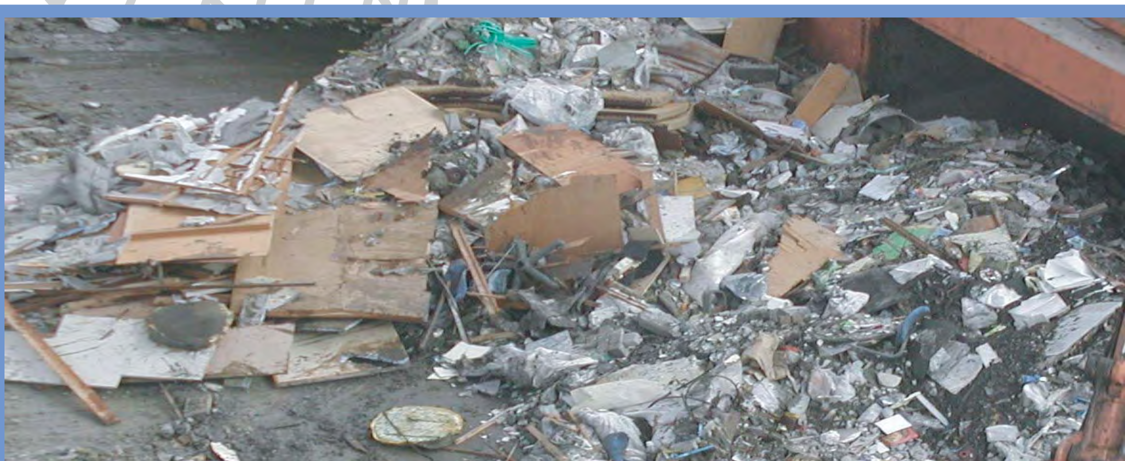
UNEP

SOLID WASTE MANAGEMENT



UNITED NATIONS ENVIRONMENT PROGRAMME

CalRecovery INCORPORATED

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Solid Waste Management

(Volume I)

UNEP

CalRecovery
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PREFACE

The collection, transport, treatment, and disposal of solid wastes, particularly wastes generated in medium and large urban centres, have become a relatively difficult problem to solve for those responsible for their management. The problem is even more acute in economically developing countries, where financial, human, and other critical resources generally are scarce.

One important contribution to the difficulties related to waste management is that which can be achieved by providing objective, reliable, and useful information to professionals in developing countries and to those from industrialized countries who may be called upon to provide assistance to those countries.

Although several publications deal with a variety of topics in the field of solid waste management, most of these documents have been published to address the needs of industrialized nations. Only a few documents have been specifically written to provide the type of information that is required by those in developing countries. Consequently, the UNEP, IETC published the *International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management* (1996). Similarly, the authors of this document prepared a book entitled *Solid Waste Management for Economically Developing Countries* (1996), which has undergone some revisions. The need was identified to update both documents once again. To maximize the use of limited available resources, it was decided to combine information from both documents, update some of the information as needed, and convert the two publications into a single document that could best serve the needs of developing countries.

This publication has been prepared primarily for two audiences: 1) decision-makers and policy makers, and 2) professionals involved in the management of solid wastes. The information in the publication would also be useful to students in environmental engineering. The material is presented such that most chapters need not be read in any particular sequence. However, if a formal class is based on the book, the chapters should be covered in sequential order.

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Solid Waste Management:

(Volume I)

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- Ms. Lizette C. Cardenas, Executive Director, Solid Waste Management Association of the Philippines
- Dr. Virginia W. Maclaren, Associate Professor, Department of Geography and Program in Planning, University of Toronto, Canada
- Ms. Jenny Tan, Project Manager, Centre for Environmental Technologies, Malaysia

Part I

Principles of Municipal Solid Waste Management

CHAPTER I. INTRODUCTION

A. Definition of developmental status

The status of development of a country may be categorised in several ways. With respect to its impact on solid waste management, in this publication status of development is categorised on the basis of availability of economic resources and on degree of industrialisation. Status of economic development is more a measure of the permanent economic framework than of the existing condition of the economy (recession vs. prosperity). In this document, the emphasis is on solid waste management in a setting that is primarily non-industrial. Such management is adapted to the nature and quantities of waste generated and to the availability of technology for handling and processing characteristic of non-industrial settings. Degree of industrialisation is measured in terms of extent of mechanisation and availability of technological resources. Justifiably or not, the terms “developed” and “industrialised” occasionally are used synonymously.

Because of localised changes in degree of development within each country, it is difficult to apply a single developmental category as far as solid waste management is concerned. For example, a large urban community (typically the capital city and surrounding area) in a developing nation may be in a stage of development that is well above that of the rest of the nation. On the other hand, these communities are not entirely immune to the limitations imposed by the status of the nation.

In this document, the authors have made an effort to incorporate in each section a range of coverage that encompasses the range of development that is typically found in economically developing nations without resorting to repetitive descriptions of technologies that do not vary substantially with scale of operation or degree of sophistication.

It is important to note that although the information presented in this document is applicable primarily to developing countries, some of it may also be applicable to a nation in transition or even to a developed or industrialised nation.

B. Characteristics of solid waste in developing countries

“Municipal solid waste” (MSW) is a term usually applied to a heterogeneous collection of wastes produced in urban areas, the nature of which varies from region to region. The characteristics and quantity of the solid waste generated in a region is not only a function of the living standard and lifestyle of the region's inhabitants, but also of the abundance and type of the region's natural resources. Urban wastes can be subdivided into two major components -- organic and inorganic. In general, the organic components of urban solid waste can be classified into three broad categories: putrescible, fermentable, and non-fermentable. Putrescible wastes tend to decompose rapidly and unless carefully controlled, decompose with the production of objectionable odours and visual unpleasantness. Fermentable wastes tend to decompose rapidly, but without the unpleasant accompaniments of putrefaction. Non-fermentable wastes tend to resist decomposition and, therefore, break down very slowly. A major source of putrescible waste is food preparation and consumption. As such, its nature varies with lifestyle, standard of living, and seasonality of foods. Fermentable wastes are typified by crop and market debris.

The primary difference between wastes generated in developing nations and those generated in industrialised countries is the higher organic content characteristic of the former. The extent of the difference is indicated by the data in Table I-1, in which is presented information relative to the quantity and composition of municipal solid wastes generated in several countries.

Table I-1. Comparison of solid waste characterisation worldwide (% wet wt)

Location	Putres-cibles	Paper	Metals	Glass	Plastics, Rubber, Leather	Tex-tiles	Ceramics, Dust, Stones	Wt (g)/ cap/ day
Bangalore, India [1]	75.2	1.5	0.1	0.2	0.9	3.1	19.0	400
Manila, Philippines [2]	45.5	14.5	4.9	2.7	8.6	1.3	27.5	400
Asunción, Paraguay [2]	60.8	12.2	2.3	4.6	4.4	2.5	13.2	460
Seoul, Korea [3]	22.3	16.2	4.1	10.6	9.6	3.8	33.4[a]	2,000[a]
Vienna, Austria [4]	23.3	33.6	3.7	10.4	7.0	3.1	18.9[b]	1,180
Mexico City, Mexico [5]	59.8[c]	11.9	1.1	3.3	3.5	0.4	20.0	680
Paris, France [4]	16.3	40.9	3.2	9.4	8.4	4.4	17.4	1,430
Australia [7]	23.6	39.1	6.6	10.2	9.9		9.0	1,870
Sunnyvale, California, USA [6]	39.4[d]	40.8	3.5	4.4	9.6	1.0	1.3	2,000
Bexar County, Texas, USA [6]	43.8[d]	34.0	4.3	5.5	7.5	2.0	2.9	1,816

[a] Includes briquette ash (average).
[b] Includes "all others".
[c] Includes small amounts of wood, hay, and straw.
[d] Includes garden waste.

Wastes generated in countries located in humid, tropical, and semitropical areas usually are characterised by a high concentration of plant debris; whereas those generated in areas subject to seasonal changes in temperature or those in which coal or wood are used for cooking and heating may contain an abundance of ash. The concentration of ash may be substantially higher during winter. Regardless of climatic differences, the wastes usually are more or less contaminated with nightsoil. These differences prevail even in wastes generated in large metropolitan areas of a developing country.

Ideally, solid waste should not contain faecal matter or urine, and the mixing of these materials with household waste should be prohibited by law. However, enforcement difficulties, combined with variations in way of life, necessitate some tolerance in this matter. Solid waste collection in a manner satisfactory with respect to environmental health is made difficult when human excretory wastes are mixed with household wastes. Handling of pathological wastes, abattoir wastes, industrial wastes, and similar materials, in association with household wastes, also should not be permitted. Nevertheless, it is important to keep in mind that despite all precautions, some pathogens and chemical residues inevitably will be present in the waste.

C. Importance of a sound solid waste management program

In an attempt to accelerate the pace of its industrial development, an economically developing nation may fail to pay adequate attention to solid waste management. Such a failure incurs a severe penalty at a later time in the form of resources needlessly lost and a staggering adverse impact on the environment and on public health and safety. The penalty is neither avoided nor lessened by a resolve to do something about the waste at a later time, when the country may be in a better position to take appropriate measures. This is true because, as is indicated by the data in Table I-1, the rate of waste generation generally increases in direct proportion to that of a nation's advance in development. Nor is the penalty lessened by the faulty rationalisation that advances in developmental status have higher priority than maintenance of a liveable environment. The greater the degradation of the environment, the greater is the effort required to restore its good quality. In summary, the effort to preserve or enhance environmental quality should at least be commensurate with that afforded to the attainment of advance in development.

C1. ENVIRONMENTAL and health impacts

The organic fraction of MSW is an important component, not only because it constitutes a sizable fraction of the solid waste stream in a developing country, but also because of its potentially adverse impact upon public health and environmental quality. A major adverse impact is its attraction of rodents and vector insects for which it provides food and shelter. Impact on environmental quality takes the form of foul odours and unsightliness. These impacts are not confined merely to the disposal site. On the contrary, they pervade the area surrounding the site and wherever the wastes are generated, spread, or accumulated.

Unless an organic waste is appropriately managed, its adverse impact will continue until it has fully decomposed or otherwise stabilised. Uncontrolled or poorly managed intermediate decomposition products can contaminate air, water, and soil resources.

C2. EPIDEMIOLOGICAL studies

Studies have shown that a high percentage of workers who handle refuse, and of individuals who live near or on disposal sites, are infected with gastrointestinal parasites, worms, and related organisms [8]. Contamination of this kind is likely at all points where waste is handled.

Although it is certain that vector insects and rodents can transmit various pathogenic agents (amoebic and bacillary dysenteries, typhoid fever, salmonellosis, various parasitoses, cholera, yellow fever, plague, and others), it often is difficult to trace the effects of such transmission to a specific population.

Due to the implementation of modern solid waste management practices, both the public health and the quality of the environment are benefited directly and substantially.

A modern solid waste management program can be implemented for a reasonable cost. This is an important fact because there are ample known situations where solid waste management costs in developing countries are high and the level of service low. But, if the underlying reasons for these situations are analysed, then one can see in many cases that cost-effective waste management systems would result if the identified deficiencies in the systems were remedied.

For example, in some developing countries, municipalities spend a disproportionate amount of financial resources on certain solid waste services, in particular waste collection and sweeping. In the past, a common approach to curing poor service provision was to simply expend more capital (e.g., the acquisition of additional equipment, design and construction of facilities, etc.) without also addressing and remedying inefficiencies inherent in the system. Unfortunately, high capital investment in the solid waste management sector in many developing countries does not necessarily lead to improvements in the quality of service. On the other hand, substantial improvements can be achieved in many cases by making low-cost, or sometimes no-cost, modifications in the existing system, with the focus being on increasing system efficiencies. Examples of such improvements are the efficient design of collection routes, modifications in the collection vehicles, reductions in equipment downtime, and public education, (e.g., education and communication leading to the production of less waste and the reduction of litter).

D. Recovery and utilisation of resources

For several reasons, resource recovery is a major element in solid waste management in developing nations. Reclaimable inorganic components (metals, glass, plastic, textiles, and others) traditionally have been recovered mostly by way of unregulated manual scavenging by private individuals (typically known as the "informal" sector). In recent years, the trend is to formalise and mechanise scavenging through the establishment of material recovery facilities (MRFs) [6]. Reuse and recovery of the inorganic components of the waste stream is an important aspect of waste management.

Special attention is given to organic (biodegradable) residues since, in the majority of developing countries, these residues constitute at least 50% of the waste (by weight). The resource recovery aspect regarding the organic component is threefold:

1. The component can be used in agriculture as a soil amendment through composting.

2. Its energy content can be recovered either biologically or thermally. Biological energy recovery is by way of methane production through anaerobic digestion. Thermal recovery is by way of combustion to produce heat.

3. The organic content can be hydrolysed either chemically or enzymatically to produce a sugar. The sugar can be used as a substrate for ethanol fermentation or for single-cell protein production.

Of the three applications, use in agriculture is the most practical. Although dating back many years, methane production ("biogasification") has only recently begun to receive serious attention as a potential alternative source of energy. Many hurdles, primarily economic in nature, must be surmounted before either single-celled protein production or ethanol fermentation become a practical reality.

An accurate knowledge of the quantity and composition of the waste input is essential to the success of a resource recovery undertaking. The composition and constancy of the amount of the input must be assured. Obviously, it would be sheer foolishness to attempt an operation of any practical size without having an assured supply of raw material. Not only must the constancy of the supply be assured, it must always be available at a reasonable cost. Additional requirements are adequate economic and qualified human resources.

As far as economically developing nations are concerned, with rare exception, adequate economic resources would preclude processes such as hydrolysis and perhaps large-scale anaerobic digestion in a reactor. These processes depend upon relatively expensive sophisticated equipment. On the other hand, composting can range from the composting carried out by individual homeowners to that undertaken by municipalities. Equipment for composting need not be sophisticated.

Last but not least, the availability, size, and continuity of a market or some form of demand for the reclaimed resource must be determined, lest recycling become merely a prelude to landfilling.

E. Scope and organisation of the book

The book is organised into two volumes. In Volume I, it is further divided into four parts, four appendices, and a bibliography and glossary. The contents of each of the four parts are summarised below:

- Part I deals with the principles of solid waste management. Including the Introduction, it consists of five chapters that collectively cover framework for management of solid waste, waste quantity and characteristics, storage and collection, and street cleaning.

- Part II deals with processing and treatment. The eight chapters include recycling, agricultural utilisation of the organic components, and biological and thermal recovery of energy. Composting is explored in detail.

- Part III is concerned with final disposal. Its single chapter covers sanitary landfilling.

