RECYCLING AND DISPOSAL OF MUNICIPAL SOLID WASTE IN LOW AND MIDDLE-INCOME COUNTRIES

Perspectives for municipal managers and environment agencies

UN-HABITAT
FOR A BETTER URBAN FUTURE

Recycling and disposal of municipal solid waste in low- and middle-income countries:

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INTRODUCTION

1. The topic

This book is about recycling and disposal of solid waste – in other words, using or getting rid of solid waste (which is also known as garbage or refuse).

When the subject of solid waste management is mentioned, many people think immediately of recycling. Many now prefer to use the term *Resource Management* instead of *Solid Waste Management* because they wish to emphasise the potential value of many of the materials that are discarded as waste.

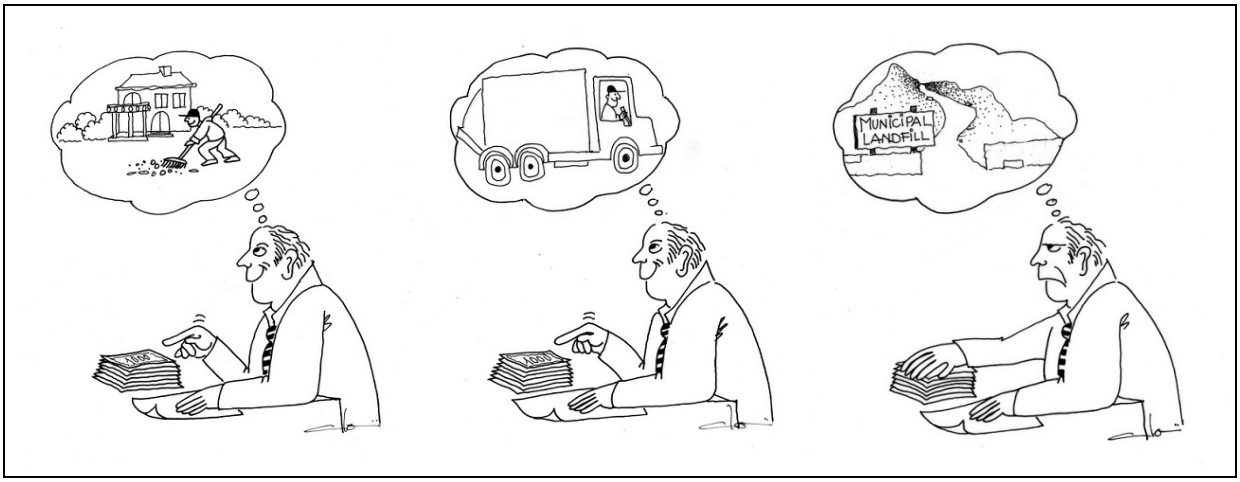
There are different reasons why people focus on recycling. Perhaps they are thinking of the opportunities for making a profit out of waste by selling discarded materials for reuse or recycling. Perhaps they are concerned about the environmental problems caused by waste, and are dreaming of a day when there is no unwanted material requiring disposal in landfills – the concept of "zero waste" – everything being reused or recycled. For others the main concern may be to meet government targets for the quantities of waste that are recycled or the reduction in the total amount of waste. All of these concerns will be examined in this publication.

In an ideal world a useful purpose could be found for all waste, but at the present time there is still the need to find ways of disposing of the unwanted residues that remain after the valued items are removed from the waste, as well as the residues from recycling processes. These residues must be disposed of in a way that causes minimum nuisance and pollution – and at an acceptable cost. Any satisfactory solid waste management system must have a means of dealing with all of the waste so that nothing is left to pollute the environment and threaten health. At the present time, recycling is not able to find a use for all wastes at a cost that can generally be afforded, so there must be a means of disposing of residues.

It has been said that "Everyone wants the garbage to be picked up, but no-one wants it to be put down." Picking up the solid waste – the collection and transport of solid waste – has been discussed in a companion publication, also published by UN-Habitat, entitled *Collection of Municipal Solid Waste in Developing Countries* [Coffey and Coad, 2010]. Following on from the collection stage, this book is concerned with putting the solid waste down, either for recycling, treatment or disposal. These are the less popular aspects of solid waste management (because no-one wants a waste processing or disposal facility close to where they live), whereas most people like to have their streets clean and garbage removed. However, steps can be taken to reduce the public hostility to such facilities.

Disposal and recycling mostly take place out of sight, away from the main population centres. As a result they attract less public concern and are often low in the list of priorities of municipal administrations, in comparison with street sweeping and waste

collection. This book explains why the less familiar functions of recycling, treatment and disposal are important and demand the attention of local government and environment agencies. It also provides guidance for improving standards at minimum cost.



Cartoon 1 Municipal priorities

Although this book is not concerned with the storage and collection of solid waste, there is always the need to regard solid waste management in an integrated way, and to avoid considering any aspect or function as independent of any other, or less important than any other. For example, the way in which solid waste is managed in the home (whether it is segregated or not) and the way in which it is collected can have a big impact on recycling or treatment. Recycling activities affect treatment options and disposal quantities. Transport costs must be considered when choosing the location of a disposal site. Successful waste management planning also considers all groups of people that may be affected and all types of influence and impact – social, economic, technical, environmental, institutional etc. Improvements are most likely to be sustainable if the planning is multidisciplinary and inclusive.

The term *integrated solid waste management* has become popular among practitioners. Some may use it to refer to a particular approach or programme. In its original – and broader – meaning, it encourages planners to take into account the wide range of issues that may influence the success of an outcome and to avoid repeating or imitating without fresh thinking and wide consultation.

2. Intended readership

If your answer to any of the following questions is *yes*, this book is for you.

- Are you concerned to increase the proportion of your city's waste that is recycled and so make better use of the waste?
- Are you looking for ways to reduce the cost of waste disposal?
- Are you concerned about what happens to solid waste after it has been picked up by the collection trucks?
- Are you concerned that the existing waste disposal facility might be polluting a source of drinking water, or causing illness or nuisance by its pollution of the air?

- Are you wondering if you need to improve or modernise the way that solid waste is managed in your town or city?
- Are you looking for a way to respond to complaints about the existing waste disposal site?
- Do you need to find a new site for waste disposal?
- Have you been offered a new method of treatment of your waste by a company or consultant and are you wondering if it would be good for your city or town?

This book has been written primarily for local government decision-makers, officers in environment agencies with responsibilities for solid waste management, and others who are concerned to reduce the pollution and the wastage of resources associated with solid waste management.

It is anticipated that readers will come from a wide variety of situations. Some will come from towns or cities that have no satisfactory waste disposal system – where the waste that is collected is just dumped somewhere outside the town. Other readers will come from cities that have already made progress in improving the standards of disposal and have a thriving recycling sector. This book is addressed to readers from both extremes, as well as to those from a situation that is somewhere in the middle. If sometimes the wording in this book seems to suggest that the situations and conditions are the same in every place, this is not the intention of the author. There are very significant differences in factors affecting solid waste management from one location to another. Readers are, therefore, asked to consider carefully the relevance of any suggestion or item of information in this book to the particular situation about which they are concerned. Based on this assessment, comments that are relevant to their locality and its challenges should be considered, and others ignored.

A summary booklet of the key points presented in this book has also been published by UN-Habitat under the title *Solid waste recycling and disposal – key considerations*.

3 Definitions and scope

It may be useful at this stage to define some of the main terms that are used in this book. Some of them are used differently by different people so it is useful to explain how they are used here. These words also indicate the main themes that are discussed in this book.

Solid waste

Unwanted materials that are discarded by households, institutions, offices, shops, restaurants, hotels and factories, and that are not discharged from these premises in a pipe or drain. These types of waste are often referred to as *municipal solid waste*.

Other types of solid waste include agricultural wastes, mining wastes, construction and demolition wastes, infectious wastes from medical facilities and hazardous wastes from laboratories and factories. This book provides only brief references to these other types of waste. Sanitation wastes of human origin (excreta) are not included within

	the definition of municipal solid waste but they are sometimes mixed with municipal solid waste.
Recycle	In this publication this word is used in a very broad sense, to include any activity that plays a part in reprocessing material from the waste stream and returning it to the economy. It includes making use of food waste and other biodegradable wastes as animal feed and soil improver. It does not include reuse (meaning that a discarded item is used again in its original form), or the recovery of energy from the waste. (However, reuse and energy recovery are also discussed in this book.)
RRR	Reduce, Reuse and Recycle. This summarises the aims for upgrading solid waste management, particularly in situations where the standards of disposal are satisfactory[1]. "Reduce" means to reduce the amount of waste that needs to be picked up by the collection agency, largely by changing purchasing habits and making use of waste within the household or business. It is also referred to as waste avoidance. "Reuse" and "Recycle" have been defined in the previous paragraph. RRR is intended to minimise the amount of waste requiring disposal and reflects a change of emphasis from waste management to resource management, in which discarded items are considered to have a potential value that should be exploited as much as possible. RRR should never be seen as an alternative to environmentally sound disposal, which is the basic requirement for residues that cannot be utilised in some way and the foundation upon which effective resource management can be built.
Disposal	This word is used to refer to the final stage of waste management. This usually means the depositing of waste on the ground at an official or unofficial disposal facility.
Treatment	The treatment of solid waste includes any chemical, physical or microbiological process that modifies the nature of waste in order to facilitate the disposal of that waste. Incineration is classed as treatment because the final stage after incineration is the disposal of the solid residues that remain after combustion. In this book, processes that are used to recover energy are also regarded as treatment.
Informal sector	The informal sector consists of working people who are not employees of a government organisation or registered private organisation, and are not officially registered as self-employed. As such, they do not pay tax and are not included in government statistics. Groups of

[1] If the standards of disposal are not satisfactory, the priority for local government spending should be to improve standards of disposal to avoid serious pollution and public health risks, whilst encouraging the informal and formal private sectors to be involved in recycling, and taking any available low-cost measures to promote reduction and reuse.

informal sector workers are usually small, but they may be part of a very extensive network. Family members often work together. The informal sector activities that are considered in this book are generally labour-intensive and most require very little or no start-up capital.

Definitions of other specialised terms and of abbreviations used in this book can be found in Annex 4.

4. The structure of this book

This book is divided into four parts. First comes this short Introduction, so that the reader knows what to expect and what the book aims to achieve. Part A – "Where are we now?" – provides an overview of the current situation, as a starting point for consideration of the options and approaches that are discussed later in the book. Part B aims to provide guidance and suggestions for political leaders and decision-makers, presenting options, as well as policy and planning issues, without going into technical details. Part C is intended particularly for managers and engineers with day-to-day responsibility for waste management, and provides more detailed information to back up the points made in Part B. Part C provides only a small part of all the technical information needed to design and manage recycling and disposal systems. This publication should not be regarded as a technical manual. Rather it is intended to assist in decision-making and to alert the reader to issues that may need particular expertise and experience.

A CD-ROM is included with this book. This disc includes a digital version of this book and the companion publication on collection of solid waste, together with PowerPoint presentations that can be used to present in a visual way some of the points mentioned in this text.

PART A: WHERE ARE WE NOW?

A1 Two viewpoints

It appears that there are two viewpoints about the recycling and disposal of solid waste.

- Consultants and educators in one group tend to focus on recycling, particularly the work done unofficially by people in the informal sector. These experts mostly come from a social science background. Their main concerns are to improve the working and living conditions and the health of waste pickers who collect items that can be recycled or reused, and to increase the incomes, employment opportunities and productivity of these recyclers.
- Experts in the other group come mainly from an engineering background and see waste as a problem. They focus mainly on machinery and the official systems for the collection and disposal of solid waste.

It often appears that neither group pays much attention to the other or knows much about what the other is doing. Both groups are essential and they need to work together in co-operation. They need to understand the challenges faced by the other group and the constraints under which the others are working. The contributions of both groups are needed – recycling by the informal sector has many benefits, and wastes that are not recycled must be collected and disposed of in an efficient and sustainable way. Most available papers and publications present the viewpoint of only one of these two groups. This book aims to bring together both strands and so provide a stronger and more sustainable approach to recycling, treatment and disposal. Integrated solid waste management considers the social aspects and recycling as well as the technical, financial and managerial aspects of all stages from storage to disposal. Integrated waste management involves citizens in general, the business community, informal sector workers, volunteers, the formal private sector and local and national government employees at all levels.

Figure 1 The two viewpoints on solid waste management (SWM)

Characteristic	Group A	Group B
Background	Social science, Environmental studies	Engineering, Public administration
Main concerns	Helping the informal sector RRR, resource management *zero waste*	Good standards of disposal, Control of all aspects of SWM Minimising cost
Blind spots	The inability of recycling to deal with all wastes and the resulting need for safe disposal	Benefits of informal sector activities and recycling, social aspects of waste management
	Both groups have important contributions and should work together. This book is concerned with both viewpoints	

It is not intended to give the impression that the only fields of expertise required in solid waste management are social science and engineering. Other important inputs that are required for efficient and sustainable solid waste management include the disciplines of accountancy, economics, environmental science, geology, law, public health, public relations, business and management.

A2. Some myths and misconceptions

Some wrong understandings regarding solid waste management are quite common, so it is appropriate to expose them at this point. Later in the book these topics will be addressed in more detail, with reasons why these ideas are unrealistic. Among these misunderstandings are the following:

Solid waste management is just a matter of common sense and does not need any specialised knowledge or experience.

> Whilst common sense is vital when any decisions or plans are made, it is not enough. Frequently decisions on technical issues such as the selection of machinery, the involvement of the private sector or the location and management of a landfill are made by political leaders without reference to managers and engineers with specialist knowledge, and the resulting problems are predictable and unfortunate. Every person who receives a solid waste collection service has some ideas about solid waste management, but the wisdom that comes from professional experience is essential when decisions and plans are being made. (Unfortunately the desire for personal gain also sometimes discourages consideration of the opinions of experts.)

Technologies and approaches that are used successfully in industrialised countries can produce the same results in low- and middle-income countries.

This misunderstanding has resulted in the wastage of huge amounts of money. There are many important differences between the situations in the North and the South and these differences mean that methods used in one situation cannot produce the same results in another. Recycling in many low- and middle-income cities is much more effective (in terms of the proportion of material recovered) and more efficient (costing the municipal authorities nothing if it is done by the informal sector) than recycling in many industrialised countries. On the other hand, incineration of municipal waste has been a complete failure in many low- and middle-income countries because of the low energy value of the waste and the high operational costs. The level of public awareness and public demand for recycling also varies greatly from place to place. There are many other reasons why an approach that works well in one situation is a complete failure in another, and these other reasons will be discussed in Section A6.

Recycling, composting and energy recovery can generate large amounts of revenue

The dream of turning garbage into gold is a dream that rarely comes true. There are many growing enterprises in industrialised countries that are dedicated to recycling, composting and energy recovery; in many cases their viability depends on subsidies for recycling and financial penalties on disposal. Informal sector recycling workers in low- and middle-income countries can earn enough to live on because they are prepared to work hard in unpleasant conditions, often with the unpaid assistance of family members, and because they have no overheads or employment costs. In general, attempts by municipal organisations to generate revenue from recycling, composting and energy recovery have not been successful, but rather have increased their costs. There are always exceptions to such generalisations, but they are rare. Carbon funding (Section B5) may open the door for successful municipal initiatives in recycling and energy recovery.

The modern target for solid waste management is "zero waste" – meaning that all waste is recycled so that there is no need for a disposal site.

"Zero waste" is an attractive slogan and concept. It would be very satisfying if all waste could be recycled. There have been isolated examples of very high recycling rates in small community projects in India, but in general and on a large scale it is quite difficult to achieve recycling rates of domestic waste much above 60%[2], and so the remaining waste must be disposed of. In industrialised countries, "zero waste" is often taken to mean that no waste is disposed of in landfills. This can be achieved by intensive recycling and incineration, provided that a use can be found for the ash and clinker resulting from incineration. If "zero waste" – meaning that all waste is recycled – cannot be achieved, it is necessary to have a disposal facility. Since "zero waste" in this sense is not being achieved anywhere – even on a town-wide scale – in low and middle-income countries, (according to the author's knowledge) there is

2 Some cities in low- and middle-income countries claim much higher rates of recycling, but the reliability of such data is questionable. Even in cities with a dynamic and effective informal recycling sector, it is very unlikely that there are accurate statistics regarding the percentage of waste that is recycled.

always a need for disposal facilities. In this connection it is important to remember that household waste is not the only type of solid waste, and that in some places it is only a small fraction of the total.

Waste disposal is purely a technical issue

The reasons why waste disposal is often so unsatisfactory and unsafe, and why so little is being done to improve the situation, are generally not only technical. The technical know-how is available. The reasons for the serious problems that we face are linked to legislation and its enforcement, the low priority given to waste disposal and environmental protection in municipal budgets, the lack of strategic planning, and the failure to develop the necessary human resources, in addition to other factors. There are certainly important technical aspects relating to waste disposal, but most shortcomings in waste disposal are the result of the failure to implement the available technical solutions. Waste disposal is definitely a technical issue, but the other aspects of the problem – institutional, management, financial, capacity development – should not be ignored.

All disposal operations are basically the same.

There are many different standards of waste disposal. Many towns and cities dispose of their waste in uncontrolled and unplanned dumps, which sprawl over a large area and pollute surface and underground water resources, and where the deposited waste is on fire so that smoke causes harmful air pollution, where children and animals have unrestricted access, where the exposed waste is a breeding ground for flies, rats and mosquitoes, and where access for collection vehicles is very difficult, particularly in the rainy season. A sanitary landfill is completely different. It is located, designed, constructed and operated to cause little pollution and maximise the utilisation of the area that it occupies, and when it is no longer used it is restored to blend in with the surrounding scenery. There are intermediate steps between the unplanned dump and the sanitary landfill, and these will be described in this book. It is a mistake to call a dump a landfill and to call a landfill a dump. A decision-maker who has never seen a well operated landfill may believe that all disposal operations are dumps.

Waste with a high organic content should be composted

The composition of a sample of waste is a list that indicates the proportions of various classes of materials (such as plastic, glass and metals) that are found in the sample. It is often said that if the solid waste generated by a city contains a high proportion of biodegradable organic waste (food waste and vegetation), then all the waste should be composted and not landfilled. Such a conclusion is misleading, because the principal factor that affects the viability of composting is generally the demand for the product. Often the demand is strongly influenced by the quality of the product, which can be spoiled by even relatively low levels of contamination of the organic waste by plastic and glass. Even cities with low proportions of biodegradable organic waste are likely to be able to satisfy the local demand for compost with the relatively small amount of organic waste that they generate. In

most cases the viability of composting depends on the demand for the output rather than the overall characteristics of a city's waste.

Good design guarantees good operations

There is an unfortunate tendency to focus effort and investment on the construction of a new facility and neglect the demands of the operation of the facility, in terms of both finance and the necessary human resources. Loans and financial support are provided for construction of facilities, rarely for operation. Operation costs must usually be found from local budgets and are subject to competition from many other recurrent expenditures. The construction of a large facility is a newsworthy event involving publicity, photographs and opening ceremonies, but day-to-day operation is less eye-catching and newsworthy and may degenerate unnoticed as it is gradually starved of resources. It is important to understand that the investment in a new waste treatment or disposal facility is wasted if the plant is not operated in a satisfactory way. There are many cases of sanitary landfills that have been constructed to high standards and at considerable expense, and that have soon degenerated to polluting dumps because insufficient human and financial resources have been devoted to operating them. Sophisticated treatment plants have stopped operating or have performed at a fraction of their expected throughput because of the lack of skilled managers and operators. More attention needs to be given to operation and maintenance.

Depressions make the best waste disposal sites

It is often assumed that the best waste disposal sites are old quarries, swamps and other areas of low-lying ground. For reasons that will be discussed in Section B4, such depressions are often the *worst* places for an environment-friendly waste disposal operation, largely because of difficulties in preventing the long-term contamination of water resources.

A3. The importance of good solid waste management

a) Priorities

Most municipal administrations have many competing demands for the available funds, so it is necessary to understand the reasons why the recycling and disposal of solid waste are necessary urban services that should be allocated sufficient resources. It is easier to understand the reasons why waste collection should be allocated a sufficient budget, but the reasons for providing adequate funding for recycling and disposal are not so obvious, even though they are also important. Every household generates waste and so demands a waste collection service, whereas only the residents living near to waste treatment or disposal facilities may be concerned about recycling and disposal. A politician who is able to deliver a good waste collection service can expect to gain the voters' approval as a result, but there are fewer votes in waste disposal. The consequences of inadequate waste collection – accumulations of waste in the streets, nuisance and the proliferation of rats and insects – are quickly obvious to large numbers of citizens, but poor operation of a disposal site may be noticed by only a few, and the

impact of pollution of groundwater supplies may take years to appear. However, if water supplies are contaminated the consequences can be very serious. Skills and experience in collecting waste are quite widely available, but there may be only a few officials and experts who understand much about waste disposal. These and other factors explain why standards of waste disposal often lag far behind standards of waste collection. It is hoped that this book will clarify the reasons why recycling and disposal should be given more importance.

b) Dangers from dumps

Waste that is collected must be put somewhere. If it is dumped in an uncontrolled fashion it will occupy more land than if it is placed according to a planned system, unless the waste is burned. The burning of waste produces toxic gases as well as smoke and these have been shown to have serious effects on the health of people living downwind. (Japanese research has shown that the largest generators of dioxins [a family of toxic chemicals] in the world were burning dumps [not landfills] in India and China[3].) Unplanned dumps can spoil large areas of land for future use.

Open, uncontrolled dumps are a hazard to local residents and their animals. Children are often attracted to play on waste dumps, exposing themselves to a wide range of serious risks, from cuts and infections, and skin and eye diseases to injury, poisoning and explosions. Animals grazing on waste often ingest large numbers of plastic bags, and many die as a result. A controlled landfill has measures to keep domestic animals and unauthorised people out of the site and to make the waste itself less accessible.

Deposited solid waste produces an offensive and seriously polluting black liquid called *leachate*. It is formed by the decomposition of organic wastes and by rainwater percolating down through accumulations of waste. Leachate is much more polluting than municipal wastewater from toilets and bathrooms, and so can seriously contaminate drinking water resources. Organic liquids such as petroleum-based oils, solvents and biocides[4] that have been discarded with the solid wastes can be even more harmful. Sanitary landfills have measures to prevent such pollution, but they must be well operated for this protection to be effective.

Disease vectors – mainly flies, mosquitoes and rats – breed in uncontrolled dumps. They spread disease and the rats consume food, cause damage and may attack infants. Good operational techniques can greatly reduce this problem.

It is, unfortunately, quite common for the solid waste from towns to be dumped on hillsides and into valleys. Whilst some of the waste decomposes, bottles, cans and plastic bags remain, making it very difficult to restore the land to a useful or safe condition, and the area retains an ugly appearance. Surface water may be contaminated and drainage of floodwater restricted. In comparison, sanitary landfills should be completed in such a way that they blend in with the local environment and even improve the surroundings.

[3] N.C.Vasuki, 2007, personal communication,

[4] Biocides include insecticides, herbicides, rat poison etc.

c) Improvements are possible

Driving collection vehicles on unplanned dumps can be difficult and result in delays and damage to vehicles. There may be large areas where the vehicles cannot go because of the piles of waste, and so the land area is not used efficiently, and dump sites become very large. Some officials and political leaders seem to believe that this is the only way of operating a disposal site. This is clearly not the case, and cost-saving improvements can be made to open dumps even if the highest standards cannot be afforded. A well-operated landfill uses the land area in a planned and intensive way, and ensures that internal site roads are adequate for access. Improvements are possible if sufficient importance is attached to waste disposal

d) Reducing quantities

As will be discussed in more detail in Part B, good solid waste management is not just concerned with improving the standards of operation at existing waste disposal sites. Satisfactory disposal of waste to land requires the acquisition of a site (which can be made difficult by the opposition of local residents) and considerable expenditure for both construction, operation and final closure. If the quantities of waste are reduced, costs are reduced and existing disposal sites have a longer life. There is a financial benefit from reducing the amount of waste that requires disposal.

