE 3
Energy Recycling of MSW Incineration

Item	Canada	Denmark	Germany	Netherlands	Sweden	USA	Japan
MSW generated	23.2×10^6 tons (1992)	2.6×10^6 tons (1994)	43.5×10^6 tons (1993)	12.8×10^6 tons (1993)	3.2×10^6 tons (1991)	207×10^6 tons (1993)	50.2×10^6 tons (1992)
MSW combusted	1.2×10^6 tons (1992)	1.5×10^6 tons (1994)	11.0×10^6 tons (1993)	2.8×10^6 tons (1993)	1.7×10^6 tons (1991)	32.9×10^6 tons (1993)	37.3×10^6 tons (1992)
Percentage combusted	5% (1992)	58% (including industrial wastes) (1994)	25% (1993)	23% (1993)	55% (1991)	16% (1993)	74% (1992)
Bottom ash generated	0.3×10^6 tons (1993)	0.5×10^6 tons (1993)	3.0×10^6 tons (1993)	0.65×10^6 tons (1993)	0.43×10^6 tons (1990)	6.84×10^6 tons (1990)	5.0×10^6 tons (1991)
Bottom ash used	0% (1993)	90% (1993)	60% (1993)	90% (1993)	0% (1990)	0% (1990)	0% (1991)
APC residues generated	0.02×10^6 tons (1993)	0.05×10^6 tons (1993)	0.3×10^6 tons (1993)	0.09×10^6 tons (1993)	0.06×10^6 tons (1990)	0.91×10^6 tons (1990)	1.16×10^6 tons (1991)
Number of facilities	17	31	53	11	21	148	1841 (1991)

TABLE 4
Comparison of Regulations for Incineration Exhaust Gas (unit: mg/Nm³, except for other Descriptions)

Pollutant	Germany (1991)	Netherlands (1989)	Denmark (1991)	Austria (1991)	Sweden (1986)	European union (1993)	Canada, Ontario (1995)	USA (1995)[**]	Japan (1995)	
									Standard	Actual criteria
Related to	O_2 11%	O_2 11%	O_2 11%	O_2 11%	CO_2 10%	O_2 11%	O_2 11%	O_2 7%	O_2 12%	O_2 12%
Dust	10 (30)	5	30	15	20	10	17	24	150	10–50
SO_x	50 (200)	40	300	50	—	50	21 ppm	30 ppm or 80% removal	Regulation of K value	10–30
NO_x	200 (400)	70	—	100	—	—	110 ppm	150 ppm	250	30–125
HCl	10 (60)	10	50	10	100	10	18 ppm	25 ppm	700	15–50
HF	1.0	1.0	2	0.7	—	1	—	—	—	—
CO	50 (100)	50	—	—	100	100	—	100 ppm	—	50
HC	10 (20)	10	—	—	—	20	—	—	—	—
Hg	0.05	0.05	0.2[‡]	0.1	0.08	0.05	0.057	0.08 or 85% removal	—	0.03–0.05
Cd	0.05	0.05	0.2[‡]	0.1	—	0.05[‖]	0.014	0.02	—	—
As	—	—	1.0[§]	—	—	0.5[§]	—	—	—	—
Pb	—	—	1.0	—	—	0.5	0.142	0.2	—	—
Cu	—	—	—	—	—	—	—	—	—	—
Others	1.0[*]	1.0[†]	—	—	—	—	—	—	—	—
Dioxin [ng TEQ/Nm³]	0.1	0.1	—	0.1	0.1	0.1	0.14	13 (0.14–0.21)[¶]	—	0.5
Sample average	24 hr (30 mins)	1 hr	—	24 hr	1 month	1 month	4 hr Average of 3 tests	4 hr Average of 3 tests	24 hr	

[*]Sb, As, Pb, Co, Cr, Cu, Mn, Sn. [†]Sb, Pb, Cr, Cu, Mn, V, Sn, As, Co, Ni, Se, Te. [‡]as Cd + Hg. [§]as Ni + As. [‖]as Cd + Tl. [¶]as TEQ basis, $O_2 = 11\%$. [**]The new Clean Air Act, MACT (Maximum achievable control technologies), increased cost $450 million.