- Part IV consists of four chapters and deals with non-technological matters: regulatory and economic instruments, financial aspects, policy alternatives, and management information systems (MIS).

The appendices of the publication include supporting and additional information related to public health, compost characteristics, performance indicators, and costs of solid waste management technologies.

Volume II describes solid waste management in several geographical regions around the world, and provides contact information for each region. *Volume II is included on a CD in the inside cover of Volume I.*

Thus, the publication covers the principal elements of solid waste management planning and implementation that would be appropriate for developing nations. Both non-technical and technical issues are discussed in detail since the planning and implementation of solid waste management systems necessarily involves an understanding of both sets of issues. Since the waste stream in developing countries is largely organic in nature, use of organic waste in agriculture and composting receive considerable attention.

The primary emphasis of this book is on the management of solid waste in an urban setting. The urban setting may be a small municipality, any intermediate size community, or a large metropolitan area. In some cases, technological aspects could be extrapolated to rural settings.

The publication is directed toward individuals who are responsible for solid waste management or have a significant role in it. The intent is to acquaint such individuals with available options and to supply background information needed to arrive at decisions that are in keeping with the country's cultural, economic, and technological conditions. Consequently, the information is geared more toward decision-making than to detailed engineering design of specific facilities at particular places. Detailed engineering design demands input by competent professionals specifically well versed in solid waste management and in sympathy with the special needs of the community seeking their professional aid. This is particularly true when the scale of a project exceeds a few tons of waste per day. Although detailed engineering design is not the focus of this publication, for many of the technical subjects covered in the publication, fundamental scientific and engineering principles are described. Consequently, the reader is exposed to the basic relationships between performance and operating conditions and can use the basic principles to analyse solid waste management systems based on a particular set of circumstances.

As the Introduction comes to a close, the authors would like to emphasise that the management of solid wastes is a difficult problem that need not be made more difficult by unnecessarily using complex (high)-technology. The avoidance of unnecessary high technology is critical to successful solid waste management in the low technology economies of developing nations. Importation of complex equipment and technology should be kept to a minimum. Too frequently, a technology that may be considered low technology and readily applicable in one country may be too sophisticated and otherwise unacceptable in the country doing the importing. This statement applies not only to methods of disposal but also to the collection of wastes and even to the devices for storing them.

F. References

1. Nath, K.J., "Solid Waste Management in the Present Indian Perspective", proceedings of ISWA 1993 Annual Conference, Jönköping, Sweden, September 1993.

2. Diaz, L.F. and C.G. Golueke, "Solid Waste Management in Developing Countries", *BioCycle*, 26:46-52, September 1985.

3. Japan International Cooperation Agency, *Master Plan and Feasibility Study on Seoul Municipal Solid Waste Management System in the Republic of Korea*, Draft Final Report, Tokyo, Japan, 1985.

4. Scharff, C. and G. Vogel, "A Comparison of Collection Systems in European Cities", *Waste Management & Research*, 12(5), October 1994.

5. CalRecovery, Inc., *Criterio de Diseño - Planta de Selección y Recuperación de Subproductos de los Residuos Sólidos Municipales*, prepared for Mexico City, Mexico, December 1992.

6. CalRecovery, Inc., *Handbook of Solid Waste Properties*, Governmental Advisory Associates, Inc., New York, New York, USA, 1993.

7. Morwood, R., "Australian Waste Management - Towards 2000", *Proceedings of 32nd Annual International Solid Waste Exposition*, SWANA, San Antonio, Texas, USA, August 1994.

8. Cal Recovery Systems, Inc., Norconsult A.S., and Engineering-Science, *Metro Manila Solid Waste Management Study - Review of Existing Conditions*, May 1982.

CHAPTER II. FRAMEWORK FOR MANAGEMENT OF SOLID WASTE

A. Integrated waste management

This document is organised by waste management topics, which range from waste characteristics, to collection, to landfilling, and to public education and information management. Although these topics are discussed in detail later in the publication, some are also discussed generally in this chapter in the context of their relevance and application to supporting the basic framework for solid waste management. Specifically, this section discusses the relationships among the key topics covered in this book. Understanding these relationships is a key element in successfully achieving integrated waste management -- a single, overall approach to managing waste in a city, town, or region.

A1. ELEMENTS of a waste management system

A comprehensive municipal solid waste management (MSWM) system includes some or all of the following activities:

- setting policies;
- developing and enforcing regulations;
- planning and evaluating municipal MSWM activities by system designers, users, and other stakeholders;
- using waste characterisation studies to adjust systems to the types of waste generated;
- physically handling waste and recoverable materials, including separation, collection, composting, incineration, and landfilling;
- marketing recovered materials to brokers or to end-users for industrial, commercial, or small-scale manufacturing purposes;
- establishing training programs for MSWM workers;
- carrying out public information and education programs;
- identifying financial mechanisms and cost recovery systems;
- establishing prices for services, and creating incentives;
- managing public sector administrative and operations units; and
- incorporating private sector businesses, including informal sector collectors, processors, and entrepreneurs.

A2. WHAT is integrated waste management?

Integrated waste management is a frame of reference for designing and implementing new waste management systems and for analysing and optimising existing systems. Integrated waste management is based on the concept that all aspects of a waste management system (technical and non-technical) should be analysed together, since they are in fact interrelated and developments in one area frequently affect practices or activities in another area.

A3. IMPORTANCE of an integrated approach

An integrated approach is an important element of sound practice because:

- Certain problems can be more easily resolved in combination with other aspects of the waste system than on their own. Also, development of new or improved waste handling in one area can disrupt existing activities in another area unless changes are handled in a coordinated manner.

- Integration allows for capacity or resources to be optimised and, thus, fully utilised; there are frequently economies of scale for equipment or management infrastructure that can be reached only when all of the waste in a region is managed as part of a single system.

- An integrated approach allows for participation of public, private, and informal sector participants, in roles appropriate for each.

- Some waste management practices are more costly than others, and integrated approaches facilitate the identification and selection of low-cost solutions. Some waste management activities cannot bear any charges, some will always be net expenses, while others may produce an income. An integrated system can result in a range of practices that complement each other in this regard.

- Failure to have an integrated system may mean that the revenue-producing activities are “skimmed off” and treated as profitable, while activities related to maintaining public health and safety fail to secure adequate funding and are operated at low or insufficient levels.

A4. METHODS for integrating a waste system

Planners can work toward integrated systems in a number of ways. The first task is to consider all aspects of the formal part of the waste system within one framework and to produce a plan based on the objectives of the entire system. One of the foundations of the framework for modern, integrated solid waste management systems is the solid waste management hierarchy, which specifies the precedence that should be given to key waste management activities that affect waste generation, treatment, and disposal. The hierarchy is discussed in more detail in the following section.

Second, in terms of jurisdictional and staffing issues, is putting all waste-related functions under the same division or agency, which is an important means of achieving integration. A third way of facilitating coordination and assessing trade-offs among all aspects of a waste management system is to create integrated financial structures that, for example, use disposal fees to finance materials recovery or public education. More broadly, it is important to assess all MSWM system costs, as well as identify opportunities for generating revenues.

A5. WASTE management hierarchy as a key element of integrated solid waste management

The waste management hierarchy is a widespread element of national and regional policy and is often considered the most fundamental basis of modern MSWM practice. The hierarchy ranks waste management operations according to their environmental or energy benefits. In virtually all countries, the hierarchy is similar to that shown in Table II-1, with the first entries having higher priority than those below them.

Table II-1. Solid waste management hierarchy

- Prevent the production of waste, or reduce the amount generated.
- Reduce the toxicity or negative impacts of the waste that is generated.
- Reuse in their current forms the materials recovered from the waste stream.
- Recycle, compost, or recover materials for use as direct or indirect inputs to new products.
- Recover energy by incineration, anaerobic digestion, or similar processes.
- Reduce the volume of waste prior to disposal.
- Dispose of residual solid waste in an environmentally sound manner, generally in landfills.

The purpose of the waste management hierarchy is to make waste management practices as environmentally sound as possible. The waste management hierarchy has been adopted in various forms by most industrialised countries. Its principal elements are also included in international conventions and protocols, particularly those dealing with the management of toxic or hazardous wastes, and in regional attempts to develop a coordinated policy on the reuse of various byproducts of waste management processes.

The hierarchy is a useful policy tool for conserving resources, for dealing with landfill shortages, for minimising air and water pollution, and for protecting public health and safety. In many developing countries, some aspects of this hierarchy are already in place, since traditional practices revolving around waste prevention, reuse, and recycling are prevalent.

At the same time, it should be recognised that all waste management practices have costs, as well as benefits. This means that the hierarchy cannot be followed rigidly since, in particular situations, the cost of a prescribed activity may exceed the benefits, when all financial, social, and environmental considerations are taken into account.

B. Stakeholders

Appropriate practice in waste management systems necessitates clear delineation of jurisdiction and responsibility, with all stakeholders participating in system design, and with those affected, at every level, aware of the lines of accountability.

Governments will generally have final jurisdiction and responsibility for overall policy and for management of the MSWM system, whether or not the government itself is performing the waste management functions. The following participants all have some important relation to waste management and, in some cases, significant levels of responsibility for policies or operations.

B1. RESIDENTIAL waste generators

Local residents' preferences for particular types of waste service, their willingness to source separate recyclable materials, their willingness to pay for the service, and their capacity to move waste to communal collection points all have an impact on the overall waste system. Incentives can affect residents' preferences and behaviour.

B2. BUSINESS waste generators

Businesses also produce waste, and the business sector can become a significant player in the waste management system, particularly, as is increasingly the case, when businesses must pay directly for their waste service. As with residents, incentives can play an important role in shaping behaviour.

B3. PUBLIC health and sanitation departments

The maintenance of public health and sanitation is an important public responsibility and, especially in developing and transition countries, is usually under the jurisdiction of the municipal public health department. In an integrated system, this department often has inspection and enforcement responsibilities, but is not directly involved in collection or disposal operations.

B4. PUBLIC works departments

These local government units most often have operational responsibility for waste collection, transfer, treatment, and final disposal. Frequently, however, the collection of recoverable materials or management of private contractors is the responsibility of a different department, often creating conflicting goals and activities that work against each other.

B5. NATURAL resource management agencies

These agencies often have responsibility at the local or regional level for activities relating to materials recovery or composting. This splits these activities away from waste management functions, resulting in poor integration. Sound practice most often means putting all of the functions under the same agency or department.

B6. NATIONAL or state/provincial environmental ministries

Overall, waste management policy generally is established at these levels. With respect to materials recovery policies, there is less policy-making at this level in developing countries. Sound practice includes not only setting policies, but putting programs in place to implement them and to establish integration consistent with the policies.

B7. MUNICIPAL governments

In most countries, city or town governments have overall responsibility for waste management operations -- ensuring that collection takes place and that the collected materials are delivered to processors, markets, or disposal facilities. Financing for vehicles, crews, and other equipment usually is provided by the municipal government, which is ultimately responsible for the entire process.

B8. REGIONAL governments

Regional bodies or large city governments often have responsibility for landfills, incinerators, composting facilities, or the like, particularly in countries where there is a shortage of disposal space at the local level. Regional governments in charge of these facilities generally have access to a stream of revenues from fees paid by waste collection companies for disposal.

B9. PRIVATE sector companies

Private sector companies tend to be involved in collection of waste, in street sweeping, in the recovery of materials, and, increasingly, in the construction and operation of landfills, incinerators, and compost plants, as concessionaires or contractors from the responsible government authority. Unlike governments, private companies do not have any direct responsibility for maintaining public sanitation or health, so their involvement is limited to functions in which they can make a profit. If there is no stream of revenue, it is not reasonable to expect private sector involvement.

The necessary revenue stream, however, can come from direct charges or allocations from government.

B10. INFORMAL sector workers and enterprises

In developing countries, but also to a significant extent in industrialised and transition countries, individual workers and unregistered, small enterprises recover materials from the waste stream, either by segregated or specialised collection, by buying recyclable materials, or by picking through waste. These workers and enterprises clean and/or upgrade and sell the recovered materials, either to an intermediate processor, a broker, or a manufacturer. Informal sector workers sometimes manufacture new items using the recovered materials, making, for example, gaskets and shoe soles out of discarded tires.

B11. NON-GOVERNMENTAL organisations

Non-governmental organisations (NGOs) are yet another set of participants in the waste management field. NGOs often have a mission of improving the environment or the quality of life for poor or marginalised groups; as part of this mission, they may stimulate small-scale enterprises and other projects. Since waste materials represent, in many cases, the only growing resource stream, these organisations frequently base their efforts on extraction of certain materials not currently being recovered and processing them to add value and produce revenue. In Latin America, a number of composting projects were started this way.

B12. COMMUNITY-BASED organisations

In a number of locations where there is insufficient collection or the neighbourhood is underserved, community-based organisations take an active role in waste management operations. These organisations, which are smaller in scale or local NGOs, may form primarily as self-help or self-reliance units, but they may, over time, evolve into service organisations that collect fees from their collection clients and from the sale of recovered materials. NGOs working with informal workers and community-based entrepreneurs often seek recognition for these organisations as part of the waste management system.

B13. POOR and residents of marginal and squatter areas

Waste service, much like other public services, frequently follows political power and clout, leaving the residents of poor and marginalised areas with inadequate service (or no service at all), dirty streets, and the continual accumulation of refuse and faecal matter on the streets and in other public areas. Very often, these people have the greatest need for improved or expanded waste service.

B14. WOMEN

Waste handling disproportionately touches the lives of women, particularly in some developing and transitioning countries. Women often collect the waste and set it out or move it to community transfer areas. Women are far more likely to be involved in materials recovery than in other comparable types of physical work. This is perhaps because they are in daily contact with the waste in their homes, and perhaps because women tend to be among the most marginalised groups of some societies.

C. Cost and cost recovery

Since proper waste collection and disposal are necessary to maintain the cleanliness and public health of a community, these services benefit both the generators and the community as a whole. In this context, proper waste collection includes both regular collection service and cleanup of wastes that generators have disposed in an unacceptable manner (i.e., litter).

Not all "waste" is considered to be waste by everyone, however. Scavengers and small-scale recyclers successfully extract value from other people's wastes. This process can potentially be managed so that the informal sector often involved in such activities complements ongoing institutionalised waste collection, rather than interfering with it. As discussed in this document, there are serious health and social problems associated with scavenging, but the point is that much "waste" actually has value to someone. Those who remove recoverable materials from the waste stream are reducing the waste disposal costs of the whole community. In industrialised countries, there is now an increasing awareness of the value of sorting out the reusable and recyclable components of the solid waste stream.