The amount of waste requiring disposal can be reduced in three main ways. The best is to reduce the amount of waste that is generated by households and businesses. Everything that is discarded requires resources to produce it and to deliver it to the point of use, so any action that reduces the consumption of non-renewable mineral resources (whether used as raw materials or for energy in manufacture or transport) is of benefit to the planet, as well as reducing expenditure both before and after use.

Waste quantities going to landfill sites can also be reduced by reuse and recycling. These practices not only reduce the costs of disposal, but also reduce the consumption of minerals (petroleum, iron ore etc.) and energy, conserving natural resources and reducing climate change effects. Recycling and reuse require that suitable items are either segregated at the time when they are discarded, and then collected separately from other wastes for further sorting or processing, or that the mixed waste is sorted to take out the items that can be reused or recycled. Segregation at the source requires the participation of a large number of citizens and results in less contamination of the items to be reused or recycled. Sorting is needed when the waste is not segregated. Reuse and recycling can reduce waste management expenditure as they reduce the quantities of waste requiring collection, transport and disposal. Reuse and recycling may also make low-cost recycled goods available to low-income groups who cannot afford items manufactured from virgin materials. Reduction, reuse and recycling are often referred to as "RRR".

e) Income generation opportunities

Recycling of waste brings many benefits. Among them is the potential for creating livelihoods, especially in the cities of low-income countries. In many nations the gap in incomes between the rich and the poor is widening, and unemployment causes increasing concern. Recycling, especially when undertaken by the informal sector and

co-operatives, provides income-generation opportunities for significant numbers of city dwellers. Starting with materials that are considered by some to have no value, paying work is created in the activities of collecting, picking, sorting, processing, transporting and trading recyclable materials, and in manufacturing useful items from these recovered resources. These benefits are in addition to the environmental benefits of reduced quantities of waste requiring disposal and reduced demand for non-renewable raw materials which, in many cases, must be purchased from abroad using scarce foreign currency.

f) Climate change

The increasing global concern about climate change has focussed attention on the methane that is produced when solid waste decomposes in the absence or air. Methane has the same greenhouse effect (trapping heat in the earth's atmosphere) as more than twenty times the amount of carbon dioxide (which is the gas normally linked to global warming). Collecting this methane and burning it (to form carbon dioxide) or putting it to a useful purpose is therefore a useful way of reducing the impact of waste disposal on the global climate. For this reason carbon credit payments are sometimes made to landfills that collect and burn (or use) the methane gas that they produce. The reduction, reuse or recycling of materials in the waste stream reduces the demand for raw materials and so reduces the carbon dioxide generated by the extraction, processing and transport of these raw materials. In this way, RRR results in a reduced impact on global temperatures. Climate change is discussed further in Section B5.

A4 The role of the private sector

In the middle decades of the twentieth century it was normal for municipal administrations to collect and dispose of municipal solid waste – and this is evidenced by the fact that household, street and commercial wastes are called *municipal* solid wastes. The legislation governing waste management in some countries may still require that waste management services are provided by employees of municipal administrations. However, in much of the world, solid waste management services were being provided by the informal sector[5] well before municipal employees were involved. The contributions of the informal sector may not have been recognised or appreciated by municipal managers, but in many cases the streets would have been much dirtier and waste management expenditures much higher without informal sector inputs. There is now a growing realisation of the important role that is played by the informal sector, both in collecting waste and in recycling it. Sections B2.5, B4.10 and B8.1 discuss the informal sector in more detail.

The involvement of the formal private sector in all aspects of solid waste management has been enthusiastically encouraged by international development agencies in recent decades. The experience has not always been positive; the blame for failures cannot always be laid at the feet of the private sector partner [Coad, 2005]. Nevertheless, in

[5] A definition of *informal sector* is provided in Section 3 of the Introduction.

the right conditions, some real advantages can be gained by involving private sector expertise, both as consultants and as service providers.

Even when the informal and formal private sectors are heavily involved in solid waste management, the responsibility for co-ordination, for setting and enforcing standards, and for upholding the interests of the citizens remains with the public authorities – municipal, provincial and national.

A5 Investigating the current situation

The first step in planning a journey with a map is to find the starting point on the map. In the same way, any plan for upgrading a solid waste management system or for reducing costs must be based on a thorough understanding of the existing situation, and on the identification of current weaknesses and opportunities for improvement. This includes admitting that problems exist and honestly investigating their possible causes.

A5.1 Information needs

It is common to begin studies of solid waste systems with measurements of waste quantities and compositions, and such data are useful if they are sufficiently accurate and collected in a way that is appropriate to the way that they will be used. However, information on other aspects is also required for a sufficient understanding of the current situation, including current recycling and disposal practices (both formal and informal), the types and nature of industrial wastes that require disposal, arrangements for revenue generation and charges, as well as the levels of public interest in recycling and public concern about disposal. Other information needs include the following two aspects:

A5.1.1 Legislation, policy and standards

In some countries legislation on waste management has not been revised for many years, and was based on the assumption that unplanned dumping was acceptable. Perhaps the laws were framed when urban communities were much smaller than they are today, and the solid wastes themselves had very different characteristics. Outmoded legislation often does not foresee the participation of the private sector. Clearly, such legislation needs to be replaced in order to provide motivation for improvements, set standards and establish a means of enforcing the standards, as well as allowing the involvement of private companies.

Outdated legislation may also prevent the development of effective institutional arrangements. As cities expand rapidly and the technical challenges of solid waste management increase, there is often a need for a fresh look at institutional arrangements. Supervision may need to be more localised, revenue generation may be inadequate, co-ordination between involved agencies may need to be established or strengthened; new means of responding to the increasing technical and social challenges may be required. Inspection of more sophisticated waste management facilities may require a specialised monitoring and enforcement agency.

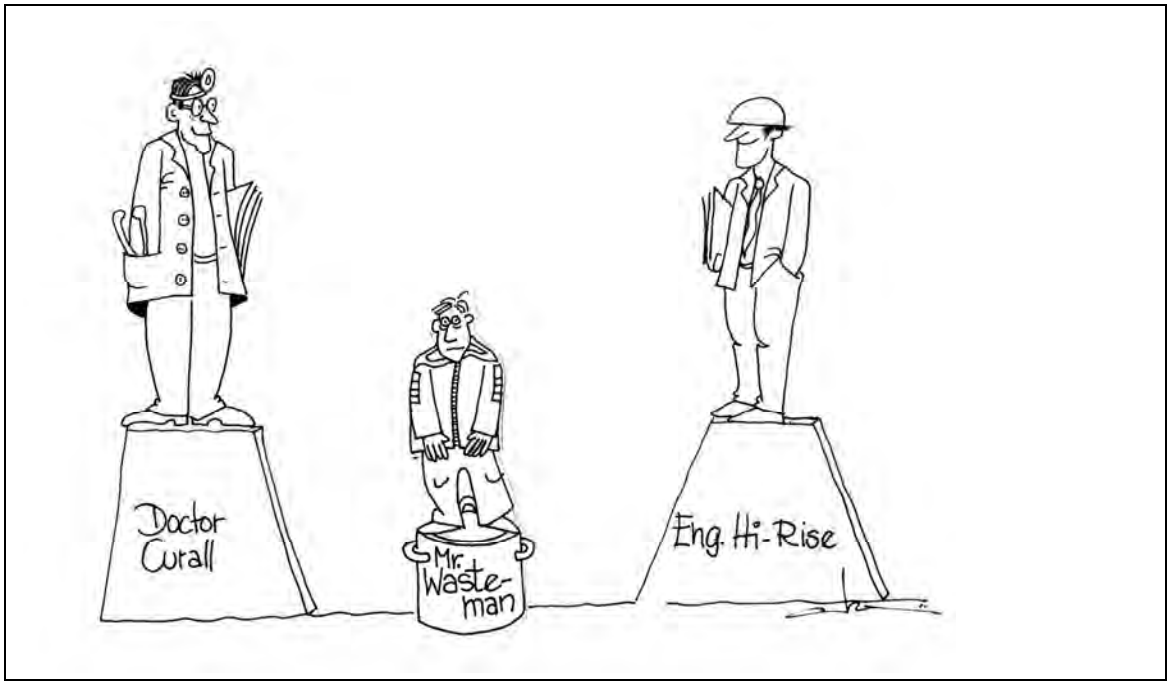
There can be a different problem with new legislation, if the recent revisions are based on standards and policies that are being introduced in some industrialised countries. In such cases the standards may be so far in advance of current practice and so expensive to implement that they cannot be achieved in the current circumstances. An example is given in Box A5.1. If the standards required by the law are too high or are to be introduced too soon, the result may be that no improvement is made.

Box A5.1 A negative impact of over-ambitious legislation

A clear example of the damage caused by unrealistic legislation was provided by a rapidly developing country that follows the European aspiration of requiring that only treated waste is disposed in a sanitary landfill – which is a well-managed disposal facility. (This has by no means been achieved in all the countries of the European Union at the time of writing.) In this particular case a solid waste treatment plant and a sanitary landfill were constructed and put into operation. However, the treatment plant did not perform as expected and could not treat the waste. Since the waste was not treated, the law did not allow it to be placed in the landfill, so it was dumped in an insanitary way on available open spaces with no environmental control, causing serious pollution. It would have been much better from an environmental and aesthetic perspective to place the waste in the landfill, even though it had not been treated. Unfortunately the law prevented this and resulted in no improvement, even after a major expenditure.

A5.1.2 Status, career prospects and public image

Senior managers need to stand in the shoes (or rather the boots) of the landfill site manager – figuratively speaking. An engineer who is managing a large landfill is building the biggest structure in the city (certainly in terms of its volume if not its height) and one that will outlast the buildings in the city. The quality of the site manager's work can have a major impact on the environment – positive or negative – particularly regarding the quality of water resources. In spite of these considerations, the post of landfill manager is often relatively junior and poorly paid, and may be given to someone who has not been trained or otherwise prepared. There may be very little opportunity or incentive for the site manager to develop the necessary expertise, and the appointment may be terminated as unexpectedly as it was initially announced. The working conditions may be unsatisfactory in terms of office accommodation, transport and working hours, and little is done to enhance the status of the site manager and waste management as a whole. The knowledge, skills and attitude of the site manager of a landfill are often the most important factors affecting the actual standards of the waste disposal operation. It is, therefore, important to understand the situation faced by this important member of the waste management team. This issue is discussed further in Section B7.



Cartoon 2 The problem of professional status

A5.2 The quality of the information

There are two essential requirements for information about the current situation:

A5.2.1 The information must be sufficiently accurate.

- High levels of accuracy in numerical data regarding solid waste are hard to achieve for a large number of reasons, including daily fluctuations, problems of measurement and the time involved. When numerical data are provided, they should be accompanied by information about how the data were collected so that the reader can assess the accuracy and reliability of the information that is provided. It is often possible to provide flexibility in a system when data are unsure so that adjustments can be made in the light of experience. In some cases, concerns about the reliability of numerical information may lead to the establishing of a pilot project before committing to full-scale implementation.
- Collecting data on informal sector operations can be difficult because of the widespread nature of the activities and the unpredictability of the methods of working. Other difficulties may arise because of the desire for confidentiality regarding incomes (because of fears about taxation) and the concern to hide activities that may be done in a way that does not meet official standards. Methods are being developed to provide a better understanding of the practices, systems and outputs of informal sector activities. [See, for example, Gunsilius et al., 2011b].
- As a consequence of these difficulties, when an item of data is needed, there is a tendency to use any numerical value that is available, without asking questions about where it comes from or what it applies to. Among the huge range of consultants' reports there are some astonishing examples of the use of data without consideration of their accuracy or relevance, but simply because they are in print somewhere. The results of this usage of any available numbers have sometimes

been the wastage of large amounts of money because unsuitable methods or equipment have been recommended on the basis of inappropriate data.

- There is a tendency to use numerical data that are taken from reports or proposals rather than to observe and measure, without checking on how the data were obtained and whether they are relevant to the particular need. For example, the potential production capacity of a composting plant may be used as the actual production rate, even when the actual production is only 20% or less of the design value quoted by the manufacturer. It is very important to observe actual operations.
- The author remembers reading a journal article about some waste treatment plants with which he was quite familiar. It seemed that the article was describing completely different plants, because it presented the plants as successful, when in fact they had virtually failed. The article gave very optimistic accounts of the contributions that the systems were making, but in fact the actual outputs were almost insignificant. One of the reasons for this lack of accuracy is discussed in the next point.

A5.2.2 The information should include the bad news as well as the good news

Every manager wants every initiative with which he or she has been involved to be a success. Unfortunately some projects are not as successful as others. Even more unfortunate is that fact that the reasons for disappointing performance are not investigated and made public so that others can avoid these problems in future. Perhaps the most regrettable aspect of solid waste management in developing countries is that we do not learn from our mistakes. There needs to be more of a teamwork mentality, so that we wish others to succeed in areas where our own performance has been in some ways disappointing.

At the more junior levels of management, the cause of this situation may be the management culture of the organisation. If any obvious failure or shortcoming is automatically punished, mistakes and problems will be covered up. If the philosophy of senior management is that we all make mistakes from time to time, that we can learn much from mistakes and unforeseen problems, and that it is acceptable to make a mistake once (provided that the same mistake is not made again), there will be a greater openness to sharing information, and the result will be progress and improvement. On the other hand, if problems are denied and hidden, opportunities for learning and improvement will be lost. Furthermore, in organisations in which promotion is given to those who do nothing wrong, the consequence may be that promotion is given to those who do nothing.

Box A5.2 Unwillingness to accept bad news

Some managers and senior officials are unwilling to admit that some of their initiatives have not been successful.

An unforgettable example of this rejection of reality was provided by a consultant who was engaged by an independent body to visit a number of treatment and disposal plants to report on their status so that lessons could be drawn from these experiences. He reported what he saw. His observations included descriptions of plants that were not operating or were operating at well below their design throughputs. When his report was published, he was shunned and denounced as being unpatriotic. He did not receive further consultancy work in this field. By rejecting his findings, decision-makers were leaving the way open for future failures and repeated large-scale wastage of public money, as mistakes which are obvious to an impartial observer are repeated. We need to learn from our mistakes and from disappointments, because both are inevitable but, but if accepted in a positive way they can help us to do better in future.

Annex 2 provides another input on this theme.

It has been said that we learn more from our failures than from our successes, but it seems that many are unwilling to learn the lessons that failures or disappointments can teach us.

A6 International differences

One of the most fundamental principles affecting the recycling and disposal of solid waste is that the wide variety of conditions that affect these activities can vary considerably from place to place. The methods that are used and the standards that are set must be selected according to local conditions and not copied from places where conditions are different. Many problems have arisen because legislation or international consultants have tried to enforce standards that are not suited to the locality. This Section will suggest factors which differ from one location to another and which have an influence on the selection of the best approach to any challenge in the fields of recycling and disposal. Some significant differences are between one country and another, or one region and another. Some of these differences also apply within a country, such as between large cities and smaller towns, according to distances from industrial centres or from a port, according to the quality of the road network, or natural geographical variations. The list of possible differences is long but it is worthwhile to consider which of these factors might affect the success in a particular location of a technology or approach that has been successful somewhere else.

A6.1 International differences affecting reduction, reuse and recycling

The size and activities of the informal sector vary considerably from place to place, as illustrated in Table A6.1. The degree to which the individuals involved are co-operating

with each other and the support they receive from NGOs and municipal administrations also vary greatly. In many cities in low- and middle-income countries there are more informal sector waste recyclers than formal sector waste workers, but this is not the case in every developing country. In many industrialised countries local and national government agencies are deeply involved in recycling. However, if the informal sector is recycling a significant proportion of a city's waste it is probably advisable not to start a local government recycling programme, because the informal sector may not leave enough material for a public sector scheme to be viable. Competition and conflicts may threaten the success of the efforts of both sectors.

Table A6.1 Material recycled by the informal sector in six cities

City	Percentage of waste recycled by the informal sector, expressed as a percentage of the total solid waste generated
Cairo, Egypt	30%
Lima, Peru	19%
Pune, India	22%
Cluj-Napoca, Romania	8%
Lusaka, Zambia	2%
Quezon, Philippines	23%

Source Gunsilius et al. 2011b

The markets for recyclables vary from place to place depending on the types of industries and agricultural activities that are in the vicinity, the distance to the nearest port and other factors. As a result the types of materials that are sought by recyclers also vary.

The amount of recyclable material in the waste generally varies with the level of economic development – more prosperous communities tend to discard more paper, plastic and metals.

The demand for compost is influenced by a range of local factors, including

- the price and availability of other soil improvers,
- the nature of the local soils and the types of crop that are grown,
- the types of local industries (which may add unwelcome heavy metals to the raw waste, spoiling the compost),
- the knowledge of potential users regarding the benefits of compost and
- the attitude of the farmers towards a material that is derived from solid waste.

Arrangements for collecting waste have an impact on the degree to which wastes from different types of sources are mixed together. For example, if domestic wastes and street wastes are collected together by the same organisation, the quality of the compost that is produced from this mixed waste may be lower than if it was made from wastes that are purely of domestic origin. If separate organisations are collecting these

two types of waste, or an organisation uses separate vehicles for each waste type, it is easier to keep these wastes separate and use only the domestic waste for composting.

A6.2 International differences that affect waste treatment and disposal

A6.2.1 Institutional framework

The legal framework, as it affects waste, varies from one country to another. The responsibility for waste collection, recycling and disposal, and for planning, provision of funds and equipment, as well as for enforcement, may be allocated to the various levels of government – national, regional and local – differently in different countries. Policies and standards affecting recycling, treatment and disposal vary greatly (Box A6.1). The legal status of the informal sector is another factor that varies considerably with location, and this affects the proportion of waste that is recycled, and therefore the composition and quantity of the waste that remains to be treated and disposed of.

Box A6.1 A policy that encourages recycling and treatment

European policy requires reductions in the proportion of biodegradable material in the waste that it sent to landfills, and a move away from disposal in landfills towards treatment. One mechanism for encouraging this is to charge a tax on every tonne of waste that is sent to a landfill, in order to make treatment and disposal of residues more competitive in cost. For example, in UK, the tax levied on each tonne of waste sent for landfilling was increased to £56 (US$ 92) in 2011 [CIWM, 2011], and this tax has the effect of trebling the cost of landfilling so that some treatment methods are competitive in price. Without this tax, landfilling would be so financially attractive that very little waste would be sent for treatment.

Governments may set targets for stepwise (progressive) implementation of desired improvements, rather than requiring that the desired methods of waste management are implemented in full immediately. By setting a realistic timescale for the achievement of each stage or milestone, compliance becomes a reasonable objective and improvements can be sustainable.

An important aspect of the legal framework for waste management is enforcement, which can include controls, incentives and financial instruments (such as tax rebates) as well as fines and prosecution. It seems that the capacity for effective enforcement takes time to develop, involving institutional development as well as the growth of motivation and confidence in each inspector. Inspectors can be put under considerable pressure to ignore or underreport noncompliance with environmental regulations, and when this pressure is effective the law has little or no impact. Inspectors who have a strong personal conviction about the importance of protecting the environment and see their work as fulfilling an important need are most likely to be able to withstand the pressures

that they face as part of their work. This kind of commitment may take time to develop and may need to be reinforced by similar convictions in significant numbers of the general public. Another essential component of enforcement is the judiciary – if the courts do not understand the importance of environmental issues and do not impose significant penalties on convicted offenders, the effort of inspectors is wasted and their motivation will diminish. The level of concern for the environment does not appear to be uniform around the world; as a consequence laws and standards that are effective in one country may have no positive impact in another.

A6.2.1 Waste characteristics

There are also significant differences in the nature of the waste in different countries, depending on many factors, including

- economic factors,
- availability and popularity of different types of food (preferred diet, types of food packaging, availability of fruit and vegetables at different seasons etc.),
- moisture content,
- types of industry,
- which building materials are commonly used (since the use of soil bricks or unpaved yards often results in large amounts of soil in the waste), and
- the degree to which some of the constituents are removed for recycling before the waste arrives at the treatment or disposal facility.

In the case of incineration – whether the aim is to recover energy or simply to reduce the volume of the waste – the energy content of the waste as it is received at the incinerator, after waste picking, is often so low that considerable amounts of fuel are needed to maintain the required temperatures, and so this method is not economically feasible in some countries.

A6.2.3 Other essential considerations

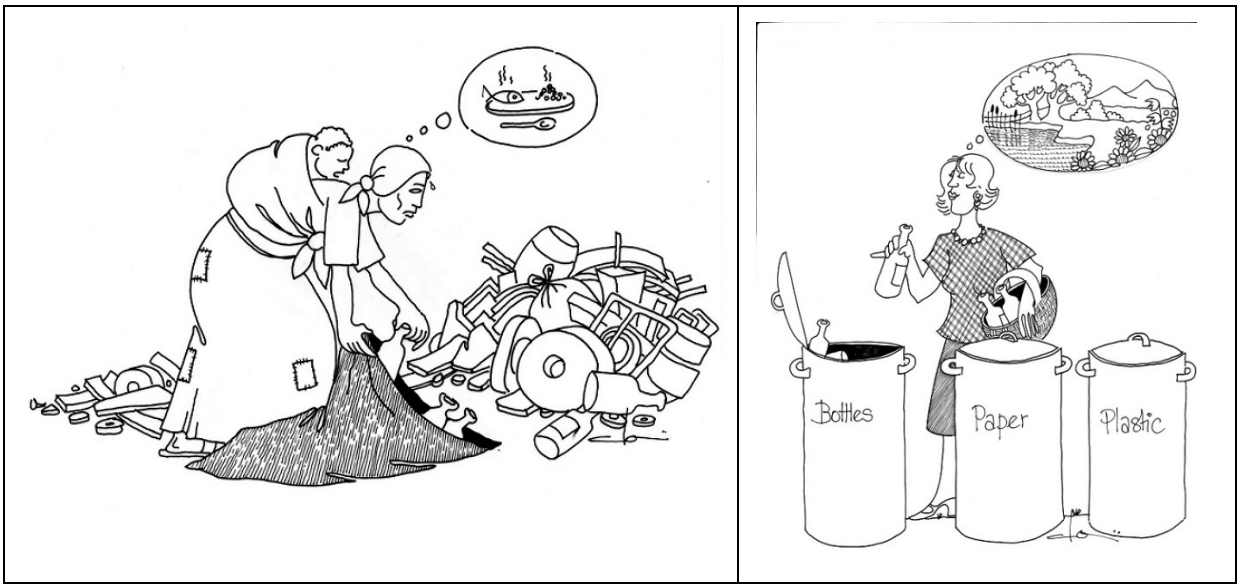
The suitability of treatment methods depends not only on the characteristics of waste (as it is when it arrives at the treatment plant) and the financing mechanisms, but also on the skill levels of the operating staff and the demand for the output of the process. Some treatment processes generate electricity as their main output, and their financial viability may depend on being able to sell the electricity for a higher price than is paid for electricity that is generated in a conventional way using fossil fuels.

Many factors affect the most appropriate approach to landfilling, including the availability of suitable land, the sensitivity of local water resources to pollution, and the local geology. The weather, particularly the rainfall and the potential evaporation, has an impact on the measures needed to control water pollution.

