CHAPTER 2 - MUNICIPAL SOLID WASTE

2.0 INTRODUCTION

In many developed countries, incineration of municipal solid waste, either with or without energy recovery, is considered one of the key components in an integrated waste management strategy. Incineration is viewed as a means to destroy pathogens and organic matter, and typically results in a 90% reduction in volume and 60% reduction in weight of the waste being combusted. Since the reduction concentrates the mineral and elemental components of the original waste, fundamental knowledge of the characteristics of the MSW stream is essential to understanding the characteristics these materials impart on incinerator residues. Consequently, this chapter provides a summary of the nature of MSW, including the gross physical and chemical composition of MSW in different countries and the strategies employed by those countries to manage their waste.

2.1 DEFINITION OF MUNICIPAL SOLID WASTE

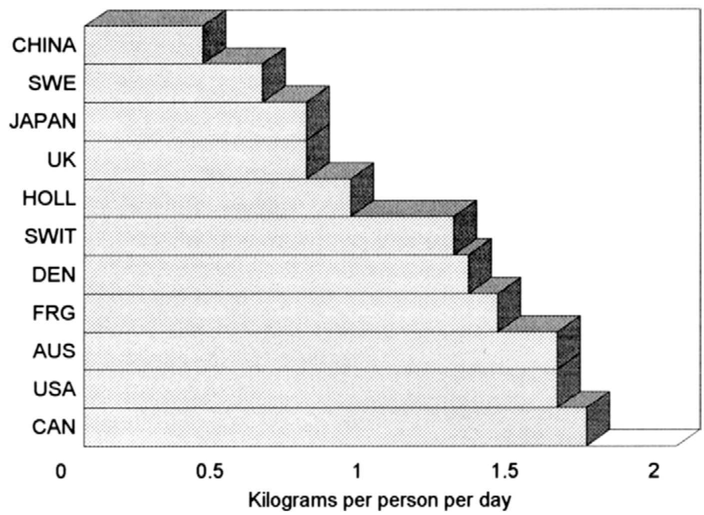
In order to better compare the quantities of MSW generated in different countries, waste production figures are generally transformed into per capita waste generation rates. The generation rates for ten different countries are presented in Figure 2.1. Although these values appear to be directly comparable, the list of waste materials included in the calculated values may vary widely. Clearly, there are a number of factors which contribute to the variations within these national generation rates, including societal customs, socioeconomic conditions and geography, however, the basic question remains "What is MSW?". Unfortunately, the definition of MSW is open to administrative interpretation which varies widely between countries, agencies and even local jurisdictions. Definitions may range from:

> "Solid waste includes residential, light industrial, commercial and institutional waste that is collected by a municipality or by contracted collectors on behalf of the municipality." (one definition taken from "The State of Canada's Environment", (Government of Canada, 1991)),

to

> "Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial mining, and agricultural activities, and from community activities..." US Resource Conservation and Recovery Act (RCRA, 1984).

Figure 2.1 Per Capita Waste Generation Statistics



Source: Environment Canada

While these definitions may represent the extremes, they illustrate the potential difficulty in directly comparing MSW related data developed by agencies or groups with different goals, responsibilities or motives. In 1989 for example, the US EPA estimated that between 11 - 13% of the MSW stream was being recycled. However, some groups insisted that automobile scrap should be included in the calculation, thereby effectively doubling the nationally quoted recycling rate (OTA, 1989). On the other hand, Japan does not include the quantity of materials which have been recycled in the definition of MSW because these materials are not considered waste. In view of the lack of a standard definition for MSW, the following definition is suggested:

> "The solid waste generated at residences, commercial establishments (e.g., offices, retail shops, restaurants), and institutions (e.g., hospitals and schools), but does not include construction/demolition debris, automobile scrap or medical/pathological waste," United States Office of Technology Assessment (OTA, 1989).

The fact that this definition says more about what is not included in MSW than what is considered MSW, merely emphasises the heterogeneous nature of the waste stream. For the purposes of this document, this general definition will be considered an appropriate compromise, since it excludes materials which are not likely to be processed through MSW incinerators. Nevertheless, it should be noted that the statistics cited in this chapter may have been developed based on different criteria in each of the different countries.

2.2 COMPOSITION OF MUNICIPAL SOLID WASTE

Municipal solid waste, as generated from residential and/or commercial sources, is heterogeneous with respect to both physical and chemical composition. Although the composition of MSW has changed throughout history, the most dramatic changes have occurred during the last 50 years, characterised by an accelerated proliferation of waste organic matter, paper and plastics (Table 2.1).

Table 2.1
Changes in Waste Composition over Time in the UK (% by weight)

Waste Category	1935	1963	1968	1974	1975	1978	1980	1982	1986	1988
Plastic	-	-	1	2.9	3	5.7	7	8.8	6	7.5
Paper	14	23	37	26.8	31.1	25.2	29	22.8	33	25
Putrescibles	14	14	18	21.3	35.5	28.3	25	23.7	20	22.8
Metals	4	8	9	8.5	5.3	7.2	8	9.6	8	13.4
Glass	3	9	8	9.5	9.3	11.8	10	9.6	9	3.5
Dust/Cinders	57	39	22	19.8	12.3	13.9	14	16.7	10	13.4
Textiles	2	3	2	3.5	1.7	2	3	2.6	4	7.6
Other	5	4	3	6.9	1.8	5.9	4	6.2	10	5.8

Adapted from Baker, 1990

The size of the various components of MSW can range from small dust particles to large bulky items such as packaging materials, tires, furniture and appliances. In addition, non-combustible and inert materials, such as metals, glass and ceramics, form a significant portion of the MSW stream. As a result, this heterogeneity creates numerous problems when characterising MSW.

Similar to the problems associated with developing a broad definition of MSW, the various choices available for the categorisation of various components in the waste have created some confusion over the exact definition of terms applied to materials in various countries. For example, garbage and garden waste are typically combined in Swedish data (SAPCSWM, 1988) and the term is assumed to cover kitchen scraps and yard waste. Yet, these materials are normally defined and reported separately in the North American data, while the British have combined these materials under the term putrescibles. The variation in definitions has prompted some calls for uniform definitions of each category (at least in Europe) (Williams, 1984):

Putrescibles - kitchen, vegetable and yard waste;
Paper and Card - paper, paper/plastic laminates, newsprint, card, corrugated cardboard;
Plastics - all plastic materials including film and dense materials;
Metals - all metallic materials;
Textiles - natural and manmade fibres;
Miscellaneous combustibles - wood, shoes, leather;
Miscellaneous non-combustibles - ceramics, stone, cinder;
Glass; and
Fines - < 20 mm size materials.

However, even with these suggested categories, identification of various components may become problematic due to the multi-component content of the materials themselves. For example, material such as laminates would be classified depending on the major component in the material, (i.e., paper or plastic) however, it may be difficult to determine which material is the major component. Furthermore, there is potential for confusion over items such as carpeting which could be considered a textile, but is classified under miscellaneous combustibles. Similarly, although bone could be classified as food waste (putrescibles), in some countries it is classified under miscellaneous non-combustibles.

In addition to the differences in national classification, there are regional differences. Management practices such as bottle-return legislation, recycling, waste reduction initiatives, and social customs result in differences in classification. At the present time, several agencies including, the International Energy Agency, UN/ECE, OECD and EUROSTAT, are attempting to develop a standardised MSW classification scheme, however, in the interim it is suggested that definitions of waste categories be sufficiently detailed to permit others to extract information for direct comparison. An example of a detailed list of materials and the higher order categories is given in Table 2.2.

Once there is an understanding of the various potential categories of waste, it should also be noted that there are inherent differences between residential/household, institutional, commercial and light industrial waste (Table 2.3). Industrial waste contains less organic material than the other source streams but higher levels of glass, wood, construction waste and miscellaneous materials. Commercial waste has the highest level of paper products. The composition of institutional waste is very similar to residential waste with the exception that institutional waste was found to contain little, or no, wood or construction waste.

Seasonal variations, including both mean temperature and precipitation, can affect refuse composition. As an example, the effects of seasonal variations on Canadian MSW composition are shown in Table 2.4, with the most notable change being in yard waste. The data indicates that a higher percentage of yard waste is disposed in spring and fall compared to summer and winter, mostly resulting from the maintenance of landscaped residential properties. Weather conditions can also vary the moisture

Table 2.2
Comprehensive List of Waste Component Categories

1. **Paper & Cardboard**	1.1		newsprint
	1.2		fine paper
	1.3		computer
	1.4		ledger/office
	1.5		magazine
	1.6		coated (waxed/plastic/foil)
	1.7		box board
	1.8		brown kraft
	1.9		other corrugated cardboard
	1.10		mixed (junk mail/flyers/etc.)
2. **Glass**	2.1		containers - beer
		2.1.1	clear
		2.1.2	green
		2.1.3	brown
		2.1.4	other
	2.2		containers - soft drink (colors)
	2.3		containers - liquor (colors)
	2.4		containers - wine (colors)
	2.5		containers - food (colors)
	2.6		containers - other (colors)
	2.7		plate glass
	2.8		other
3. **Ferrous Metals**	3.1		containers - beer
	3.2		containers - soft drink
	3.3		containers - food
	3.4		strap metal and banding
	3.5		other (toys/tools/etc.)
4. **Bimetallic Items**	4.1		containers - beer
	4.2		containers - soft drink
	4.3		containers - food
	4.4		electric motors
	4.5		other
5. **Non-Ferrous Metals**	5.1		containers - beer
	5.2		containers - soft drink
	5.3		containers - food
	5.4		other packaging
	5.5		die cast
	5.6		other
6. **Plastics**	6.1		film
		6.1.1	LLDPE
		6.1.2	LDPE
		6.1.3	HDPE
		6.1.4	other
	6.2		container - beverage
		6.2.1	PET
		6.2.2	polyprop., etc
	6.3		container - food (types)
	6.4		container - household product
	6.5		other (toys/furniture/etc.)
7. **Oversized & Bulky Waste**	7.1		construction debris
		7.1.1	gypsum & plaster
		7.1.2	wood
		7.1.3	concrete/ stones /rubble
		7.1.4	fibre glass
	7.2		white goods
	7.3		furniture
	7.4		automobile parts
	7.5		bicycles/motorcycles
	7.6		other
8. **Organics**	8.1		food waste
	8.2		yard waste
	8.3		garden waste
	8.4		textiles
	8.5		leather
	8.6		rubber
		8.6.1	tires
		8.6.2	other
9. **Misc. Inorganics**	9.1		ceramics
	9.2		asbestos
10. **Household Hazardous Waste**	10.1		automotive batteries
	10.2		other batteries
		10.2.1	carbon
		10.2.2	ni-cd
		10.2.3	mercury
		10.2.4	other
	10.3		water based paints
	10.4		other paints
	10.5		solvents
	10.6		waste oils
	10.7		pesticides/herbicides
	10.8		other (acids/antifreeze/etc.)
11. **Household Biomedical**	11.1		diapers
	11.2		bandages, etc.
	11.3		sharps
12. **Fines**			