In the end, though, some quantities of waste must be collected and disposed, and this service must be paid for in some manner. Additionally and depending on local circumstances, other waste management services may require funding in some form, including public education and processing of waste for recovery and reuse of recyclable materials.

C1. FEES and charges

Until recently, in most countries, especially developing countries, countries in transition, and European social democracies, the management of waste has been considered to be the responsibility of government, financed by general revenues. In recent years, partly as a result of austerity and structural adjustment policies and pressures from multilateral financial institutions, and partly as a result of pressures to limit taxes, governments have increasingly focused on identifying specific revenue sources for waste management. This has led to a series of innovations relating to fees and charges for waste collection and disposal.

C1.1. Charging directly for waste service

One approach to the financing of waste systems is to obtain payment from those who benefit from the service. On the simplest level, waste generators benefit from collection service, and there have been some attempts, particularly in North America, to get households to pay directly for their own waste removal on the basis of how much waste they are setting out. The system of unit fees for waste removal works well and represents sound practice when individuals want to get rid of their waste and can afford the fees. It works poorly when people are too poor to pay fees, when the fees are simply too high, or when there are ready alternatives and no controls for disposing of wastes, such as by throwing them into the countryside.

Fees can be used to finance waste collection or other aspects of the waste system. Fees can also be used as incentives to generators to create less waste.

C1.2. Indirect charges

In some locations, charges for waste are linked to other public services that people are willing to pay for, such as water or electricity. Including waste charges in water and (if present) sewer charges allows some cost recovery; studies have shown that water and electrical energy consumption are rough indicators of waste generation.

C1.3. Incentives and penalties

Charges and fees can also be used as incentives to encourage “good behaviour” and to discourage “bad behaviour”. For example, the price of disposal can be increased and the cost of materials recovery subsidised to give people incentives to source separate. In some instances, fines can be used to discourage illegal dumping.

C2. STRUCTURING financing for waste management systems

Sound practice in financing waste management systems usually entails differing treatment of fixed costs and variable costs. Fixed costs, which establish waste or materials collection, processing, or disposal capacity, may be paid from general tax revenues. The rationale for this is that there are benefits to all members of society for having the overall solid waste management system in place. Once societies reach a certain level of sophistication, they may be able to recover a certain portion of fixed costs from commercialised collection, processing, and disposal operations, and not rely solely on general tax revenues to fund these activities.

Variable costs can appropriately be paid from direct or indirect fees, thereby being linked to the activities giving rise to the costs in the first place.

One key to developing sound cost recovery systems is tracking all costs accurately. A surprising number of municipal governments do not actually know the total costs of collection or disposal, so they have no basis on which to set or defend fees. Establishing well functioning, transparent, full-cost accounting systems should be a high priority wherever they do not yet exist.

C3. STRATEGIES for cost containment and enhanced efficiency

This section discusses some examples of practices that can result in improved financial management and cost recovery.

C3.1. Privatisation

Pressures on government to reduce taxes, while increasing and improving levels of service, are leading to an exploration of privatisation as an option for waste management functions. Privatisation can take various forms. A government can award a contract to a private firm for specified MSWM services; it can contract with a private firm to construct a waste management facility, which the firm may subsequently own or operate; it can license a private firm to carry out MSWM activities and recover its costs directly from those served; or it can allow qualified firms to participate in open competition.

Certain functions in municipal solid waste lend themselves well to being privatised, while in other cases sound practice will almost always involve government control and operation.

Privatisation tends to work well in the following areas:

- collection of waste or recyclables -- payment to the private contractor is based either on total waste collected or on number of households in the service area;
- construction of waste facilities;
- operation of transfer stations, compost facilities, incinerators, or landfills under contract to a public-sector entity;

- development of private waste facilities, once the price for landfilling has risen to a level where other strategies become cost competitive; and

- in circumstances where there is sufficient government infrastructure to manage a competitive bidding process, to contract with the private firm, to monitor its work, and to hold the private firm accountable for adequate performance of tasks.

Privatisation does not usually work well:

- in small or sparsely populated areas, since there usually is insufficient earning potential due to low waste volumes;

- when the government entity with jurisdiction is too small or too politically weak to be able to manage the contracting processes effectively;

- when badly designed; for example, if there is little no monitoring and enforcement of contract terms; or

- as a substitute for government responsibility, such as if a private firm were to be hired to monitor compliance with environmental regulations by other private firms.

C3.1.1. Importance of competition in privatisation

A key issue in privatisation of municipal solid waste management is the role and management of competition. This is particularly important in developing countries, where the private sector, both informal and formal, may not be sufficiently mature to offer effective competition.

Competition may improve a privatised waste function. Competition promotes good performance by private contractors, since their desire to maintain a contract is a powerful incentive for performing well. Competition is healthy:

- at the time of bidding or contract negotiation;

- to ensure that the full range of services is available;

- when it is well managed through contracting, granting of concessions, or franchising; and

- to prevent formation of monopolies.

At the same time, there are limits to the effective use of competition in solid waste management. One such limit is in the collection of wastes from households -- "unbridled" competition, though avoiding monopoly, can drive up prices because of the high costs of numerous low-volume operators. In such instances, using a competitive process to select a single operator for a period of time may be a better alternative.

It is, of course, advisable to introduce new approaches with care so that they do not unwittingly kill off marginal, informal sector activities best viewed as complements to the formal waste management system.

C3.2. Support for small-scale enterprises

Recognition of and support for small-scale and informal sector waste-related enterprises is a significant element of sound practice, especially in developing countries, and to a lesser extent in transition and industrialised countries as well. These businesses usually remove materials from the waste stream, at low cost, saving the government money. Disruption of their operations can increase the burden on public works and sanitation budgets significantly.

In recent years, a number of projects have attempted to gain official recognition for these enterprises, to institutionalise their market niche, and to shelter their operations from disruption during waste system upgrading and modernisation. This has been done by:

- awarding or arranging contracts between informal sector enterprises and the city or formal private sector collection companies;
- organising cooperatives;
- providing equipment, supplies, clothing, gloves, and shoes, or even vehicles, to improve working conditions; and
- designing new waste facilities to include rather than exclude these operations.

Taking these and other steps to support small and informal enterprises generally improves efficiency and cost effectiveness while supporting subsistence activities and an important economic niche.

D. Other important issues and strategies

D1. UNDERSTANDING characteristics of waste generated

An important element in improving waste management systems is the need to attune chosen technologies to the character of the waste that is generated in a particular location. If wastes are wet and dense, as they are in most developing countries, buying compactor trucks will often be a waste of money. If wastes have low calorific value, it will not be possible to incinerate them without using supplementary fuel. If considerable amounts of toxic waste have entered the general municipal solid waste (MSW) stream, leachate from dumps will be particularly dangerous. On the other hand, if a portion of the waste stream consists of organics or can be easily separated into organics and non-organics, composting may become a viable waste management strategy.

D2. MAJOR differences between industrialised and developing countries

One theme that appears consistently throughout this book is the enormously different conditions in which industrialised and developing countries must work to solve MSWM problems. Developing countries often have:

- low labour costs and extreme shortages of capital, which together call for low-tech solutions to MSWM problems;
- a waste stream dominated by organic waste, which means that: a) incineration is difficult unless undertaken in conjunction with a program that achieves source separation of organics, and b) composting is especially important if large amounts of waste are to be diverted from landfills;
- a complex informal sector that is very active in the collection, separation, and recycling of waste;

- significant mixing of industrial hazardous wastes with MSW;
- few people who are adequately trained in solid waste management activities, and a high proportion of the urban population with low levels of education; and
- inadequate physical infrastructure in urban areas, which makes collection of waste particularly difficult.

At the same time, it should be recognised that there are also similarities between industrialised and developing countries with regard to MSWM issues. In neither case does the public want MSWM facilities near residential areas and, in both cases, the amount of waste being generated is increasing. In both industrialised and developing countries, adopting an integrated approach to waste management is important. Related to this, people throughout the world are recognising the importance of waste reduction as the first stage of the waste management hierarchy and as an essential element of MSWM. Methods of waste reduction are described in more detail in the last part of this chapter.

D3. IMPROVING management capabilities

In many instances, particularly in developing countries, the greatest impediments to efficient and environmentally sound handling of MSWM issues are managerial, rather than technical. Improving the operational and management capabilities of individuals and institutions involved in MSWM at the local level is therefore extremely important. For this reason, this book considers these issues in two of the topics addressed: management and planning, and training.

Even with new efforts to make funds available for MSWM activities, it is certain that funds will at least appear to be insufficient for the foreseeable future. Managers must therefore be attuned to every opportunity to use their resources more efficiently.

D4. PUBLIC involvement

The public can play a role in promoting efficient, financially sound, technically competent management of waste issues by demanding accountability from the MSWM system. Although in many countries the public has long grown accustomed to having low expectations of government, the pressing and very visible problems brought about by the absence of effective MSWM systems may inspire stronger demands for good performance from public managers and any private companies with whom they work.

Public education is important in achieving the goal of public involvement. This book includes a section on public education for each of the regions.

D5. SPECIAL wastes

Special wastes are those types of solid waste that require special handling, treatment, and/or disposal. The reasons for separate consideration include: 1) their characteristics and quantities (either or both may render them difficult to manage if they are combined with “typical” municipal solid waste); or 2) their presence will or may pose a significant danger to the health and safety of workers and/or the public, to the environment, or both.

Some examples of special types of wastes are given in Table II-2. These wastes are very different from each other, so they should be managed and handled separately if feasible. Typically, in developing countries, special wastes are set out for collection, collected, and/or disposed along with wastes from commercial businesses and residential generators. Ideally, these wastes should not enter the municipal solid waste stream, but quite frequently they do, particularly in developing countries.

Table II-2. Examples of types of special wastes

- Pathological or infectious medical waste from hospitals, clinics, and laboratories
- "Hazardous" waste in the household waste stream (e.g., oil-based paints, paint thinners, wood preservatives, pesticides, household cleaners, used motor oil, antifreeze, batteries)
- Discarded tires
- Used oils
- Electronic waste (e-waste)
- Wet batteries
- Construction and demolition debris
- Municipal wastewater treatment (sewage) sludge, septage, and slaughterhouse wastes
- Industrial hazardous waste, and some types of industrial solid waste (e.g., metal cuttings from metal processors or cannery waste)

Special wastes can cause significant health and environmental impacts when managed inadequately. Persons that may come into direct contact with the wastes, such as waste collectors and scavengers, may be subject to significant health and safety risks when exposed to some types of special wastes, e.g., industrial hazardous waste. Toxic components of these wastes can enter the environment, for example, poisoning surface and groundwater bodies. Hazardous wastes can also degrade MSW equipment used to manage solid waste (e.g., collection vehicles), or the performance of the equipment.

Special wastes are discussed in this document because of the potential negative effect that they can have on the MSWM system. Still, it is important to point out that this section only superficially reviews the topic of special wastes. If the reader is involved in any part of the management process for special wastes, further additional reference materials and training are extremely important.

Proper management of special wastes is quite difficult in most developing countries, particularly in those countries where regular MSW is not managed adequately. Three issues are usually always relevant: 1) the party or organisation responsible for managing special wastes is seldom clearly identified and the necessary entity may not even be in existence; 2) available resources to manage solid waste are scant and priorities have to be set; and 3) the technology and trained personnel needed to manage special wastes are seldom available.

In the absence of countervailing reasons, the development of sound practices in the management of special wastes should follow the integrated waste management hierarchy applied in other areas of MSWM, i.e., waste reduction, minimisation, resource recovery, recycling, treatment (including incineration), and final disposal. As with the management of other types of MSW, the proper application and programmatic emphasis of this hierarchy to special wastes depends on local circumstances (e.g., available technologies, waste quantities and properties, and available human and financial resources).

Effective management of special wastes begins with an assessment of their potential impacts on human health and safety and on the environment. The environmental benefits of properly handling hazardous wastes can be very large, since in some cases small quantities of hazardous wastes can cause significant damage. However, even though all hazardous wastes present some risks, the quantities are not always sufficient to warrant separate collection and disposal. As points of reference, Organization for Economic Co-operation and Development (OECD) guidelines and US environmental regulations specify minimum quantities of material that need special treatment as “hazardous waste”. Obviously, specific decisions regarding the management of special wastes will necessarily depend on the capabilities of individual countries to carry out such programs.

A number of alternatives for handling of special wastes have been or are in the process of being devised in response to the various needs of developing and industrialised countries. These practices are summarised in this section for the most frequently encountered special wastes.

D5.1. Medical waste

Medical waste is one of the most problematic types of wastes for a municipality or a solid waste authority. When such wastes enter the MSW stream, pathogens in the wastes pose a great hazard to the environment and to those who come in contact with the wastes.

Wastes generated within health care facilities have three main components: 1) common (general) wastes (for example, administrative office waste, garden waste and kitchen waste); 2) pathogenic or infectious wastes (these types also include “sharps”); and 3) hazardous wastes (mainly those originating in the laboratories containing toxic substances). The quantity of the first type of general wastes tends to be much larger than that for the second and third types.

Segregation of medical waste types is recommended as a basic waste management practice, as indicated in Table II-3. However, thorough separation is possible only when there is significant management commitment, in-depth and continuous training of personnel, and permanent supervision to ensure that the prescribed practices are being followed. Otherwise, there is always a risk that infectious and hazardous materials will enter the general MSW stream.

Table II-3. Recommended methods for managing medical waste

Source separation within the health care facility	• Isolates infectious and hazardous wastes from non-infectious and non-hazardous ones, through colour coding of bags or containers • Source separates and recycles the relatively large quantities of non-infectious cardboard, paper, plastic, and metal • Source separates compostable food and grounds the major fraction of organic wastes and directs them to a composting facility if available • Includes and is characterised by thorough management monitoring program
Take-back systems	• Where vendors or manufacturers take back unused or out-of-date medications for controlled disposal
Tight inventory control over medications	• To avoid wastage due to expiration dates (a form of waste reduction)
Piggy-back systems for nursing homes, clinics, and doctors' offices	• Can send respective wastes for treatment to proper health care waste treatment facilities using health care waste collection and transport systems located in the vicinity
Treatment of infectious waste through incineration, or by disinfection	• Includes autoclaving, chemical reaction, microwaves, and irradiation • In the case of incineration, the processing may be performed within the premises of the health care facility (onsite) or in a centralised facility (offsite). An incinerator is difficult and expensive to maintain, so it should be installed in a health care facility only when the facility has sufficient resources to properly manage the unit. Otherwise, a centralised incinerator that provides services to health care facilities in one region or city may be more appropriate. Regardless of location, the incinerator must be equipped with the proper air pollution control devices and operated and maintained properly, and the ash must be disposed in a secure disposal site. In the case of disinfection, residues from these processes should still be treated as special wastes, unless a detailed bacteriological analysis is carried out.
Proper disposal of hospital wastes	• In many developing countries, none of the treatment systems discussed in this table are widely available, so final disposal of infectious and hazardous components of the wastes is necessary. Since in many developing countries there are no landfills specifically designed to receive special wastes, infectious and hazardous health care wastes normally are disposed at the local MSW landfill or dump. In this case, close supervision of the disposal process is critical in order to avoid exposure of scavengers to the waste. Final disposal should preferably be conducted in a cell or an area specially designated for that purpose. The health care waste should be covered with a layer of lime and at least 50 cm of soil. When no other alternative is available for final disposal, health care wastes may be disposed jointly with regular MSW waste. In this case, however, the health care wastes should be covered immediately by a 1 m thickness of ordinary MSW and always be placed more than 2 m from the edge of the deposited waste.