A6.3 International differences in public attitudes towards recycling and disposal

The reasons why members of the public (who are not employed by waste/resource management organisations) become involved in recycling can be completely different

from one nation to the next. For some, recycling is the only available option for earning enough to live on. Others spend part or all of their working day collecting or processing recyclables because this activity provides a better income than other options for earning. In some prosperous countries members of the public spend time to segregate their waste because of environmental concern or legislation.



a) In low-income countries b) In prosperous countries

Cartoon 3 Why do people get involved in recycling?

Public attitudes towards waste itself, and towards the recycling, treatment and disposal of waste, can have an important impact on the selection and success of waste management initiatives. The influence of the community may be expressed as public demand or opposition, willingness to pay, compliance with regulations, and voting at local elections. Willingness to participate in recycling by segregating the household's waste is another reflection of attitudes that vary greatly within and between nations. Public opinion can affect the recruitment and status of professionals and other staff – if environmental protection is generally regarded as being of high importance there may be greater interest in choosing a career in waste management.

Public attitudes are shaped by many factors, including culture, education, personal and collective experiences, and the media. Waste management organisations can influence public opinion, either positively by taking the initiative to provide *good news* stories to the news media or negatively by neglecting this opportunity so that only unfavourable news about waste and recycling is found in news reports. Site visits and visits to schools can improve public attitudes and co-operation. (See also Section B6 below.) Environmental NGOs may also be a significant influence, usually towards recycling and away from incineration and landfilling.

The building of awareness and of the demand for environmental improvement takes time and requires repeated reinforcement. (Many trace the beginnings of environmental awareness in the USA to the book "Silent Spring" which was published by Rachel Carson in 1962.) Environmental disasters (actual or potential) also seem to play a part in

creating awareness and demands for improvements. (Examples are Love Canal[6] in the USA and the discovery of children playing with drums of toxic waste in UK.) Measures that aim to reduce pollution and reduce cost, and that depend on public co-operation, may be effective in countries with high levels of environmental awareness, but they are likely to have little impact where there is little concern for the shared environment.

In some countries consumers are prepared to pay more for recycled paper products, preferring them to products made with virgin pulp. In other countries there is no significant market for recycled paper. Similar choices may be seen regarding waste-derived compost and other products made from recycled waste.

In many of the more affluent countries it is now considered normal that waste should be segregated at source so that it can be collected in separate streams for recycling. Box A6.2 provides two examples. This readiness to segregate is not found in every country.

Box A6.2 At-source segregation in Switzerland and England

The author moved to eastern Switzerland in 1997 and soon found that he was required to segregate his waste into eight categories – three colours of glass, cans, plastic bottles, paper, cardboard and residual waste. This required extra effort from residents and extra storage space within the home, but was done because there was general public support for this system, because of enforcement measures, and because the disposal of unsegregated residual waste was charged according to volume. (Residual waste was not collected if it was not discarded in special plastic bags for which the purchase price included a considerable fee.) Charging for waste collection in this way provided a financial incentive for discarding as much as possible as segregated waste, because there was no charge for discarding the materials destined for recycling. In addition to this arrangement, there were also neighbourhood composting schemes. This degree of segregation, and the compliance with the requirement that waste could be discarded only in expensive official plastic bags, could not be realistically expected in many countries, but it was operating successfully in Switzerland.

In some European countries collection trucks are fitted with devices that automatically weigh each load of waste and invoice the generator according to the weight of waste collected. In general, the citizens receiving such a collection service are prepared to pay the costs of the collection and disposal of their own waste, and do not put their waste into a neighbour's bin or discard it illegally on public ground. Paying for the collection of residual waste encourages them to segregate out and recycle as much as possible, and to reduce the amount of waste that they generate.

Segregation of waste in the home has been promoted and encouraged for many years in the UK, and long campaigns of persuasion and publicity have been effective in encouraging most residents to segregate their waste. When the author is living in England he is required to sort his waste into three categories – glass, other

[6] See Box B3.2 in Section B3.6.

recyclables and mixed waste. The only incentive to minimise the amount of mixed waste is the refusal of the collection crews to empty the mixed waste bin (which is of a standard size) if it is overflowing, or to collect waste that is not in the official bin.

It appears that there is a reasonable (though variable) level of environmental awareness in Europe, and that citizens are more willing to segregate their waste – in order to "do something for the environment" – than to take other steps to reduce pollution, such as reducing the amount of waste they generate or reducing their consumption of vehicle fuel or consumer goods.

In the UK and probably in other European countries there was an interesting change of attitudes towards waste management in the last decades of the twentieth century. Most waste management experts born in the years 1940 to 1960 seem to have come into a career in waste management more or less by accident, rather than having had this field of work as an aspiration from their youth. More recently, young people have been deciding on a career in waste management even before starting their university studies. This change indicates a significant shift in attitudes to waste management that probably has not been observed globally.

There seems to be one significant exception to the rule that there are large differences between attitudes in different countries. It is the opposition of the public to any plans to locate a waste treatment plant or landfill close to their homes or places of recreation. This opposition appears to be universal.

A6.4 International differences in service providers

The capacity of a municipal organisation can be defined largely in terms of the skills, experience and knowledge of the staff, the effectiveness of the management and the financial and physical resources that are available to the organisation. The capacity that is required to operate a solid waste treatment plant or a landfill depends on the type or sophistication of the facility. For example, the skills needed to operate a basic controlled landfill are much less than those required to operate a sophisticated sanitary landfill (with equipment to utilise the gas that is produced and a plant to purify the polluting leachate coming from the waste). The design of a treatment or disposal facility should be compatible with the capacity of the organisation that will operate it. As will be discussed in more detail in Section B8.2, the level of capacity needed to monitor a private sector operator effectively is similar to the level needed to actually operate the facility or service *in-house* (that is, by public sector staff).

The capacity of a municipal or local government organisation depends on the following factors, among others, and it is observed that these factors vary from place to place.

1. The skills, experience and knowledge of the staff, as well as the fields of relevant expertise that are covered by the staff vary from city to city. This competence is not so much related to university degrees and training courses attended but more to on-the-job training and the confidence and ability to solve new problems. A high staff turnover rate or frequent internal transfers of staff from one department to another result in lower capacity.

   The importance of experience cannot be overemphasised. Experience develops both confidence and understanding. The necessity of experience is one reason why it is difficult for an organisation to operate a sophisticated facility if it has had no previous experience of facilities with at least some aspects in common with the new facility, and it is one of the reasons for advocating stepwise or progressive improvements.

   All medium-sized and large treatment and disposal operations depend on mechanical or electrical machinery – to different degrees, according to the complexity of the facility. Maintenance of machinery therefore plays an important part in ensuring the reliability of the system. The requirements for successful maintenance include appropriate specification of the equipment before purchase, a system of scheduled preventive maintenance, skilled mechanics, the necessary tools and facilities, and ready access to spare parts. A shortfall in any of these aspects usually results in unreliable operation and additional expenditure. In situations where maintenance capacity and performance are inadequate, technical sophistication should be avoided and efforts should be devoted to improving maintenance standards.

   Access to new information and the experience of others can also play a part in developing capacity. Information can be obtained by reading relevant books, journals and conference proceedings, by attending carefully selected conferences and meetings, and by access to the internet to learn from websites and to network with others by e-mail. Opportunities for building networks and sharing information have been very successful when supported by employers, but in many organisations it is very difficult for technical staff to access the information that they need to improve their performance.

2. The motivation of the staff in waste management organisations is not geographically uniform. The willingness of the staff to develop their skills and take reasonable risks is affected by the working environment within the organisation. Staff motivation is influenced by the career structure, the opportunities for personal development and the allocation of responsibility, in addition to the more obvious factors of pay and working conditions.

As these factors vary from one organisation to another and from one country to another, in the same way the capacity of municipal organisations to manage and operate different types of waste facility will vary. The level of capacity must be taken into account when deciding on the methods that are likely to be successful in a particular location.

In some places two or more cities join together to provide and operate a waste treatment or disposal facility that is used by all the participating cities. This option will be discussed further in Section B8.3. The financial benefits and the success of such inter-city co-operation depend not only on the distances between the contributing cities

and the shared facility, and the quality of the road network, but also on the willingness of each participating administration to surrender some of its authority and work for the common good. The differing allocation of responsibilities between cities and regional, provincial or district organisations may also have an impact on the suitability of shared disposal facilities. Some city leaders have been unwilling to hand over any of their responsibilities to such partnerships. Inter-city partnerships also require a means of settling disputes that is accepted by all the partners. It has also been found that some local government administrations are unwilling to allow waste from other communities to be brought into the area of their jurisdiction. In some contexts there may be great financial and technical advantages in the sharing of facilities, but joint action of this kind may be ruled out for emotional or political reasons.

A6.5 Taking account of these international differences

The next Part of this book is concerned with planning. Planning involves (i) the agreement on the formulation of a policy which states objectives and priorities, (ii) the development of a strategy to allocate responsibilities and outline implementation stages and timing, and (iii) the preparation of more detailed action plans. The whole planning process must take into consideration all of the international differences that have just been mentioned.

Many nations have published formal documents which may be known as *national strategies* or *master plans* and generally include these three stages of plan formulation. In many cases they have been prepared with considerable contributions from outside consultants. If most of the work is done by outside consultants there are the two risks of (i) a lack of ownership by local decision-makers, and (ii) an inadequate allowance for local conditions and constraints. If the policy is prepared by national experts, there is the risk that they feel obliged to include items that they find in the policies of other nations, without adequate consideration of local factors and international differences.

Box A6.3 gives examples of two items commonly found in national policy and how their inclusion in a national strategy may have undesirable consequences in certain contexts.

Box A6.3 Possible negative consequences of common policy elements

a) The waste management hierarchy. This hierarchy lists the various ways of dealing with wastes in order of priority. One version states that reduction is the best solution to waste management issues, followed by reuse, with recycling being the least desirable of the three. Another, expanded version, widely used in Europe, can be summarised as follows:

Priority	Measure	Explanation
Highest	Prevention	Taking action so that the particular material is no longer discarded as waste
	Minimisation	Taking action so that the quantities of this material that are discarded are as small as possible
	Reuse	Using the waste item for its original purpose again and

		again
	Recycling	Changing the form or nature of the waste material so that it can be returned to the economy and used for a different purpose.
	Energy recovery	Using the waste material to obtain useful energy that can reduce the consumption of fossil fuels
Lowest	Disposal	Relocating the waste material in the environment in a way that causes the minimum negative impact on the environment

These hierarchies are sometimes understood to imply that disposal is of no significance and all efforts should be concentrated on the measures at the top of the hierarchy. The result of this thinking is that wastes which are not reused and recycled, and residues from energy recovery, are discarded in a careless way. This is not the intention of the hierarchy. Whilst it is right to work to increase the reliance on measures of high priority, it is essential to provide satisfactory disposal for the remaining wastes. While there are residues there must be good disposal.

b) The *polluter pays* principle This policy element can be summarised as requiring that the person or organisation that creates waste or other forms of pollution should be responsible for paying all the costs involved in repairing any damage caused by their waste or action, and compensating any who have been adversely affected by it. An obvious application in waste management is that waste generators should pay the full costs for the collection, treatment and disposal of their waste. Whilst this is fair and just, it can result in serious pollution because waste generators may prefer to discharge their waste illegally at no cost rather than paying for it to be collected or paying a fee at the entrance of an official disposal site before delivering the waste for proper disposal. The environmental damage caused by illegal dumping of waste can be very expensive to remedy, and, if it is not known who has dumped their waste in this way, the costs must be borne by an organisation other than the polluter. Waste collection and disposal services are not the same as some other infrastructure benefits (such as electricity or piped water) for which the household suffers deprivation if the service is not paid for so that the service is cut off. Waste generators do not suffer in the same way if they dump their waste illegally to avoid payment; it is the whole community that suffers. The *polluter pays* principle is therefore only applicable where the level of public awareness and the control and enforcement of waste management practices are sufficient to ensure that all but a very few waste generators are prepared to pay the full costs of waste management rather than to save money by dumping their waste illegally. This willingness to pay is not found in the majority of the population of many countries.

There are other common policy principles, such as the proximity principle, the precautionary principle and the principle of proportionality, but these do not need to be discussed here.

In order to assess whether a particular method of treatment or a particular approach to recycling or disposal is likely to be sustainable and beneficial in a particular situation, it

may be necessary to collect a considerable amount of numerical and factual data. It is also necessary to become well acquainted with the proposed development. It is very useful to see the process or approach in action somewhere else. Regrettably decision-makers often do not take this step (of checking that the proposed system is working satisfactorily in a similar situation elsewhere) and conclude that the process or approach will deliver the same results in their own city. Viewing the process or approach in action elsewhere is an essential step, *but it is only the first step*. After learning as much as possible about the factors leading to success or failure, it is necessary to go back to one's own location and collect all necessary information (referring to all the points mentioned earlier in this Section) in order to determine if the local conditions are right for the proposed process or approach. Salesmen can be very persuasive and enthusiastic, and they may offer excellent hospitality, but they cannot offer objective advice. It should not be assumed that the promoter of a particular system, on a short visit to a city, will take sufficient account of factors in the target location that could lead to failure or serious financial loss.

Sometimes it is possible to test a production process or means for facilitating a necessary behaviour change on a small scale before embarking on the scale of operation that is foreseen. In some cases it may be possible to test the market for a waste-derived product using an equivalent product brought from somewhere else.

Each situation has its peculiar features and constraints, so in all aspects of solid waste management it is important to take account of local factors before making a decision. If this is not done the result may be a huge waste of money. There are many examples to support this conclusion – some examples are well-known, but many more are kept confidential (though often the decaying remains of failed treatment plants bear silent witness to the failure to take account of international differences).

PART B DEVELOPING A STRATEGY

B1 The planning process

B1.1 Key considerations in planning

There are various approaches to planning and various terminologies, but the following terms for the stages of planning are often used.

- Planning starts with the formulation of a **policy** which states the principles and priorities to be followed in developing solid waste management systems. For example, most waste policies devote considerable importance to reducing the amount of waste that is disposed to the ground, by advocating reduction and recycling. An important element that is missing from many strategies is the recognition of the value of incremental or stepwise improvements instead of attempting huge leaps forward.
- The outline plan for implementing the policy is called a **strategy**. The strategy sets objectives and milestones (targets in terms of time) for monitoring progress in achieving the objectives, and indicates the organisations that are to be responsible for making this progress. Waste management strategies must set realistic time frames, since the development of new landfills can take several years and the necessary strengthening of capacity in terms of human and financial resources can be a slow process.
- The steps required to implement the strategy are elaborated in a document that is often called an **action plan**. The action plan should propose actions to be completed in the set period (between two and ten years), with provision for amendment during that period, and include an investment plan that estimates anticipated capital and recurrent expenditures.

Policies and strategies should be seen as tools, not public relations gimmicks. Some national strategy documents are attractively presented and it seems that their purpose is to show the citizens, national politicians or international development agencies that the solid waste management sector is modern and progressive, rather than to provide a basis for taking action. Sometimes plans may be prepared without any serious determination to adopt the policy and implement the strategy.

It is easy for a municipal or national administration to hand over responsibility for preparing planning documents to international or local experts who might do the work with very little input from the institutions actually responsible for implementing the plans. Documents prepared in this way tend to be ignored. For example, foreign consultants may prepare attractive documents that call for sophisticated recycling and treatment technologies that the nation concerned does not want and cannot afford. If there is no sense of ownership of the plans nor a commitment to implementing them, the plan documents are solid waste.

The chances of the plans being implemented will be much greater if there is a widespread sense of ownership of the proposals and commitment to their implementation. The sense of ownership can be established and strengthened if solid waste management decision-makers and practitioners are consulted in a meaningful way during the preparation of the strategy and action plan. This consultation process should demonstrate that all reasonable contributions are carefully considered. It takes time to collect and assess recommendations and comments, but time spent at this stage in the planning process can reduce the time and effort that are needed at a later stage to inform local government decision-makers about the final plans and to persuade them to adopt them.

An important stage in the planning process is the development and consideration of a range of options, instead of assuming that there is only one way to proceed with making improvements.

The plans that are prepared should be realistic and achievable, taking into account the existing financial constraints, the availability of skills and experience, and the time needed to make the necessary changes in the habits and behaviour of the citizens. If the time allowed for making improvements is too short, the plan will lose credibility and the failure to comply with the requirements of the plan may lead to frustration and feelings of alienation or inadequacy. Defining milestones or stages in the upgrading process is preferable to assuming that the desired improvements can be achieved in one big leap.

Before being finalised, the policy and strategy should be circulated for review by all concerned agencies and a broad spectrum of civil society, so that the resulting comments can be taken into consideration and there is an increased sense of ownership of the plans.

First efforts and prototypes are rarely perfect. In most spheres of activity improvements can be made on the first product. This is true of plans. Corrections should be made when unwelcome and unforeseen consequences appear. Clarifications and additional explanations may be needed. It may be necessary to make some exceptions to general requirements. Timescales may need to be revised. The policy and objectives would normally remain unchanged, but strategies and plans need to be amended and updated from time to time.

The Strategic Planning Guide for Municipal Solid Waste Management [Wilson et al., 2001] is a valuable and comprehensive resource for planning. It can be downloaded on the internet (the weblink is in the list of references) as well as being available on CD. It presents an interactive process which involves all stakeholders. Among its many recommendations is the suggestion that municipal organisations may be able to improve their credibility and gain public support early in the planning process by making relatively small improvements that show their commitment to a longer and deeper process of development.

B1.2 Objectives

Often there are two sets of objectives. One set includes objectives that are written on documents and stated in public, such as protecting the environment, sustainable development and getting value for money. Objectives may be selected for official documents because they reflect practice in the countries that are most advanced in solid waste management, or because they are dictated by a funding agency. However, looking at the way some decisions are made, it seems that many decision-makers have another set of objectives which are not written down and which may even be subconscious. Examples of these unwritten objectives are wanting to find an easy solution which will not cause problems until after retirement or the next election, or wanting to have a *monument* – a large treatment unit that is very modern and impressive. It appears also that in some cases the unwritten objective is to gain as much personal financial benefit as possible. Our choices, not our declarations, reveal what our true objectives are.

Objectives should be a tool. Sometimes an objective is like a tape measure that indicates whether we have achieved enough. Sometimes an objective may be used as a knife, to cut away ideas and proposals that are not really necessary. An objective is a compass to indicate the direction to be followed. Clearly, if objectives are to be effective in these ways they must be realistic and affordable – taking into consideration local conditions and resources – and have the commitment of political leaders and senior management.

The objectives in a policy should be used as tools in the development of the strategy.

B1.3 Some basic issues for possible inclusion in a policy

Concerning the recycling and disposal of solid waste, the following issues should be given thoughtful consideration at the highest level, and the consensus view on each should be included in the policy.

An essential first step is to review the existing administrative structure for all issues and aspects of solid waste management, to ensure that all aspects are covered, and that responsibility for each issue is allocated to the appropriate administrative level – central, provincial or municipal. If it is found that the capacity at the preferred administrative level is inadequate for any particular task, it may be necessary to make interim arrangements, such as moving a responsibility to a higher level while capacity at the desired level is built up, or involving the private sector. (For example, if inspection is considered to be a task for provincial administrations, but there is currently an insufficient expertise at provincial level, it may be necessary to manage inspection at the central level for two to three years while provincial inspectors and managers are trained.)

Box B1.1 lists some of the tasks related to solid waste management which should be allocated to particular government organisations at one or more of the three administrative levels. In order to minimise problems of communication and decision-making, the number of ministries and departments involved at any administrative level

should be kept as small as possible. The exception to this rule is that inspection, monitoring and enforcement should be kept distinct from operational functions.

Box B1.1 List of some of the government functions related to solid waste management

Legislation: Developing legislation, by-laws and regulations relating to all aspects of solid waste management, ensuring that they are appropriate and have robust means of enforcement.

Planning: Determining and communicating policy, strategy, procedures, norms and standards, and reviewing them regularly.

Co-ordination: developing effective links between government departments and ministries that are concerned in some way with solid waste issues.

Capacity building: Estimating appropriate levels of resource provision and effective management structures for all relevant organisations, and developing mechanisms for meeting the resource needs. Developing effective training programmes is clearly an important aspect of capacity development, but consideration should be given to all relevant human resources aspects, including career structure. Enabling public sector clients to work effectively with the private sector may be one particular aspect for which capacity should be strengthened.

International relationships, including training opportunities and directing bilateral and multilateral aid.

Monitoring, inspection and enforcement, including legal support for prosecutions.

Data collection, including data on revenues and costs, quantities, manpower, operations, pollution, contractors and prosecutions.

Social aspects, including informing and involving the public, and the involvement of the informal sector. Promoting waste reduction and recycling, and developing the demand for compost and goods made of recycled materials.

Operation of recycling and disposal facilities, whether at municipal or district level or monitoring the performance of private sector partners.

Particular issues to be considered in the development of a policy may include the following.

- The role of the informal sector and the desired relationship with local government. In many places the recycling of waste by informal sector workers has been ignored or even opposed by local officials, but there are cases in which municipal administrations have formed mutually beneficial partnerships with informal sector recyclers, and research[7] shows that informal sector work in this field brings significant economic and environmental benefits. A particular aspect of this issue is whether informal sector waste pickers will be allowed to work on disposal sites.
- Segregation at source Some recycling options require that waste is segregated at source and collected separately so that the desired components of the waste are not

[7] Gunsilius et al. 2011b

contaminated by unwanted materials. It is often necessary to invest considerable resources into informing the general public and motivating them to segregate their waste, before a sufficient degree of segregation can be achieved. The additional costs of separate collection of the segregated streams must also be considered.

- The extent to which the private sector and its contractors will become involved in recycling and treatment of solid waste. Decisions on this issue depend on the role allowed for the informal sector, as well as on political attitudes to private sector involvement and financial implications.
- The level of resources that will be devoted to the disposal of residual solid wastes in order to improve the standards of landfill operation and reduce the level of pollution generated by waste disposal. Consideration should be given from an early stage to the rehabilitation of the site when no more waste is to be deposited there. A particular aspect of this issue is the appointment and seniority of the site managers of landfills.
- Revenue generation to cover waste disposal costs. A key factor of this issue is whether there will be a gate fee payable when wastes are delivered to the landfill, and if gate fees are imposed, who will be required to pay this fee and what measures will be taken to prevent illegal dumping.
- The approach to be used in legislation. In particular: will the concept of stepwise or progressive improvement be embraced, or will the law require immediate improvements to a high standard of operation and monitoring. It is also vital to consider how the legislation will be implemented and enforced.
- The means to be used to encourage and enforce higher standards of waste disposal. This not only concerns the selection of the agency that will monitor disposal operations, but also the resources to be devoted to the training, equipping and motivation of inspectors. Encouragements to improve performance may also include grants or other financial incentives from central government, and carbon credits paid by means of the Clean Development Mechanism discussed in Section B5. Since the goal is to improve operational performance, rather than simply to encourage the construction of facilities (which may subsequently be operated badly) it is better to reward operational standards rather than the existence of facilities. For this reason, carbon credit arrangements, if properly administered, can be effective in motivating good operational practice.

These issues will be discussed further in the coming sections.

B1.4 Challenges to planning

There are several reasons why planning in this way may not be carried out or is given a low priority, or perhaps handed over to external consultants. These reasons include:

- Absence of a culture of planning – The lack of delegation and the volume of administrative work to be handled by senior officials may result in a lack of time for consideration of planning.
- Conflicting currents – Local politics, the proposals and priorities of international donors, as well as the demands of environmental agencies and NGOs, may result in

a confusing array of urgent tasks and programmes, deflecting attention from wider or longer-term considerations.