Table 2.3
Comparison of Institutional, Commercial and Light Industrial Waste Composition (% by weight)

Component	Residential	Institutional	Commercial	Industrial
Paper	36	41	50	40
Metal	7	5	5.5	4.5
Plastics	7	15	15	13
Organics	31	29	18	6
Glass	7.5	6	4	9
Wood	2	0	3	12
Construction Waste	2	0	0.5	2
Miscellaneous	7.5	4	4	13.5

Adapted from Government of Ontario, 1992; Gore and Storrie, 1992

Table 2.4
Seasonal Variations in Waste Composition (% by weight)

Category	Component	Spring	Summer	Fall	Winter
Combustibles	Paper, cardboard	33.9	38.9	36.6	36.5
	Food waste	28.4	24.6	24.9	32.9
	Yard Waste	12.3	4.4	6.1	0.8
	Plastic, rubber	4.7	5.4	5.7	5.1
	Textiles	3.7	4.3	4.4	4.7
	Wood	2.7	5.0	5.7	3.5
	Misc. Organics	0.9	0.9	1.7	1.2
Non-combustibles	Glass, ceramics	7.6	9.7	8.1	8.1
	Metals	5.8	6.8	6.8	7.2

Adapted from Bird and Hale, 1977

content of the waste, both on a seasonal and a daily basis. This underlines the problem of calculating the proportionate weight of each category based on an "as-discarded" or "as-received" basis. The mixing of waste can cause the moisture levels of the components to vary from their "as-discarded" level. For instance, wet food wastes may transfer moisture to paper and textiles during storage and transportation (Table 2.5).

Table 2.5
Estimated Percent Moisture in Waste

Component	% H_2O in As-received	% H_2O in As-discarded
Paper	24.3	8
Metal	6.6	2
Plastic	13.8	2
Yard Waste	37.9	55
Food Waste	63.6	70
Textiles	23.8	10
Glass	3	2
Wood	15.4	15
Leather & Rubber	13.8	2
Miscellaneous	3	2

Niessen, 1970

In light of the numerous problems associated with characterising MSW, there are some guidelines which should be followed when reporting MSW data. In general, the more comprehensive the list of materials, the better the definition of MSW. Secondly, seasonal variations should be considered when reporting MSW data. Even comparisons within the same jurisdiction should be made on data collected under the same conditions, i.e., seasonally adjusted figures or data collected at the same time of year, under similar weather conditions.

2.3 QUANTITY AND MANAGEMENT

Typically, quantities of MSW produced in various countries are calculated based upon the sum of materials handled through controlled MSW processing facilities, although nationally reported data is seldom accompanied by a description of the procedures used to develop the statistics. Although the quantities are usually reported on the basis of wet weight, in some instances it is difficult to determine whether the influence of moisture has been taken into account. Some current estimates of per capita discards of MSW range from 0.5 kg/day in China to 1.7 kg/day in Canada (Figure 2.1), (Environment Canada, 1989). In view of the numerous waste material control measures being implemented in various countries, it is expected that generation rates will decrease slightly or remain the same during this decade. However, the trends in some countries have been to the contrary. For example, the United States is anticipating a waste/capita generation rate increase of 1 to 2% per year up to the year 2000 (Franklin, 1988), and the Japanese were experiencing an increase of about 4% per annum earlier in the decade (Eller, 1992). Irrespective of any national waste minimisation policies, MSW will continue to be generated and require management employing the options available under the "Waste Management Hierarchy":

- separation for reuse,
- separation for recycling,
- separation for composting,
- incineration, or,
- direct landfilling.

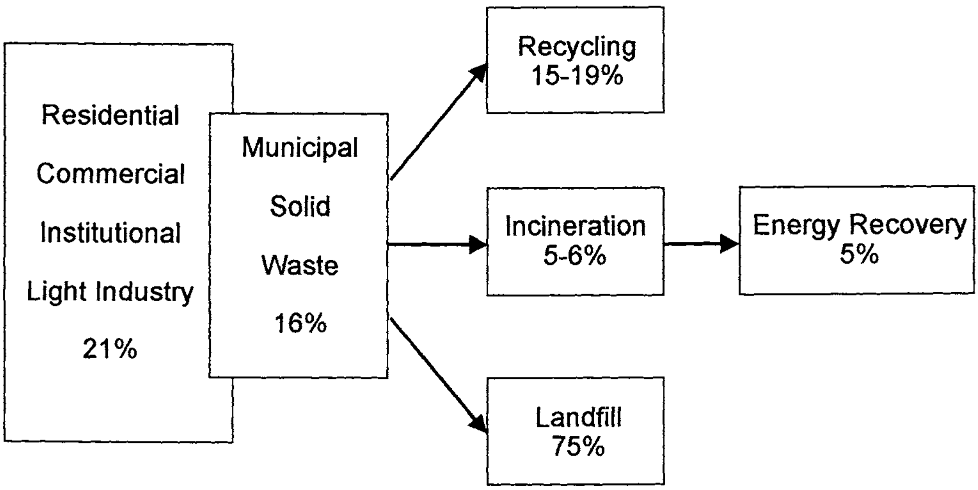
All of these methods are utilised to some extent, however, in many countries landfilling continues to be the most utilised means of disposal. Each method has limitations, most of which are the result of the nature of the material, including quality, durability and practicality of collection. Other considerations in the selection of alternatives are economic viability, available space, geographical location and terrain, and public opinion. The following is a synopsis of the current MSW situation in several developed countries and the management strategies employed therein. Since the main focus of this publication is MSW incinerator residues, emphasis has been placed on detailing the use of incineration technology.

2.3.1 Canada

The most recent statistics available (1992) indicate that it costs Canadians about $2.2 billion (Cdn) per year to manage the estimated 30 to 35 million tonnes of non-hazardous waste that is generated in Canada annually (Environment Canada, 1996). More than half of the 30 million tonnes is MSW (Figure 2.2), an estimated 1.7 kg of waste per person per day. The results from recent studies suggest that the composition of MSW in Canada is similar to that of the United States (Figure 2.3).

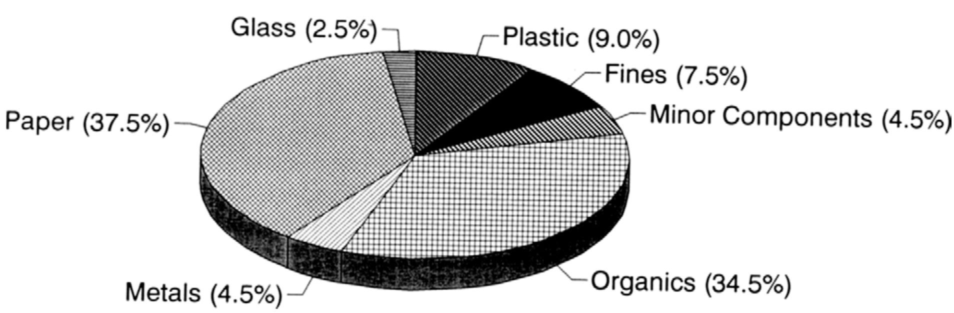
In Canada, although the federal government does maintain some regulatory authority over MSW management, regulation is generally the responsibility of municipal and provincial levels of government. As a result, regulations have varied from province to province based on regional differences. In order to unify federal and provincial policies, the Canadian Council of Ministers of the Environment (CCME) was established to deal with issues concerning resources and the environment. Within the CCME framework, committees consisting of representatives from both levels of government develop guidelines and standards for specific environmental issues. The rationale behind this concept was to provide the individual provinces with the ability to develop draft guidelines cooperatively, which then could be readily adopted as provincial legislation.

Figure 2.2 MSW Management in Canada - 1992 (million tonnes)



Environment Canada, 1996

Figure 2.3 Canadian MSW Compositional Statistics



Environment Canada, 1995

In 1990, CCME set a national objective of 50% diversion of waste from landfill by the year 2000 using the hierarchical approach of reduction, reuse, recycling and recovery (CCME, 1990a). This was followed up by a National Packaging Protocol, which set a target of 50% reduction in packaging sent for disposal by the year 2000, using the approach of source reduction and reuse to achieve at least half of the diversion and recycling for the remainder (CCME, 1990b). The aim of the initiatives is to drastically reduce the reliance on landfill, which ultimately accepts about 82% of the currently disposed MSW. Approximately 15 - 19% of the MSW stream (excluding the C&D waste fraction) is recycled at the present time, and although there are some facilities in the planning stages, there are few major composting plants in operation. About 5 - 6% of MSW is incinerated, most of which (more than 92%) involves energy recovery.

Most of the operating energy-from-waste (EFW) facilities are situated in the most densely populated areas of Canada, namely, the lower mainland of British Columbia, south-central Ontario and southern Quebec. Two major EFW facilities are operating in the maritime provinces. Several small modular incinerators (without energy recovery) are located on Vancouver Island and in Newfoundland, some of which are in the process of closing. It was estimated that there was a potential capacity to incinerate approximately 11 to 12% of the 16 million tonnes of MSW generated in Canada per annum in 1991 (Finkelstein, 1991), however, only about 50% of the potential capacity was realised. Although a new facility was constructed in Ontario (Peel) in 1992, one large incinerator in Quebec (Montreal) was closed in 1994, reducing the capacity dramatically. A summary of operational and proposed EFW plants is given in Table 2.6.