D5.2. Household hazardous waste

Households generate small quantities of hazardous wastes such as oil-based paints, paint thinners, wood preservatives, pesticides, insecticides, household cleaners, used motor oil, antifreeze, and batteries. Examples of such wastes are shown in Figure II-1. It has been estimated that household hazardous waste in industrialised countries such as the United States accounts for a total of about 0.5% (by weight) of all waste generated at home [1]. In most developing countries, the percentage probably is even lower.

Courtesy: CalRecovery, Inc.

Figure II-1. Examples of household hazardous wastes

There are no specific, cost-effective, sound practices that can be recommended for the management of household hazardous wastes in developing countries. Rather, since concentrated hazardous wastes tend to create more of a hazard, it is best to dispose of household hazardous wastes jointly with the MSW stream in a landfill, where the biological processes tend to exert a fixating effect on small amounts of toxic metals, while other toxic substances are diluted by the presence of MSW or are broken down into less toxic intermediates during the process of decomposition in the fill.

When resources are available (typically in industrialised countries), appropriate methods and necessary conditions for separation of household hazardous wastes from the rest of the MSW stream include those given in Table II-4.

D5.3. Used tires

The management of used tires poses a potential problem for even the more modern MSWM systems, for reasons related both to the tires' physical properties and their shape. Tires are composed primarily of complex natural and synthetic rubber compounds, both of which have substantial heating value, and various other materials. The recovery of rubber from used tires can be very energy-intensive, and such processing may generate hazardous substances and other types of process residues. Illegal stockpiles of used tires can create substantial land use problems, harm the environment, and serve as breeding grounds for insects and other small animals that harbour pathogens that are detrimental to human health. Stockpiles can self-ignite and cause fires that are very difficult to control, resulting in negative human health and environmental impacts.

Table II-4. Methods and conditions for promoting the separation of household hazardous wastes (HHW) in industrialised countries

- The priority waste streams for separation are identified with reference to the damage that they may cause when released into the environment, and with reference to the type of disposal that would be available if the waste were not separated. For example, the separate collection of mercury-based batteries might be a priority if the primary means of waste disposal was incineration, a process ill suited to ease of control of mercury emissions.
- Frequent public education and convenient collection service are required for successful HHW source-separation programs.
- Notification at the point of purchase, or on the packaging, that certain consumer items contain dangerous or hazardous materials necessitating special handling and disposal practices.
- Utilisation of point-of-purchase take-back systems for those items that can be collected using such systems, such as used batteries, discarded medicines, and used oil.
- Emphasis placed at the policy and program levels on redesigning consumer products to make them less dangerous or hazardous (such as reducing or eliminating the mercury content in batteries).
- Personnel handling HHW must receive initial and subsequent training, but do not necessarily have to be licensed or trained chemical technicians.

When whole tires are disposed in a landfill, they often rise to the top and make it difficult to maintain the soil cover over the wastes. When dumped illegally, tires can become breeding grounds for mosquitoes and other forms of life that can spread disease, such as dengue. Some appropriate methods of managing used tires are described in Table II-5. The informal sector oftentimes serves as a means to reuse or recycle used tires.

D5.4. Used oil

Used oils are generated primarily in gas stations and in mechanics' shops. These oils generally are discharged in the most convenient location and frequently enter the sewage system, causing problems in the treatment plants or in the receiving bodies of water. When oil is collected haphazardly as part of the MSW stream, it causes problems at the landfill and often becomes part of the landfill leachate. Some recommended methods of managing used oils are described in Table II-6.

Table II-5. Appropriate methods for managing used tires

• **Reuse** through retreading for extended service; shredding and grinding for use in road paving material; and cutting them up for use as padding in playgrounds and buffers on railway tracks. It should be noted that processing of tire materials must be conducted under controlled conditions, as it generates dust and buffings, which may be carcinogenic to workers and are potentially dangerous when released. • **Thermal destruction in cement kilns** with subsequent energy recovery. This process requires cement kilns, adapted to receive solid fuels. This form of final disposal of tires has been shown to be practical in both industrialised and developing countries. • **Processing in pyrolytic reactors.** Emissions control systems are critical as organic vapours are generated. As a result, the process can be relatively expensive and will usually become cost effective only when the accumulation of tires becomes a hazard due to potential fires or expensive due to conflicting land use.

Table II-6. Some methods of managing used oil

• **Re-refining into lubricating oil.** Processing used oil for reuse as a lubricating agent is a good method of managing used oil. However, one potential hazard associated with such processing is that the residues from re-refining may be deposited in the MSW stream or in drains. Education must utilised to explain the problems caused by this casual, improper method of disposal. Ideally, residues should be burned in a cement kiln equipped with the proper type of pollution control systems. When this is not possible, residues should be placed in sealed containers and placed in a special area at the landfill disposal site. • **Use as a fuel.** Used oil has considerable value as a fuel due it its high specific energy content. However, combustion of used oil can result in emissions of heavy metals into the environment if the combustion system lacks suitable environmental control equipment. When used oil is serves as a cement kiln fuel, an added measure of pollution control is achieved by virtue of the fact that the heavy metals present in the oil are absorbed into the cement matrix.

D5.5. Electronic waste (e-waste)

During the last few years, there has been a substantial reduction in the cost and a commensurate increase in the availability and usage of a variety of electronic products. Although the list of relatively new products is long, some of the most common products include personal computers, printers, monitors, television sets, and cellular telephones. As the usage of these and similar products increases, a large number of them are replaced and disposed each year. Improper treatment and unsafe final disposition of these materials has resulted in several problems, which have far reaching implications. One key problem is that related to the fact that most electronic products contain several types of hazardous materials, such as mercury, arsenic, lead, cadmium, and others. If the electronic products are improperly treated or discarded along with the general municipal solid waste, the hazardous materials in the products can be released and result in negative impacts to the public health and to the environment.

One practical solution to the management of e-waste involves the implementation of segregated collection and adequate processing. Current methods for the treatment of e-products include mechanical and chemical processing of the products for the recovery of valuable materials and the removal and/or reduction of the toxicity of the residue.

D5.6. Wet batteries

Used wet batteries are typically generated by car maintenance facilities and vehicle battery suppliers. This type of battery contains acid and lead, both of which are hazardous to humans and to the environment if not properly managed. Environmentally acceptable processing of wet batteries for materials recovery requires trained and experienced facility personnel. Recycling of batteries typically involves draining and neutralisation of the acidic liquid**,** and recovery of the lead in a non-ferrous foundry.

D5.7. Construction and demolition debris

Construction and demolition (C&D) debris are generated regularly in urban areas as a result of new construction, demolition of old structures and roadways, and regular maintenance of buildings. These wastes contain cement, bricks, asphalt, wood, metals, and other construction materials that are typically inert. In many cases, the biological inertness of C&D debris means that it can be disposed in landfills with lesser restrictions than those required for MSW, which has substantially higher biodegradable content and potential for polluting the environment. However, it must be pointed out that C&D debris may contain some hazardous materials, such as asbestos and PCBs, although this circumstance is most probable in the case of industrialised countries. Very large volumes of demolition waste are generated during natural disasters (earthquakes, floods, typhoons, and others) and during wars.

City authorities need to protect against disposal of these wastes in the streets and on vacant lands, since these locations can become illegal, uncontrolled dumps with their attendant negative consequences. On the other hand, disposal of C&D debris in MSW landfills can be costly and a poor use of landfill capacity. Thus, other alternatives to disposal of C&D may be warranted and should be considered in any event. Processing and recycling, as shown in Figure II-2, are alternatives.

Courtesy: CalRecovery, Inc.

Figure II-2. Storage of construction and demolition debris at a processing facility

Sound practices for the management of C&D wastes are based on the concept of prevention, reuse, and recycling of waste. When these practices cannot be implemented, proper disposal must be considered. Since these wastes are primarily inert or they can be processed to be so in some cases, they can be used for fill, for example in former quarries, as road base, or in coastal cities, to gain land at the ocean front or for the construction of levees. Some sound practices for diverting C&D debris from landfill disposal are described in Table II-7.

Special landfill sites for the final disposition of construction and demolition landfill sites are also an option. Siting of these landfills is less difficult than for regular MSW landfills since the potential environmental impact in the majority of cases is relatively small.

Table II-7. Sound practices for diverting construction and demolition debris from landfill disposal

- Waste prevention can be promoted through **inventory control and return allowances for construction material.** This ensures that unused materials will not get disposed of unnecessarily.
- **Selective demolition.** This practice involves dismantling, often for recovery, of selected parts of buildings and roadways before the main demolition (wrecking) process is initiated.
- **Onsite separation systems,** using multiple smaller containers at a construction or demolition site to store sorted recyclable materials, as opposed to gross disposal of mixed materials in using a single roll-off or compactor.
- **Crushing, milling, grinding, and reuse of secondary stone, asphalt, and concrete materials.** These materials can be processed to conform to a number of standards for construction materials. Recovery and reuse of these types of materials is facilitated by the existence of approved specifications for road construction materials and by governmental procurement policies that promote or stimulate purchase of recyclable materials.

D5.8. Bulky metallic waste

Bulky metallic waste is composed of metallic objects that occupy large volumes (e.g., greater than 1 or 2 m^3) and are composed of high-density material, either when encountered singularly or in combination. Examples of bulky metallic waste are old vehicle bodies, structural steel, large metallic appliances, and discarded fabricating equipment. The most prevalent material of construction for bulky metallic waste is steel, although other types, such as aluminium, are also encountered to a lesser extent. This type of waste is considered a special waste because it is difficult to handle, process, and dispose using the more common and conventional municipal solid waste management equipment. Special, large-capacity equipment is normally required to collect, process, and dispose of bulky metallic waste. Also, much of bulky metallic waste is potentially recyclable. However, the feasibility of recycling is a function of the costs of processing, availability of markets, transportation costs, etc. An example of bulky metallic waste is given in Figure II-3.

Management of bulky metallic waste is a particularly difficult problem for rural and isolated communities (e.g., remote islands) because of limited space for storage and/or disposal, limited financial resources, and long distances to recycling markets.

D5.9. Municipal wastewater treatment (sewage) sludge, septage, and slaughterhouse wastes

Municipal wastewater treatment (MWWT) sewage sludge (biosolids) is generated as a consequence of processing municipal wastewater for safe discharge to the environment. The sludge is composed of the semi-solid or solid residues remaining after processing of wastewater. Septage, on the other hand, is the material pumped from septic tanks serving residences. Both MWWT sludges and septage contain large quantities of pathogenic organisms, and they often contain chemical contaminants, as well, if liquid discharges at the source are not pre-treated before disposal into the sewer. These materials, therefore, require proper treatment and disposal.

Courtesy: CalRecovery, Inc.

Figure II-3. Bulky metallic waste being loaded for transport to market

Slaughterhouse wastes can be used to produce ingredients in the manufacture of soil amendment, animal feed, and glues. The traditional methods of sun-drying, breaking up bones manually, composting in pits (sometimes with the addition of household organics), and steam digestion carry various types of health risks, and cannot be considered acceptable practices.

Small-scale aerobic composting of animal wastes, including manures, hide scrapings, and tannery and slaughterhouse wastes, can also produce a soil amendment, but carries some risks in terms of spreading pathogens if the wastes are not properly sterilised. All of these activities generate leachate and the associated unpleasant odours, and are typically associated with poor working conditions and risks to worker health, but may be profitable and provide subsistence income. Appropriate methods of management of these types of materials could involve introducing technical and health improvements, rather than entirely eliminating the activities themselves. Other appropriate methods of management are described in Table II-8.

D5.10. Industrial waste

The collection of industrial waste typically is not under the jurisdiction of municipal authorities in industrialised countries. However, in developing countries, where proper industrial waste management systems are not in place, such waste often enters the MSW municipal solid waste stream.

Waste generated from industrial sources can have non-hazardous and hazardous components, with non-hazardous waste usually representing the greater part of the volume. The hazardous component of this waste, while generally being relatively small in volume, can pose significant environmental and public health problems.

Table II-8. Practices for reducing and handling sewage sludge and septage

- **Preventing the generation of large volumes of sludge,** through separation of sewers and storm drainage systems.
- **Minimisation of reliance on centralised sewage systems,** through the installation of onsite treatment of human waste and household wash water, when feasible.
- **Land application,** but only when very frequent sludge testing shows that metal, salt, nitrogen, etc. contents are within tolerable limits, and when the administering authority has the resources and commitment to maintain high standards for monitoring and testing. In practice, this will mean that in many situations the safety of land application is questionable as a viable and appropriate method of management.
- **Treatment such as drying, liming, composting,** or co-composting with yard waste or organics, followed by land application. These methods are designed to return the organic matter in the waste to the land. As indicated above, however, certain constituents of the sludge can make land application inadvisable.
- **De-watering and disposing in landfills.** It is important to note that sludges should be de-watered as much as practical before entering a landfill in order to avoid the production of large volumes of leachate.

Appropriate methods for the proper management of hazardous industrial wastes vary substantially, depending on the specific quantities and characteristics of the waste, cost of management, local regulations, and other factors. The planning and design of methods and facilities for managing industrial hazardous waste are beyond the scope of this publication. The Bibliography, however, includes a useful work by Batstone, et al., which can be used as a general reference. In any case, best waste management practices incorporate separation of hazardous industrial waste from MSW. In those cases where municipal authorities are forced to provide a temporary solution for the disposal of hazardous waste, specially designed cells should be provided within the municipal landfill. These cells must be isolated so that scavengers cannot come into contact with the hazardous waste.

D6. WASTE reduction

The logical starting point for the proper management of solid waste is to reduce the amounts of waste that must be managed, either informally managed within the generator’s site or formally (externally) managed by another entity once the waste is discarded by the generator. Thus, the reduced waste quantities do not have to be collected or otherwise managed.