- Uncertainties – The cycle of elections and the resulting changes in local government political and administrative leadership, or other reasons, may lead to the absence of a long-term – or even a medium-term – view. If actual financial allocations to various municipal functions are made in an ad-hoc and unplanned way, according to urgent needs rather than budget plans, it becomes difficult to have confidence in the value of planning. If decisions are made by the senior executive or by local councils without reference to agreed plans or the relevant experts, the motivation for planning dissolves away. If decisions about investments or recurrent financial allocations are made at national level, the relevance of some aspects of planning at local level becomes questionable.
- Lack of data and information – Plans should be based on reliable and relevant data. These may include numerical data or objective descriptive information about experience elsewhere. However, a strategy should be based on local conditions and resources, not copied from somewhere else or excessively influenced by outsiders. Some of the challenges associated with obtaining reliable data are discussed in the next Section and also in Section C1.
- Difficulties leading to delays – Because of the challenges associated with identifying, agreeing on and acquiring a new waste disposal site, and the time required to construct a new waste disposal landfill, municipal decision-makers are tempted to postpone taking action on waste disposal issues for too long. The threat of public opposition may cause them to delay any decisions until after the next election. (This mentality has been characterised as the "NIMTOO" syndrome – *not in my term of office* – which can be added to the NIMBY[8] syndrome as a hindrance to waste management planning. A mayor or senior executive may decide to delay an unpopular decision or a major expenditure until after her/his term of office, in order to avoid the associated hard work or political challenges.) Waste management plans should have a time horizon of at least ten years, and it is preferable that planners should look even further ahead, but the anticipated difficulties sometimes cause officials to avoid the issue until the disposal site is nearly full and the situation has become an emergency.

B1.5 Information inputs to the planning process

Sometimes the biggest problems are caused by visits overseas. City officials see large incinerators or other types of waste treatment plant in prosperous cities and decide that this technology is the answer to their problems. There are many cases of sophisticated plants that have failed (or even never been used) because of the costs of operation, the unsuitability of the waste or the problems of operational control and maintenance. It is essential to focus on the outcomes, not the mere presence of the facilities. It is better to have a clean city, even if simple technology is used, than to have advanced technology

[8] NIMBY = *Not In My Back Yard*. NIMBY refers to the reluctance of citizens to accept the siting of any waste management facility near their residence.

and a mess. *Appropriate technology is sustainable technology*[9]. (In this context, "appropriate" means suited to the local conditions, capacities and needs, and "sustainable" means not only that the system keeps operating, but also that it does no lasting damage to the environment.)

In many cases the best way forward to is improve the techniques that are already being used, rather than to change to a very different method. Too often it seems that senior officials are unwilling to listen to their own experts or to seek objective and independent advice. The salesmen of the manufacturers of sophisticated recycling and treatment installations make bold (and sometimes false) claims for what their products can do; they are enthusiastic and they are able to offer attractive inducements. The results have been seen in many countries, again and again: facilities and machinery not working, and the loans used to buy them being repaid for years after the facilities have stopped working.

For all planning it is important to know the quantities of waste that are to be managed. Attention is often focussed only on household waste, but in some situations the quantities of waste generated by industrial and commercial activities are comparable, if not greater. For some purposes measurements or estimates of waste quantities arriving at the waste disposal site are enough. If a contract for waste treatment or disposal stipulates the quantities of waste to be received, more accurate measurements of waste quantities should be obtained before signing the contract.

Solid wastes can be categorised in various ways. They can be categorised according to the type of the source – household, commercial, industrial etc. They may also be categorised according to the agency responsible for collecting them or the way in which the service is charged. Another system of categories may be to consider whether the waste is inert, biodegradable, difficult or hazardous. According to the use to which the data will be put, it may be necessary to measure the quantities of waste according to any of these systems of categories. Landfills can accommodate a wide variety of waste types at fluctuating daily rates, but most types of treatment facility require waste of consistent characteristics coming in at a relatively constant rate.

Considerable effort is often devoted to measuring the composition of the waste – the relative proportions of the various types of material that constitute waste in a particular category. Such information may be of little value unless the method of sampling and measurement has been carefully designed to suit both the local conditions and the use to which the resulting data will be put. For example, costly errors are made when the amounts of recyclable material in the waste stream are confused with what can actually be recycled. Section C1 provides more information on this topic.

[9] Jarrod Ball, personal communication, 2012

B2 Options for reduction, reuse, recycling

B2.1 Introduction

Costs are incurred by the handling of every tonne of solid waste that must be transported and disposed in a landfill. Reducing the quantity of waste by any method that costs less per tonne than the expenditure on transport and disposal is therefore a financial benefit to the public.

There are also environmental costs associated with the use of resources and the generation of waste. Global warming is the result of the consumption of fossil fuels to provide energy when raw materials are extracted and processed in order to make goods that are later discarded as waste. Fossil fuels are also burned when raw materials, finished goods and waste are transported. Natural resources – especially non-renewable resources in the form of ores and minerals, as well as petroleum and other fossil fuels – are depleted by the extraction and processing of raw materials, in the manufacturing of goods, and in the disposal of waste. Any means of reducing the scale of carbon dioxide emissions that cause climate change is a universal benefit. Any means of reducing the environmental damage associated with consumption and waste generation is to be welcomed.

The best way of reducing the financial and environmental costs of consumption and waste generation is to consume and discard less. Reusing items that might otherwise be discarded brings a similar benefit. If materials that would otherwise require disposal can be processed in a way that causes a low level of pollution and so that the demands for raw materials and energy are reduced, there is an environmental benefit. If this process of recycling creates employment, there is a significant economic and social benefit.

(There is sometimes confusion regarding the definitions of reduction and reuse, because materials that are reused instead of being discarded represent a reduction in waste generation. In this book, measures that are used by the generator to reuse items or materials are considered to be part of reduction, but if the items or materials are prepared for reuse by an external agent – and not the generator – this is classed as reuse.)

B2.2 Reduction

There is a wide range of measures that can be used to reduce the generation of waste, and the selection of the most effective measure varies according to the particular economic sector and a range of local factors and conditions.

Reduction is also taken to include the reduction of environmental impact by replacing highly polluting materials by alternatives that cause less pollution, are less hazardous or degrade naturally. Some examples of measures to reduce waste are introduced here, but the list is far from complete.

a) Cleaner production

Wastes from industries can be reduced in a variety of ways, such as

- modifying production processes so that smaller volumes of chemicals are needed, or less polluting chemicals are used;
- making more efficient use of raw materials;
- improved production control so that fewer items are scrapped because they are substandard;
- internal reuse of scrap, and redesigning products so that less waste is produced.

Measures of this kind, and changes that result in lower energy consumption, usually generate savings for the factory owner, and so it is reasonable to ask the owner to pay at least part of the costs of a cleaner production advisory service. Publicising case studies may encourage other factory owners to participate in the drive for cleaner production.

b) Other measures adopted by manufacturers

- Some manufacturers reduce the environmental impact of their packaging by selecting materials that can be recycled. An example of this is the replacement of moulded expanded polystyrene blocks used in packaging to protect electrical goods by moulded formers made from paper pulp.
- Compact fluorescent lamps (CFLs) are replacing conventional incandescent light bulbs. They have a longer working life than incandescent bulbs and so there will be fewer light bulbs in the waste in the years to come. Unfortunately CFLs are classed as hazardous waste because of their mercury content and so are more expensive to dispose of in an environmentally acceptable way. (Apart from their longer life, their other great advantage is that they are much more energy-efficient than conventional incandescent bulbs.)

c) Reduced wastage of farm produce

Some methods of packaging and transporting produce from the farm to the market result in considerable spoiling of the food, and therefore larger quantities of food waste. Improved access routes can reduce the time needed to take the produce to the market. Improved transport crates can prevent damage to fruit and vegetables. Crates may be made from locally available wood (saving non-renewable resources). Alternatively, reusable plastic crates that can be folded flat for the return journey may be used.

d) Retail initiatives

Citizens can change their shopping habits to achieve reductions in waste quantities, as the following examples show:

- Plastic bags are often the focus of waste reduction initiatives. In many countries shoppers expect to receive a plastic bag with every purchase. The weight of these bags is small, but they may be regarded as a priority for waste reduction because of the nuisance and the visual impact of plastic bags transported by the wind. The consumption of plastic bags by livestock is a cause of concern in some countries, because it is the cause of many animal deaths.

  Some of the measures that have been used to reduce the use of plastic bags are:

- Awareness campaigns to persuade the public to reuse plastic bags or to take their own robust and reusable (cotton or polypropylene) bags when they go shopping;
- Supermarkets charge for plastic bags and encourage shoppers to purchase strong reusable bags;
- The use of strong paper bags instead of plastic bags
- The banning of very thin plastic bags (which are considered to cause most problems) or of all types of "one trip" plastic bags.
- The use of bags made of biodegradable plastic (which is not reducing the number of bags but instead reduces the pollution potential). However biodegradable plastic polymers are expensive and need further development.

- Reduction in the use of packaging – Supermarkets depend on packaging for protecting foodstuffs that may be handled by many people and for catching the attention of shoppers. One example of reduced packaging is that some tubes of toothpaste are no longer packaged in boxes and are displayed standing on their caps. Retailers may be obliged to take back any unwanted packaging around the goods they have sold, and producers may be required to pay towards the cost of disposal of the packaging around their products. Shoppers are urged to select goods with less packaging.
- Reducing wastage of food - Supermarkets often aim to attract customers and clear items that are near their sell-by date by offering two items for the price of one – "Buy one and get one free" (BOGOF). Such measures may encourage shoppers to buy more than they need, resulting in wastage. Some organisations are opposed to such practices because they are concerned to reduce waste.
- Packaging food in smaller quantities – Small households may experience difficulties in buying small quantities of food because the packages in supermarkets contain more food than they require, and so some of the food is spoiled before it is eaten. Another example is being able to buy half a water melon instead of the whole, or a small water melon instead of a large one. Making food available in smaller quantities may result in less waste

e) <u>Household habits</u>

- Wastage of food might be reduced by avoiding buying and preparing more food that is required. Unfortunately, in some cultures it is expected that there is always more food on the table than can be eaten, especially when guests are present.
- Yard composting by individual households can turn food scraps and peelings, as well as garden waste, into a useful soil improver. Special bins are available to facilitate the production of useful compost. A scheme for motivating and training householders to start home composting has been described by Scheinberg and Yuan [2008].
- Items which would otherwise be discarded can be reused within the home. Worn-out clothes can be used as cleaning rags or stuffing. Glass jars can be reused for storage, and plastic tubs and cut-down plastic bottles might be used as flower pots.

It may be possible to buy drinking water in large reusable containers rather than one-trip bottles.

- It may be possible to repair broken items or use them for another purpose rather than discarding them.
- When purchasing durable items (i.e. that are not classed as consumables) there is often a choice between cheaper items with a short life and higher quality items that are more expensive but have a longer life or can be repaired. The latter result in less waste.

All of these measures involve changes in habits or procedures and so require promotion in one form or another, such as the raising of awareness, training, financial incentives or demonstration projects. It is helpful to collect data on waste quantities so that the impact of promotion initiatives can be known and demonstrated, and so that achievable targets can be set.

It might be argued that many of these waste reduction measures are harmful to the growth of an economy which depends on the success of industries in producing and selling as much as possible. Answers to this objection include that it is likely that the impact on production will be small, and that it is important to work towards sustainable development as well as economic growth.

The quantities of sophisticated electronic equipment that are discarded are causing increasing concern, largely because of the risks to recyclers from the materials that are found in such equipment. Discarded mobile phones, televisions, computers are other related gadgets are classed as *waste electrical and electronic equipment* (WEEE, also referred to as *e-waste*), and they are discussed in more detail in Section C5.2 below. The rapid development of new features and capabilities results in very short useful lives for many types of electronic equipment (especially mobile phones and computers); if citizens can be persuaded to keep these items for a longer period the amount of electronic waste would be less.

B2.3 Reuse

Reuse is taken to mean the activities of people and organisations other than the original owner to return a discarded item its original purpose. An obvious example is glass soft drink bottles that are returned to a bottling plant for washing and refilling.

Another example is the repair of bicycles, furniture or household appliances that have been discarded by their original owner, so that they may again serve their original purpose. Repair of discarded items not only reduces the amount of solid waste requiring disposal but also provides employment for the people who repair the items, and low-cost furniture and appliances for low-income households.

Solvents and other chemicals used in industry are sometimes collected and refined so that they can be reused for the same purpose. Since some of these chemicals are hazardous, reuse in this way has very great environmental benefits since it prevents these chemicals from being released into the environment and causing serious pollution.

There are some practices involving the reuse of waste which are harmful. The most common example is the reuse of plastic mineral water bottles by waste pickers. These bottles are not intended for reuse. If they are refilled before they are effectively washed and sterilised, or refilled with water or another beverage that is not safe to drink, there is a serious risk of disease transmission. Life-threatening diseases can be transmitted if medical equipment (especially needles and syringes) is reused without being completely sterilised. Drums and cans that have contained toxic chemicals should not be reused unless they have been adequately cleaned.

Reuse may also be commercially harmful. For example, in Egypt, plastic bottles in which shampoo and cosmetic products had been sold were being refilled with other liquids and sold as recognised products, according to the label that was on the bottles. The manufacturers of these products were understandably very concerned about this unauthorised reuse of their bottles and the selling of counterfeit products. Therefore they initiated a scheme in which they paid waste pickers to collect empty bottles that had once contained their products. These bottles were then punctured or otherwise disfigured so that they could be recycled but would no longer be reused illegally.

B2.4 Recycling

B2.4.1 Introduction

In this publication the term *recycling* is used in a very broad sense, to include any activity that plays a part in returning material from waste to the economy after some form of processing. Some experts are now using the term *valorisation*, in the sense of gaining value from the waste, for the same meaning. *Resource recovery* is another term that may be used in the same way, but it may also include the recovery of energy from waste, which is regarded as *treatment* in this book.

Discussions about recycling necessarily include aspects of all waste management stages, from storage and collection to disposal, since recyclable materials can be recovered from the waste at any stage, and the way in which recyclable materials are obtained from the waste stream is a very important aspect of the recycling process.

B2.4.2 The motivation for recycling

As has been discussed in Section A6, there are various factors that motivate involvement in recycling, and the relative importance of these factors varies greatly around the world. The factors that lead to involvement in recycling can be divided into two basic categories – environmental and economic.

a) Environmental concern

In Section A3 the environmental impacts of solid waste were mentioned, together with the reduction in impacts that can be achieved by recycling. Environmental impacts can be considered on two levels – local and global – as shown by the following lists:

- Local impacts are caused by

- unplanned and unsatisfactory waste disposal operations, resulting in air and water pollution, the breeding of disease vectors, scattering of paper and plastic by the wind, visual pollution and degraded land;
- wastes that are discarded by individuals in public places and open countryside, including lightweight items such as paper and plastic bags which are carried by the wind;
- smoke from burning piles of refuse and open dumps which are on fire;
- unpleasant smells from waste piles and waste processing operations;
- contamination of ground (soil) by hazardous industrial wastes;
- local water, air and soil pollution caused by inadequately controlled waste recycling activities;
- transporting of wastes and recyclables.

- Global impacts affect not only the nation responsible for the pollution, but also the whole world. The most significant global impacts of unsatisfactory waste and resource management are global warming, depletion of the ozone layer (by the release of chemicals containing chlorine from scrapped refrigerators and air conditioners), and the avoidable consumption of non-renewable mineral resources. Some of these impacts can be reduced significantly by recycling, even though some recycling practices may actually cause local pollution. It is generally difficult to quantify environmental impacts in money terms, but recent research (Box B2.1) has shown that the environmental benefits of reduction, reuse and recycling in terms of their impact on global warming are very significant indeed. It should be remembered that it is only biodegradable wastes (including paper) that generate greenhouse gases at disposal sites, and so the benefits from the recycling of other materials arise mainly from reductions in the use of virgin material.

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Box B2.1 Expressing environmental benefits in money terms

As will be explained in Section B5, the impact of emissions of carbon dioxide on the global climate is often expressed as a price for every tonne of carbon dioxide that passes into the atmosphere. This price has recently been used in innovative research to set a monetary value on the benefits of recycling or valorisation. Reduction, reuse and recycling of waste reduce emissions of greenhouse gases (in this case carbon dioxide and methane) by

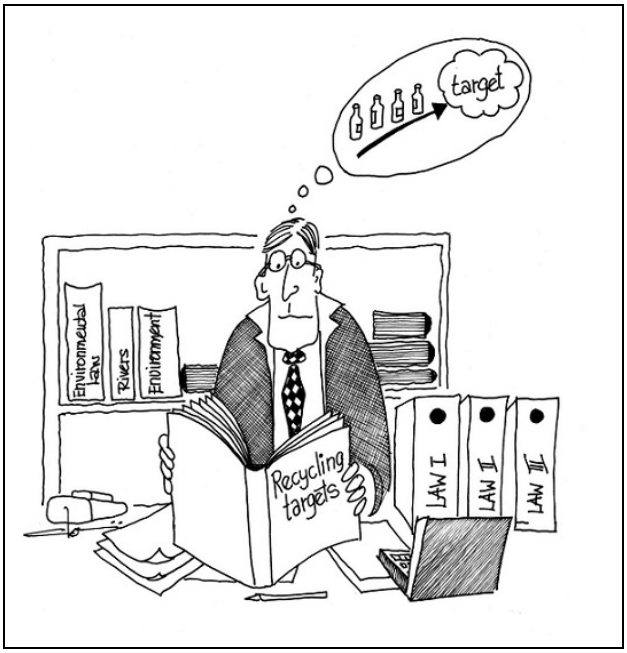
- reducing emissions from the extraction and refining of raw materials (because the required quantities of these raw materials are reduced),
- reducing the emissions relating to the transport of virgin materials and of waste to landfills (because of the reduction in the quantities of both), and
- reducing the emissions of greenhouse gases from landfills (if the quantities of biodegradable waste sent for disposal are reduced).

The research, based on data from six cities in four continents, showed that informal sector recycling resulted in very significant environmental benefits. In two of the cities – both having well-developed informal sector recycling activities – the annual savings were estimated to be over six million Euros for each city. The reduction in emissions from transportation was found to be the least significant of the three causes.

source Gunsilius et al., 2011b

Some ways of using waste reduce the quantity of waste going to disposal sites but they do not reduce the consumption of raw materials. Such practices are often called *recycling* but can be referred to more precisely as *downcycling.* A good example is the processing of plastic waste to make garden furniture and other structural items which would otherwise be made of wood. Wood is a renewable resource so the use of recycled plastic in this way is not reducing the consumption of non-renewable resources, but it does divert the plastic away from disposal to land.

Environmental concern is driving the efforts to promote reduction, reuse, recycling and energy recovery in many industrialised nations. Investment in these fields is pulled by public demand and pushed by government policy expressed in laws, targets, incentives and penalties. Government grants may be used to encourage new recycling initiatives or to promote the purchase of goods made with recycled material. Waste generators who are expected to help achieve a target are often kept informed of progress in reaching the target, and encouraged to do better.



Cartoon 4 Laws and targets

Increasingly, legislation requires that targets are met for reduction, reuse and recycling. Such laws aim to reduce quantities going to landfills and also to reduce consumption and pollution.

For example, within Europe there are targets relating to the amount of waste that is recycled and the reduction of the landfilling of biodegradable material. Penalties can be imposed if targets are not met. Taxes are levied on landfilling to reduce the quantities of waste disposed to land and the prices paid for electricity generated using energy derived from waste are higher than the prices paid for electricity generated using coal, oil or natural gas. Promotion of recycling in Europe is not based only on environmental awareness and persuasion, but is also encouraged by legislation and financial instruments.

When considering the benefits of recycling, it is important to have a holistic or integrated assessment of all environmental impacts and costs, as well as the benefits. For example, significant quantities of water may be used for cleaning material to be recycled, and water and air pollution can result from processing of recyclables. Cartoon 5 shows an extreme example, in which a small quantity of recyclable material is being transported a long way by a vehicle that is polluting the environment by its heavy exhaust smoke. The journey is consuming fuel and possibly adding to traffic congestion and damage to the road surface. The environmental costs per tonne of recyclable material in this case would be more than the environmental benefits. Photo B2.1 tells a different story, because here the truck is fully loaded with selected and baled cardboard, and the distance it must travel is relatively short.

Cartoon 5 Heavy pollution, light load

Photo B2.1 Truck loaded with baled carton

b) Financial, economic and social motivation for recycling

In general, informal sector waste recyclers are not motivated by a concern for the environment but are working to support financially themselves and their families. Examples have been documented of informal sector recyclers earning significantly more than the minimum wage or the wages paid to unskilled factory workers in low- and middle-income countries [Medina, 2006 and Gunsilius et al., 2011b]. In spite of this, there is no doubt that many are earning barely enough to survive.

In the right conditions, formal sector recycling can generate modest profits, but it is unreasonable for municipal organisations to expect that recycling can significantly reduce their solid waste management operating costs. The large numbers of informal sector waste pickers earn their living by honest hard work in difficult conditions, often with the unpaid assistance of family members. The wages paid to unskilled labourers by formal sector recycling companies are low, and productivity in the public sector is likely to be lower than in the informal sector. Mechanisation of the sorting process adds to investment and operational costs, requires good maintenance and a motivated workforce. There are certainly dealers and entrepreneurs in the recycling business who have become wealthy, but the commonly-held view that traders and bosses in waste recycling are all very prosperous is unlikely to be supported with evidence. These

considerations support the experience of recycling by the formal sector, namely that it cannot be expected to generate a significant income. For this reason many experts recommend that, in situations where recycling is done successfully by the informal sector, it is not advisable for the formal sector – public or private – to set up in competition.

The prices paid for recycled (or secondary) materials often fluctuate wildly so it is common for traders to have the space and working capital that allow them to stockpile material when prices are low. Prices fluctuate with supply and demand. The importation of cheap recyclable material can lower local prices. The demand for products (such as paper) that are made with recycled materials depends on many factors. (For example, it may be possible to stimulate the demand for recycled paper by public education and government subsidies). Prices are also influenced by the prices of competing materials, as well as by transport costs and the quality and quantities of the material offered for sale. The prices paid for recycled materials increase if they are cleaned and sorted.

Photo B2.2 Washing, drying and sorting pieces of plastic according to colour and composition increases the price paid for the material.

There have been cases of municipal administrations that have tried to sell mixed municipal waste to recyclers (rather than letting them have it at no cost) when the administrators have learned that the recyclers are earning a living from the waste. In most cases this is unreasonable. Recycling is often only viable if the recycler is paid for each tonne of waste that is diverted from disposal – because of the *avoided costs* that are not incurred for transport and landfilling. It is reasonable that the recycler is paid a fee equivalent to the costs that would be incurred if that waste were disposed of in a landfill. Just as a disposal site is paid a gate fee for taking a load of waste for disposal, so a recycling operation should be paid a gate fee for taking waste for recycling. It is also fair that the recycler is expected to pay for the disposal of reject material that is not processed. The key point is that recycler should be paid for taking waste, rather than being charged.

Recycling in industrialised countries generally costs much more than disposal to land, but governments are willing to support recycling for environmental reasons. As already discussed, taxes levied on disposal to land make recycling more financially attractive. Charges for the collection of unsegregated or residual waste make source segregation more attractive to the generator if the charge for waste collection is based on the quantity of the residual waste to be collected. If charges are based on quantity, householders can save money by segregating their waste, and thereby avoid paying the collection charge for the waste that is diverted for recycling.