TABLE 5
Ash Regulations and Uses in European Countries, USA and Japan

Item	Canada	Denmark	Germany			Netherlands			Sweden	USA	Japan
Leaching test type	Batch agitated (reg 309 LEP)	None (under formulation)	Batch Agitated (DEV S4)			Column (NEN 7343)			None (under formulation)	Batch agitated (TCLP)	Batch agitated (JLT-13)
Steps	1		3			—				1	1
L/S per step	20		10			up to 10				20	10
Solid	50 g (< 10 mm)		100 g (< 10 mm)			500 g (< 4 mm)				100 g (< 10 mm)	10 g (0.5–5 mm)
Leachant	Acetic acid (pH 4)		Demineralized water			Initial pH 4				Acetic acid (2 pHs)	Distilled water
Duration	24 h		24 h/step			21 days (7 fractions)				24 h	6 h
Filtration	0.45 μm		0.45 μm			0.45 μm				0.45 μm	1.0 μm
Regulatory limits		None	Cat 1	Cat 2	LAGA	C4	C3	C2			
Pb [mg/L)	5.0		0.2	1	0.05	0.04	4	25	None	5.0	0.3
Cd [mg/L]	1.0		0.05	0.1	0.005	0.0004	0.05	0.2		1.0	0.3
							L/S1	mg/kg			
Bottom ash use/disposal	—Varies by province, to be tested and used in B.C.	—Extensively used in land reclamation, road base	—Utilization limit of bottom ash			—Used in embankment and in road base			—Bottom ash use being considered	—Bottom ash use under consideration in road construction applications	—Controlled landfills
	—Other provinces, disposal as solid waste in landfills	—Utilization criteria (pH in a 1% slurry > 9.0, alkalinity > 1.5 eqv/kg)	—Used bottom ash, scrap metal			—More than 90%				—Normally "monofill"	
APC residue use/disposal	—Considered hazardous, sent to hazardous waste landfills	—National disposal facilities to be constructed	Hazardous waste landfills —Salt mines			—ESP fly ash: non-hazardous landfills, or use as asphalt filler			—APC residues must be disposed in a secure landfill	—Double lined landfills with caps, leachate collection	—Considered hazardous, must be treated with a specified method
		—Presently sent to lined landfill facilities or stored	—Recovery			—APC residues: big bags at a controlled landfill					

and the Netherlands, have implemented ash utilisation guidelines. It should be noted that ash utilization criteria in Denmark are being reviewed with the intention of replacing the "total concentration" limits for trace metals (i.e. < 3000 mg/kg of Pb, < 10 mg/kg of Cd and < 0.5 mg/kg of Hg) with leaching criteria.

With respect to the management of fly ash, in addition to disposal as a hazardous material there are four generic treatment technologies which have been used or are under consideration. These include solidification, chemical stabilisation, ash melting or vitrification and extraction/recovery processes. Comparing the different technologies requires not only an assessment of the costs involved, but the characteristics of the products generated from each process as well. Consequently, the high costs of vitrification or extraction processes may be deemed acceptable in light of the potential use or volume reduction of material being generated. Conversely, the lower costs of solidification or stabilisation processes must be tempered with the additional weight of the solidification reagents and the potential long-term instability due to the high salt contents of the treated material.

SUMMARY AND CONCLUSIONS

Most countries adhere to the premise of the "Waste Management Hierarchy" as a menu for developing integrated strategies for managing municipal solid waste. Each country has developed its own federal initiatives to promote the concepts of waste minimisation, reuse and recycling, ranging from policy driven diversion targets to tax incentives or subsidies for specific management options. There are also differences in other factors which impinge upon the selected strategies, such as existing transportation infrastructures, population densities, resource bases, land availability, energy requirements and environmental regulations. Consequently, the extent to which any one management option is used within a country can vary considerably.

Despite the emphasis on waste minimisation and recycling, it is recognised that society will continue to generate waste requiring either incineration or landfill disposal in the foreseeable future. As a result, the use of incineration with energy recovery is expected to increase in many countries over the next decade, especially in light of regulations which limit the organic content of waste materials destined for landfill. To address public concerns, countries have adopted stringent regulations to minimise the atmospheric emissions of acid gases and other contaminants from MSW incinerators. In addition, regulations have also been implemented to ensure that the residues from incinerators are managed in an environmentally sound manner. These regulations include criteria for the utilisation and disposal of bottom ash, as well as the treatment of the various fly ash streams.

However, the dynamic nature of consumer products, packaging materials, environmental regulations and public attitudes has made the development of waste management strategies an increasingly complex task. As the year 2000 approaches, it is likely that a greater degree of flexibility will be required to ensure that there is a sustainable means of maintaining adequate protection of human health and the environment.

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