As used in this document, the term “waste reduction” means reduction, or in the limit, prevention, of waste at the source or potential of generation. Waste reduction includes reuse of wastes within a generator’s site or related sites (e.g., reuse of industrial scrap in the manufacture of products), or reuse of materials in essentially their current form by a similar group (e.g., reuse of secondhand clothes). Waste reduction includes reduction in quantities or in toxicity of waste. Methods of waste reduction include preventing the generation of waste in the first place.

Reduction of waste is a primary element of solid waste management hierarchies, promoted by a number of international, regional, and national agencies or organisations. A number of economically developing countries have solid waste management hierarchies that list reduction of waste as the highest priority among the generic methods to manage solid waste (other generic methods include, but are not limited to, recycling and land disposal). This hierarchy follows that enumerated in Agenda 21, the agreement reached among participating nations at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. In particular, Chapter 21 of Agenda 21 emphasised that reducing wastes and maximising environmentally sound waste reuse and recycling should be the first steps in waste management. At the World Summit on Sustainable Development held in Johannesburg in 2002, these principles of Agenda 21 were reaffirmed. Additionally, the Summit advocated an increased urgency and effort to accelerate implement the principles.

D6.1. Importance of waste reduction

In affluent countries, the main motivations for waste reduction are frequently related to the high cost and scarcity of suitable sites associated with the establishment of new landfills, and the environmental degradation caused by toxic materials in the deposited wastes. The same considerations apply to: 1) large metropolitan areas in developing countries that generally are surrounded by other populous jurisdictions, and 2) isolated, small communities (such as island communities). However, any areas that currently do not have significant difficulties associated with the final dispositions of their wastes disposal pressures can still derive significant benefits from encouraging waste reduction. Their solid waste management departments, already overburdened, are ill-equipped to spend more funds and efforts on the greater quantities of wastes that will inevitably be produced, if not otherwise controlled, as consumption levels rise and urban wastes change.

D6.2. Key concepts in municipal waste reduction

Action for waste reduction can take place at both the national and local levels. At the national level, some strategies for waste reduction include:

- redesign of products or packaging;
- promotion of consumer awareness; and
- promotion of producer responsibility for post-consumer wastes.

At the local level, the main means of reducing waste are:

- diversion of materials from the waste stream through source separation and trading;
- recovery of materials from mixed waste;
- pressure on national or regional governments for legislation on redesigning packaging or products; and
- support of home composting, either centralised or small-scale.

D6.3. Building on what is working

As explained in the following paragraphs, people in many developing countries already carry out significant waste reduction practices. In designing strategies for further waste reduction, the first principle should be to build on what exists and appears to be working. In general, sound practices for the majority of cities and towns in the developing world rest upon:

- facilitating the existing private sector (formal and informal) in waste reduction where current practices are acceptable, and ameliorating problems encountered by all relevant stakeholders through access to capacity-building, financing, and education; and

- designing such assistance to be an integral component of the strategic plan for municipal solid waste management.

Developing a feasible strategic plan requires an understanding and assessment of local practices in waste reduction, waste recovery, and recycling.

D7. SYSTEMS of waste reduction

D7.1. Industrialised countries

Perhaps in no field of municipal solid waste management are the differences between the industrialised countries and the developing countries so apparent as in waste reduction and materials recovery. Rising overall living standards and the advent of mass production have reduced markets for many used materials and goods in the affluent countries whereas, in most of the economically developing countries, traditional labour-intensive practices of repair, reuse, waste trading, and recycling have endured. Thus, there is a large potential for waste reduction in economically developing countries, and the recovery of synthetic or processed materials is now being emphasised. Public or consumer financing of the full range of initiatives for waste reduction (from changes in manufacturing and packaging, to waste reduction audits to identify waste reduction opportunities) are practiced by several affluent industrialised countries.

One of the main motivations, from the point of view of municipal authorities, is to reduce materials that must be collected and deposited in landfills. At the national level, under the concept of producer responsibility, governments have created agreements and legal frameworks designed to reduce the generation of waste. For instance, industry is given responsibility for achieving certain levels of packaging reduction goals of a certain percentage within a given time period.

D7.2. Developing countries

In many developing countries, waste reduction occurs naturally as matter of normal practice because of the high value placed on material resources by the people, as well as other factors. Consequently, reuse of a variety of materials is prevalent. The motivations for materials reuse in developing countries include: scarcity or expense of virgin materials; the level of absolute poverty; the availability of workers who will accept minimal wages; the frugal values of even relatively well-to-do households; and the large markets for used goods and products made from recycled plastics and metals. Wastes that would be uneconomical to recycle or of no use in affluent societies have a value in developing countries (e.g., coconut shells and dung used as fuel). If one takes into account the use of compost from dumps sites as well as materials recovery, in countries like India, Vietnam, and China, the majority of municipal wastes of all kinds are ultimately utilised.

Waste reduction that could be achieved by legislation and protocols (such as agreements to change packaging) is not, at present, a high priority in these countries, although some are now moving in this direction. Because unskilled labour costs are low and there is a high demand for manufactured materials, manufacturers can readily use leftovers as feedstock or engage in waste exchange. Residuals and old machines are sold to less advanced, smaller industries. Public health is benefiting from plastic and boxboard packaging that reduces contamination of foods, and much of the superior packaging is recovered and recycled.

In offices and institutions, cleaners and caretakers organise the sale of paper, plastics, etc. At the household level, gifts of clothes and goods to relatives, charities, and servants are still significant in waste reduction. All cities and towns have markets for used goods. However, the greatest amount of materials recovery is achieved through networks of itinerant buyers, small- and medium-sized dealers, and wholesaling brokers. The extent to which the waste trading enterprises are registered ("formalised") varies in developing regions: in Latin America and Asia, there is more formal registration than in Africa. The system is adaptive to market fluctuations, as the lowest level workers form a dispensable labour cushion: they must find other work, if they can, when there is reduced demand for the materials that they sell.

From the point of view of waste reduction, the traditional practices of repair and reuse, and the sale, barter, or gift-giving of used goods and surplus materials are an advantage to the poorer countries. Quantities of inorganic post-consumer wastes entering the MSW stream would be higher if these forms of waste reduction did not exist.

D8. PRIORITIES for cities of developing countries

The hierarchy advocated in many industrial countries with high standards of living (with waste reduction given highest priority) may not be appropriate for most communities of less developed countries. Rather, the first priority in most cases should rest with identifying methods to divert organics from entering the municipal solid waste stream, which then requires organised collection and other forms of management. The reason is that organics are usually the largest component of MSW and the greatest reduction in wastes for collection and disposal can be achieved by diverting this component of the waste stream.

Due to lack of development of manufacturing capacity in most developing countries, waste reduction in that sector is not as important as it is in industrialised countries. Nevertheless, developing countries need to be alert to the growth of wasteful practices that may result from modern industrial processes and new modes of consumption. With reference to the latter, for instance, increased usage of and reliance upon thin plastic film for packaging can lead to increased littering of this material, which, if not controlled, can eventually clog surface drainage systems and pollute rivers and other bodies of water. Implementing legislation and incentives at the national level is one potential means of properly dealing with materials that may pose special problems related to management of litter and to adverse environmental consequences of disposal.

E. Summary

The range of issues to be considered in designing a well functioning MSWM system can be overwhelming, even to planners who have considerable resources available. In most of the world, where such resources and expertise are scarce, MSWM issues are even harder to resolve. MSWM, despite its prominent position as an urban problem, is not the only problem competing for the attention of urban managers. Its low status as a field of work has meant that MSWM issues often receive less attention than other urban problems.

The keys to making progress in this field lie in these areas:

- responsible planning and design of an integrated MSWM system, which works to reduce the quantity of waste generated and to handle waste in a coordinated fashion. Essential to this is understanding the nature of the wastes generated.

- adoption of new strategies for revenue generation that move away from sole reliance on a government-owned and -operated MSWM system. In many cases, a balanced mix of public and private systems can lead to a waste management system that is more flexible and efficient than a wholly publicly-owned and operated system.

- incorporation of small-scale enterprises and the informal sector into the MSWM system; and

- installation of a system of accountability and responsibility at the local level. Residents and businesses can be motivated to act responsibly in MSWM issues. But, most importantly, accountability entails significantly improving the training and capabilities of the managers and planners responsible for the MSWM system.

F. Reference

1. CalRecovery, Inc., *Characterization and Impacts of Nonregulated Hazardous Waste in the Solid Waste of King County*, prepared for Puget Sound Council of Governments, Seattle, Washington, USA, December 1985.

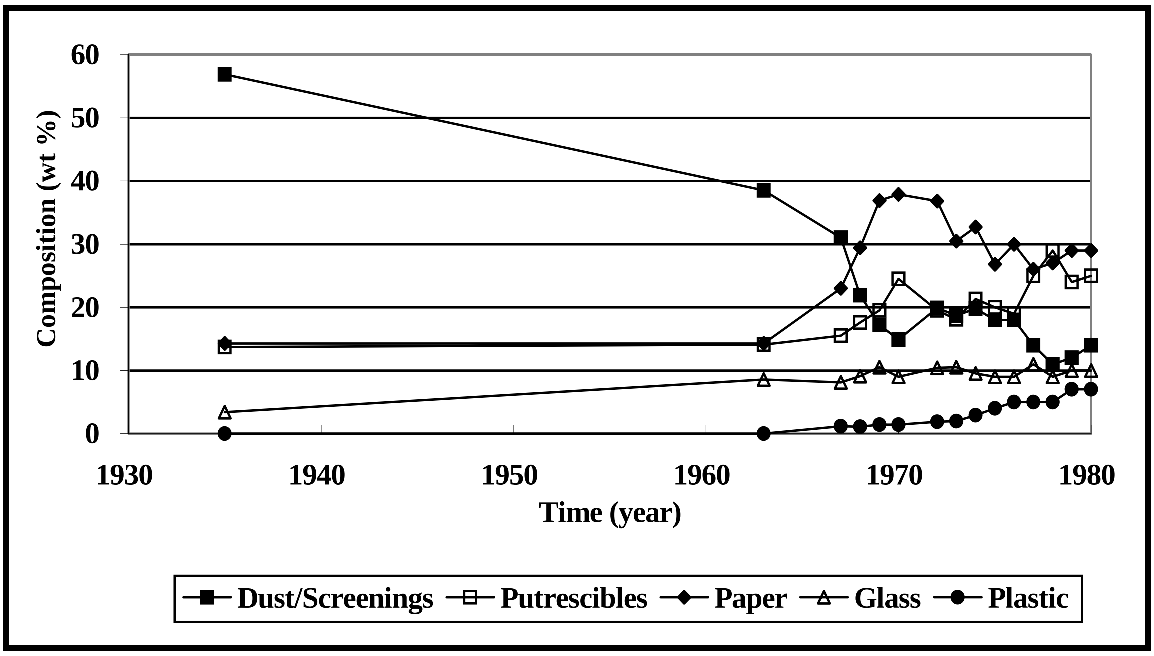
CHAPTER III. WASTE QUANTITIES AND CHARACTERISTICS

A. Introduction

The range of the numerical values presented in Chapter I (Table I-1) illustrates the wide variation that can be expected to exist between countries with respect to the quantity and composition of waste generated. On the other hand, careful scrutiny of the data indicates that despite the variation, three general trends do exist. The first trend is in quantities. It suggests that increases in per capita waste generation parallel increases in degree of economic development. The second trend concerns the concentration of paper in the waste stream. According to the data, the development of a country is closely accompanied by an increase in the concentration of paper in the waste. The third, and perhaps the most important, trend concerns biological solid waste and relates to the quantity of putrescible matter and ash. According to the data in Table I-1, the amounts of putrescible materials and ash in MSW generally decrease as the development of a country advances.

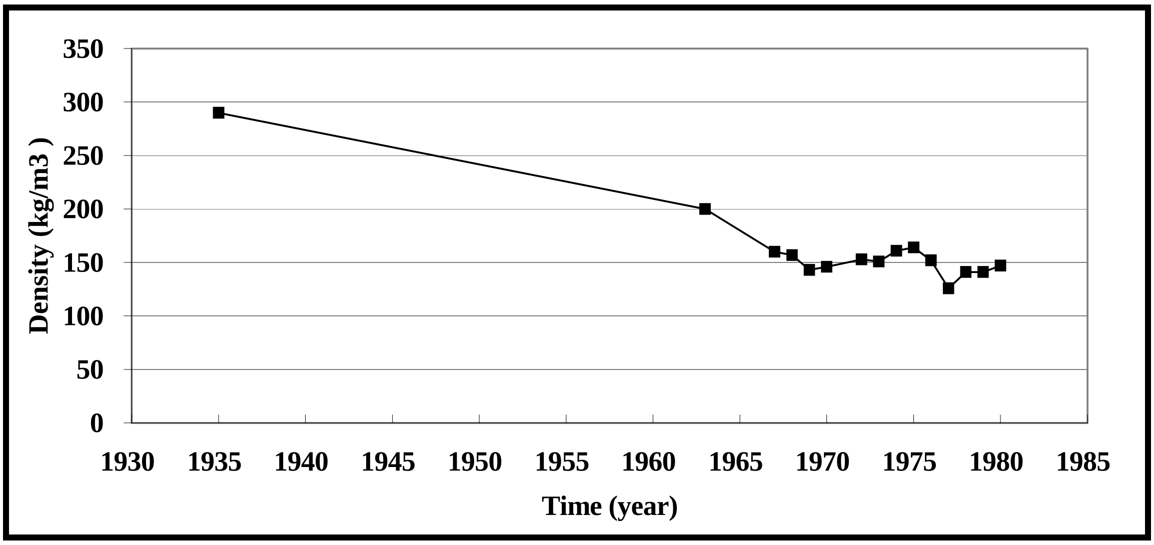
The variation and trends in quantity, composition, and other characteristics of urban waste are not confined to the national level. Indeed, they persist even at the community level. The persistence is due to the fact that the characteristics of the waste stream are affected by an array of factors. Ranking high among these factors are degree of industrialisation, extent and nature of socioeconomic development, and the climate.

Both short-term (e.g., seasonal) and long-term (e.g., 5-year periods) variations in characteristics occur in the case of solid waste; thus, the need for measurements. Two examples of long-term and significant changes in the composition and bulk density of the waste stream of the United Kingdom (UK) are illustrated in Figures III-1 and III-2, respectively. The historical trends shown for the UK are similar to those of many economically developing countries, except shifted forward in time by 40 to 60 years.



Source: Reference 14.

Figure III-1. Historical changes in MSW composition in the United Kingdom



Source: Reference 14.