Recycling provides work and a source of income on a very significant scale. Waste recycling is creating increasing numbers of jobs in the more prosperous economies. In low- and middle-income countries the economic benefits of informal sector recycling are even greater and the beneficiaries can be divided into two groups. One group consists of individuals who choose to work in waste recycling because it provides a greater income than alternative occupations, and, in many cases they value the independence of being their own boss rather than working for others. For the other group, waste collection and recycling provides a source of income for families who might otherwise be forced to resort to begging, or tempted to turn to crime or prostitution. For some, waste picking is a temporary occupation, resorted to when other employment (such as farm work) is not available, or taken up by new arrivals or refugees before they find a job that they prefer. This generation of employment from waste (which would otherwise be regarded as of no value and a nuisance) is a very strong argument in favour of informal sector recycling. Employment is created not only for the waste pickers and others who collect materials for recycling, but also for dealers, people involved in sorting, cleaning and processing the waste, and people involved in manufacturing goods from recycled materials. It has been estimated that, in some cities, one percent of the population is supported by income from informal sector recycling; this figure is considerably more than the numbers benefitting from jobs in the formal sector of solid waste management [Gunsilius et al., 2011b]. In addition, useful goods (at lower prices because they are manufactured from recycled materials) are made available to customers who cannot afford items manufactured from virgin materials.

Some commentators have said that waste picking on the streets and at disposal sites is degrading and unhygienic work and, for that reason, should not be allowed. However, it is important to consider the alternatives for the large numbers of unskilled people who have no capital and no other means of support; in many cases they have no alternative options for earning their living in an honest way. Of course, every opportunity of improving their working conditions and health status should be taken. In many cases the first step to improving their situation is to stop official and unofficial harassment by the authorities or their representatives. Further discussion of the role and situation of the informal sector can be found in Section B2.5 below.

Photo B2.3 A big load of cardboard for recycling: – landfill volume saved and income earned.

c) Key points

- It can be seen from this discussion that the reasons for the growth of recycling depend on local factors, and can be very different in low-income countries compared to industrialised countries.
- The global environmental benefits apply to all recycling activities anywhere, but they may only have significant motivational impact in countries where there is a high level of environmental awareness and where legislation provides effective incentives and penalties.
- In many low- and middle-income countries, recycling provides the opportunity for poor people to earn an income that is sufficient to meet the basic needs of their families.

B2.4.3 Some general principles and observations regarding recycling

- Recycling happens spontaneously when it is economically viable. Where it is not economically viable, however, it must be subsidised or the cost of alternatives (usually disposal) must be artificially increased.
- The best quality of material is obtained from at-source segregation, because there is less contamination of the material to be recycled.
- The law of diminishing returns – this means that it is easier to recover material from a sample of mixed waste at first, but then it becomes more and more difficult after the best items have been taken and the supply reduces. As recovery continues from the particular source sample of waste, the cost of recovery increases, while the quality of the material that is retrieved decreases. [Ball, 2008]
- There is a limit on the number of times that some materials can be recycled. For example paper fibres are shortened each time that paper is recycled, so that after several cycles the quality of the recycled paper becomes poor. This is not necessarily the case with aluminium and glass and some other materials.
- The costs of transport are a major factor that affects the financial viability of recycling. The pollution related to transporting materials for recycling should be factored into any consideration of the environmental benefits of recycling. The recycling of some materials from small towns that are far from processing operations may not be financially viable because of transport costs. Each truckload should be

as much as possible (up to the legal payload of the vehicle) so that it is often necessary to shred or compress materials that are destined for recycling, because these processes enable a greater weight of material to be contained in the same volume. Trucks carrying recyclable material are often loaded very high so that the weight that they carry is economically worthwhile.

Large quantities of some items and materials (such as PET plastic and discarded electronic items) are transported by ship over long distances in containers that would otherwise be empty.

- Prices can fluctuate wildly according to supply and demand, as well as the quantity and purity of each individual consignment.
- The energy required to recycle common materials is less than the energy required to extract and process the same weight of virgin material.
- Designers and manufacturers should be obliged to consider what will happen to their products when they are discarded. This consideration has already had an impact on the design of cars, especially on the choice of the plastic polymers, which are often selected according to their potential for recycling. Composites that are difficult to separate should be avoided whenever possible.

B2.4.4 Comments on the recycling of various waste materials

- Biodegradable (organic) waste is often the largest proportion of municipal waste, and it causes the most problems in collection and transport (because of its acidic nature and the lingering smell it causes in storage containers and collection trucks) and in disposal (because of the gas, odour and leachate it generates in landfills as it decomposes). Recycling of biodegradable wastes avoids most of these problems and is therefore of great benefit in environmental and financial terms.

  There are three main ways in which biodegradable waste can be used, thereby achieving the important benefit of reducing the amount of waste that needs to be transported and disposed of. Food waste can be fed to animals[10], biodegradable wastes (including foliage) can be composted to produce a soil improver, and biodegradable waste can be decomposed in the absence of air (anaerobic digestion) to produce methane gas, which can be used as a fuel. These processes can be categorised in different ways, but in this book the use as animal feed and composting are considered to be recycling and anaerobic digestion is classed as an energy recovery process and considered in the section on treatment.

  Biodegradable materials produce greenhouse gases (which are considered to be responsible for climate change) when they decompose. Under certain circumstances (Section B5) carbon credits are payable when measures are taken to reduce the production of greenhouse gases, such as reducing the quantities of waste that are disposed in landfills.

[10] Feeding food waste to animals has been prohibited in Europe because of concern about the spread of animal diseases such as BSE and foot-and-mouth disease. It is widely practised in many other countries.

- Glass can cause injury and puncture vehicle tyres, but it causes no chemical pollution. Glass jars and bottles are often recycled but flat window glass and heat resistant glass are not, and should be kept separate.
- PVC is one form of plastic that should never be burned because it forms toxic dioxins during the combustion process.
- Lead-acid vehicle batteries and some types of dry cell batteries contain heavy metals which cause serious air pollution if they are processed in a primitive way, without effective air pollution control equipment.
- Fluorescent light tubes and compact fluorescent lamps contain mercury and so should not be broken in the open air, but should be recycled and disposed of by operators which have the necessary equipment.

B2.4.5 Sources of recyclable materials

Recyclable materials can be recovered from the waste stream at many different points between the source and final disposal. This section discusses some key factors about recovery at each stage.

a) <u>At-source segregation</u>

Segregation in the home is a normal practice in many places. Food waste may be segregated for feeding to animals or for backyard composting, because of the benefits to the household of these uses. Old newspapers and magazines may be saved for collection or sale at the door or for selling to junkshops for resale or recycling. Bottles and metal cans may be collected or sold. Scrap metals and broken gadgets, old clothing and shoes may also be put aside until a collector comes to the door.

In other locations, at-source segregation may be required by law or encouraged by financial incentives.

As already mentioned, factories can often reduce the amount of waste that they discard by redesigning their processes and reusing process scrap. The residual wastes that they discard may be valued for recycling because they are relatively clean and homogeneous.

Wastes that are segregated by the generator are of better quality than wastes which are picked from mixed waste and so they command higher prices. At-source segregation has been found to be of great benefit for composting schemes. Up till the 1980s it was common for composting plants to be designed to receive mixed waste and for a sorting station to be installed as a first stage to take out materials that were not desired in the compost, such as plastic, metals and glass. These sorting stations, whether manual or mechanical, were not able to remove all the unwanted materials, and even small fragments of plastic and a few shards of broken glass caused a marked reduction in the demand for the compost. Furthermore, the inclusion of small particles from vacuum cleaners and street sweeping, which could not be removed from the mixed waste, were thought to have a negative impact on the quality of the compost. In some cases the inclusion of waste from factories increased the heavy metal content of the product to the extent that it was unfit for use. The trend now is to use only source segregated waste for the production of compost; with careful control of the input a much better product quality is achieved.

Segregation in the home, shop or office requires extra effort from the generator and extra storage containers. Therefore, if government – local or national – wishes to promote at-source segregation, it is necessary to find a way of motivating householders and employees to meet these additional demands. Itinerant waste buyers pay for the materials they receive at the door in cash or vouchers or by exchanging household items for the recyclables. Sometimes recyclables are kept for door-to-door collections and handed over as a humanitarian gesture rather than for cash. Municipal schemes generally rely on information and persuasion, backed up by legislation, to encourage segregation of recyclables at source. If children are taught to segregate waste at school they may motivate the other members of their families to take up this habit. Participation may be assisted by financial incentives, such as a fee charged for the collection and disposal of any waste that is not segregated, as exemplified by the Swiss approach mentioned in Box A6.2 in Section A6.3. Even after a long campaign of information and persuasion it is likely that the waste will not be completely segregated because some of the citizens have recently moved to the area, or do not care, or do not understand the criteria for deciding where each item of waste should be discarded.

1. In England b) In China

Photos B2.4 Bins for waste that has been segregated at source

It would appear to be obvious that at-source segregation should be accompanied by separate collection (or *selective collection* as it is sometimes known), but the author knows of several cases where this requirement was not obvious to the officials who were implementing the practice of segregation:.

- In one case, the head of a waste management department planned to introduce at-source segregation with bags of two colours, with no consideration of how the two different streams would be collected separately. (He was not able to explain what benefit he was expecting to obtain, but planned to do this because he considered it to be modern practice.)
- In other cases, pilot projects were set up to determine whether residents would be willing to segregate their waste, but no provision was made for separate collection of the different types of waste – they were simply mixed together in the collection truck. When the residents saw that their carefully segregated wastes were being subsequently mixed together, they lost motivation to continue the trial, and it will probably be much more difficult to persuade them to segregate their wastes in future, because of this experience.

Separate collection of segregated waste can be organised in a number of ways, depending on the local situation. In towns and cities where there are many informal sector waste pickers, it is likely that these recycling workers will try to collect or sort through the containers or bags of segregated recyclables before they are collected by the official collection service, and so it may be advisable to integrate their involvement in some way. In many parts of England, recyclable waste and residual waste are collected on alternate weeks. Elsewhere waste collection agencies use sophisticated collection trucks that have multiple compartments for the various categories of materials; each compartment can be loaded and emptied separately by hydraulic systems.

An alternative to separate collection from each house is to establish recycling points throughout the urban area so that residents can take their recyclable wastes a short walking distance to a single bin (for all recyclables), or to a group of colour-coded bins that allow the recyclables to be collected according to various categories – glass, plastic, metals etc. If these recycling stations are at some distance and residents take their recyclables by car, there is a risk that the environmental damage caused by the car journey is more than the environmental benefit derived from the recyclables.

b) Sorting by employees

Household servants, caretakers or janitors of apartment blocks and office buildings, and shop employees may be asked to separate out recyclables or they may choose to do it so that they can sell the material that they recover. Good quality scrap paper from offices and cardboard from supermarkets can generate useful additional incomes in some cases.

c) Sorting during collection

In this case the waste is not segregated, but mixed waste is put out for collection and recyclable materials are recovered by collection labourers who sort the waste during the collection process.

- Mixed waste may be sorted as it is collected by a handcart, pedal-powered tricycle cart or other small vehicle. The operator may be an informal sector worker or an employee of the collection agency. In both cases the recyclables should be the property of the collection labourer so that the income from sales can increase the income derived from the collection service. This can be a very satisfactory way of sorting the waste because the waste is received in small quantities and the labourer can invest as much time as (s)he wishes in sorting the waste (provided that the daily quota of houses are all served). A flat surface for examining the waste and additional bins or bags for storing the sorted recyclables can assist in this work. Regular contact with residents can be mutually beneficial, since residents may partially segregate the waste for the benefit of the collector or put aside for the waste collector items such as old clothes and shoes, and the waste collector may return items discarded in error, such as knives and spoons. Recyclables that are removed from the waste at this stage are still relatively uncontaminated.
- When waste is collected in small open trucks, it is quite common for the collection labourers to look for materials that they can sell for recycling. In many cases they are not allowed to do this (because it distracts them from the work of collection) but the practice persists. Sometimes the collection crews invite a friend or relative to

join them in order to sort the waste that they have collected. In the Philippines the wages paid to collection workers are low because it is expected that the employees will supplement their pay with income from the sale of recyclables.

- If waste is collected in compactor trucks, looking for recyclable items is more difficult. Picking material out of the rear hopper can be very dangerous because of the hydraulic loading plate that works in it. Any delays in the collection operation because the loaders are searching for material they can sell have greater financial consequences than when cheaper and smaller vehicles are used. Recyclables in the waste that is collected in compactor trucks are likely to be more contaminated than wastes collected in open trucks because the wastes are compressed and mixed by the loading mechanism.

a) The collection crew look for recyclables during the collection round

b) A sack containing recovered recyclables hangs on the back of the truck

Photos B2.5 Picking by collection crews

d) Sorting at transfer stations

In cities where small vehicles are used for collection and the disposal site is at some distance from the urban area, it is often economical to establish a transfer station where the waste is transferred from the small primary collection vehicles to much bigger and faster trucks that take large quantities of waste to the disposal site. It has often been suggested that transfer stations are good places for the sorting of the collected wastes to recover recyclables. This may be a good idea in some situations, but any decision to allow this must be made after careful consideration.

The advisability of sorting at a transfer station depends on the size and location of the facility. Transfer stations are often located as near as possible to the urban area that is served by the primary collection vehicles, and, if it is not currently surrounded by houses, it may be soon as the city grows. This means that the transfer station must be kept as clean as possible, that operations should cause the minimum disturbance to the neighbours, and that the site itself may be very limited in size. If waste sorting activities are added to the transfer function, a considerable additional area will be needed for sorting and for storing the materials that are recovered, and considerable supervisory

effort will be needed to ensure that the site is kept clean and that no waste stays on the site for longer than necessary (often just a few hours). Since the waste must be spread out for sorting, it is more likely that paper and plastic bags will be carried away by the wind. If informal sector workers are allowed to sort wastes here, some form of organisation may be needed to prevent conflicts, as discussed later for the context of disposal sites, in Section B4.10.2.

If the whole transfer station is not covered, there may be advantages in building an enclosed area where the sorting takes place. Another suggestion is to build terraces for sorting, so that the waste is sorted at the top level and then moved down to the next level, and so on, until the unwanted residues are loaded into the large bulk transport trucks from the lowest level. Alternatively, a materials recovery facility (MRF) may be set up at the transfer station.

e) Materials Recovery Facility

A materials recovery facility (MRF) is a facility that is designed and built specifically for the purpose of sorting waste so that recyclable material can be recovered. It may be located either at a transfer station or at a facility where solid waste is treated or disposed, or it may be at a separate location, not linked to any other waste management operations. The incoming material may be mixed waste (at a *dirty* MRF) or waste that has been partially segregated (such as *dry* waste that has been segregated at source from the *wet*, biodegradable fraction, at a *clean* MRF).

Techniques have been developed for automatic sorting of waste. The most common techniques are the rotating cylindrical screen (illustrated in Photo C6.3 in Section C6) which separates according to size, and the overhead magnet which picks up items containing iron or steel. Other, more sophisticated technologies have been developed for separating according to density or colour and for removing items made of aluminium or other metals. However these more sophisticated processes are not widely used, even in industrialised countries, because of their limitations and the challenges of keeping them operating well.

A common arrangement for MRFs is to use a conveyor belt (often known as a picking belt) which carries a thin layer of waste slowly past a team of pickers. The pickers remove items that can be recycled. Measures are usually needed to minimise the level of dust that the pickers are exposed to, such as screening of the waste before it reaches the belt, extractor fans drawing air through hoods above the belt, and the use of dust masks by the pickers. The waste should be fed onto the belt in a steady stream, rather than in pulses or piles. This work requires continuous concentration and so the motivation of the pickers is important; therefore it may be advisable to pay them according to the amount of useful material that they recover. An overhead magnet is usually fitted over the downstream end of the picking belt.

Photo B2.6 Picking belt

Photo B2.7 Magnet suspended over the end of a picking belt

f) Sorting at the disposal site

There are several disadvantages in delaying the recovery of recyclable materials until they arrive at the disposal site, rather than removing the recyclables at an earlier stage in the waste management chain:

- The recyclable materials are more contaminated by other materials;
- The waste pickers are exposed to more health hazards resulting from skin contact with the waste, and the risks of working close to moving machinery;
- The operation of the disposal site may be hindered, because the pickers obstruct the movement of machinery..

If the waste pickers are allowed to work freely, they may appreciate the lower level of harassment (compared to the harassment they face when working in the urban area) and the access to large quantities of waste.

Photo B2.8 Waste pickers at a disposal site

Cows sheep and goats are sometimes found grazing on mixed waste a disposal sites. Feeding on waste may weaken or kill them because they eat plastic bags together with the food waste and the plastic bags accumulate in and block their digestive systems.

Photo B2.9 Animal scavengers at a disposal site

A more detailed discussion of picking on a landfill site can be found in Section B4.10.

g) Landfill mining

Waste picking at the disposal site is not the last opportunity to recover something of value. Waste that has been decomposing at disposal sites for some years is sometimes dug up and screened, and the fine decomposed material is used as a soil conditioner to improve the structure and fertility of the soil, in the same way as compost. If soil has been placed on the waste each day (daily cover), landfill mining also recovers this soil for further use or other applications. Wastes may be dug up for reuse or recycling in

order to create additional volume for waste disposal as an emergency measure, but it is likely that the volume occupied by the coarse material that cannot be used as a soil conditioner (and is therefore put back into the landfill) results in a relatively small gain of volume for waste disposal. Landfill mining could also be carried out to expose the base of the landfill so that an impervious liner could be installed or upgraded, but only in rare cases would the expense of such an operation be justified. Photos B2.10 show landfill mining being done on a small, informal scale, and the case study in Section C6 provides an example of a larger-scale operation.

a) In India

b) In Vietnam

Photos B2.10 Recovering soil improver by screening decomposed waste dug out from a landfill.

The main concern about this form of recycling is that there may be an unacceptably high concentration of one or more toxic heavy metals in the recovered material, so that it could poison the soil if used in large quantities. These heavy metals are most likely to come from industrial waste and printed paper, but discarded dry-cell batteries and waste that is swept up or collected in vacuum cleaners may also be a cause of high concentrations,. It is therefore essential to test samples of the recovered material before it is applied to the soil. There may also be concern about the presence of hazardous healthcare waste, especially needles. It is also important that the decomposition process has largely been completed, because if the material is not fully

decomposed it may take nitrogen out of the soil, reducing fertility instead of increasing it. The release of odours must also be considered.

The screened material may be used by farmers and market gardeners on their soil. It can also be used with topsoil on the final cover of a landfill to encourage the growth of plant cover to prevent erosion of the cover soil and to improve the appearance of a completed landfill. The author is not aware of the coarse fraction (that does not pass the screen) from such operations being used for any purpose. This material is likely to be seriously degraded and therefore of little value. In many cases this material would have a higher calorific value than the mixed waste that was initially disposed of, so it could be incinerated if an incinerator is available, but the quantities would be small in most cases, so it is usually returned to the landfill.

B2.4.6 Preparing and handling recyclables

As already mentioned, some waste-derived materials need to be processed so that heavier loads can be accommodated in the vehicles used for transporting the material. The simplest ways of doing this include:

- flattening and tying together bundles of cardboard boxes,
- puncturing and compressing plastic bottles into bales, or shredding them,
- compressing steel scrap (including scrapped cars) into bales.

Large recycling plants may use static compactors that compress recyclable materials into large, closed containers which are carried on hooklift trucks.

a) Bales of plastic b) Bales of cans

Photos B2.11 Recyclable material that has been baled to reduce transport costs

Most recyclable materials need cleaning and sorting. Cleaning usually involves washing and drying. This work should be done in such a way that excessive use of drinking water and water pollution are avoided. Materials may need to be sorted according to material and colour. A number of plastic polymers (low-, medium- and high density polyethylene, PVC, PET, polystyrene and polypropylene) are commonly found in municipal waste and they are normally distinguished by the way they are used – for example, mineral water and carbonated drinks are normally sold in bottles made of PET. Plastic polymers can also be distinguished by their density and the way that they burn. Glass bottles and jars

are normally sorted according to their colour. Paper and cardboard may be sorted according to quality. Automatic equipment has been developed to sort some materials according to their colour and density, but manual methods are often preferred, even in industrialised countries.

The main processes for making useful products are fabricating and remelting (followed by moulding or extrusion). Fabricating involves cutting, bending and fixing – processes used when making toys or kitchen implements from cans (Photo B2.12) or making shoe soles or flower pots from old vehicle tyres. Plastic scrap is cut into small pieces before remelting, and either formed into pellets or used immediately for manufacturing new products. Plastic recycling in this way can be undertaken on a small scale, as shown in Photo B2.13.

Photo B2.12 Toy cars fabricated from drinks cans, Madagascar

Photo B2.13 Manufacture of coat hangers from recycled plastic in a small workshop in Cairo.

Food waste is often fed directly to animals after checking that it contains no harmful materials such as glass, plastic and metals. The waste should be as fresh as possible, preferably collected every day. Households that have their own animals often give their food waste directly to their animals. For many years it was common in some industrialised countries to cook food waste before feeding it to pigs in order to prevent the spread of trichinosis. Feeding food waste to animals is now banned in some countries.

The recycling of demolition waste and asphalt road surfacing requires a large screen to grade the pieces according to size, as shown in Photos B2.14. This is often done in conjunction with a crushing plant that breaks the recycled material into small fragments.

a) Loading stones onto vibrating screen

b) Coarse material falls outside the screen unit

Photos B2.14 Vibrating screen for separating fine and coarse demolition waste

B2.4.7 Trading recyclables

Factories that process recovered recyclables and agents involved in shipping recyclable material are normally not prepared to accept waste in small quantities, so there is a need for middlemen or dealers who buy materials from many waste pickers and other sources and sell them on for processing or shipping when a sufficient quantity has been accumulated. Dealers may also sort, clean and bale the waste, and provide an unofficial guarantee of the quality and purity of the material. After doing this work for some time they possess considerable understanding of their business and learn how to maximise their profits and cope with periods when prices are low.

Some waste pickers always sell to the same dealers and may receive assistance from the dealers, such as the loan of a handcart to enable them to collect more material, or a cash advance at the start of each day to enable them to buy segregated material, or loans to help the waste pickers with personal financial difficulties.

Dealers or middlemen are often accused of exploiting individual waste pickers, and so some NGOs and development agencies encourage waste pickers to form co-operatives [Medina, 2006]. Such co-operative associations not only represent the interests of waste pickers but sometimes also take on the work otherwise done by the middlemen,

with the intention of paying the waste pickers higher prices for the recyclables that they collect.

B2.4.8 Composting

Composting is the process of converting biodegradable organic waste into rich humus that improves soil and promotes plant growth. This process is accomplished by providing the right conditions for bacteria and fungi to convert the organic waste to compost. The potential benefits of composting are great and compelling, but unfortunately these benefits are often not realised and the financial costs can be too high so that production cannot continue. When approached in the right way, composting can be a very useful means of recycling. Composting operations vary in size, from small household-scale compost bins to large factories receiving hundreds of tonnes of waste every day.

A high quality compost can be obtained by *vermiculture* - using a particular species of worm which feeds on the compost - but difficulties have been experienced in scaling up this process, perhaps because of the need to maintain ideal conditions of shade and moisture so that the worms can thrive.

There are various methods that can be used to compost waste. The simplest is the windrow method that uses long piles of waste which are turned or disturbed so that there is enough air within the waste for composting to take place. Methods of composting will be discussed briefly in Section C2.