Table 2.6
Summary of Energy-from-Waste Facilities in Canada

Incinerator Type	Number of Facilities	Proposed	With Energy Recovery*	Total Capacity (tonnes/day)*
Mass Burn	5	2	3	1800
Two-stage	11	0	5	1000
Semi-suspension	1	0	^1	550
Total	17	2	9	3350

* - not including proposed facilities ^ - energy recovery system not used
Adapted from Sawell, 1992; Environment Canada, 1994

Under the umbrella of CCME, the Municipal Solid Waste Incineration Sub-Committee released the "Operating and Emission Guidelines for MSW Incinerators" in June of 1989 (CCME, 1989). The performance standards recommended by CCME were supported by a large test data base and information generated directly through Environment Canada's National Incinerator Testing and Evaluation Program (NITEP).

Based on the scientific evidence provided by NITEP and the stringent standards recommended by CCME, the federal government presently views modern incineration technology (with energy recovery) as a viable option for reducing the burden on landfills under the "4R's" hierarchy (reduction, reuse, recycling and recovery). This view was further supported by the Province of Ontario in 1995, when it rescinded the highly publicised four year old ban on constructing new MSW incinerators and adopted new strict atmospheric emission limits.

2.3.2 Denmark

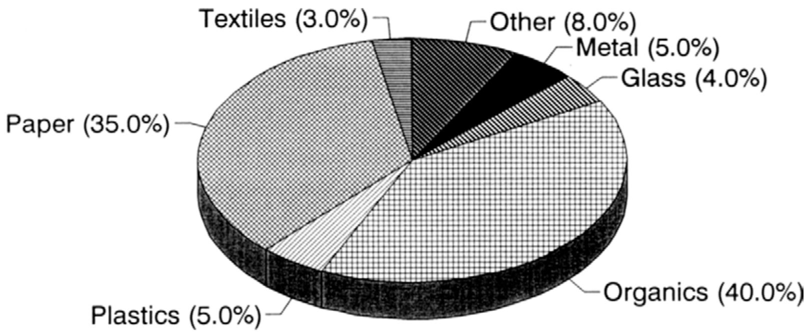
The latest statistics available (1993) indicate that approximately 9.6 million tonnes of nonhazardous waste are generated in Denmark each year by its 5 million inhabitants (Danish National Agency of Environmental Protection, 1995). About 23% of the total is considered MSW from residential sources (Table 2.7), representing about 1.2 kg of MSW generated per person per day. It was estimated to be increasing at the rate of 1.5% annually in the early Ninety's (Haukohl, 1991), however, this has been revised and is now expected to decrease. The composition of MSW in Denmark is similar to that of other European countries with the bulk of MSW being food and yard waste (around 40%) (Figure 2.4).

Table 2.7
MSW Management Statistics in Denmark (millions of tonnes)

Category	Incinerated	Utilised/recycled	Landfilled	Total
Residential	0.9	0.1	0.2	1.2
Yard Waste	0.04	0.16	0.2	0.4
Commercial	0.6	0.9	0.8	2.3
Residential Bulky	0.03	0.05	0.22	0.3
Total (1985)	1.57	1.21	1.42	4.2
Total MSW (1990)				2.6
Projected %*	25	50	25	100

* = 5 year projection based on nonhazardous waste - sewage sludge, demolition waste & coal ash
Adapted from Hjelmar and Johannesen, 1992

Figure 2.4 Danish MSW Compositional Statistics



Danish National Agency for Environmental Protection, 1990

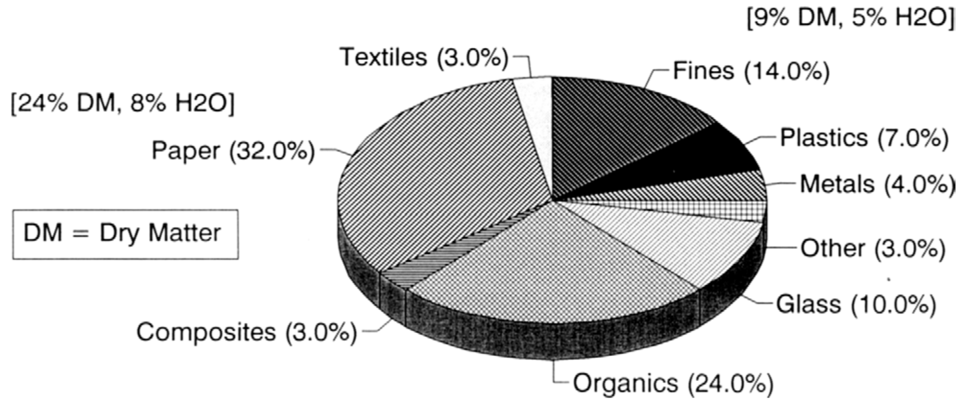
Incineration plays a major role in MSW management in Denmark with more than 48% of the MSW stream (including household, trade, bulky and garden wastes) being combusted at 29 large incinerator facilities (Rijpkema et al., 1992). A total number of 31 facilities were operating in 1993 (Hjelmar, 1996). Energy is recovered at each facility. Landfill and recycling/utilisation play an equal role in the management strategy. Projections are that the dependence on landfill will decrease during the next five years due to increased recycling or utilisation of wastes, whereas the quantities of MSW incinerated will remain stable. It is assumed that the 43,000 tonnes of yard waste sent for composting in 1990 (Vestforbrænding, 1990) would be included in the recycle/ utilisation category.

The Danish Government instituted an "Action Plan for Waste and Recycling for 1993 - 1997" which set targets for the various waste management options, including 54% recycling, 25% incineration and 21% landfill by the year 2000. In addition, a target was set for reducing the use of PVC packaging by 82% by the year 2000, which is anticipated to help reduce the reliance on landfill and incineration (Danish Environmental Protection Agency, 1995).

2.3.3 France

Approximately 18 million tonnes of MSW (19.5 million tonnes including bulky residential waste), or 0.88 (0.95) kg/person/day, were generated by the 56 million inhabitants of France in 1990 (Baltzinger, 1991). The composition of MSW in France is illustrated in Figure 2.5 (Rousseaux et al., 1988). Similar to most other countries, the largest component in MSW consists of paper products. Also note that the moisture content data for the different component fractions is also provided in Figure 2.5.

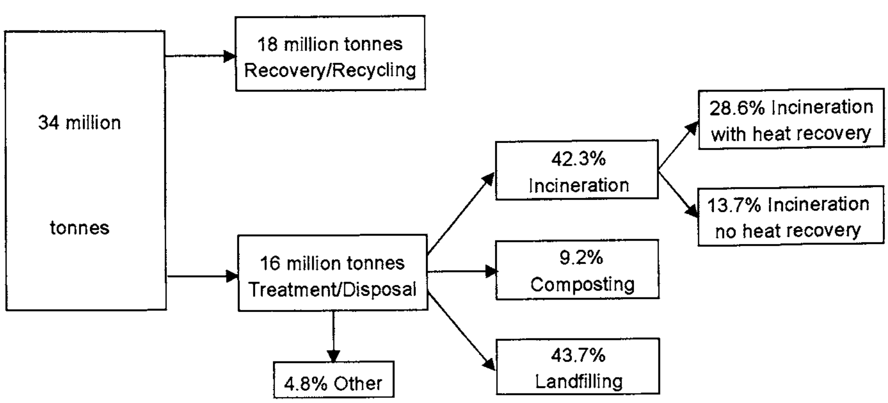
Figure 2.5 French MSW Compositional Statistics



Rousseaux et al., 1988

Of the 18 million tonnes, 0.6 million tonnes were collected separately for recycling (mostly glass and paper) and the remainder was sent for treatment and disposal. Incineration plays a very major role in MSW management in France. As illustrated in Figure 2.6, about 42% of the MSW collected for treatment and disposal is incinerated, 10% composted and the remainder landfilled. Of the total amount incinerated, 75% is processed through incinerator facilities with energy recovery capabilities. A summary of French incinerator facilities is given in Table 2.8. Note the number of French facilities quoted by sources ranges from 170 to 315 (Knoche, 1992; Baltzinger, 1991; Rijpkema et al., 1992). Table 2.8 offers an extensive breakdown by facility capacity.

Figure 2.6 MSW Management in France



Adapted from Beltzinger, 1991

Table 2.8
Summary of Incinerator Facilities in France (1990)

Capacity (tonnes/day)	Number of Facilities	With Energy Recovery	Total Capacity (tonnes/day)
>720	7	6	10,368
>480 - <720	9	9	5,400
>240 - <480	30	23	9,708
<240	152	50	11,952
Total	198	88	37428

Adapted from Baltzinger, 1991

2.3.4 Germany

Since the records regarding waste management within the former East German infrastructure were difficult to interpret, most of the information given here pertains to the former West German data and post reunification data. In 1990, the West German population of 62 million generated approximately 35 million tonnes of MSW, whereas approximately 43.3 million tonnes were generated by Germany's 90 million inhabitants in 1993. This includes, residential, bulky residential, commercial, light industrial (similar to household) and yard/garden waste. Therefore, the estimates that the new eastern provinces would generate between 3.6 and 5 million tonnes of MSW (Umweltbundesamt, 1990/91; Reimann, 1991) were reasonably accurate.