Figure III-2. Historical changes in MSW bulk density in the United Kingdom

Despite the obvious fact that a thorough understanding of the characteristics of the waste is requisite to making rational decisions in solid waste management, it remains a prevalent practice to pay little heed to conducting a comprehensive and accurate survey of quantity and composition. Instead, reliance is had on some inaccurate method, especially the traffic count. Although traffic counts, if coupled with estimates of volume, may give an indication of the quantities being disposed; strictly speaking, they serve to ascertain solely that which is implied by the term -- namely, the number of vehicles entering the disposal site.

Rigorous, scientifically performed studies of waste quantities and characteristics are required to proper design, operate, and monitor solid waste management systems.

This chapter is concerned primarily with describing important waste characterisation parameters, and methods of determining them, so that designers can have a firm foundation to plan and implement waste management systems. The parameters and methods of determination are described in the following sections.

B. Quantities and composition

Quantity and composition surveys have an essential role in determining the dimensions of the key elements in solid waste management. A list of such elements would certainly include method and type of storage, type and frequency of collection, crew size, method of disposal, and degree of resource recovery. The utility of the surveys extends not only to the evaluation of present conditions, but also to the prediction of future trends. Consequently, frequent and ongoing surveys are the mainstays of a successful solid waste management program.

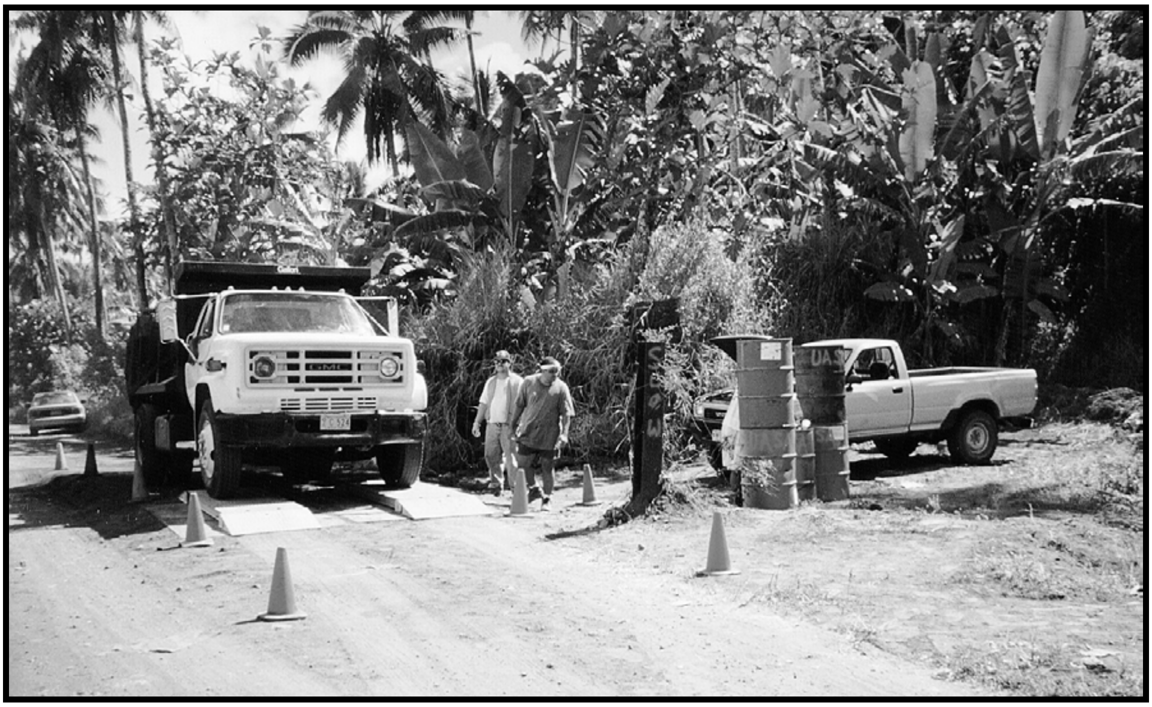
Surveys either of quantity or of composition must take into consideration scavenging and illegal dumping.

B1. PROCEDURES

B1.1. Quantities

Several methods are available for determining the quantity of wastes that require disposal. The accuracy of the results depends upon the method followed.

Perhaps the only means of arriving at an accurate estimate of the quantity of wastes is one that involves weighing each vehicle and its load of wastes as it enters the disposal site. The approach involves the use of a weighing scale sufficiently large to accommodate vehicles of all sizes that come to the site. Several types of scales can be used. For example, the scales may be permanently installed, or a portable version may be used. The authors have not encountered difficulties in the use of portable scales. The portable scales are equipped with load cells that can be powered by either direct or alternating current. Of course, tare weight (weight of the empty vehicle) also must be determined. An example of a collection vehicle being weighed using a set of portable scales is shown in Figure III-3. A sample data sheet for a weight survey is presented in Figure III-4.



Courtesy: CalRecovery, Inc.

Figure III-3. Collection vehicle being weighed on a set of portable scales

To account for changes due to seasonal or other temporal factors, the weight survey should be conducted for a minimum two-week period, at either two or four intervals distributed throughout the year.

If circumstances make it unfeasible to weigh every loaded refuse vehicle, then recourse can be had to a procedure that entails the weighing of a few randomly selected incoming vehicles. To arrive at the total input, the sample weights are multiplied by the number of loads per day. Although results obtained by such a modified weight survey may be less accurate than those obtained by weighing each vehicle, they are better than those obtained without recourse to any actual weighings.

The third and final method to be described herein is the least accurate of the three in terms of results obtained. It involves the collection of the following data: 1) average density of waste, 2) number of loads collected per day, and 3) average volume per load. The latter quantity is obtained by measuring the vehicle body. The total daily weight is the product of all three, i.e., density, volume, and number of loads per day. For example, if the density is 300 kg/m^3, the average vehicle volume is 4 m^3, and the total number of loads per day is 100, then the total daily input to the disposal site is 120 Mg.

At times, the degree of the accuracy required may be beyond that attainable with any one of the three preceding methods. Instances in which such a high degree of accuracy would be a necessity are the determination of the extent of storage needs, the required capacity of a transfer station, or the potential for resource recovery. The deficiency as far as the three cited instances are concerned arises from the fact that the methods are based only on those wastes that are brought to a recognised disposal site. They do not take into account the wastes disposed elsewhere.

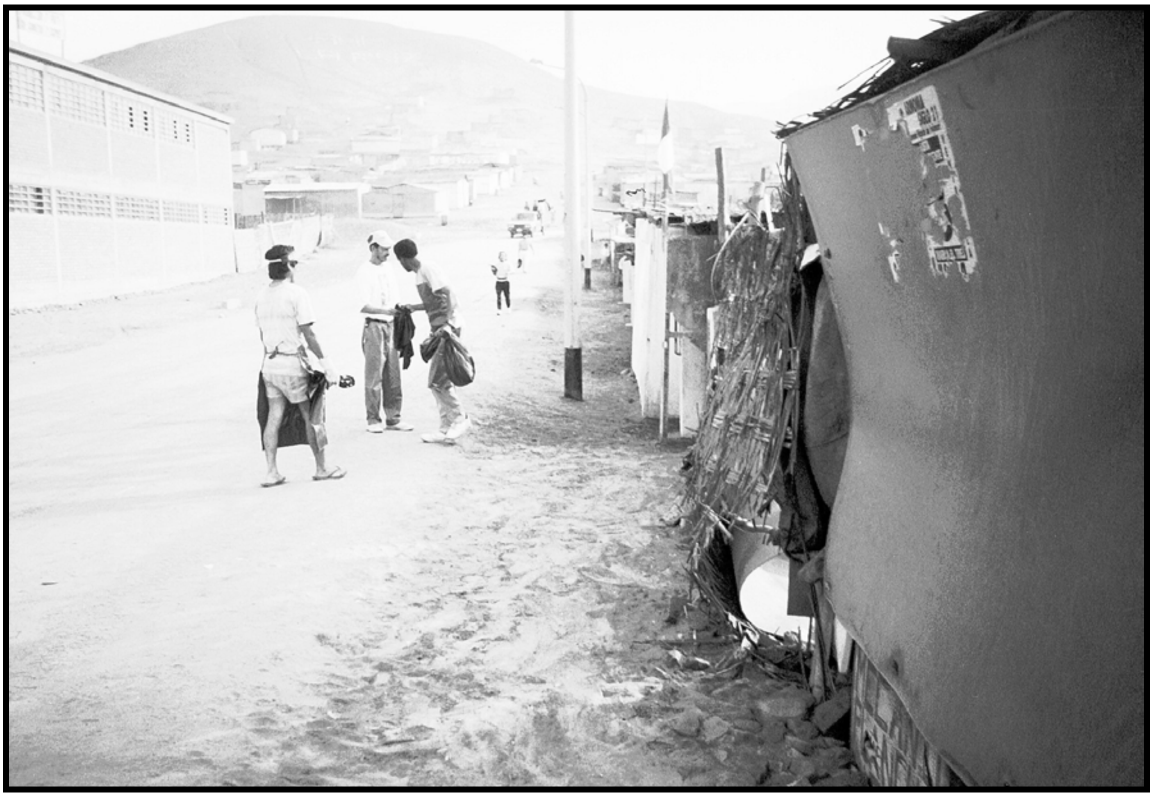
Generator			Weight/Volume				Self-Haul Wastes							
							Self-Haul Vehicles					Waste Categories		
Residential	Commercial	Industrial	Gross Weight (kg)	Tare Weight (kg)	Capacity of Vehicle (m^3)	Volume of Waste (%)	Pickup Truck	Other Truck	Automobile	Handcart	Other	Yard Waste	C&D[a]	Other[b]
Recorded by: _______________								Date: _________________						

[a] C&D = Construction and demolition debris.
[b] "Other" - describe.

Figure III-4. Sample data sheet for a weight survey

A means of determining the real total generation, i.e., wastes brought to the disposal site plus wastes destined for disposal elsewhere, is to multiply the per capita rate of generation (e.g., kg/cap/day) by the number of individuals in the generation area (e.g., community, nation). A difficulty with this approach is that any attempt to reach a truly representative number for the per capita generation rate would be beset with many difficulties. Obviously, it would be physically and economically unfeasible to measure each individual's output even in a small, highly organised community. Consequently, resort must be had to sampling at the generation source.

Rather than attempt to carry on such a sampling program on a large scale, in terms of practicality and economic feasibility, it is better to set up a modest program in which special sampling areas are selected and defined. In setting up areas, care should be taken that all socioeconomic groups are represented. Each participating household in the sampling area is provided with a container of some sort, perhaps a plastic bag, in which the day's output of wastes is placed, as shown in Figure III-5. Each day, the containers are collected and tagged by the agency making the study and are transported to a central point to be weighed, and the weights and other information (e.g., number of individuals in the household, social status) are recorded. Ideally, the containers should be collected daily and the participant be supplied with a new (i.e., empty) container only when the filled one is collected, as shown in Figures III-6, III-7, and III-8. Samples should be collected for at least a 10-day period.



Courtesy: Alternativa

Figure III-5. Distribution of plastic bags for waste characterisation program

Courtesy: Alternativa

Figure III-6. Collection of bags

Courtesy: Alternativa

Figure III-7. Determination of total weights

Courtesy: CalRecovery, Inc.

Figure III-8. Bags used to determine quantity of waste generated

To ensure full cooperation, the sampling program and the rationale behind it should be fully explained to the participants. An individual best qualified for such a task would be a local social worker.

By reconciling the numbers obtained from a weight survey at the disposal site with those based on per capita generation as determined through sampling, it is possible to arrive at an estimate of total waste generation that is sufficiently accurate to meet most needs, whether they be for facility and equipment design or for waste management planning. Table III-1 presents estimated quantities of waste collected (expressed in kg/cap/day) in various cities.

B1.2. Composition

A full knowledge of the composition of the wastes is an essential element in: 1) the selection of the type of storage and transport most appropriate to a given situation, 2) the determination of the potential for resource recovery, 3) the choice of a suitable method of disposal, and 4) the determination of the environmental impact exerted by the wastes if they are improperly managed.

A reasonably realistic estimate of the composition of a community's waste output requires an analytical period of two weeks' duration, repeated two to four times per year. During the two weeks, samples are taken from the collection vehicles at the disposal site. All types of municipal wastes should be sampled, i.e., residential, commercial (offices and markets), and light industrial. The ratio of the number of samples of each type of waste to the total number of samples should be the same as that of the quantities of each type to the total quantity disposed. For example, if the output of residential waste is ten times greater than the combined commercial and light industrial wastes, then the number of samples of residential wastes should be ten times that of the other two combined.

Table III-1. Estimated quantity of waste collected in various cities and countries

Location	Estimated Quantity (kg/cap/day)[a]
India	0.3 to 0.55
Bolivia	0.3 to 0.6
Guatemala City, Guatemala	0.3 to 0.6
Lima, Peru	0.3 to 0.8
Philippines	0.4
Asunción, Paraguay	0.46
Malaysia	0.5
Uruguay	0.5 to 0.9
Tegucigalpa, Honduras	0.52
Rio de Janeiro, Brazil	0.54
Jakarta, Indonesia	0.6
Buenos Aires, Argentina	0.6 to 1.0
Mexico DF, Mexico	0.68
San Salvador, El Salvador	0.68
San José, Costa Rica	0.73
Papua, New Guinea	0.8
Santiago, Chile	0.9 to 1.2
Caracas, Venezuela	0.91
Fiji	0.91
Japan	0.91
Singapore	1.0
Vienna, Austria	1.18
Antigua	1.25
Guam	1.35
Paris, France	1.43
Hong Kong	1.68
Australia	1.87
Seoul, Korea	2.0
New Zealand	2.0

Sources: References 9-11, 15, 16.

[a] Ranges indicate data collected from different cities in the country or from different sectors in a city.