Photo B2.15 Composting yard using the windrow method

a) Advantages

Composting can be considered to be either a disposal process or a production process.

Viewed as a disposal process, it offers a number of benefits over sanitary landfilling. As already mentioned, the biodegradable constituents of solid waste pose the most problems in disposal because of their potential for causing global atmospheric pollution and relatively local water pollution. Composting converts this troublesome waste into a useful and hygienic material, and if the process is controlled correctly, no methane is produced and the small amount of leachate can be recycled. Composting is one of the processes used in *mechanical-biological treatment* (MBT) before landfilling to reduce the environmental impact of landfilling. If the compost can be sold, or put to a good use in parks, for reclaiming land that has been damaged by mining or quarrying, or used as final cover material on landfills, the amount of waste that goes to the landfill is reduced, extending the useful lives of disposal sites. If compost is landfilled, as is the case with

MBT, the volume occupied by the material is less, and the pollution resulting from the landfilled compost is minimal, if the composting process has been allowed to continue to completion.

Compost brings many benefits to the soil. It makes heavy, clay soils easier to work and it improves the water retention of sandy soils. It promotes plant health and growth by providing needed micro-nutrients as well as small quantities of the basic nutrients.

Discussions about composting often stop here, and it is decided to invest in composting as the (apparently) perfect solution to waste disposal. However, these benefits are not the whole story and other factors must be considered.

If composting is viewed as a production process, and significant revenue is expected from sales, it is important to involve the agricultural sector and marketing expertise. The product must be attractive, competitive and of dependable quality. These points are discussed further towards the end of this Section.

The failure to consider all aspects of composting (especially the demand for the product and the financial aspects) has led to many failures and large wasted expenditures. It is intended that the remainder of this Section provides a balanced view of the prospects for composting.

b) Unrealistic expectations

It is important to get a complete picture of the benefits and costs of composting, and this involves avoiding common misunderstandings and unrealistic expectations. Among them are the following:

- Compost is not a substitute for artificial fertiliser. The basic nutrients required for plant growth are nitrogen, phosphorus and potassium. Compost contains all three, but in small quantities. A farmer can usually expect more crop growth by investing in artificial fertilisers rather than compost. In the long term, the regular use of compost results in more fertile soil and less erosion, but it must be understood that compost and artificial fertilisers do not bring the same results.
- The benefits of compost are clear, but farmers may be reluctant to buy compost for various reasons, including:
  - their objection to using a product that is derived from municipal waste,
  - concerns about the quality or purity of the product, particularly the presence of toxic heavy metals, viable weed seeds or small pieces of plastic and glass,
  - the costs of transporting and spreading the compost, since relatively large quantities of compost must be mixed with the soil to have a useful effect, and
  - an unwillingness to take risks with a new farming practice, because their livelihood depends on the success of every harvest.
- Because of the costs of transporting compost, there is a limit on the amount of compost that can be sold, and it is likely that only a part of a city's biodegradable waste can usefully be composted. A sanitary landfill is needed for the biodegradable waste that is not composted as well as for all the other residual waste that is not recycled, so a composting plant cannot be considered to be a substitute for a sanitary landfill.

- The complex microbiological processes that are involved in composting take time. Promoters of composting systems may claim that their processes are much quicker than others, but under ideal conditions the time needed to make mature compost is about ten weeks, so any claim that good compost can be made in a shorter time should be treated with suspicion unless proven correct by laboratory tests. The use of immature compost can have an adverse effect on plant growth. If conditions are not optimum the composting process can take much longer, even two years or more.

c) Discouraging experiences

There is no doubt that the returning of vegetative matter to the soil is good ecology, but unfortunately it is not always good economics. Many large composting operations have been closed after a short time. An example, quoted by Ali et al. [1999] is of a private sector plant established in a major Asian city which was abandoned after operating for only a few months. Some of the reasons for disappointments in composting are mentioned below.

- Accounts – The financial return from the sales of compost are often not sufficient to pay the operating costs.
- Quality – Unsatisfactory product quality can lead to difficulties in selling all of the compost that is produced. Poor quality may be caused by impurities in the feed material, inadequate control of the processes, or pressure to sell the product before it is ready or mature.
- Output – Operational and maintenance problems may keep the production rate of a composting plant well below the intended rate of production.
- Nuisance – Under optimum operating conditions, a composting plant should not produce any strong smells, but operational errors and variations in moisture content can cause unpleasant smells which lead to strong opposition from citizens living nearby. Complaints from neighbours have led to the closure of composting plants. In one particular case a composting plant was closed because local fruit growers complained about the dust caused by the vehicles that were bringing the waste to the plant.
- Maintenance – Small composting schemes can be operated entirely by manual labour, but larger schemes need mechanical equipment, and this equipment must be kept in good condition. Composting equipment is subject to accelerated corrosion and abrasion, causing steel parts to wear out more quickly than may have been anticipated.

Photo B2.16 Abandoned compost plant – a waste of money?

d) Recommendations for sustainable composting.

Experience has shown that there are certain steps that can be taken to increase the chances of success in composting and to reduce any wastage of resources on initiatives that fail.

- Start small – Small composting operations can be started with a modest capital input. A small plant provides the opportunity to develop supplies of satisfactory input waste, to gain experience in the control of the microbiological processes and to assess and develop the demand for compost.
- Decentralised plants help to reduce the distances over which the input material and the product must be transported [Rothenburger et al., 2006].
- Capacity development – Any organisation that has a composting operation should ensure that the processes are operated by people who understand them well, that adequate numbers of staff are deployed, that maintenance of equipment is well managed and that the necessary testing and laboratory facilities are provided, used well and kept in good order.
- Control the input – If possible the use of mixed solid waste as the input for a composting process should be avoided. It is difficult to remove all items that might reduce the quality of the product, and so it is better to choose input material that is relatively free of impurities. Segregated waste from markets, food processing operations, large institutions and restaurants is suitable. Segregated food waste from households is another potential source, though the waste may not be well segregated. Many composting operations in Europe use only green waste from parks and gardens, because of concerns about the quality of food residues and special regulations that are imposed on meat waste because of its potential for spreading foot-and-mouth disease to farm animals.
- Production not disposal – It is preferable to consider that composting is a production process looking for markets in agriculture rather than a way of disposing of waste. Officials and experts from the agriculture sector should be involved. Many agriculture ministries have extension workers who work directly with farmers, and they should be involved in promoting the use of compost – as a benefit for farmers,

not to assist with waste disposal. Companies which market and distribute agricultural chemicals and equipment may be interested in selling compost, perhaps blending it with other materials or chemicals and marketing it as their own brand.

- Marketing – Compost will not be sold in significant quantities unless is it marketed and advertised. It is necessary to investigate and stimulate demand and develop the market. The marketing of compost has been discussed fully by Rouse et al. [2008]. Some of the means that can be used to increase the sales of compost include:
  - a survey of the existing market, investigating the uses, prices and sales of competing products (such as products made from agricultural wastes) in order to determine where the demand for compost is likely to be and at what times of the year demand will be greatest; sales for market gardening, household gardening, parks and land reclamation should also be considered;
  - the development of a sales strategy, looking at how the compost should be packaged and also sold in bulk, possible collaboration with existing distributors, arrangements for transport;
  - the demonstration of the benefits of compost by means of trial plots and subsidies for farmers to run their own trials and demonstrations.
- Quality assurance – a scientific and independent programme of sampling and laboratory testing is needed to demonstrate that the compost meets appropriate quality standards;
- Financial viability – Expectations regarding the financial viability of composting should be realistic, and subsidies may be necessary, particularly in the early years. As a minimum, composting operations should be paid a fee for each tonne of waste that is processed equivalent to the avoided costs that are saved by not transporting the waste to the disposal site and disposing of it in a landfill. Carbon credits can improve the financial viability of composting; these credits are payable in certain circumstance because the composting process, if properly managed, avoids the production of methane that occurs in landfills. (More information on carbon credits can be found in Section B5.)

Some technical details of the composting process are discussed briefly in Section C2.

Photo B2.17 Marketing of compost. Compost is being packaged in small portions so that city-dwellers can try it for their house plants.

B2.4.9 Legal aspects of recycling

Before discussing the involvement of the informal sector in recycling, it is appropriate to mention two relevant legal considerations relating to waste – definition and ownership. (In many countries the waste management legislation may not be sufficiently developed for these issues to be of any legal significance.)

a) Definition

The precise definition of waste is an issue that has generated a surprising amount of legal debate, as the following examples suggest:

- A dead animal is usually regarded as solid waste (though there may be special conditions imposed on how it should be disposed of), but if the animal was a household pet, the members of the household may be unwilling for it to be treated as such.
- It is sometimes difficult to decide at which stage (along the waste management and recycling chain) material that is discarded as waste should be regarded as secondary material that is being prepared for recycling. The definition may depend on what will happen to the material at a later stage. For example, one can consider two similar piles of construction and demolition debris – one may be taken to a landfill and the other may be waiting to be recycled, so at what stage do they acquire a different status under waste management law?
- Cars may be parked on a street, but if a car has been in the same place for a long time, it may be necessary to determine whether the car has been abandoned and can be removed as scrap, or whether it is still valued by its owner.

b) Ownership

There can be formal and informal understandings of who owns waste. In some cases truck drivers assume informal ownership of the waste that they are transporting and expect to be paid for the delivery of that waste at a certain place (so that the waste can be sorted by recyclers). Janitors or caretakers may expect to be paid for recyclable waste that is generated at their place of work. In some countries street sweepers informally buy the right to sweep the streets in a certain area where they can anticipate significant extra income from recycling, and payments for additional work done informally for residents. These informal arrangements may conflict with the law and the requirements of the official waste management agency.

In a situation where a formal waste management company invests time and resources in promoting at-source segregation, an informal sector recycler may have no legal right to take material from the segregated waste that has been put out on the street for collection by the formal organisation.

Even if a municipal waste management organisation is not involved in recycling, it may be the legal owner of the waste, and, for this reason, oppose the activities of informal sector waste pickers who do not have the legal right to make use of the waste.

B2.5 The informal sector

B2.5.1 What is the informal sector?

There is no widely accepted definition of the informal sector[11], and its boundary with the formal sector is sometimes blurred. However, it is clear that the informal sector plays a very important role in most low- and middle-income countries, providing livelihoods in a range of activities for a considerable proportion of their populations. Informal sector activities are not confined to waste management, but cover a wide spectrum of services, including roadside stalls, public transport (from minibuses that operate without a service licence to tricycle rickshaws) and informal classes given by schoolteachers in their homes outside school hours.

Informal sector activities in solid waste management usually fall into two categories – primary collection of solid waste and recycling. Primary collection services are arranged directly with the generators – householders, shopkeepers and other businesses – and paid for directly by the generators, with no reference to, or direct involvement of, the municipal authorities. Informal sector recycling encompasses a wide range of activities, including collecting mixed waste from houses and businesses, buying or collecting recyclables directly from individuals, houses and businesses, waste picking at any stage of the waste management chain, sorting, cleaning, trading, transporting and processing recyclable materials, and manufacturing (if using recycled material).

People who visit homes and businesses to buy recyclables directly from the generators are called *itinerant waste buyers*. Various names are given to people who earn a living by picking out from mixed solid waste items that they can use or sell; they are called *scavengers*, *rag pickers*, *waste pickers*, *street* or *dump pickers,* or *recuperators*. In this book the term *waste pickers* is normally preferred.

The factors that motivate people to work in waste recycling have been discussed in Section B2.4.2b, so they will only be summarised here

- Waste pickers do this work because there appears to be no other way of earning enough money to live on, or the alternatives are less attractive, for example, because they pay less.
- Waste picking is open to almost anyone because there is usually no barrier to starting to work in recycling. A waste picker does not need any capital or equipment to start this work, and normally there are no socio-cultural barriers to prevent someone from collecting recyclables – neither race, nationality nor religion exclude participation. People may collect recyclables on an occasional or continuous basis, and work part-time or full-time. Itinerant waste buyers can work more productively if they have a cart or tricycle, and they may need to negotiate with other informal sector operators to have access to a route or area where they may work.
- Some may work as waste pickers in order to find items for their own use. Examples of the items that are sought are condemned or expired food [Medina 2006] and food processing residues, clothes, and materials for building shanty housing.

[11] The understanding of the term *informal sector* that is used for this book can be found in Section 3 of the Introduction.

Informal sector recycling is more than waste picking. In many large cities there are complex networks of middlemen or dealers, and many others involved in sorting, cleaning, transporting and processing. Some dealers specialise in particular types of waste. (The author remembers visiting a dealer who specialised in particular non-ferrous metals, and had two large sacks on show – one was full of the small squares of aluminium foil that had been used to package individual medicinal tablets and the other was full of the brass tips that had been taken off cheap ball-point pens. This showed not only the care with which the waste is sorted to look for anything of value, but also the high degree of specialisation of particular dealers and the size of the network, since these items must have been supplied by a very large number of waste pickers.)

B2.5.2 Learning about the informal sector

It is difficult to get data about informal sector activities, partly because the authorities usually have no data (since the informal sector has no connection with the authorities.) Some recycling workers are reluctant to talk about their situation because of mistrust and fear of authorities. Informal sector dealers seem to be especially reluctant to give information, probably because they fear that they will be taxed. However, in spite of these difficulties, there is a considerable body of research on the subject of informal sector recycling. In some cases the data must be regarded as indicative rather than accurate, since estimates must be used when measurements are not available.

A major new study of informal sector waste management activities [Gunsilius et al., 2011b] investigated informal sector activities in six cities in four continents. Some of the findings of this study have already been referred to; a brief introduction to it is provided in Box B2.2

Box B2.2 The Economics of the Informal Sector in Solid Waste Management – an introduction to a ground-breaking study

Small groups of consultants, known as *City Partners*, were contracted to collect data on informal sector activities in the six cities where they work – Cairo in Egypt, Cluj Napoca in Romania, Lima in Peru, Lusaka in Zambia, Pune in India and Quezon City in Metro Manila (Philippines). The information that was collected enabled the tracking of waste quantities all along the waste management chain, from generation to processing or disposal. Socio-economic data were also collected to learn about the livelihoods and living conditions of the workers and their families. The reduction in global pollution that resulted from their work was computed (see Box B2.1). Data for the informal and formal sectors were compared. The data that were collected gave a good picture of the existing situation.

The City Partners also developed two "*what if"* scenarios to anticipate the impact that changes would have on the informal sector activities. One scenario looked at what would happen if the activities of the informal sector were restricted – the "subtraction" scenario. The other – the "addition" scenario – considered the likely outcomes of a more positive attitude towards the informal sector, leading to a greater degree of involvement and integration with the formal solid waste management service. These scenarios were developed by considering relevant legislation and in discussion with local officials. This approach is seen as a useful tool for formulating policy.

The estimates of the percentage of the total solid waste of each city that was recycled varied from 2% to 30%, and in five of the six cities the informal sector was recycling more than the formal sector. Most of the percentages indicate very significant reductions in the tonnages of waste going for disposal, resulting in cost savings and longer lives for the disposal sites. The six cities together have a combined population of almost 23 million, with approximately 73,000 informal sector workers who recycle more than 3 million tonnes per year.

Other results from this study are reported in the related parts of this book, and the summary booklet is included on the CD.

Reference: Gunsilius et al. 2011b

B2.5.3 Links and comparisons with the formal sector

Distinctions between formal sector recycling and informal sector recycling are not always clear. Recovered materials may pass back and forth between the formal and informal sectors on their way to final processing and manufacturing, and employees of the formal may also work informally. [Gunsilius et al., 2011b]

- Recyclables that are collected by the informal sector may be processed in a formal sector factory.
- Individuals and organisations may operate in both sectors. For example, municipal waste collectors (formal employees) separate recyclable materials from the waste they collect (working informally, often against the instructions of their employers) and sell the materials that they recover to informal sector dealers. Another example is that co-operatives and community-based enterprises that are involved in informal sector recycling may also have contracts with the authorities for street cleaning services.
- Recycling by the informal sector reduces the quantities of waste that must be disposed of in landfills, saving on the costs of formal sector disposal. This benefit comes at no cost to the formal solid waste management authorities. The authorities generally have no official data to indicate the scale of this benefit.

It often appears that attempts by municipalities to recycle materials from solid wastes are more expensive, less effective and less sustainable than systems operated by the informal sector. The informal sector may use simple equipment and methods, but there is usually a complex network of dealers and manual workers of different specialisations that has evolved, based on long experience and a good knowledge of the materials and markets. The motivation of most of informal sector participants is high because they know that their income depends on what they can recover, since they have no monthly salary and no social safety net. The motivation, and hence the productivity, of unskilled municipal workers is probably much lower, because their wages do not depend on the amount of material that they recover, and because they often have the right to continue in their current employment until they retire.

There is a wide range of attitudes towards informal sector recycling, ranging from co-operation and support, through apathy to repression and exploitation. In many cases,

municipal officials would like to stop all informal sector activities concerned with waste. The attitude of the general public is likely to depend on the impact of these activities on the local environment, and whether they benefit from a primary collection service provided by informal sector workers. Organisations concerned with environmental protection, social welfare and development are likely to have favourable attitudes. Some reasons for these viewpoints are suggested in the following paragraphs.

a) Negative attitudes towards informal sector recycling

The following reasons are suggested as explanations for negative attitudes that public officials and individual citizens may have towards informal sector recycling. (Most of these objections relate to waste picking, which is the aspect of recycling that is most seen by the general public.) These negative attitudes may cause the officials to wish that informal sector recycling could be stopped or reduced. The list is not in any order of priority or magnitude, and is intended to illustrate the perceptions of some individuals rather than reflect the opinion of the author.

- Waste picking may be associated with a particular social grouping – such as a racial or cultural minority, foreigners or refugees – which is regarded as inferior or alien.
- The rural origins of some waste pickers, their lack of education and low literacy, or their lack of middle-class manners may result in them being shown little respect. Because of such discrimination, the children of waste pickers may avoid going to school, even when they have the opportunity to attend [Koehs, 2006].
- Any work that involves direct contact with waste may be regarded negatively, so that any social contact with such people is avoided.
- Waste pickers may be classed as criminals, perhaps because criminals are thought to live in the same areas as waste pickers [Chaturvedi, 2008]. Consequently, the presence of waste pickers in a prosperous residential community may be seen as a threat to the community and its property.
- If waste pickers are dressed in shabby or dirty clothing, they may be despised for this reason.
- It is sometimes believed that all involved in recycling are rich, so envy may be a reason for hostility. This belief may also lead minor officials to seek bribes from informal sector workers.
- Waste pickers are often accused of scattering waste around street bins and of leaving a mess where they have been sorting waste. (It should be remembered that there are other possible causes of waste being scattered, such as the carelessness of waste generators who dump their wastes outside the containers, and scattering by scavenging animals.) Scattered waste adds to the costs of street sweeping and waste collection.
- Waste picking on disposal sites can cause disruption to landfilling operations, as discussed in Section B4.10.
- To varying degrees, informal sector workers operate outside the law. They do not pay tax, they do not have licences for the work they do, and they often do not comply with planning or zoning regulations. The working conditions in processing workshops – particularly lighting, ventilation and safety guards on machinery – may

also be less than the law requires. Legal definitions regarding the ownership of waste are ignored. In many cases informal sector workers are probably unaware of the laws that govern the work that they do. Law enforcers are therefore opposed to their way of working.

- Informal sector recycling may conflict with formal waste collection and recycling operations (whether provided by the private or the public sector). The conflict may be focused on the provision of competing collection services (Box B2.3) or competition to collect source-segregated recyclables [Medina, 2006].

Box B2.3 Conflict in Cairo

Conflicts with the formal waste management system mostly arise when the formal waste collection system is being modernised. This may result in competition for the waste itself. For example, in many parts of Cairo, for over half a century, informal sector workers collected waste regularly from outside the doors of each apartment because they wanted to use it – initially as fuel, and later as animal feed and for recycling. For this service a small fee was collected directly from the householders. When a new system of collection – based on street bins and provided by large, official contractors – was introduced, many householders continued to pay to the traditional collectors for their more convenient service and were unwilling to pay the new, official charge in addition. The informal sector collectors also sorted through the contents of the street bins before the official collection vehicles arrived. Some of the plastic street bins provided by the official contractors were even cut up and recycled by the informal sector workshops.

Recent developments in Cairo include (i) the start of the process of registering these traditional informal sector waste collectors and recyclers into formal companies, (ii) the possibility of their inclusion in the bidding for waste collection contracts and (iii) official approval of a request for the formation of a syndicate to represent the interests of the traditional waste collectors and recyclers. [Laila Iskandar, personal communication, 2012]

- The working practices of many waste pickers expose them and their children to health risks. Small children are sometimes seen playing on disposal sites while their parents sort through the waste. Babies are strapped to the backs of their mothers while they sort through the waste in bins. Concerns for their health lead to the opinion that this kind of work should be stopped. A memorable example of exposure to health risks was observed at a disposal site, where all the waste pickers suddenly stopped what they were doing and ran to where a truck was unloading waste from a hospital, so that they could collect items of medical waste. They did this because of the high prices paid for some items of medical waste (which may be infectious, or hazardous in other ways).
- The involvement of child labour may cause opposition, because of international and national law, health risks and the reduced opportunities for schooling.
- Some recycling activities cause unacceptable levels of local pollution. Informal sector activities often do not comply with zoning regulations, so that industrial

activities take place in residential areas. The sorting and storing of waste in residential areas can result in serious nuisance in terms of smell, polluted water and large numbers of flies and rats. Primitive technologies for processing recycled metals can cause serious localised air and water pollution and contaminate soil. The smoke resulting from the burning of electrical cables to remove the insulation is particularly hazardous. The burning of items covered with lead-based paints is another concern.

- Some products made from recycled or reused items may be dangerous. One example is the reuse of drums and other containers that have previously contained toxic substances and have not been properly cleaned. Some items and materials found in healthcare waste can be infectious or toxic.

Photo B2.18 Children of waste pickers may spend their days on the waste. (Older children help their parents).

Some of these issues can be resolved by communication between the informal sector and municipal authorities, and by co-operation. There may also be other reasons why waste pickers are opposed, harassed or ignored. Negative attitudes and lack of protection by the law sometimes result in recycling workers being asked for bribes by the police or junior officials, or forced to do work for them. Informal sector workers are more at risk of violence, including rape.

Before debating at length whether or not to stop informal sector recycling, it is worthwhile to remember that, in many cases, it is not easy to prevent informal sector waste picking, so the debating may be academic rather than practical. New bylaws and fences at landfills do not deter waste pickers if they have no other way of earning enough to provide food and shelter for themselves and their families. This leads to a consideration of the benefits of informal sector recycling, and reasons for a positive attitude towards people who earn their living from it.

b) Reasons for a positive attitude towards informal sector recycling

The list of reasons for a positive attitude towards informal sector recycling may not be as long as the list of causes of negative attitudes, but these reasons are generally stronger and more honourable, and are therefore worth careful consideration.