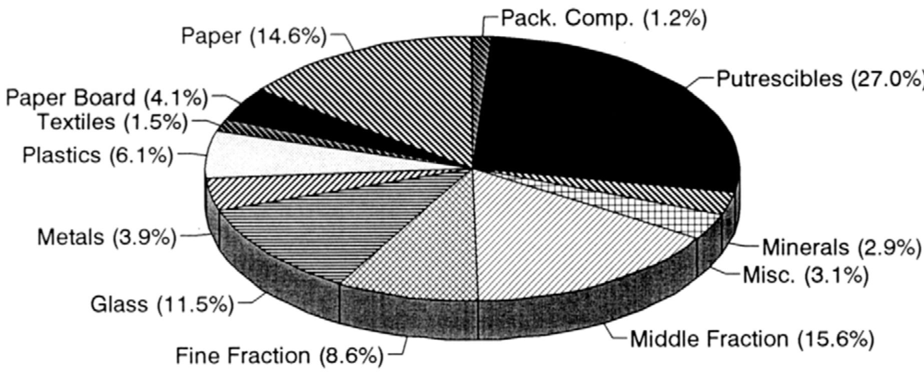
In 1986, the federal government passed the Waste Management Act which set out national policy on waste management. Avoidance of waste was given the highest priority which is to be facilitated by mandating:

1) reuse of beverage containers through deposit/return laws,
2) an aggressive Packaging Ordinance (1990) which set targets for recovery and reuse/recycling of all packaging materials,
3) a Paper Ordinance (1991) designed to divert paper products from landfill, and
4) a Plastic Ordinance which set a target of 80% reuse/recycling of plastics.

A decade later, the "Closed Cycle Economy Law" was adopted to refine the Waste Act by regulating the use and disposal of materials, and thereby helping to promote an environmentally compatible and sustainable economy. More important, the new law makes the recovery of energy from waste materials equal in priority to materials recycling within the "Hierarchy" (Vehlow, 1996).

The collective result of these initiatives is estimated to be a 45% diversion of waste from landfill via reuse/recycling. The largest single component of the MSW stream is kitchen waste (Figure 2.7) which represents a substantial potential for composting, although an emphasis has been placed on producing quality compost (marketable) by maintaining strict control of the source materials. The Waste Act stipulates that the remaining combustible MSW must be treated thermally (preferably with energy recovery) prior to disposal, as evidenced by the Technical Directive for Residual Waste which severely restricts the organic content of waste destined for landfill (see Table 2.9). As a result, incineration will continue to play a major role in German waste management.

Figure 2.7 German MSW Compositional Statistics



Vehlow, 1992

Table 2.9
Regulations under the Technical Directive for Residential Waste and the LAGA

Parameter	Landfill Class I	Landfill Class II	LAGA
Loss on Ignition %wt	3	5	
Total Organic Carbon %wt	1	3	1

Adapted from Vehlow, 1996

About 11 million tonnes (36%) of MSW were incinerated in 51 incinerator facilities, all of which recover energy (Reimann, 1991; Rijpkema et al., 1992) (Table 2.10). Although recycling and composting strategies must be exhausted prior to incineration, it is estimated that the current incineration capacity will have to increase by more than 80% within the decade to keep pace with the increase in waste and still adhere to the targets set within the Waste Act (Umweltbundesamt, 1990). At the present time, four facilities are under construction and there 19 incinerator facilities in the planning stages, representing a potential capacity of 3.5 million tonnes per year. Some of the shortfall is expected to be taken up by modifying existing facilities to accommodate an increase of half a million tonnes of MSW/year. A summary of existing incinerator facilities in Germany is given in Table 2.11.

Table 2.10
Municipal Solid Waste Treatment per Category in Germany

Component	Municipal ktonnes/year	Solid Waste %
Recycling	4000	16
Composting	500	2
Landfill	11500	46
Combustion	9000	36
Total	25000	100

Adapted from Rijpkema, 1992

Table 2.11
Summary of MSW Incineration Facilities in Germany

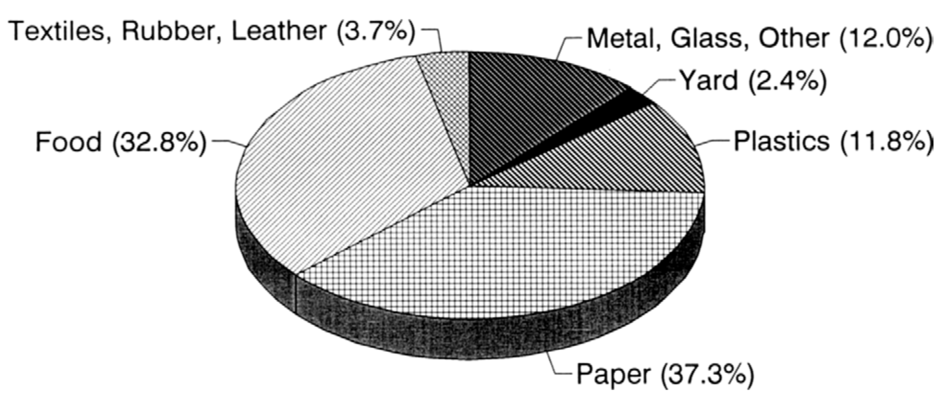
Capacity (tonnes/day)	# of Facilities	# with BA Utilisation	# with Dry APC Systems	# with Wet APC Systems	Ash Generation (tonnes/day)
>1200	13	10	9	6	4,937
>720 - <1200	15	13	3	12	3,100
>480 - <720	7	4	3	4	966
<480	16	11	6	10	1,060
Total	51	37	21	32	10,063

Note: total # of facilities & capacities include those capable of incinerating sewage sludge and hospital waste
Adapted from Barniske, 1989; UBA, 1991; Vehlow, 1996

2.3.5 Japan

Approximately 50.2 million tonnes of MSW were generated in Japan in 1992. This translates into a 1.1 kg/person/day generation rate which was 1.1% lower than the previous year (Sakai, 1996), reversing a trend of a 4 - 6.5% increase per year between 1988 and 1991 (Eller, 1992). This decrease is due mostly to regulations enforcing reuse and recycling of materials. The latest statistics on the composition of the Japanese waste stream indicate that the largest components of MSW are waste paper (37%) and food waste (32%) (Figure 2.8), whereas metals, glass, plastics, etc., combined make up only about 30% of the MSW stream.

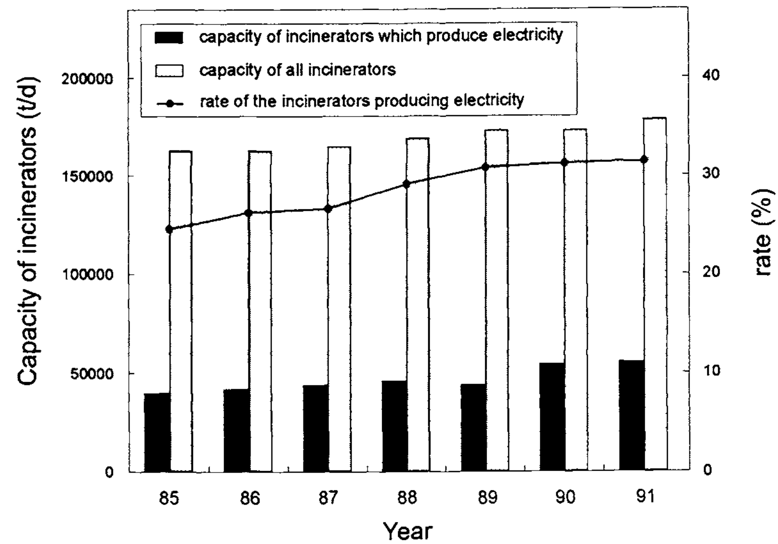
Figure 2.8 Japanese MSW Composition Statistics



Eller, 1992

Only about 15 % of the total MSW stream was landfilled in 1992 (Sakai, 1996). Since landfill capacity in the country is becoming more scarce (see Figure 2.9), MSW management in Japan is increasingly reliant on incineration (Patel and Edgcumbe, 1992). Almost 85% of MSW was incinerated in 1992 (Sakai, 1996). The most common practice in Japan is to separate MSW into combustible and non-combustible fractions. The non-combustible fraction is not included in national generation statistics, but is estimated to represent about 30% of the total amount of waste generated. Only a small fraction of waste (about 3%) is composted (Eller, 1992). The bulk of the 48 million tonnes of combustible material (about 70-77%) is incinerated in 1,893 incinerators around the country (Government of Japan, 1990; Tsukamoto, 1991; Patel and Edgcumbe, 1992). The remainder is landfilled or sorted to remove metal and glass.

Figure 2.10 Summary of Japanese Electricity Production from MSW Incineration 1985-1991



Ministry of Health and Welfare, 1994

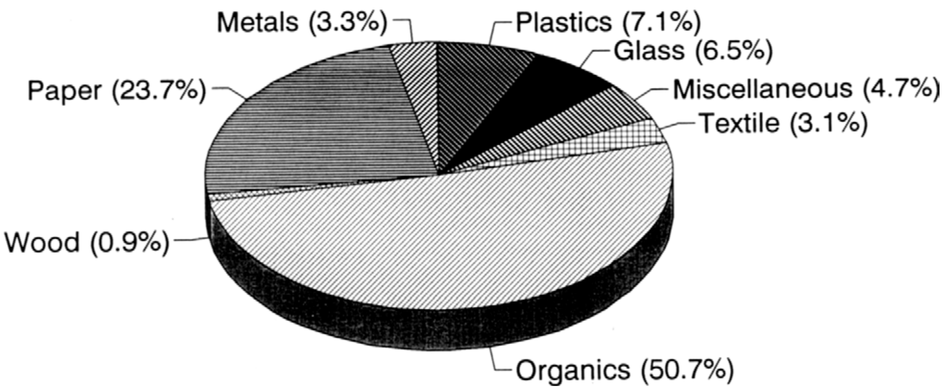
2.3.6 The Netherlands

Approximately 28 million tonnes of what is defined as "Priority Waste" is generated each year by the Netherlands' 14 million inhabitants (Government of the Netherlands, 1988 and 1991a).

About 12 million tonnes (43%) of the total could be classified as MSW and less than 6 million tonnes (<22%) are considered household waste (Folmer, 1991). Although the quantities of domestic waste discarded annually have increased at the rate of 5 - 10% (Government of the Netherlands, 1988; Folmer, 1991), it is anticipated that the implementation of new policies will effectively drop the rate to a net 1.4% increase during each of the next 25 years (Government of the Netherlands, 1992). The results from compositional studies indicate that the largest component in household waste is food and yard waste followed by waste paper (Figure 2.11).