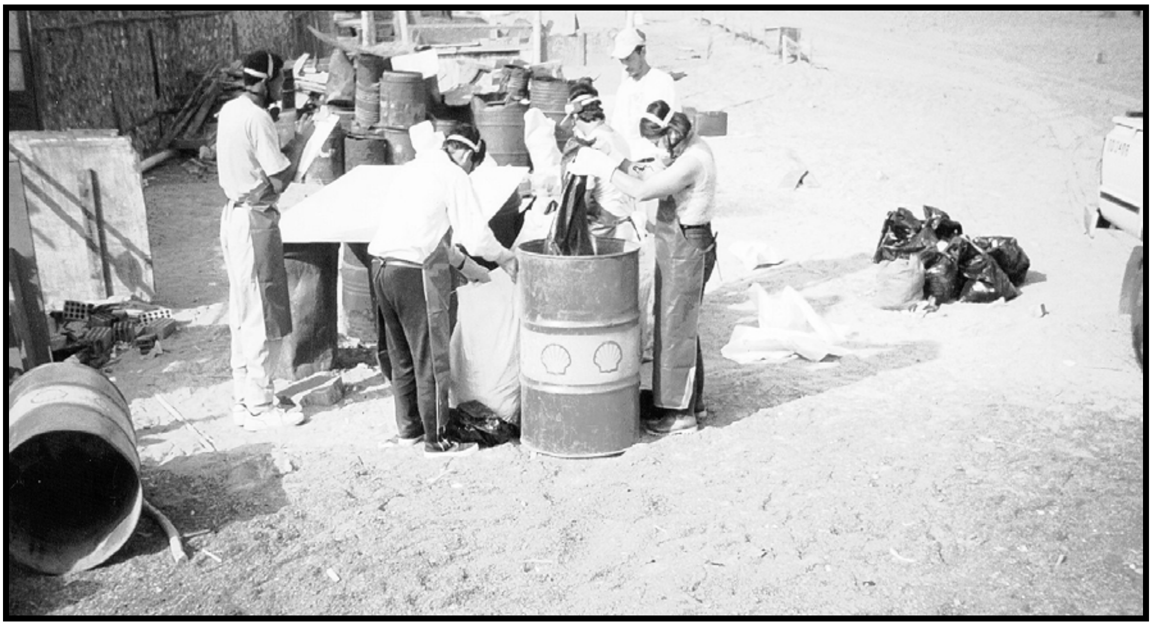
Regarding sample size, the minimum weight per sample should be on the order of 100 kg. If the sample size is too small, the possibility of obtaining a representative sample is lessened. On the other hand, accuracy is not improved sufficiently to warrant taking samples greater than 100 kg in size [1].

To reduce the magnitude of errors arising from moisture change and from decomposition, analysis of the samples should be begun within two to three hours after collection.

A sample data sheet developed for the conduct of compositional studies in the United States is shown in Figure III-9. Because the data sheet shown in the figure is very comprehensive, it may be modified as needed. Indeed, in some countries, it may not be necessary to sort the refuse into every category shown in the figure. For example, mixed paper, newspaper, and cardboard can be combined under the single category of paper. To carry out the analysis, the wastes in the samples are sorted according to the categories listed in the selected data sheet. In the sorting process, each type of waste is placed in its appropriate container (see Figure III-10). At the completion of the sorting, each container and its contents are weighed (gross weight). Gross and tare (empty container) weights should be recorded. The difference between the two weights is the net weight of the individual components.

Sample #	**Start Weight**		**Date**	**Recorded by**	
CATEGORY	**Gross Weight**	**Container Type/Tare**	**CATEGORY**	**Gross Weight**	**Container Type/Tare**
Paper			**Other Organic**		
(a) Corrugated/Paper Bags			(a) Food		
(1) Uncoated Corrugated			(b) Yard/Landscape		
(2) Coated Corrugated			(1) Leaves/Grass		
(3) Brown Paper Bags			(2) Prunings/Trimmings		
(b) Newspaper			(3) Branches/Stumps		
(c) Office Paper			(c) Ag. Crop Residues		
(1) White Ledger			(d) Manures		
(2) Coloured Ledger			(e) Wood		
(3) Computer Paper			(f) Textiles		
(4) Other Office Paper			(g) Tires		
(d) Mixed Paper			(h) Remainder/Composite		
(1) Magazines/Catalogues			**Other Inorganic**		
(2) Phone Books/Directories			(a) Inerts		
(3) Other Mixed Paper			(1) Rock		
(e) Remainder/Composite			(2) Concrete		
Glass			(3) Brick		
(a) Clear Bottles/Containers			(4) Soil & Fines		
(b) Coloured Bottles/Containers			(5) Asphalt		
(1) Green Bottles/Containers			(6) Gypsum Board		
(2) Brown Bottles/Containers			(b) Remainder/Composite		
(c) Flat Glass			**HHW & Special Waste**		
(d) Remainder/Composite			(a) Household Hazardous		
Metal			(1) Paint		
(a) Ferrous Metals			(2) Automotive Fluids		
(1) Tin/Steel Cans			(3) Batteries		
(2) Other Ferrous			(4) Remainder/Composite		
(b) Non-Ferrous Metals			(b) Special Waste		
(1) Aluminium Cans			(1) Ash		
(2) Other Non-Ferrous			(2) Biosolids		
(c) White Goods			(3) Industrial Sludge		
(d) Remainder/Composite			(4) Treated Medical Waste		
Plastic			(5) Bulky Items		
(a) HDPE			(6) Remainder/Composite		
(1) Natural HDPE			**Mixed Residue**		
(2) Coloured HDPE			**Comments:**		
(b) PET					
(c) Film Plastic					
(d) Other Plastic					
(1) PVC					
(2) PP					
(3) PS					
(e) Remainder/Composite			(continue on reverse side if needed)		

Figure III-9. Sample waste composition data sheet



Courtesy: Alternativa

Figure III-10. Waste composition analysis in a peri-urban area

C. Other characteristics

In addition to analysing for composition, it is recommended that the sampling program include provisions for determining moisture content, bulk density, and particle size distribution. The measurement of these three properties is especially recommended if no prior scientific waste characterisation study has been performed locally. These particular characteristics have a substantial influence on determining: 1) wastes that will be difficult to manage, 2) proper and best methods for storing, collecting, processing, and disposing of the wastes and 3) marketability of potentially recoverable materials. In addition to the moisture content, particle size, and bulk density, a knowledge of several other properties of solid waste are also required for properly planning, designing, and operation waste management programs. Among such other properties are chemical/thermal and mechanical analyses.

Moisture Content

The moisture content is determined as follows: The sample is weighed as received ("wet weight"). It is then allowed to stand until it is air-dry, i.e., its moisture content is in equilibrium with that of the ambient air. The percent moisture content is then obtained through the following formula:

$$\text{Moisture Content (\%)} = \frac{W_W - W_D}{W_W} \times 100$$

where:

- W_W = wet weight of sample, and
- W_D = dry weight of sample.

C1. BULK density

The bulk density can be measured by filling a container of known volume with wastes and then weighing the loaded container, as shown in Figure III-11. (The container should be constantly shaken during filling.) The bulk density is calculated by dividing the net weight of the refuse (weight of loaded container minus weight of empty container) by its volume. The result is expressed as kg/m^3. Bulk densities obtained in various countries are presented in Table III-2. In addition, bulk densities of various types of wastes are given in Table III-3. For comparison purposes, the densities of virgin materials are presented in Table III-4.

Courtesy: CalRecovery, Inc.

Figure III-11. Determination of bulk density

C2. SIZE distribution

Size distribution may be determined with the use of a set of manually manipulated screens. The screens should have square openings, particularly those with large openings, and the sizes of the openings included in the set should be 100, 50, and 25 cm. The screens, particularly those with large openings, can be easily made with lumber and wire, as shown in Figures III-12 and III-13. The sample size should range from 150 to 300 kg.

Table III-2. Bulk densities of residential wastes for various countries

Country	Density (kg/m^3)
United Kingdom	150
United States	100
Egypt	330
Nigeria	250
Singapore	175
Tunisia	175
Bangladesh	600
Burma	400
India	400 to 600
Indonesia	400
Mexico	300 to 500
Nepal	600
Pakistan	500
Paraguay	390
South Korea	200 to 450
Sri Lanka	400
Thailand	250
Tanzania	330

Sources: References 3, 4, 6.

Table III-3. Typical bulk densities of mixed MSW and various components of MSW

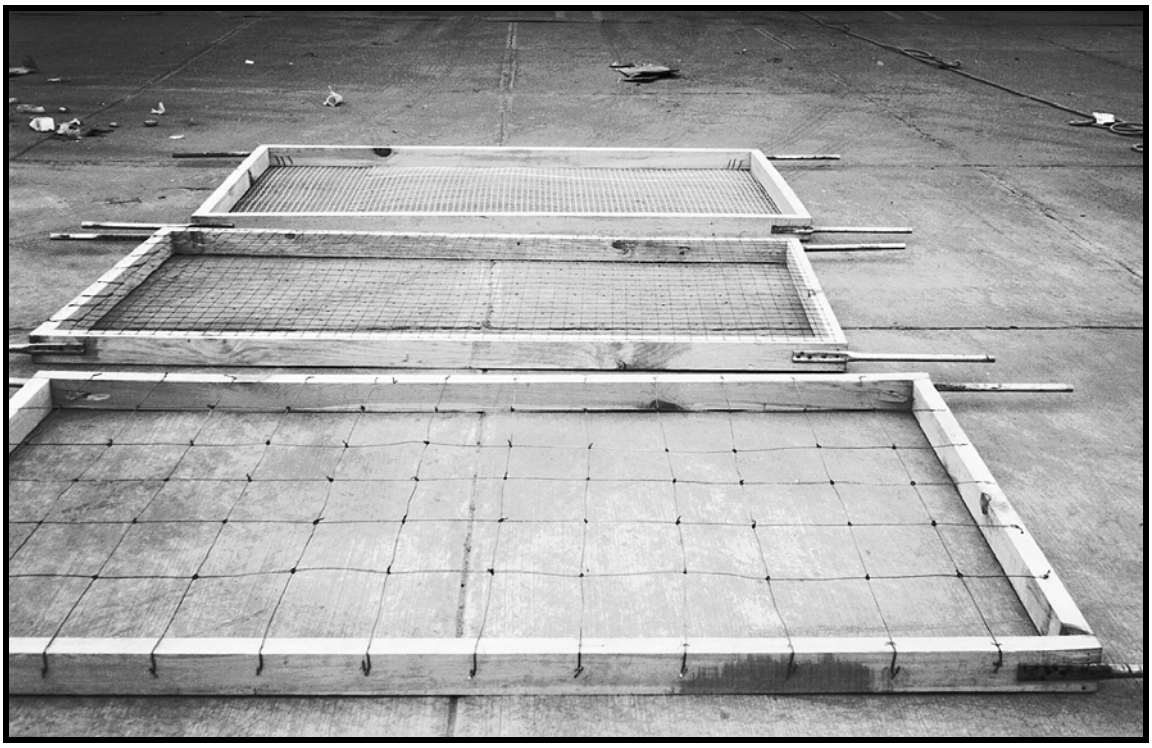
Component	Density (kg/m^3)
MIXED SOLID WASTE	
Mixed MSW	
Loose	90 to 178
After dumping from compactor truck	207 to 237
In compactor truck	297 to 416
In landfill	475 to 772
Shredded	119 to 237
Baled	475 to 712
Mechanically-Recovered Fractions (Loose)	
dRDF	481 to 641
Aluminium scrap	224 to 257
Ferrous scrap	369 to 417
Crushed glass	1,042 to 1,363
Powdered RDF (Eco-Fuel)	417 to 449
RECOVERED MATERIALS	
Loose	
Corrugated	16 to 32
Aluminium cans	32 to 48
Plastic containers	32 to 48
Miscellaneous paper	48 to 64
Garden waste	64 to 80
Newspaper	80 to 112
Rubber	209 to 258
Glass bottles	193 to 305
Food waste	353 to 401
Tin cans	64 to 80
Densified	
Baled aluminium cans	193 to 289
Cubed ferrous cans	1,042 to 1,491
Baled corrugated	353 to 513
Baled newspaper	369 to 529
Baled high grades	321 to 465
Baled PET	209 to 305
Baled HDPE	273 to 385

Source: Reference 8.

Table III-4. Bulk densities of virgin materials

Component	Density (kg/m^3)
Wood	593
Cardboard	689
Paper	705 to 1,154
Glass	2,501
Aluminium	2,693
Steel	7,855
Polypropylene	898
Polyethylene	946
Polystyrene	1,042
ABS	1,026
Acrylic	1,186
Polyvinylchloride (PVC)	1,250

Source: Reference 8.



Courtesy: CalRecovery, Inc.

Figure III-12. Screens specifically made to determine size distribution of waste

Courtesy: CalRecovery, Inc.

Figure III-13. Testing of the screens by crew members

Representative waste from the sample is placed on the largest of the screens (100 cm). The screen is shaken until particles of refuse no longer pass through the openings. Material remaining on the screen (oversize) is collected and weighed. The material that has passed through the screen (undersize) is placed on the screen with the 50-cm openings, which is shaken as in the preceding step. The process is repeated until all three screens have been used. The fractions that are sized are weighed, and the weight values are used to plot a size distribution curve. Typically, the size distribution is plotted as cumulative percent passing versus screen size. A sample data sheet is shown in Figure III-14. Sample size distribution curves for some waste components generated in the United States are shown in Figure III-15, and those for wastes generated in Mexico City in Figure III-16.

C3. CHEMICAL/thermal properties

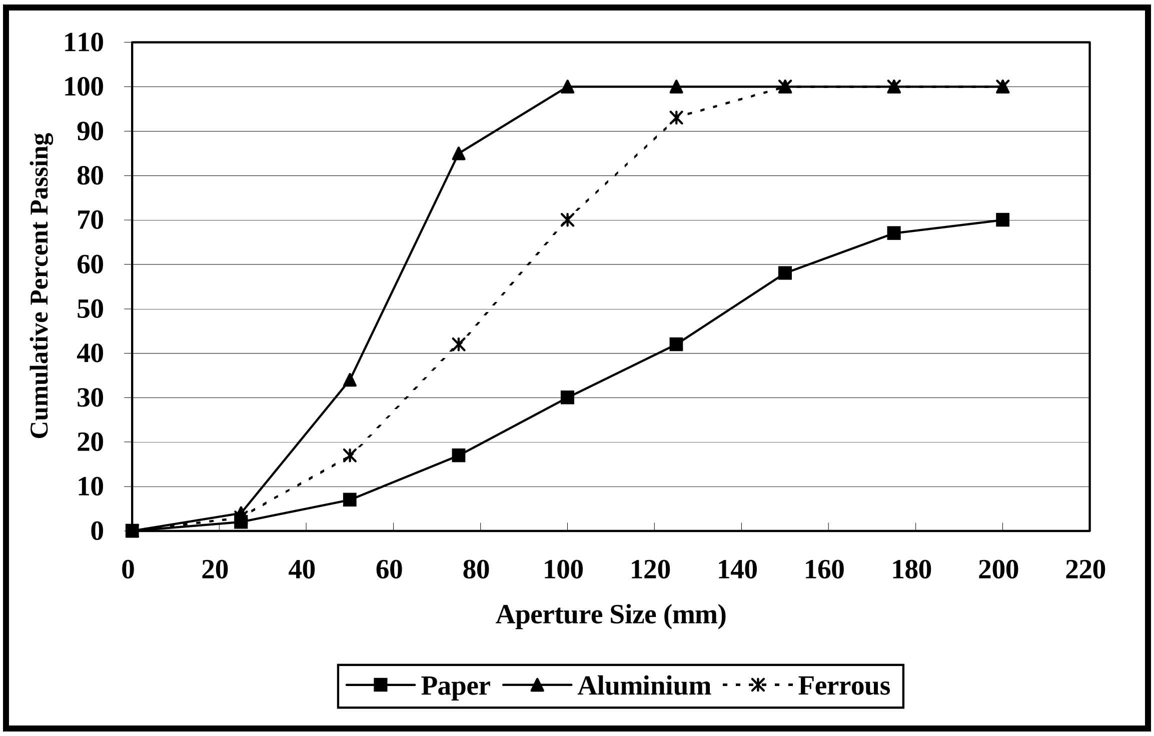
Determination of chemical/thermal properties of solid wastes or its components would be necessary in order to ascertain the most appropriate type of treatment. These analyses must be conducted by a reliable laboratory. The authors generally rely on either governmental laboratories or universities to perform the work. Typical analyses include moisture and ash contents; calorific value; and the concentrations of carbon, nitrogen, hydrogen, oxygen, and some heavy metals if there are reasons to suspect that they may be present. The results of analyses conducted in various countries are presented in Table III-5. Additional properties of MSW and its components can be found in Reference 13.