- Livelihoods – in many large cities in the developing world it is likely that the numbers of informal sector recycling workers are well into the tens of thousands. Large numbers of citizens have food and shelter at no cost to the state because of the income they derive from waste. A thriving segment of the economy is based on material that others consider to have no value. Without informal sector recycling there would be many more destitute families, beggars and criminals.
- Reducing waste quantities – It is widely agreed that it is necessary to reduce the amount of waste that is sent for disposal, even if waste disposal sites are operated to the highest standards. In low- and middle income countries, waste reduction and recycling initiatives by local government administrations have generally not been successful and sustainable in comparison with the work of the informal sector. Some governments have set targets for the percentage of waste that is to be recycled, but it may be that the informal sector is the key to achieving these targets. Municipal administrations rarely collect data on the operations of the informal sector and so are unaware of the reductions in waste quantities that result from informal sector operations, until an independent investigation is carried out.
- Reducing pollution – City officials may blame the informal sector for increasing pollution – blaming recyclers for local pollution around storage containers and pollution around their processing facilities – but the informal sector reduces local pollution from disposal operations (by reducing quantities sent for disposal) and reduces the global pollution that is associated with climate change (by reducing quantities of waste transported and sent for disposal, and by reducing the demand for virgin materials). In many cities informal sector street pickers remove recyclable items from the litter that is left on the streets, reducing this form of pollution and assisting the local administration in its task of keeping the streets clean.
- Reducing costs – Many cities benefit from waste collection services provided by the informal sector at no cost to local government. (The most famous example is Cairo, where, for decades, informal sector waste collectors were collecting waste from a large part of the city, deriving their income from a small fee collected from each household and the sale of recyclables separated from the waste.) Transport and disposal costs are reduced according to the proportion of waste that is recycled. The lives of landfills are lengthened because the quantities of waste arriving each day are reduced.

c) Options for improving the informal sector

Communication

Many of the reasons for opposing the informal sector can be undermined by establishing channels of two-way communication and building up trust. This includes better understanding between people with a concern for the social welfare of waste pickers and officials and managers who are responsible for operating large urban solid waste management systems, but this alone is not enough. There must be communication between waste pickers and city officials. This implies that there must be representatives of the waste pickers, who can speak and negotiate on behalf of informal sector workers, and, on the other side, local government officials or senior staff of private sector service providers who are designated to liaise with the informal sector. These officials need to

have respect for their informal sector counterparts, flexibility (that is, a willingness to consider what can be changed and to try new and unconventional approaches) and a clear understanding of priority objectives. If each side understands the concerns and requirements of the other side, progress can be made.

NGOs can play a valuable role in bringing the two sides together [Chaturvedi, 2008]. If the informal sector workers have no organisational structure or natural leadership, it may be necessary for an NGO to assist them in developing a structure so that they have representatives who can discuss with municipal officials.

The Inclusive Cities project[12] is an example of how informal sector recycling workers can make their voice heard.

Defining objectives

Before any attempts to improve the working conditions and productivity of informal sector recycling are initiated, it is important to ensure that the proposed improvements are needed and are likely to be effective. This requires a good understanding of the existing system of recycling and extensive consultation with representatives of the people involved. The general support of the informal sector recyclers themselves is a key requirement for any initiative that aims to improve their situation. It will usually be necessary to undertake a baseline study of the situation before any initiative is implemented so that the impact of the initiative can be demonstrated.

The aims of initiatives involving the informal sector might include

- a reduction in the unofficial harassment by junior city officials
- increasing the amount of material that is recycled,
- the reduction of local pollution resulting from recycling activities,
- the reduction of child labour and increased school attendance by the children of recycling workers,
- the improvement of the health status of recycling workers (waste pickers and others working further down the chain of recycling activities),
- improvements in the living and working conditions of informal sector workers, and
- improved co-operation between the informal sector and the formal sector service providers.

Options for action

There is a wide range of initiatives that can be taken to make progress towards achieving these aims. The first steps may often be small ones, in order to build confidence and to understand the needs more fully. Concessions or support from the authorities may be conditional on improvements made by the waste pickers (such as reduced use of child labour or changes intended to minimise local pollution). Measures that have been implemented or proposed in various cities include:

[12] "Inclusive Cities" addresses urban poverty by supporting and building the capacity of membership-based organisations (MBOs) of the working poor. Through organising, advocacy and policy analysis, the Inclusive Cities project helps informal workers to make their needs heard within the urban planning process. See the website www.inclusivecities.org.

- Keeping waste pickers informed of planned changes that may affect them,
- Taking measures to reduce unofficial harassment by police and municipal officials (such as violence, confiscation of carts or recyclables, demands for bribes or labour),
- Providing some form of recognition of waste pickers, by recognising their work as a legitimate occupation [Dias, 2006] or providing identity cards [Chaturvedi, 2008], so that their work is seen as an accepted component of the solid waste management system. In Pune, India there is the category of "Authorised Waste Pickers" with a union to represent them [Gunsilius et al. 2011b],
- Providing sanitary facilities at places frequented by waste pickers, and giving training in hygiene and safe working practices in order to reduce injuries and illness,
- Providing land for waste pickers to sort and store their waste, so that they are not doing this work on the streets or in other public places; providing them with handcarts so that they can collect recyclables more efficiently [Dias 2006],
- Providing legal assistance – with the aim of improving relationships with the police [Chaturvedi, 2008], or to help informal sector enterprises to gain a formal status, (This is discussed more in the section on formalisation below.)
- Allowing an organisation of waste pickers the right to pick over waste at disposal sites before it is levelled and buried (Section B4.10),
- Assistance in forming a co-operative or similar organisation, which could perform many roles, including negotiating and advocacy on behalf of waste pickers, providing medical insurance, providing equipment and facilities, educating in health and welfare issues and buying recyclables at better prices than those offered by conventional dealers,
- Providing childcare for pre-school children and helping the children of rag pickers to adjust to the challenges and disciplines of schooling [Koehs, 2006]; providing vocational training to the older children of waste pickers [Iskander Kamel, 1994],
- Private companies and municipal organisations that are providing waste collection and recycling services may wish to employ informal sector workers, because of their willingness to work with waste and their expertise in recycling. However some municipal administrations are required to reduce their unskilled workforces and so would not be able to recruit in this way. Informal sector workers who have become accustomed to being autonomous may be unwilling to be obliged to work particular hours and take instructions from a foreman. It cannot be assumed that individuals who are currently in the informal sector will work with the same efficiency if they join a formal sector workforce and receive a fixed wage irrespective of their output or efficiency. Even if some individuals move from the informal sector to the formal sector in this way it is likely that there will continue to be informal sector waste pickers, as newcomers drift into this activity.
- Integration - In general it is not possible for local government to enter into a formal contract with an informal sector association. Within some legislative frameworks a semi-formal status may be considered. It may be possible to integrate the informal sector into the waste management system by means of *gentlemen's agreements* rather than legal contractual documents.

For this to happen the informal sector workers must have some form of structure, such as a co-operative or at least a recognised leader – as was mentioned at the start of this Section. Such arrangements may be used on disposal sites to co-ordinate picking with unloading and covering operations and to ensure that minimum standards (such as not starting fires on the site or smoking) are upheld. Similarly an informal sector primary collection service can be co-ordinated with a municipal secondary transport service. Another option is to engage an informal association to sort waste at a transfer facility. If at-source segregation of recyclables can be instituted, the informal sector could be offered the task of collecting the segregated recyclables (and/or food waste for feeding animals) while the formal sector service collects mixed waste and rejects.

There may also be opportunities for closer integration of the informal sector with the larger-scale operations of the formal private sector. This may take the form of closer links between informal sector primary collection with the secondary collection service provided by an official contractor. Another option is the formation of closer links between some aspects of the informal sector recycling network and registered companies involved in the processing of recyclables and manufacturing.

- Formalisation - Some informal sector organisations may wish to be registered as formal sector enterprises, being ready to pay taxes and submit to regulations, but the processes of registration may be expensive and too complex for them to undertake without the advice of an expert in legislation.

  Complete transfer to the formal sector may involve considerable expenditure on lawyers' fees and licences and may be a daunting prospect for a semi-literate waste worker who has hitherto operated on the margins of society and taken care to avoid any contact with officialdom. The support of an NGO can be very helpful. Informal sector entrepreneurs may be motivated to engage in the process of formalisation in order to avoid the harassment and demands for unofficial payments that they experience because of their current informal status. The taxes that are payable in the formal sector may be less than the bribes that they have paid as informal sector workers.

  Workshops wishing to become formalised may be required to relocate to industrial areas and invest in improved equipment and facilities. In some cases requirements may be relaxed or extra time allowed for complying with the law's demands.

  If the informal sector is formalised there is a strong possibility that other people will take up recycling activities as a truly informal sector if they do not have access to the newly formalised arrangements or if there are advantages in being truly informal.

As with other proposals for change, it is important to consider the potential impact of the changes on women, children and minority groups.

Potential obstacles

The extent to which a local government administration is willing or able to invest time and resources into improving informal sector recycling may be limited by

- the attitudes and prejudices of municipal officials

- financial restrictions;
- political considerations, if the electorate is hostile or apathetic towards informal sector recyclers;
- legislation – if, for example, the law may allow waste pickers who are supported in some way by local government to demand that they are given the status of employees (especially if the local administration is trying to reduce the size of its workforce), or if the law states that informal sector recycling is illegal; in such cases it may be possible to revise the legislation;
- the response of the informal sector workers to previous initiatives – if the workers are not sufficiently co-ordinated, if they have not fulfilled the responsibilities that they had agreed to in earlier negotiations, or if they are not prepared to co-operate.

B2.5.4 Some key points

- Informal sector waste recycling enables large numbers of people to earn enough income to support their families.
- Informal sector workers in solid waste management make a large and positive impact in many cities in developing countries;
- Communication and co-ordination between informal and formal sectors can bring significant benefits to both sides.
- GIZ has published a useful review of informal sector involvement in waste recycling [Gunsilius et al. 2011a]

B3. Options for treatment

B3.1 General considerations

In this book, treatment is considered to mean the processing of solid waste in order to

- reduce its volume or weight,
- reduce its potential for causing pollution or other undesirable impacts before final disposal, or
- recover energy from the waste.

According to these objectives, composting could be considered to be a treatment process. However, in this book it is considered as a recycling process, because generally it is undertaken in order to make a marketable product.

It is unfortunate that in recent years, in low- and middle-income countries, there have been many examples of money, time and effort being wasted on treatment processes that have not performed as expected. Some treatment facilities have been built but never operated successfully, and others have operated for only a short time or at a fraction of their intended throughput. In some cases there were very unrealistic expectations of profits that could be earned from outputs. The author is not claiming that all treatment processes are always failures, but is urging that any decisions

concerning waste treatment facilities in developing countries should be made with great care and consideration.

Various institutional arrangements are used to introduce and operate treatment facilities. Simple and small-scale treatment processes may be acquired and operated by local government, private entities or NGOs, but it is common for larger facilities to be established and operated by the private sector under a *build-own-operate-transfer* concession arrangement.

One common reason for these failures is that decisions to adopt them have been made without adequate consideration of technical information. Such decisions may have been made for the following reasons:

- Inadequate consideration is given to local conditions, in particular the composition of the waste as it is received at the treatment facility, and the seasonal variations of this composition, and perhaps also the quantity of waste. Decision-makers may visit a city in a highly industrialised country where a facility similar to the one proposed is operating, and be impressed by the efficiency of solid waste management and the cleanliness of the city, and be persuaded that they key to having a modern and effective system is the treatment process that is being promoted. The desire to be modern and to use sophisticated technology can lead to unwise decisions.
- Decisions may be made by senior political leaders on the basis of information provided by the suppliers of the equipment, possibly influenced by the provision of hospitality or other incentives. Information provided by the suppliers may not tell the whole story and may not be appropriate for the location being considered.
- The failure to investigate the operating record of similar facilities working in similar conditions. (As mentioned in Section A5, it can be very difficult to get accurate published information about actual operating experiences. For this reason it is necessary to investigate the operations of similar facilities in some detail, to learn about operating experiences first-hand from the operators and engineers and to observe and measure actual operations.)
- Insufficient attention is given to details of the concession agreement with the supplier and operator of the treatment facility. Some proposed agreements seem to load all of the risks onto the operator, but fine print clauses in the agreement that are ignored by the local administration result in the payment of large compensation payments to the operator. For example, such clauses may require compensation payments if the quantity of waste delivered falls below a defined amount, or the composition of the waste does not meet certain criteria. In some cases the operator may be more interested in gaining access to land or waste collection contracts than in treating waste.
- Attention is focused on the establishment of the plant, whilst insufficient attention is given to the demands of the operation of the facility. Actual recurrent costs – particularly the costs of energy and maintenance – may be much higher than anticipated, or the available operating and maintenance skills may prove inadequate.
- The requirements or guidance of donor or lending organisations, which may be represented by an enthusiastic but inexperienced staff member who wishes to establish a treatment system that has been successful in industrialised countries but

is unsuited to the locality of the particular project. In some cases the success of a donor project may be judged according to the size of the loan and the impressive nature of the resulting treatment plant, rather than according to the impact on solid waste management in the following ten to twenty years.

Other reasons for failures of composting and treatment plants have included the failure to consider all environmental impacts and the opposition of local residents.

In all but the most sophisticated waste management systems, landfills are needed for the disposal of rejects and residual waste. It is strongly recommended that treatment is not considered until a sanitary landfill is operating according to a good environmental standard. The human and financial resources needed for any treatment facility should not be taken from the landfill, because it is necessary that the landfill continues to be operated in a satisfactory way.

Concession agreements that specify a minimum quantity or particular composition for the waste that is delivered each day for treatment may impose limitations on reduction, reuse and recycling. RRR measures could reduce the quantity of waste below the threshold in the concession agreement or change the composition of the waste so that it does not satisfy the requirements in that agreement. According to the waste management hierarchy (Box A6.3), reduction, reuse and recycling should have a higher priority than treatment.

There is a large range of treatment processes – if processes that are found only in text books and experimental installations are included. Some of the processes that are sometimes mentioned as possible ways of treating solid waste are only suitable for particular types of waste and not worth considering for municipal solid wastes in low- and middle-income countries. Processes that have been proposed for treating municipal wastes in middle- and low-income countries are introduced in the remainder of Section B3. The inclusion of these processes in this book should not be taken as a recommendation that they should be used in low- and middle-income countries. The author believes that in most cases they are unsuitable and should be avoided.

B3.2 Screening

Screening is simply the separation of waste constituents according to their individual size by passing the waste over a mesh with apertures of an appropriate dimension. Simple screens are no more than an inclined sheet of mesh on which the waste is introduced at the top so that fine material falls through the mesh and coarse material slides over it to the bottom. More sophisticated arrangements for continuous feeding include vibrating screens and rotating drum screens. Further comments about the various types of screens can be found in Section C3.2.

Waste may be subjected to screening for a number of reasons related to recycling. Some common objectives are:

- to reduce the amount of fine material in the waste to that there is less dust nuisance in subsequent sorting operations;

- to separate material that is largely organic or largely inorganic from the rest of the waste. (for example in some cases food waste – such as rice – has a small particle size, whereas in other wastes the fine material is mostly sand and soil). This may be the first stage in the sorting needed for recycling;
- to classify demolition debris that is to be recycled, since the fine and coarse fractions may have different uses or require different processing;
- to prepare a fine and uniform compost as the last stage of the composting process, and
- to prepare material that can be used as a soil improver by screening decomposed waste that is dug up from a disposal site.

B3.3 Treatment to reduce transport and disposal impacts

B3.3.1 Baling

Baling is the compression of material into rectangular bales. Baling is often used for recyclable materials in order to increase the load that can be carried by one truck, thereby reducing the costs of transporting the material. Bales of inert material are stable in the sense that they do not change their form or nature with the passing of time, but bales of biodegradable material are unlikely to be stable for even a few days. Some materials form bales that do not need tying to keep them together, but bales of other material need to be held together with wires, bands or rope.

There have been some examples of the baling of mixed municipal waste, with the intention of increasing the load that can be transported by each vehicle and increasing the density of the waste in a landfill. (A high density in a landfill can only be achieved if the bales are very carefully placed.) There is evidence to believe that the benefits of baling mixed municipal waste do not justify the extra capital and recurrent expenditure involved, particularly if the waste initially has a comparatively high density, as is usually the case in low-and middle-income countries. Furthermore, bales of mixed waste may be unstable, making handling more difficult. Therefore it is recommended that baling of mixed municipal waste is not considered, except perhaps in exceptional cases.

Photo B3.1 Bales of waste

B3.3.2 Size reduction

Size reduction is the breaking or cutting of the individual pieces of the solid waste into smaller fragments. Size reduction may be recommended in order to

- reduce the volume occupied by a given weight of solid waste in order to reduce transport costs and required landfill volume. (This is a good reason for shredding tree branches before they are transported, and may be applicable for used tyres before disposal.);
- make the waste more homogeneous and less attractive to flies;
- accelerate the process of composting, by increasing the surface area presented to bacteria,
- prepare wastes for a subsequent treatment process, such as automatic sorting or the disinfection of healthcare waste by microwaves, or
- to disfigure wastes that may be visually offensive, so that they are no longer offensive and recognisable. This may be a reason for size reduction of waste from hospitals. This treatment of infectious waste from hospitals is discussed in Section B3.6 below.

There are many technologies that are used for size reduction of solid wastes. The three most common types of equipment are trommels, shredders and hammermills. They are discussed briefly in Section C3.1

B3.3.3 Mechanical-biological treatment

Mechanical-biological treatment (MBT) comprises various combinations of treatment and recycling processes that have been developed to reduce the environmental impact of the wastes when they are landfilled. They are used to treat mixed municipal waste. The primary objective of the various schemes is to treat the biodegradable wastes so that they do not cause significant water and air pollution when placed in a landfill. An additional objective may be to get some value from the other (non-biodegradable) wastes, either by recycling them or using them as a fuel. One MBT process chain first subjects the waste to screening to separate out the larger items that are mostly not biodegradable and then allows the finer, mostly biodegradable fraction to undergo a rough composting process, so that the output is relatively stable and does not produce methane and polluting leachate[13]. Other methods of treatment may also be proposed.

Mechanical-biological treatment is generally complex and should not be considered until a satisfactory standard of sanitary landfilling has been achieved. If the biodegradable fraction of the waste is not fully treated (i.e. not completely stabilised so that it decomposes further when placed in the landfill), it will still be necessary for the landfill to be able to protect the environment from pollution. Some of the processes used in MBT are not reliable and require significant additional expenditure. Resources should not be

[13] Leachate is polluted water that originates in the waste or that infiltrates from outside the waste and trickles down through the waste, collecting material from the waste as it travels. Leachate usually has a strong black colour with an oily appearance, and contains very high concentrations of organic chemicals, as well as ammonia and other toxic substances. It is much more difficult to treat than municipal wastewater from homes.

taken from sanitary landfilling in order to implement and manage MBT processes. If a local government administration is not able to operate a landfill to a good standard (i.e. as a sanitary landfill), it is very unlikely that it will be able to provide effective and reliable mechanical-biological treatment for its solid wastes.

B3.3.4 Key point

If a solid waste management system does not have a well-operated sanitary landfill, no consideration should be given to adding the treatment methods described in this section. Effort and expenditure should be concentrated on improving the landfill.

B3.4 Options for obtaining energy from waste

B3.4.1 Incineration

Burning waste in an incinerator is totally different from burning waste in the open air or in a simple structure. Incinerators that are designed to burn municipal waste generally have capacities of at least several hundred tonnes a day, and are carefully controlled so that the combustion temperature is maintained within a defined range. A large part of the equipment of a modern incinerator is concerned with ensuring that the gaseous emissions from the tall chimney stack are largely free of smoke and contain only very small quantities of harmful chemicals. Modern incinerators are designed to produce heat energy which is used to generate electricity while also providing heat for local housing, amenities or industry. The volume of the residue after burning depends on the composition of the incoming waste and the effectiveness of the combustion process; at best it is in the region of 5% to 20% of the volume of the waste input. In this way incineration can reduce the volume required for final disposal in a landfill.

Incineration is widely and successfully used in many European countries, but it has been a complete failure where it has been tried in low- and middle-income countries. For this reason, incineration of municipal wastes is not discussed in detail in this section[14], but instead the reader is asked to consider the reasons why incineration is not an effective or affordable means of waste treatment in developing countries. Examples of experiences are given in Box B3.1.

a) <u>Reasons for the failure of incineration in low- and middle-income countries</u>

1. The nature of the waste

   Municipal waste contains many components, and the relative proportions of these components vary greatly from one place to another. Municipal waste can be characterised by its energy value, which is the amount of energy that is released when one kilogram of the waste burns. Some components of waste, such as plastics, paper and wood, burn well and produce useful energy when they burn. Other components, which are inert, such as metals, bricks and soil, do not burn and so do not provide any energy. Some components, notably fruit and vegetable waste, contain large amounts of water, and do not burn until this water has been

[14] More information about incineration can be obtained from [World Bank, 1999] – a decision-makers' guide which is listed in the References annex and can be downloaded from the internet.

evaporated – and large amounts of energy are needed to evaporate this water. Therefore, solid waste that contains very little paper and plastic, but is mostly food waste and sand, has a low energy value and may require large amounts of additional fuel, such as gas or oil, in order to make it burn and achieve the necessary temperatures. (If the required temperatures are not maintained, much more air pollution is produced, the fabric of the incinerator may be damaged and the energy output is reduced.)

Municipal solid waste in developing countries is usually composed of higher proportions of fruit and vegetable waste and lower amounts of paper and plastic, in comparison with the waste of industrialised countries. Studies of the composition of domestic solid waste usually investigate samples of waste taken directly from households. In many countries, waste pickers remove much of the plastic and paper from the waste before it arrives at the treatment or disposal stage. In such cases, because the waste pickers have taken these materials, the waste that would be received at an incinerator would have a very low energy content, and would not burn without expensive inputs of fuel. Estimates of the energy value must be based on the composition of the waste as it would be received at the incinerator, not the composition of waste as collected from the sources.

Because the composition of the waste has such a big impact on the feasibility of incineration, it is vital to have accurate information about the quality of the waste. Wastes from different parts of a city and different types of sources have different compositions, and so it is necessary to blend data for different sources to get a reliable overall figure.

The composition of waste varies from season to season – according to rainfall and evaporation if the waste is exposed, but particularly according to the availability of fruit and vegetables. The waste must have a sufficient energy value at all times of the year; it is not sufficient to have a satisfactory annual average figure for the energy value, because the incinerator burns the waste that is actually collected on the day or the previous day.

2. Financial aspects

Incinerators are large and sophisticated facilities. The need complex air pollution control stages to prevent serious environmental pollution. Therefore, the investment costs are large. Even if no fuel is needed to keep the waste burning, the operation costs are high, because of the maintenance of the range of equipment needed to keep the facility running – some of it relatively complex.

The potential sources of income for a waste-to-energy plant should be evaluated carefully. The generation of electricity may not be financially worthwhile unless the electricity that is generated can be sold to the grid or to local consumers at a price that is higher than the price charged for electricity that is generated in the conventional ways. If electricity prices to the consumer are kept low by subsidies, a substantially larger subsidy would be needed if the generation of electricity using heat from an incinerator is to be profitable.

The income of waste-to-energy incinerators in Europe is increased by selling the heat energy that remains in the steam after it has passed through the generator turbines. In warm and tropical climates there are fewer potential customers (compared to the situation in temperate climates) for year-round heat (transported as hot water), since houses and factories do not require heating. Carbon credits (Section B5) may provide some help with the costs of electricity generation.

Even if both electricity and heat energy can be sold, the income will not be enough to bring the net costs down to the level of the costs of sanitary landfilling. If a city is unable to pay the operating costs for a good sanitary landfill, how will it find the money to pay the much higher operating costs associated with incineration?

3. Human resources

   A skilled workforce is needed to operate a large incinerator. The waste must be well mixed and the operating conditions controlled to ensure good combustion and minimal air pollution. A variety of electrical and hydraulic machines, some of which operate at high temperatures, must be kept in good condition and repaired when necessary. The air pollution control equipment must be kept at optimum efficiency. The skill levels required are higher and more specialised than the skills needed to operate a sanitary landfill.