At the present time, it is estimated that about 55% of the "Priority Waste Stream" generated is landfilled, 35% is reused or recycled and about 10% is incinerated. This translates into about 35% of the household waste being incinerated (Rijpkema et al., 1992). Although there is an initiative to compost only vegetable, fruit and garden wastes, there is no data available on the success of the program. Previous studies have shown that compost from unsorted municipal waste is rendered unusable due to the high contents of trace metals (Table 2.13).

Figure 2.11 Dutch MSW Compositional Statistics



Government of the Netherlands, 1991

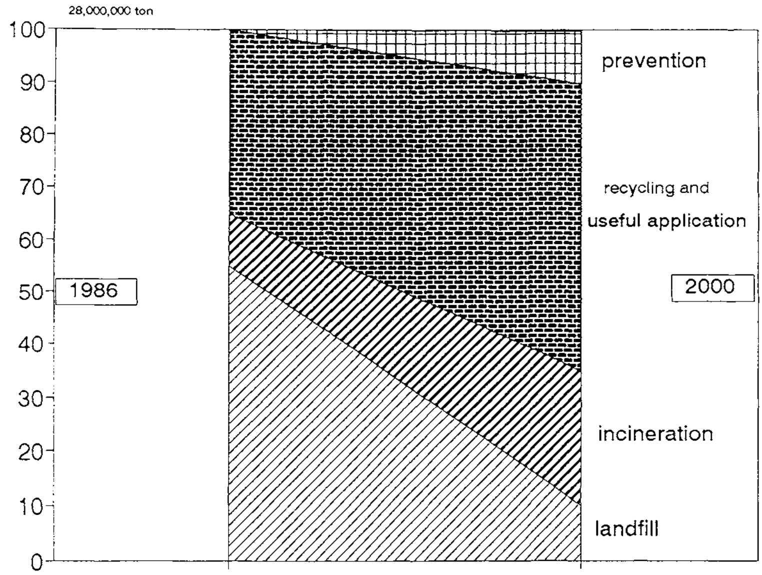
Table 2.13
Average Concentration of Trace Metals in Compost from Different Sources (μg/g)

Trace Metal	Food and Yard Waste	Municipal Solid Waste
Cadmium	1	2
Chromium	20	120
Copper	32	120
Lead	73	450
Nickel	9	45
Zinc	149	600

Adapted from Government of the Netherlands, 1991b

The current national policy for MSW management was set out in the publication "Memorandum on the Prevention and Recycling of Waste" (Government of the Netherlands, 1988) and is similar to that used in most other countries, namely a hierarchical approach of prevention, reuse, utilisation (recycling), incineration and landfill. The projected target is to decrease the amount of material landfilled by more than 70% by the year 2000, relying mostly on recycling/utilisation and incineration (Figure 2.12).

Figure 2.12 Projected Targets for MSW Management in the Netherlands



Government of the Netherlands, 1991

With respect to incineration, the Dutch government's new policy is toward promoting the use of energy recovery. Previously, many of the facilities were not capable of recovering energy, whereas now about 6 of the 8 currently operating facilities recover energy (Folmer, 1991). The new trend is also aimed at modernising or replacing some of the older facilities with an increased waste capacity. A summary of Dutch incinerator facilities is given in Table 2.14.

Table 2.14
Summary of Incinerator Facilities in the Netherlands

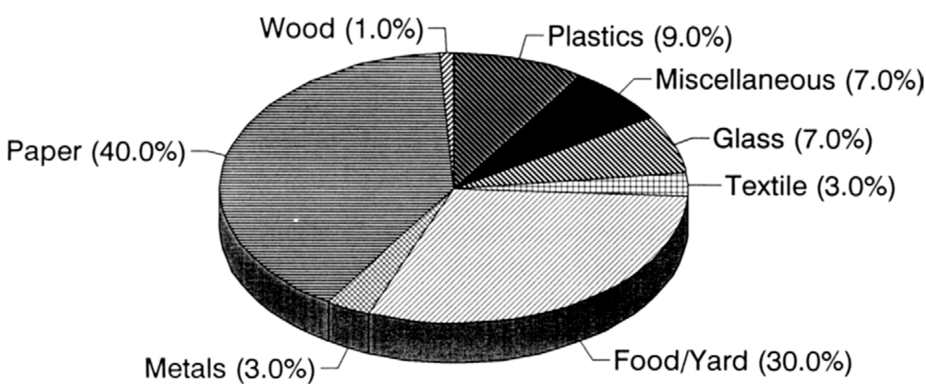
Furnace Type	Capacity (tonnes/day)	Facilities	Energy Recovery	Tonnes of MSW Processed (1990)
Mass Burn	>300	4	4	2075000
	>100 - <300	4	2	648,000
	<100	2	0	111,000
Semi-suspension	<100	1	1	75,000
TOTAL		11	7	2909000

Adapted from VEABRIN, 1991

2.3.7 Sweden

Approximately 2.7 and 3.2 million tonnes of household waste or MSW were generated in 1990 and 1991, respectively, by Sweden's 8.5 million inhabitants (Nilsson, 1991; RVF, 1994). These statistics do not include the waste materials recovered or reused such as bottles, cans, newsprint or cardboard. The latest statistics indicate that about 63% (375,000 tonnes) of waste newsprint and paper, and 94,000 tonnes of glass were recovered for recycling in 1991 (RVF, 1994). Based on these data, it is anticipated that the amount of MSW sent for treatment or disposal will decrease, especially in light of the 1994 legislation stipulating producer responsibility for collection of packaging waste. The goal of the legislation is to recycle 75% of paper by the year 2000. The largest components of MSW are waste paper, and food and yard waste, which constitute up to 45% and 35% of the weight of total discards, respectively (Figure 2.13).

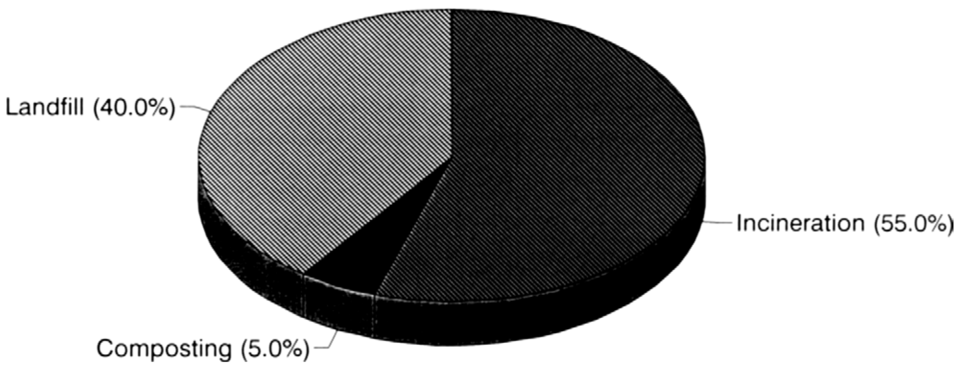
Figure 2.13 Swedish MSW Composition Statistics



Adapted from Nilsson, 1991

After separation of recyclable materials, it is estimated that the bulk of MSW discarded is incinerated (55%) or landfilled (40%) (Rijpkema et al., 1992) (Figure 2.14). Only about 5% of the MSW stream is currently sent for separation and composting. This figure is down from 1988, when it was estimated that 10% of MSW was sent for separation and composting (Bergström, 1988; SAPCSWM, 1988). However, the demand for higher quality materials from the separation process has limited the success of this process. The market for composted material is also very limited (about 30% of the total produced is sold) due to the content of trace metals. Most compost produced is only used for landfill cover. In the future, it appears that the Swedish government is going to emphasise more utilisation of wet kitchen waste and other non-combustibles for landfilling to enhance landfill gas production. This may decrease the amount of MSW incinerated, however, the decrease will be made up with alternative heating value fuels (Nilsson, 1991).

Figure 2.14 MSW Management in Sweden



Adapted from SAPCSWM, 1988

All 21 of the operating incineration plants in Sweden are capable of recovering energy from the 1.8 million tonnes of household and industrial waste incinerated annually (RVF, 1994). About 98% of the energy recovered is used to generate steam for district heating purposes, representing about 13% of the country's district heating requirement (Nilsson, 1991). Most of the remaining 3% is used for generating electricity. A summary of incinerator facilities is given in Table 2.15.

Table 2.15
Summary of Incinerator Facilities in Sweden

Furnace Type	Capacity (tonnes/day)	Facilities	Total Capacity (tonnes/day)
Mass Burn	>200	7	3,710
	<200 - >100	4	540
	<100	7	380
Fluidised Bed	<140 - >50	2	195
	<50 - >14	3	96
TOTAL		23	4921

Adapted from Nilsson, 1991

2.3.8 Switzerland

More than 3 million tonnes of MSW were generated by Switzerland's 6.6 million inhabitants (1.4 kg/person/day) in 1991 (WRI, 1992). The largest components of MSW are food/yard waste and waste paper products, comprising 30 and 33% of the total MSW stream, respectively (Tabasaran, 1984).

The current Swiss policy on MSW management is outlined in the "Ordinance Relating to Treatment of Waste" and is based on the hierarchical approach taken in most other countries, namely reduce, reuse, recycle and recover. However, the policy includes stipulations that every waste treatment process must "produce materials that either are recyclable or have final storage quality." In addition, the processes used must also be economically viable and must result in a net benefit to the environment, i.e., create less pollution than the disposal of the waste or the production of the product from virgin material (Swiss Environmental Protection Agency, 1988). These stipulations have had an impact on the methods used to manage waste.