C4. MECHANICAL properties

Despite the fact that the proper design of processing plants as well as final disposal facilities should include a thorough understanding of the properties of refuse and its components, this requirement has, up until recently, been ignored. Perhaps this can be explained by the absence of reliable information readily available in the literature. This problem is particularly more pronounced in economically developing countries. Mechanical properties are especially important in the design of sanitary landfills and ancillary systems. This section presents the results of analyses carried out using raw (fresh) MSW, fractions of MSW, as well as landfilled MSW generated in industrialised countries in Western Europe. Due to the sharp differences in the composition and characteristics between these wastes and those from economically developing countries, it is recommended that the data presented in these sections be used simply as references and modified to suit the conditions of the particular location.

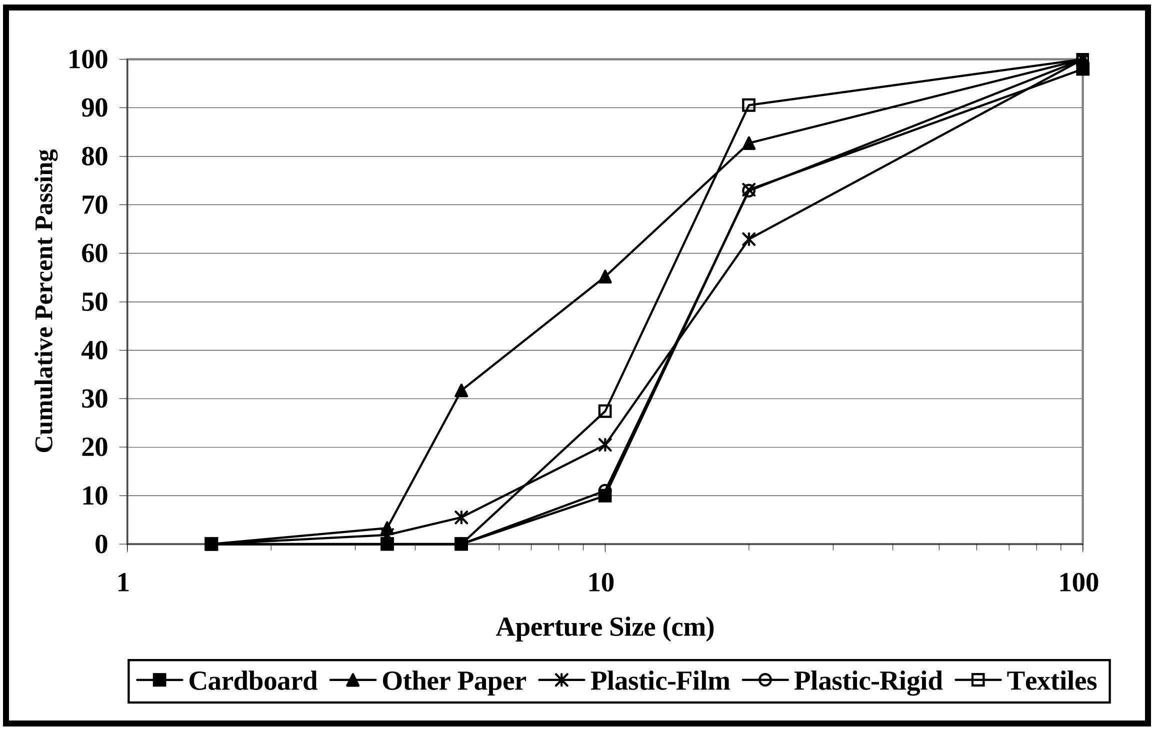
Date:			**Sample Wet Weight:**		
Location:			**Sample Dry Weight:**		
Sample No.:			**Moisture Content:**		
Type of Material:			**Type of Generator:**		
Screen Size	**Gross Weight Retained by Screen**	**Tare Weight**	**Net Weight Retained by Screen**	**% of Feed on Bottom Screen**	**Cumulative Wt % Passing Bottom Screen**
Total Sample Weight:					

Figure III-14. Sample data sheet for size distribution analysis



Source: Reference 2.

Figure III-15. Sample size distribution of raw MSW components in the United States



Source: Reference 5.

Figure III-16. Sample size distribution of MSW components in Mexico City

Table III-5. Physical and chemical characteristics of residential wastes from various countries

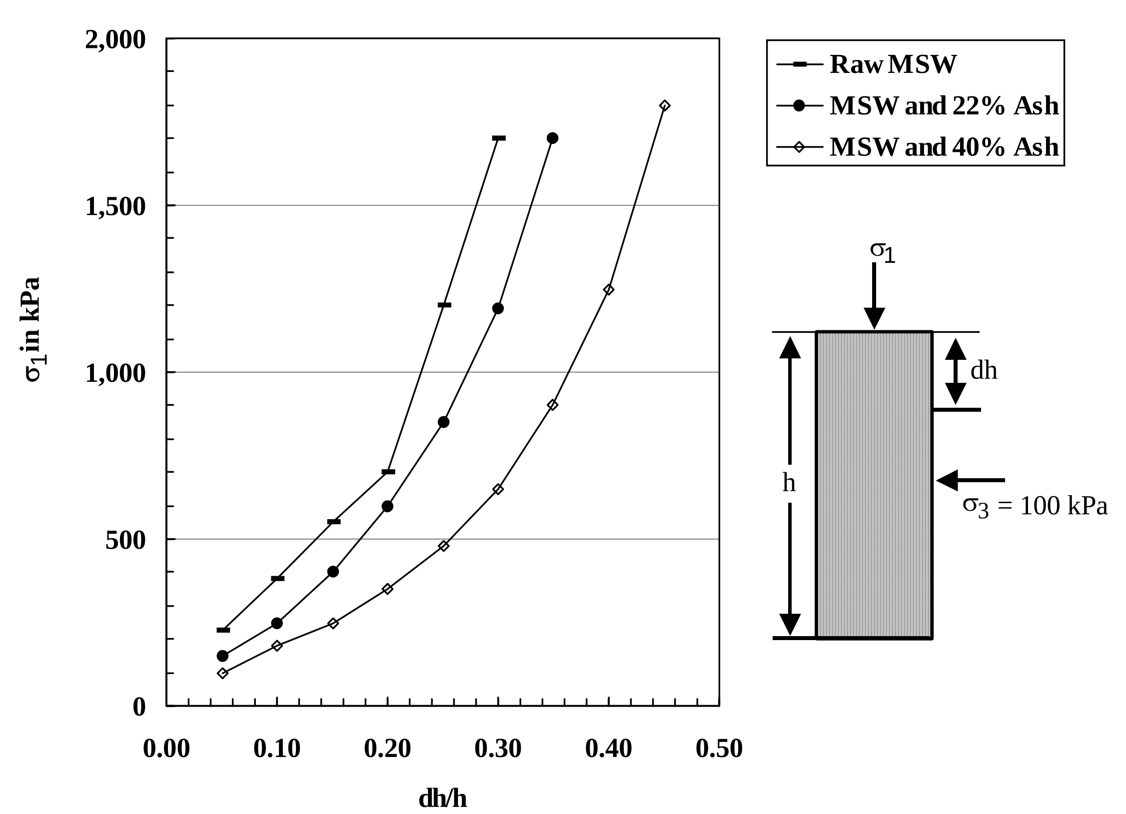
Location[a]	M.C. (%)	VS (%)	Ash (%)	C (%)	H (%)	N (%)	P (%)	Cl (%)	S (%)
Manila, Philippines	42.6	33.8	23.6	18.3	2.2	0.24			
Mexico City, Mexico	50	32.5	33	15	1.5	0.9			
Calcutta, India	42	32	26	18	N/A	0.55	0.55		
Seoul, Korea	44.2	17.7	38.1	8.9	1.2	0.47		0.22	0.04

Sources: References 4-7.

[a] Summer, medium-level residences.

C4.1. Stress-strain

The results of triaxial compression tests conducted on raw MSW and on mixtures of MSW and incinerator bottom ash are given in Figure III-17. As shown by the curves in the figure, ash has a considerable impact on the behaviour of refuse.



Source: Reference 10.

Figure III-17. Stress-strain curves for MSW samples

C4.2. Relationship between stress and dry density

The results of laboratory tests to ascertain the impact of normal stress on the dry density of different types of refuse are presented in Table III-6. The data in the table demonstrate that the samples of degraded refuse have substantially higher densities than the samples of fresh refuse.

C4.3. Absorptive and field capacities

Tests have been carried out using a large-scale compression cell to determine several hydrogeological and geotechnical properties of refuse. The results of these analyses are useful in the evaluation of leachate management systems. The tests to determine the absorptive and field capacity of the samples are presented in Tables III-7 and III-8, respectively.

Table III-6. Impact of normal stress on the dry density of refuse

Normal Stress (KN/m^2)	Dry Density (Mg/m^3)			
	Raw[a] Refuse	Residual[b] Refuse	Decomposed[c]	Mined[d]
100	0.54	0.58	0.89	
200	0.64	0.65	0.95	1.04
300	0.72	0.72	1.01	1.00
400				1.10

Source: Reference 11.

[a] As collected, without separation.

[b] Without "organic" components.

[c] Raw refuse after 1.5 yr of degradation in piles.

[d] Excavated from landfill after 5 yr.

Table III-7. Absorptive capacity of refuse

Material	Initial Moisture Content (% wet wt)	Initial Field Capacity (% dry wt)	Absorptive Capacity (L/Mg wet wt)
Raw refuse	34	112	393
Raw refuse	35	102[a]	332
Shredded refuse	28.8	141	718

Source: Reference 12.

[a] Field capacity at stress of 40 kPa.

Table III-8. Field capacity of refuse as a function of stress

Applied Stress (kPa)	Shredded Refuse		Unprocessed (Raw) Refuse[a]	
	Dry Density (Mg/m^3)	Field Capacity (% dry wt)	Dry Density (Mg/m^3)	Field Capacity (% dry wt)
Initial	0.25	141	0.33	N/D[b]
40	0.29	115	0.39	102
87	0.35	103	0.43	101
165	0.43	76	0.49	88
322	0.53	64	0.62	73
600	0.60	60	0.71	61

Source: Reference 12.

[a] Moisture content = 102% on a dry weight basis.

[b] N/D = Not determined.

D. References

1. Diaz, L.F., G.M. Savage, and C.G. Golueke, *Resource Recovery from Municipal Solid Wastes: Vol. I, Primary Processing*, CRC Publishers, Inc., Boca Raton, Florida, USA, 1992.

2. Diaz, L.F., G.M. Savage, L.L. Eggerth, and C.G. Golueke, *Composting and Recycling Municipal Solid Waste*, Lewis Publishers, Ann Arbor, Michigan, USA, 1993.

3. Diaz, L.F. and C.G. Golueke, "Solid Waste Management in Developing Countries", *BioCycle*, 26:46-52, September 1985.

4. CalRecovery, Inc., *Metro Manila Solid Waste Management Study - Waste Stream Characterization*, prepared for Ad Hoc Committee, Republic of the Philippines, May 1982.

5. CalRecovery, Inc., *Criterio de Diseño - Planta de Selección y Recuperación de Subproductos de los Residuos Sólidos Municipales*, prepared for Mexico City, Mexico, December 1992.

6. Nath, K.J., "Solid Waste Management in the Present Indian Perspective", proceedings of ISWA 1993 Annual Conference, Jönköping, Sweden, September 1993.

7. Japan International Cooperation Agency, *Master Plan and Feasibility Study on Seoul Municipal Solid Waste Management System in the Republic of Korea*, Draft Final Report, Tokyo, Japan, August 1985.

8. CalRecovery, Inc., *Conversion Factor Study - In-Vehicle and In-Place Waste Densities*, prepared for California Integrated Waste Management Board, USA, March 1992.

9. CalRecovery, Inc., *Solid Waste Management Options in American Samoa*, prepared for National Renewable Energy Laboratory, March 1994.

10. Grisolia, M., Q. Napoleoni, and G. Tancredi, "Contribution to a Technical Classification of MSW", *Proceedings of the Fifth International Landfill Symposium*, Volume II, Cagliari, Italy, 1995.

11. Kolsch, F., "Material Values for Some Mechanical Properties of Domestic Waste", *Proceedings of the Fifth International Landfill Symposium*, Volume II, Cagliari, Italy, 1995.

12. Beaven, R.P. and W. Powrie, "Hydrogeological and Geotechnical Properties of Refuse Using a Large Scale Compression Cell", *Proceedings of the Fifth International Landfill Symposium*, Volume II, Cagliari, Italy, 1995.

13. CalRecovery, Inc., *Handbook of Solid Waste Properties*, Governmental Advisory Associates, Inc., New York, New York, USA, 1993.

14. World Health Organization, Regional Office for Europe, *Urban Solid Waste Management*, edited by Institute for the Promotion of International Health Actions (IRIS), Copenhagen, Denmark, 1991.

15. Morwood, R., "Australian Waste Management - Towards 2000", *Proceedings of 32nd Annual International Solid Waste Exposition,* SWANA, San Antonio, Texas, USA, August 1994.

16. Scharff, C. and G. Vogel, "A Comparison of Collection Systems in European Cities", *Waste Management & Research*, 12(5), October 1994.