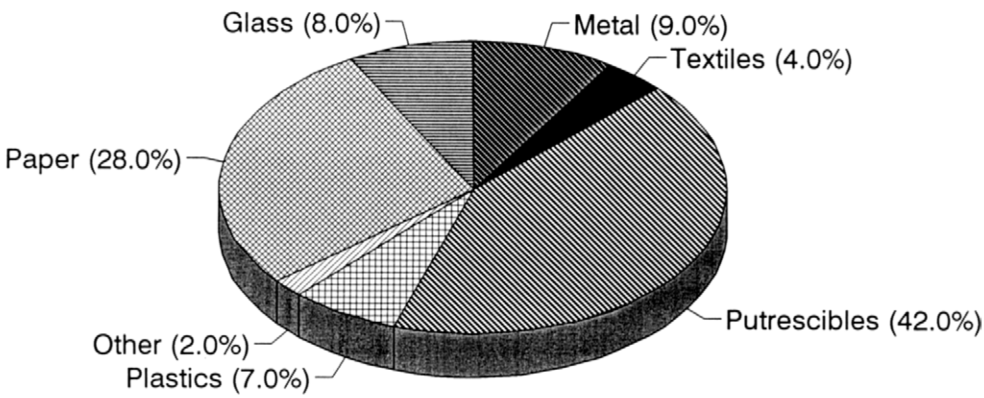
Any component of MSW stream which is deemed non-useable and reactive, must first be inertised by thermal treatment prior to disposal. Consequently, the Swiss incinerate approximately 80% of the MSW generated annually, which is the highest rate of MSW incineration in the world (WRI, 1992). Latest substantiated data indicate 30 incinerator facilities are in operation. Approximately 50% of the incinerator facilities are capable of recovering heat (Rijpkema et al., 1992).

2.3.9 United Kingdom

Approximately 19 - 20 million tonnes of household (residential) waste were generated per year in the UK between 1987 and 1994 by a population of 58 million, including 5 million tonnes of yard waste and bulky wastes (Krol and Dent, 1988; UK Dept. Of Environment, 1995). This number increases to 30 - 35 million tonnes if similar waste from the commercial and light industrial sectors are included (Baker, 1991; UK Department of Environment, 1995). The latest data available indicate that putrescible (food and yard) wastes (almost 42%), and paper (28%) comprise the bulk of the household waste stream in the UK (Figure 2.15).

The current range of estimates on the methods of MSW disposal are that 85 - 88% of the total quantity is landfilled, 4 - 9% is incinerated, and 3 - 11% is disposed or processed by other means including recycling and production of refuse derived fuel (Krol and Dent, 1988; Hinchcliffe, 1992). Recent developments, including the introduction of the Environmental Protection Act (EPA) 1990 (HMIPC, 1990), the EC Landfill Directive and proposed Landfill Tax, are likely to raise both standards and the costs associated with landfill in the UK. The EPA also obliges the local authorities to consider recycling options for MSW. In addition, the 1990 White Paper on the Environment (HMSO, 1990) set a target for recycling 25% of all household waste by the end of the century. This level is being achieved by some local authority initiatives, but the general level of recycling remains at about 3%.

Figure 2.15 UK MSW Composition Statistics



Baker, 1990

Although it seems likely that landfill remains the dominant disposal route for the non-recycled waste stream, the recent introduction of financial incentives for energy-from-waste projects may lead to the building of new incinerators over the next few years. Facilities in London, Birmingham and Cleveland have been or are in the process of being constructed. Many facilities will be phased out once the EC emissions standards come into force in December of 1996. Consequently, eight further facilities are in the planning stages and some of these will make up for the lost capacity. A summary of existing MSW Incinerator Facilities in the UK is provided in Table 2.16.

Table 2.16
Summary of MSW Incinerator Facilities in the UK

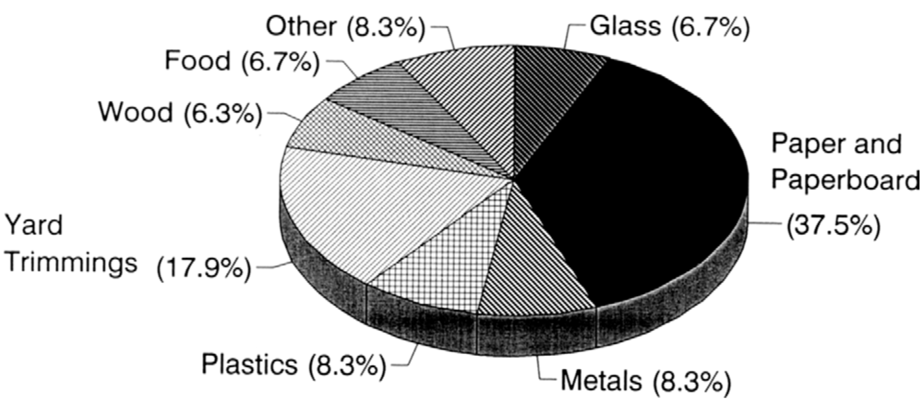
Capacity (tonnes/day)	Number of Facilities	With Energy Recovery	Total Capacity (tonnes/day)
>720	5	2	4,320
>480 - <720	9	2	4,512
>240 - <480	10	2	3,168
<240	12	1	1,956
Total	36	7	13956

Adapted from Baker, 1990

2.3.10 United States

Between 300 and 320 million tonnes of residential, commercial and light industrial waste were generated per year in the United States in 1990 - 1993, half of which (163 million tonnes) was considered MSW (US EPA, 1991; Steuteville, 1994). The quantity of MSW generated (1.8 kg/person/day) is anticipated to grow at a rate of 2% per year (Franklin, 1992). The major component of the MSW stream is waste paper which accounts for about 72 million tonnes (40% by weight) of the MSW discarded (Figure 2.16). If food and yard wastes were classified together, they would comprise about 30% of the total MSW stream.

Figure 2.16 US MSW Composition Statistics (1990)



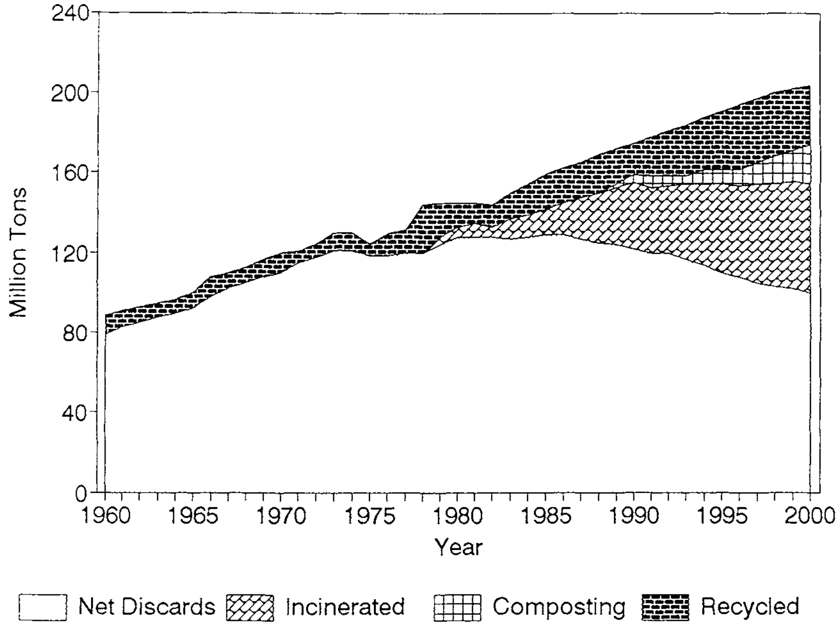
US EPA, 1992

The federal policy regarding MSW management in the US is based on the "4R's", reduce, reuse, recycle and recover. The latest statistics indicate that between 62 - 67% of MSW was disposed in landfill, 10 - 16% was incinerated and 21 - 23% was recycled. The quantity of MSW sent for composting was negligible. Although there have been national targets set, including 20% incineration, 25% recycling and 55% landfill (US EPA, 1991), regulation and management of MSW falls directly under the jurisdiction of state and regional governments. Consequently, the management strategies vary widely depending on the jurisdiction.

Nationally, it is projected that the quantities of MSW destined for landfill (net discards) will decrease during the decade as existing landfills close and greater percentages of the waste are diverted using recycling, composting and incineration processes (Figure 2.17). As of September 1991, 189 MSW incinerator facilities were operating in the

United States, representing a total design capacity of about 92,000 tonnes per day. Many of the facilities are located in the densely populated northeastern states. A summary of incinerator facilities is given in Table 2.17.

Figure 2.17 US Trends in MSW Management



US EPA, 1991

Table 2.17
Summary of MSW Incinerator Facilities in the United States

Incinerator Type	Capacity (tonnes/day)	Number of Facilities	With Energy Recovery	Total Capacity (tonnes/day)
Mass Burn	>500	44	39	51275
	>100 - <500	25	21	6760
	<100	30	None	950
Two-stage	>100	16	16	3145
	<100	34	33	1957
RDF	>500	18	18	25320
(Semi-suspension)	<500	9	8	2200
Total		176	135	91607

Adapted from Waste Age, 1992

2.4 CHEMICAL CONSTITUENTS

The various components in the waste stream all have a unique chemical composition. Most of the materials have varying quantities of carbon, hydrogen and nitrogen in their basic composition. During the incineration process organic-based materials such as paper, kitchen waste and plastics are generally oxidised to H_2O, CO_2, CO and minor constituents. Conversely, the elements, inorganic compounds or mineral phases in the waste feed either:

1) remain as solid particles and are trapped in the various residue streams;

2) are volatilised and carried in the flue gas stream until sorbed or condensed out onto particles; or

3) are discharged with the flue gases.

Since most of the potential environmental effects of waste disposal are related to the chemicals in the waste, developing data on the chemical composition of the waste stream is important. In relation to this document, the trace chemical composition of the waste is an important issue which needs to be examined, since it ultimately influences the chemical composition of incinerator residues and hence their eventual impact on the environment.

For the most part, analyses of MSW have generally been performed for the purposes of ascertaining the feasibility of energy from waste treatment alternatives and centres on determination of the burning characteristics of the waste. Bulk waste samples are the most frequently analysed for this purpose after care has been taken to make the samples representative of the mass of waste being tested. Examples of these tests are:

1) Proximate Analysis - to determine the percentages of volatile matter, fixed carbon, moisture and ash in the waste;

2) Ultimate Analysis - to determine the percentage of moisture, C, H, S, N, O_2 and ash in the waste; and

3) Heating Value - to determine the amount of energy available from combustion of the waste.

Tables 2.18 and 2.19 provide examples of these analyses of MSW from different Canadian cities and Figure 2.18 shows a phase diagram of the proximate analysis results from a German study on 400 samples of MSW. MSW contains both high heating value components (plastic, rubber, paper and wood), and low heating value components (food and yard wastes). Notice that at a 50% confidence interval, the German waste consisted of between 29 - 43% moisture, 21 to 35% ash and 29 - 38% combustibles, which is consistent with most of the Canadian data.

Table 2.18
Examples of Ultimate, Proximate, and Heating Value Analysis Results for MSW from Three Canadian Studies

Analysis	Parameter	Hamilton, ON	Charlottetown, PEI	Quebec City, PQ
Ultimate (%)	Carbon	38.5	25.6	25.6
	Hydrogen	2.9	3.1	3.6
	Nitrogen	0.5	0.3	0.4
	Oxygen	23.0	21.2	13.9
	Sulphur	0.1	0.1	0.2
	Chlorine	NA	0.4	0.8
	Moisture	25.0	35.3	31.2
	Ash	30.0	14.0	24.2
Proximate (%)	Volatile Matter	38.5	42.4	41.0
	Fixed Carbon	6.5	8.2	3.6
	Moisture	25.0	35.3	31.2
	Ash	30.0	14.1	24.2
Heating Value	(kJ/kg)	11,165	10,527	9,792

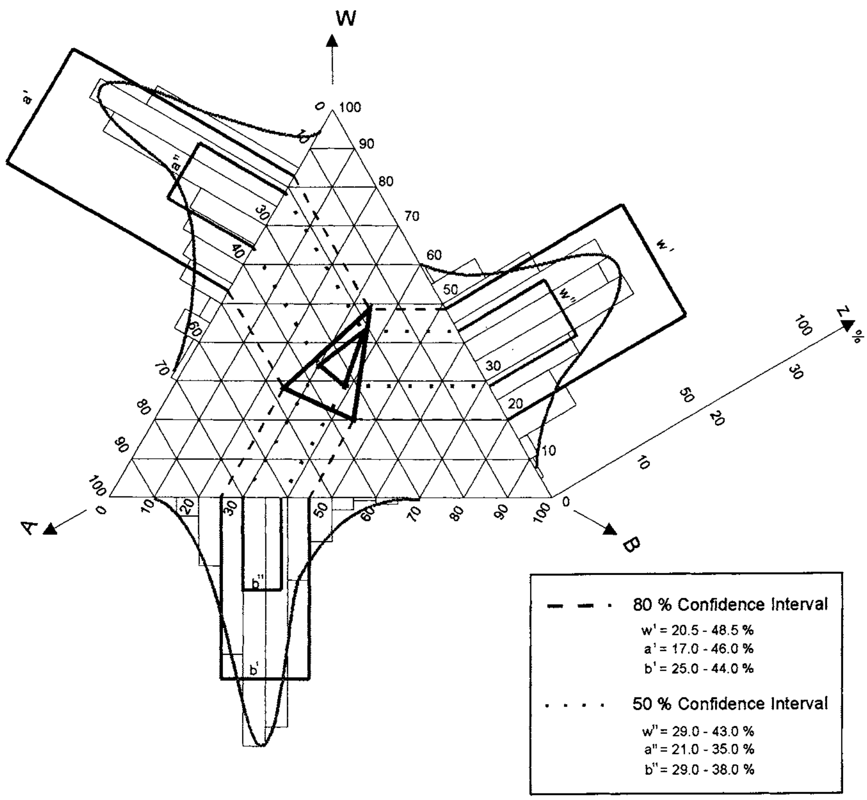
Adapted from Walls, 1982; Environment Canada, 1985 & 1988

Table 2.19
Summary of Higher Heating Values of Various Components in MSW

Waste Component	Heating Value (MJ/kg)
Paper	12.2 - 18.6
Plastic/paper laminates	17.1
Food waste	4.1 - 38.3
Wood (dried)	15 - 17
Yard and garden waste	4.8 - 18.6
Tires	32.1
Rubber	26.1
Plastics	22.7 - 45.8
Textiles	16.1 - 18.5

Adapted from Haley, 1990

Figure 2.18 Tanner Diagram of the Proximate Analysis of MSW



(A=Ash, B=Combustibles, W=Water)

Reimer, 1975

The sources of trace elements in MSW are diverse. For example:

1) consumer products such as batteries and circuit boards may contain cadmium, lead, mercury and zinc;

2) pigments used in printing inks, paints, glass and plastic may contain cadmium, chromium, lead and zinc; and

3) preservatives or fungicides used in paints and lumber products may contain arsenic, copper or mercury.

Several other examples of trace metals used in consumer products are given in Table 2.20.

Table 2.20
Some Potential Uses of Selected Trace Metals in Various Consumer Products

Element	Compound	Use or Product
Cadmium	cadmium benzoate	plastic stabiliser (chloride scavenger)
	cadmium sulphide	yellow pigment for plastic
Chromium	various chromate compounds	yellow, red and green pigments
		leather tanning agent
Copper	copper arsenate	lumber/finished wood preservative (fungicide)
	phthalocyanine Cu	blue pigment
Lead	lead chromate	yellow pigment
	lead sulphate	white pigment
	lead oxide	lead crystal
Zinc	zinc chromate	yellow pigment
	zinc dithionite	paper processing bleaching agent
	zinc oxide	widely used, e.g., paints, rubber products, inks, soaps, plastics, textiles, etc.
	zinc sulphide	luminous materials, fluorescent lights

Adapted from Rousseaux, 1988; Hammond, 1992; Chandler et al., 1992

Although bulk samples of MSW have been collected to determine their trace metal composition, obtaining a relatively small representative sample (1 to 10 grams) from a large quantity of heterogeneous material such as MSW is extremely difficult. Examples of reported concentrations of a wide variety of elements and trace metals in bulk MSW were determined during Environment Canada's NITEP Program and are provided in Table 2.21.

In general, the statistics indicate that there is a high degree of variability in measurements for some metals, especially cadmium, chromium, lead and mercury, and certainly between sample sets from different locations.

In addition to bulk analysis, there are two other methods that have been used to evaluate and characterise the trace metals in different components which make up the MSW stream, namely, a direct and an indirect approach. The direct approach is extremely labour intensive since it involves actual sampling and analyses of the various components of the waste stream. Typically, this method requires a large number of samples to generate statistically valid data, but is capable of producing an accurate picture of specific local waste streams. It should also account for all the various components in the waste stream, specifically the organic, soil and fines fractions. Alternately, the indirect approach is based on material flow models which involve examination of production data and estimation of product life expectancy. The data generated from this method is quite useful for providing benchmark data on a national or regional level and monitoring long-term trends which are free from seasonal variation and sampling biases. However, the data is often not specific enough to develop local waste management strategies. There are numerous other advantages and disadvantages to both approaches, some of which have been summarised in Table 2.22.

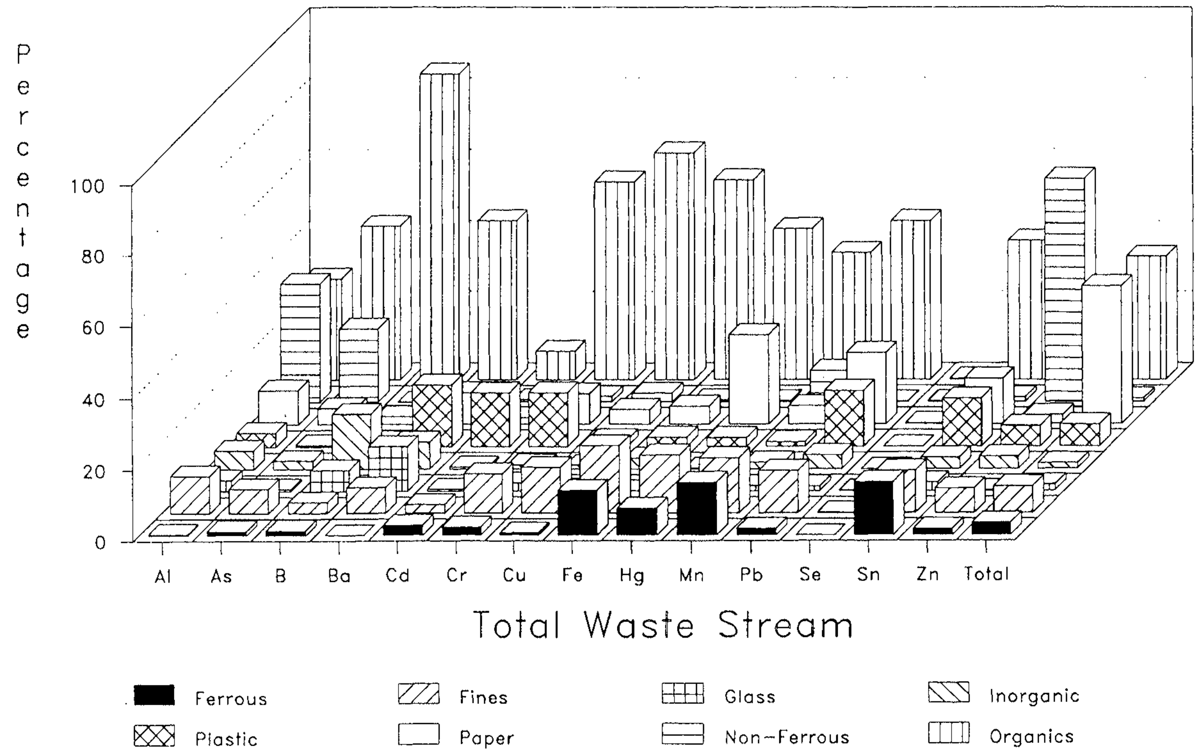
Table 2.21
Summary of Elemental Concentrations in Various Fractions of MSW

	Charlottetown, PEI (Combustibles) *n*=12			Quebec City, PQ (Combustibles) *n*=12			Hartford, CT (RDF) *n*=12		
Element	*x*	*s*	*m*	*x*	*s*	*m*	*x*	*s*	*m*
Al	12,050	4,060	12,225	5,530	1,740	5,233	72,220	19,930	66,200
Ba	1.2	4.04	0	147	66.9	145	385	130	395
Ca	5,140	1,375	5,125	20,060	6,470	17,250	76,260	14,460	79,700
Cd	0.75	1.14	0	8.06	7.39	5.5	30.3	10.1	29.0
Cr	21.8	16.3	16.5	172	215	112	433	495	275
Co	0.17	0.58	0	3.71	1.76	2.8	52.8	34.2	42.9
Cu	48.3	25.4	41	430	660	108	8,930	17,130	1,720
Fe	2,365	1,830	1,960	6,050	1,385	5,970	31,930	20,205	23,050
Pb	82.4	47.4	79	732	1,080	255	2,760	2,155	1,820
Hg	0.17	0.39	0	1.23	1.04	0.74	0.11	0.10	0.08
Na	3,040	2,070	2,400	2,470	1,010	2,170	71,960	63,550	53,000
Ni	4.25	2.22	4	45.1	8.01	43	442	407	280
Sn	14.2	5.51	12.5	54.9	108	20	889	337	875
Zn	146	61.5	134	429	243	39	5,870	9,050	2,560

x = arithmetic mean *s* = standard deviation *m* = median
Adapted from Environment Canada, 1985, 1988 & 1991

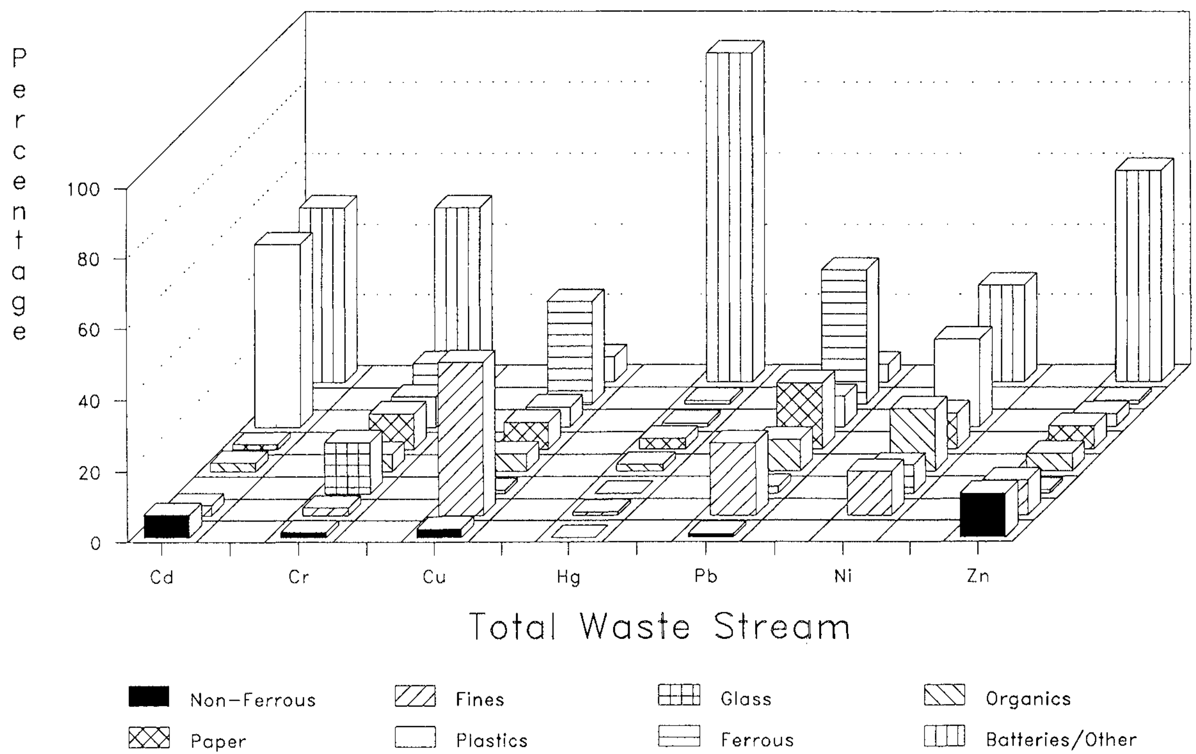
Examples of data generated from three studies which used the direct approach for evaluating MSW composition are given in Figures 2.19, 2.20 and Table 2.23. The data generated from the French study conducted under the R&D Programme on Recycling and Utilisation of Waste were based on a survey of results from 26 smaller studies of MSW from five different countries, namely, France, Germany, Netherlands, Switzerland and Sweden (Rousseaux, 1988). The results from the Waste Analysis, Sampling, Testing and Evaluation (WASTE) Program were based on 31 separate samples of MSW from Vancouver, British Columbia (Chandler et al., 1992). The Dutch study of household waste from the Bilthoven area was based on analysing several 700 kg samples of waste. All of the programs used similar classification systems to define the waste. The distribution of elements within the different waste categories from the studies indicates that the organic, fines and battery fraction of MSW contribute substantial proportions of many elements to the waste stream.

Figure 2.19 Distribution of Trace Metals in North American MSW



Chandler et al., 1992

Figure 2.20 Distribution of Trace Metals in European MSW



Adapted from Rousseaux, 1988

Table 2.22
Comparison of Direct and Indirect Approaches to MSW Characterisation

Approach	Advantages	Disadvantages
Direct	Accurate for site-specific studies which are useful for developing local solid waste management strategies Accounts for all materials in the stream including organics (kitchen and yard), soils and fines fractions Can account for variations in waste caused by waste source, recycling initiatives, season & climate Samples can be fully characterised, including potential leachability	Large number of samples required to be statistically valid Susceptible to generating skewed data if methodology selects atypical samples Labour intensive & expensive Data is time dependent & must be repeated if comparisons are to be made Requires very careful sample preparation and analyses
Indirect	Provides composition data on a broader context than direct, i.e., national data Can account for variations caused by imports and exports Useful for developing national or regional management strategies by ability to track trends in production	Model must include data on organic, soil & fines fractions Model must be comprehensive and account for all significant input of metals Data is not site, nor source, specific, i.e., may not be accurate for specific city or apply to specific residential or commercial waste streams Product life-span estimates are generalised and susceptible to biases Stability of waste components and other component characteristics cannot be measured

Adapted from Rousseaux, 1988; US EPA, 1992; Chandler et al., 1992

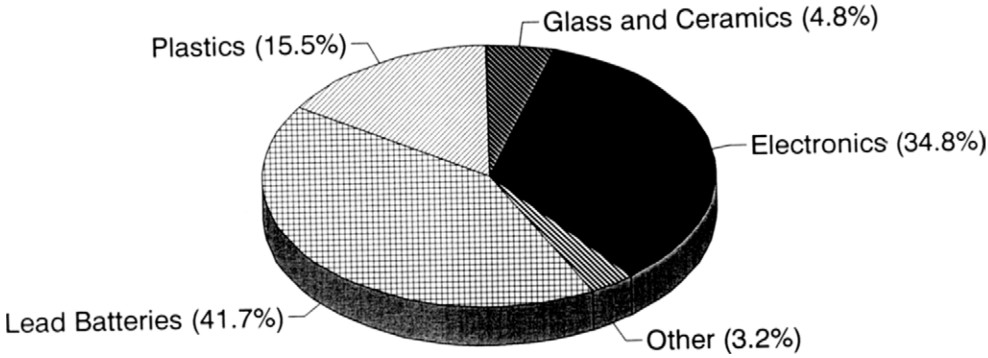
An example of the indirect approach is a study commissioned by the US Environmental Protection Agency to identify potential sources of various trace metals in the waste stream by examining production data and material flows (Franklin, 1989). The material flow model used scenarios of 80 and 90% recovery of batteries for recycling to estimate the contribution of lead acid batteries and other materials to the waste stream. Based on the result from this study, lead acid batteries were believed to be responsible for contributing more than half of the lead in the waste stream (Figure 2.21). This is inconsistent with the data from the WASTE Program which indicated that the organics fraction contributed the greatest proportion of lead to MSW and underlines the importance of accounting for the composition of the organic, soil and fines fractions of the waste stream in the material flow model.

Table 2.23
Distribution of Trace Metals in Dutch Household Waste

Component	As	Be	Cd	Co	Cr	Cu	Hg	Fe	Mg	Mo	Ni	Pb	Sb	V	Zn
Organics	8.1	0.76	1.0	69	607	56	0.31	1.2%	208	70	673	407	0.15	44	1,010
Paper	0.81	0.16	5.26	2.44	10.9	68.1	0.10	396	28.8	1.0	19.9	44.3	<0.02	1.16	393
Plastic	0.36	0.02	40.4	4.43	106	157	0.06	450	7.3	7.8	40.2	602	25	0.59	284
Glass	26	<0.3	1.83	4.7	275	26	<0.02	0.4%	127	7.0	19	628	28.8	6.5	74.7
Ferrous	58	<0.7	<0.7	97	1,120	860	ND	68%	654	44	1110	104	17.9	107	290
Nonferrous	5.2	0.14	2.54	5.8	98.2	25%	ND	0.4%	90.5	2.73	676	0.8%	24.6	6.42	3.7%
Textiles	3.37	0.19	32.6	18.5	3,160	109	0.22	0.2%	61	3.84	157	773	4.98	4.32	0.4%
Bread	0.1	0.01	<0.03	4.83	2.0	3.2	0.04	15	15.8	0.17	20.7	4.87	0.08	0.23	20.7
Ceramics	10	1.33	3.8	73.3	137	34	<0.02	1.7%	722	4.17	41.3	0.4%	36.2	65	1,030
Wood	1.9	0.02	2.64	8.97	18.4	13	0.17	647	56.4	0.33	7.85	751	3.4	0.61	1.1%

Adapted from Beek et al., 1988

Figure 2.21 Estimated Contributions of Lead to MSW in the US (90% Battery Recycling)



IEI, 1990

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