4. Environment

   Incineration with energy recovery is ranked lower than reduction, reuse and recycling in the waste management hierarchy. Therefore the requirements of incineration should not reduce the recycling of paper, cardboard and plastic. (The operator of the incinerator may wish to burn as much of these materials as possible in order to reduce the dependence of the incinerator on supplementary fuel.) The quality of the gaseous emissions of the plant depends on the combustion temperature and the effectiveness of the air pollution control equipment. The bottom ash that falls through the grate in the combustion chamber and the fly ash that is removed from the exhaust gases may be classed as hazardous waste because they contain pollutants in concentrated and soluble form, so they must be disposed in a good sanitary landfill or recycled under carefully controlled conditions.

   When PVC plastic and other materials containing chlorine are burned, toxic chemicals called dioxins are formed, and even careful operation cannot eliminate this problem. The best solution is to ensure that very little PVC is incinerated.

5. Operational aspects

   Incinerators are designed to operate 24 hours a day and 7 days a week, but there are times when the facility must be shut down for routine maintenance and because of unforeseen breakdowns. On such occasions it is necessary to have an alternative means of disposing of the waste – either taking the waste directly to a sanitary landfill or using another incinerator. Customers who buy the electricity and heat must be able to access alternative supplies until the waste-to-energy facility is operating again.

Operating conditions that are not ideal can lead to increased maintenance and downtime because the products of combustion at lower temperatures can be more corrosive and attack the fabric of the incinerator.

6. Public relations

There is often public opposition to incineration, especially if the facility emits visible smoke. Incinerators are often located closer to residential and industrial areas than landfills, so a larger proportion of the population is aware of the existence and operation of the plant. At least one major international environmental NGO is strongly opposed to incineration as a matter of policy.

Box B3.1 Examples of incinerators in low- and middle-income countries

- In a major West African city – The author was told about three incinerators that were built in one city but had not been successful. One had been completely demolished and one had been converted into a community centre. The fate of the third was not known.
- In a major Asian city – The author visited an incinerator that was not used because of the low energy value of the waste. The city had a very large commercial and administrative area, which would be expected to generate a large quantity of paper waste, but little of this paper reached the incinerator because it was removed for recycling by waste pickers. The incinerator was kept in excellent condition but was not used because the cost of the fuel needed to burn the waste was too expensive.
- In a middle-income Mediterranean city – An incinerator had been constructed and was being used, partly because of difficulties in landfilling the city's waste. However, the energy value of the waste was not sufficient to attain the required temperatures in the combustion chamber, so the fabric of the incinerator was being damaged by corrosive gases. Based on the belief that the high moisture contents of the waste were caused by rain entering waste in the communal street containers, new street bins with hinged lids were purchased so that the rain could be kept out of the waste (if the lids were kept closed by the users), in the hope that this would improve the performance of the incinerator. Later it became clear that the high moisture contents were occurring in the summer – not in the winter because of the rain – because of the large quantities of watermelons and other fruit that were being consumed.

If the only impact of this book is to stop the installation of one incinerator for municipal waste in one city where it will not operate sustainably, then all the effort and expenditure that has been devoted to the preparation and publication of this book will have been worthwhile.

b) Wastes other than municipal wastes

Specific wastes may be burned in an incinerator to generate heat. For example, used vehicle tyres can be burned to recover energy, provided that combustion conditions are carefully controlled to prevent the emission of smoke. Reliable data on the supply of used tyres and on costs should be carefully considered before any decision is made to

implement such a facility. Some factories producing large quantities of wood waste use it to heat their boilers. Other industrial wastes are also used to fire boilers.

Incineration is the only disposal method that can be used for certain hazardous industrial wastes, and there are considerable advantages of co-processing such wastes in cement kilns [GTZ-Holcim, 2006]. Incineration has been used successfully for the treatment of certain wastes from hospitals and other healthcare facilities, but even with these small incinerators there are often operational problems including the production of large quantities of smoke and the reluctance to purchase the necessary fuel. These uses are discussed below in Section B3.6 Small incinerators may also be used for destroying illegal drugs, confidential documents and condemned bank notes. Incinerators may also be used for destroying animal carcasses and condemned food, but supervised burial in a landfill site is usually satisfactory for the disposal of such wastes.

B3.4.2 Refuse-derived fuel

A further method of obtaining energy by burning waste involves selling the components of the waste that have a useful energy content as a fuel for use in industrial boilers. One way of doing this is to compress the shredded waste (to which a binder substance may have been added) at a high pressure and force it through a circular aperture to form solid, cylindrical pellets (often about 15 mm in diameter and 20 to 40 mm long). These pellets can be sold, transported and used in industrial boilers. Sometimes the combustible material is not formed into pellets but is sold as dry shredded waste, often known as *fluff*. The pellets or fluff are known as refuse-derived fuel (RDF). RDF burns faster than coal so its use may require some adjustments to boiler feed mechanisms.

<u>Operational problems</u>

- The first challenge is to find waste that has a sufficient energy content. As with other energy recovery technologies, it is essential to have reliable data about the energy content of the waste as it would be received at the processing plant, not as it is at the point of generation. Recycling (which is higher up the waste hierarchy than energy recovery) takes out the paper and plastic which provide much of the energy when waste is burned. Soil, building materials and stones must be removed because they do not provide any energy. It may be necessary to remove biodegradable material because it would start to decompose if the RDF becomes moist, causing the pellets to disintegrate. Finally the moisture content of the product must be low, so energy must be used for drying the feedstock before it is processed.
- The working life of the machinery used to process the waste into RDF is often short because of the abrasion caused by grit and other hard material in the waste. Maintenance and replacement of this machinery adds significantly to the cost [Nema, 2009].
- If there is any PVC plastic in the waste it will burn to form toxic dioxins. The combustion conditions of small industrial boilers are not controlled as carefully as is the case for large incinerators, and industrial units have shorter chimneys, so dioxins are of greater concern for RDF applications compared to municipal incinerators.

B3.4.3 Anaerobic digestion

When biodegradable wastes such as food waste, garden waste and paper decompose in the absence of air and in the presence of water, the gases methane (CH_4) and carbon dioxide (CO_2) are formed. This happens in landfills soon after the oxygen in the interstices of the waste has been used up and continues until the waste is stabilised (meaning that it undergoes no further chemical change, even if the conditions are suitable for microbiological decomposition). The microbiological action will also stop if there is insufficient moisture in the waste. The methane gas that is produced in this way can be used as a fuel – on a small scale for cooking or lighting and on a large scale for generating electricity. The scientific name for this process is *anaerobic digestion*, but when practised on a small scale it is called *biogas* generation and in some countries it is referred to as *biomethanation*. The process usually involves adding water to the waste, and stirring and warming the liquid mass in a closed vessel for some days. Apart from the gas, which is collected in the closed chamber, the output is a partially stabilised slurry which can be used as a soil improver.

Anaerobic digestion has been used for many decades for the treatment of sludge from large wastewater treatment plants, and for the small-scale treatment in biogas plants of animal manures and human faecal waste. More recently it is being used to treat segregated food waste. This food waste is collected from canteens, restaurants, markets and slaughterhouses, or by separate collection of household food waste that has been segregated for this purpose in the home. India has been vigorously promoting the use of small-scale anaerobic plants by, for example, requiring that new housing developments set up biogas plants in order to get permission to build [Voegeli and Zurbrügg, 2008]. The usefulness of the methane gas as a fuel is the incentive for keeping the plants operating (though the amount of gas generated would probably not meet the needs of all the contributing residents in the housing development).

The process is most efficient when the temperature inside the digester chamber is kept constant and above 30C, and the composition of the feedstock is also kept constant. The process is also improved when the particle size of the waste pieces is reduced by shredding or an equivalent process. The contents of the digester are stirred.

The success of this technology on a small scale has not translated into sustainable treatment of mixed municipal solid waste on the citywide scale. Some entrepreneurs have been keen to sign contracts with city administrations for large units that are intended to treat mixed municipal solid wastes, but this application of anaerobic digestion is still in the experimental stage, and the author is not aware of any successful large-scale plants.

One problem facing this application is the heterogeneity and variability of municipal solid waste, leading to problems caused by materials that float and cause a scum and others which sink to form a dense sludge. The quality of the feedstock is a very important factor. If the input is supposed to be food waste that has been segregated in each home, and if the segregation is not accurate and consistent there will be significant amounts of other wastes mixed with the food waste. In some cultures it may be a huge task to inform and persuade citizens to segregate their food waste.

Control of the conditions within the digester may also be a problem. Sand and grit may cause abrasion damage requiring frequent replacement of components. The methane gas may need refining before it can be used in an engine that is able to burn this fuel.

For a large plant the utilisation or disposal of the output slurry may present difficulties. If only food waste is treated, there will need to be a sanitary landfill for residues that are not treated or recycled, as well as for food waste when the plant is not working or when the quantity of incoming waste exceeds the capacity of the treatment plant.

Some experiences of larger anaerobic digesters in Asia have been reported by Nema [2009], but there is a great need for a more comprehensive documentation of experiences related to the setting-up and operation of large anaerobic digestion plants for treating municipal solid waste. Until favourable – and accurate – accounts of such plants are available, the use of this technology for treating municipal waste should be considered to be in the experimental stage, and not appropriate for large-scale use in developing countries.

It is appropriate to mention here that methane (as a component of landfill gas) can be collected from sanitary landfills that are well operated. This gas can be used to generate electricity or as a fuel. This is discussed further in Sections B4 and C4 below.

B3.5 Other methods of treatment of municipal wastes

Some researchers and entrepreneurs are fascinated by the challenge of converting waste into useful materials. Because of the heterogeneity and variability of municipal solid waste, it would be useful to find a process that can produce a useful product from mixed waste. Several innovative processes have been developed and demonstrated at pilot scale. Some solid waste management textbooks mention these processes and it is tempting for the reader to consider these processes as alternatives to the well-developed technologies[15] that have already been mentioned. Before any technology is considered to be an option, it is essential to investigate the operation of the technology in working conditions that are similar to the situation being considered and to take careful account of local conditions.

One other process that has been shown to be technically feasible in research conditions is mentioned in Section C3, but its mention in this book should be taken to signify that it is a feasible option for the treatment of municipal solid waste in low- and middle-income countries, according to the state of their development and application at the time of writing. Academics and research scientists may make enthusiastic claims for their proposals for turning waste into riches, but the day-to-day world of waste management is very different from the laboratory. There is an on-going danger that money, effort and expertise will be wasted on unreliable and unfeasible treatment technologies when the urgent need is to focus on recycling and landfilling.

[15] These "well-developed technologies" have been successful in certain situations, but this description of treatment technologies is not intended to indicate that these technologies are effective in all waste management situations.

Large amounts of money and effort have been spent on large plants for treating municipal solid wastes in low- and middle-income countries. Unfortunately, these investments have usually been wasted. If lessons can be learned from these failures, the expenditures are not all wasted, but if the problems and failures are kept a secret, and no lessons are learned, the waste of resources is absolute and complete.

Table 3.1 summarises the conditions in which these methods of treating waste might be sustainable, and suggests possible applications for these processes in low- and middle-income countries.

Table B3.1 Summary of applications for treatment processes

Process	Conditions and applications for which this process might be considered in a low- or middle-income country
Incineration	Municipal solid waste as delivered for disposal has a low moisture content and high energy content; capital is available to cover investment costs; strong revenue base for funding operation costs; high level of operation and maintenance skills. Possible application; treatment of infectious healthcare waste.
Refuse-derived fuel	Waste input has low moisture content, low content of mineral material and high energy value; high human and financial capacity for maintaining mechanical equipment, high cost of alternative fuels. Possible application: large industries burn their waste to fire their boilers.
Anaerobic digestion	Input waste stream is biodegradable waste of consistent quality and containing very little other material; selected design of plant has proved reliable and economical in similar conditions elsewhere; experienced process control engineers available; large local demand for fertilising slurry. Possible applications: Processing animal and human excreta, or kitchen waste from restaurants and canteens.
Composting	Input is segregated waste that contains very little non-biodegradable material; strong local demand for soil conditioner made from solid waste; financial subsidy or gate fee to support operating costs; skilled operation and maintenance team. Possible applications: Composting of waste from markets, canteens, parks and gardens; operations increasing in size as demand grows.

B3.6 Treatment of hazardous wastes

There are certainly hazards associated with municipal wastes. Examples are the risk of injury from broken glass and the health hazard associated with the breeding of flies in decomposing food waste, because flies spread disease. However, certain solid wastes pose significantly greater hazards, compared to municipal solid waste, because they are flammable, explosive, toxic, carcinogenic, corrosive, reactive or infectious. They are

generated mainly by a small proportion of industries, by laboratories and by medical establishments. Radioactive wastes clearly also represent a serious hazard, but they are normally handled and controlled by specialist agencies. Small quantities of hazardous items or materials are also found in household wastes (such as used needles from hypodermic syringes, unwanted medicines, fluorescent tubes and certain household chemicals). This book is largely concerned with municipal wastes (which do not include hazardous wastes) but it is felt appropriate to depart briefly from this main theme to make some key points about the management of hazardous wastes. This Section discusses the key points regarding hazardous waste management that should be understood by planners. Further brief information about the techniques for treatment and disposal of hazardous wastes can be found in Section C5

The potential health impacts of the ineffective management of hazardous wastes are illustrated by the infamous happenings that are summarised in Box B3.2.

Box B3.2 Love Canal – How a disaster sparked an awakening

A partially constructed canal in a periurban area near to the Niagara Falls in the northern USA had been used for dumping residues from the petrochemical industry and military programmes for some years before it was bought, in 1947, by the Hooker Chemicals and Plastics Corporation for the disposal of its toxic wastes. In the next five years the owners buried 21,800 tons of hazardous waste on the site, covering the waste with a layer of clay.

The city wanted the site for a school, but Hooker was reluctant to sell, because of the risks posed by the wastes. Finally, Hooker was persuaded to sell the whole site, and the asking price was only $1. The dangers posed by the wastes were explained in the contract. These warnings were ignored and a school was built. The foundations of the school pierced the protective clay layer. Later, trenches were dug in the site and sewer pipes laid, and houses were built on part of the site. Soon, local residents started complaining of strange smells and unknown coloured substances appearing in their house yards and basements.

It was not until 1978, when a local newspaper reporter published articles on the problems caused by the hazardous wastes, that public health data came to light. It was learned that the area suffered from extremely high rates of cancers and alarming numbers of cases of birth defects and genetic damage. A survey found that 56% of the children born from 1974-1978 had at least one birth defect. It was subsequently shown that these personal disasters were caused by the wastes that had been dumped on the site up to fifty years previously. Hundreds of families were relocated, and hundreds more were affected by the release of toxic chemicals that resulted from the efforts to clean up the site.

As a result of legal action, Occidental Petroleum, the parent company of the Hooker Corporation, paid $20 million in compensation to the residents and contributed over $200 million towards the costs of cleaning up the site.

This disaster sparked a revolution in awareness of environmental issues and in concern about the management of hazardous sites. It led to new legislation, including the creation of the *Superfund* to help finance the costs of remediation of

sites contaminated by hazardous wastes. The costs of this remediation work are astronomical.

Source: www.envirojustice.org

a) Hazardous industrial wastes

The costs of the methods that are used to treat and dispose of hazardous wastes can be more than ten times the costs for municipal solid wastes, so it is important to keep the quantities of hazardous waste as small as possible. This can be done by reduction, reuse and recycling. Waste exchange schemes facilitate the use of wastes from one industry as a feedstock for another. Manufacturers should be encouraged to replace hazardous chemicals with substitutes that are less hazardous – for example, replacing toxic PCB transformer oils with a safer alternative. The quantities of waste classified as hazardous can also be minimised by careful segregation so that no general (i.e. not hazardous) wastes are mixed with hazardous wastes.

Little can be done to manage hazardous industrial wastes in a safe way until legislation is in force to define which wastes are considered to be hazardous, to set standards and to designate the agencies that are responsible for enforcing the standards and the legislation. In countries where such legislation does not exist or where it is outdated or ineffective, there is a great need for NGOs and environmental agencies to create awareness about this issue and create pressure for the enactment of effective legislation. If legislation does exist, the biggest challenge in hazardous waste management may be to ensure compliance with legislation and regulations. Some large manufacturers and multinational companies may take care of the treatment of their hazardous wastes as an expression of their social responsibility, even if there is no effective enforcement of good practice. Unfortunately, the majority of the generators of hazardous waste seem to pay little attention to waste disposal unless they are compelled by law to ensure safe treatment and disposal of their wastes. One common feature in hazardous waste legislation is the responsibility of generators for the way their wastes are transported, treated and disposed of; their responsibility does not end when their wastes is taken away by a transport contractor. Another common feature is a system of documentation that allows each consignment of waste to be tracked through each stage of its journey from the factory gate to the disposal site.

The author has argued for a the acceptance of lower standards of municipal waste disposal as an interim measure, to facilitate stepwise upgrading of waste management practice, but the risks associated with hazardous industrial wastes are so great that a high standard is needed now in every country.

Since the costs of treating and disposing of hazardous wastes are so much higher than the costs for other wastes, there is a great temptation to hide the hazardous wastes within municipal wastes instead of keeping them separate, in order to avoid these much higher costs. There have been numerous cases of hazardous wastes that are dumped on farm land or waste land, sometimes with the consent of a landowner who does not understand the dangers involved and is happy to receive a small payment. Hazardous wastes have been shipped to low-income countries and war zones where there is no means of protecting the environment from the waste. It is therefore necessary to enact

legislation that defines the waste materials that are considered to be hazardous, prescribes the methods that are to be used for treating and disposing of these wastes, and provides an effective means of monitoring and enforcement of segregation, separate transport, and appropriate treatment and disposal.

Some hazardous wastes cause particular concern because they are liquids that can flow down through the ground to pollute water resources, because they do not degrade naturally with time, and because of their polluting or toxic properties. Organic chemicals of this kind are referred to as POPs – *persistent organic pollutants*. They should never be disposed in a landfill but should be incinerated in an incinerator that is specially designed for destroying such chemicals, or in a cement kiln[16]. If such facilities are not available within the country the hazardous wastes should be exported in accordance with international legislation to a country that has the required capacity. Treatment with chemicals can be used to render some hazardous wastes harmless – an example is the neutralising of acidic or alkaline wastes. Some hazardous wastes can be modified chemically so that they are no longer soluble, and so they remain where they are deposited. For example, wastes containing heavy metals can be changed to hydroxides which are insoluble provided that they are not subsequently mixed with acid wastes.

Even if lawmakers understand the urgency of ensuring safe disposal of hazardous wastes, it takes time to establish satisfactory treatment and disposal routes and to develop effective enforcement mechanisms. What can be done to minimise the risks to health and the environment now, and until the required regulatory system is in operation? It is important to consider the choices faced by the manager of a factory that is generating hazardous waste. If there is no guidance about how hazardous wastes should be managed, and no facilities are available for the treatment and disposal of hazardous wastes, it is likely that such wastes will be mixed with municipal wastes, dumped in a river or stream, or stored or dumped illegally on public land or land owned by the company.

While preparations are being made for scientific management of hazardous wastes, consideration should be given to interim measures that should be put in place as soon as possible; these short-term measures are likely to include,

- collection of data on the types, sources and quantities of hazardous wastes,
- increasing the awareness of factory managers, environmentalists lawmakers and the media regarding the risks associated with hazardous wastes,
- the provision of incentives and technical support to reduce the quantities of such wastes,
- the disposal of some types of waste in the most secure landfill available, and
- the export of wastes that should not be landfilled, for processing and disposal in countries that have the required facilities. The Basel Convention controls international movements of hazardous wastes and restricts export of wastes to ensure that the wastes will be given the appropriate treatment in the receiving country.

[16] Co-processing of hazardous waste in cement kilns is discussed in [GTZ-Holcim, 2006].

More about the treatment of hazardous industrial wastes can be found in Section C5.3 below.

Many people think of wastes from healthcare activities when they think of hazardous wastes, but healthcare wastes are only one type of hazardous wastes, and hazardous wastes industrial sources are likely to have a much greater environmental impact.

b) Infectious healthcare wastes

Less than 20% of the wastes from most hospitals and other healthcare facilities can be considered hazardous. There are several categories of hazardous waste that are found in hospitals and other healthcare facilities. The different categories should be carefully segregated at the point of generation so that each type of waste is treated in the appropriate way and the quantities of hazardous wastes are kept as small as possible (by ensuring that no non-hazardous general waste is mixed with them). Usually the main category of hazardous healthcare waste is the infectious waste – items likely to cause the spread of an infectious diseases such as HIV, tuberculosis or hepatitis. Other wastes may be toxic (or hazardous in other ways), such as disinfectants, laboratory chemicals and pharmaceuticals used in the treatment of cancer. Of the infectious wastes, used needles and blades, as well as wastes from isolation wards, are the cause of most concern. The people most at risk of infection are hospital staff and workers handling the waste, though waste pickers at disposal sites are also at risk, as are the general public if syringes and needles are picked from the waste and reused. A significant proportion of the wastes classed as infectious probably represent a very slight risk to public health (and negligible risk to the environment), but the health risk posed by used needles and blades is serious. The risks to the general public are made worse by the facts that waste from hospitals has a high resale value and that children like to play with some of the items found in hospital waste.

There are two common methods of treating infectious healthcare wastes. One is incineration. The incinerators that are used for this purpose should be of an advanced design so that they can be expected to burn completely all of the waste at the required temperature and to emit minimal levels of pollution into the air. Unfortunately, incinerators that are well designed are often operated badly, with the result that the waste is not burned completely and large quantities of noxious black smoke are produced. (See photo B3.2) This unacceptable performance is often the result of inadequate training for the operators or the lack of fuel to fire the incinerator. However, if high standards of operation are ensured, incineration can be a very satisfactory way of treating infectious healthcare wastes.

Photo B3.2 Smoke from this hospital incinerator is an environmental hazard

The other common method of treating infectious waste is autoclaving (Photo B3.3), which is the killing of almost all the bacteria in the waste by exposing it to high-pressure steam. Infectious waste is loaded into a pressure vessel and the process of bringing the steam into contact with every part of the waste is controlled automatically. The treatment of one batch typically takes about one hour. Syringes and needles coming out of this process are still recognisable. Wastes may be shredded before or after treatment.

Photo B3.3 Autoclave for treating infectious waste

Planners concerned with healthcare waste management tend to focus on these methods of treatment of infectious waste, but, in doing so, they may make three serious mistakes.

- One mistake is to focus on the treatment equipment, but not on the whole waste management chain that begins when an item is considered to be no longer useful. Many of the risks faced by hospital workers arise before the waste arrives at the treatment stage, so the provision of safe and convenient containers may be much more important that the equipment for treating the waste.

- The second mistake is to concentrate attention on the provision of the equipment rather than its operation – the operating costs, the training and supervision of operators, and the maintenance of the equipment.
- The third mistake is to ignore the need for safe management of the waste when the treatment equipment is not available – before it is operational, when it is defective and awaiting repair, and in medical facilities that do not have access to treatment facilities. Simple measures, such as pits for needles and blades and a focus on the most hazardous waste items, should also be available.

Above all, the most important key to the safe management of infectious healthcare waste is leadership. If a hospital has one reasonably senior staff member (often either an infection control officer or a matron) who understands the risks, knows how to minimise them, and is ready to work hard to maintain good standards of waste management, then the staff and public will be protected, even if the equipment is basic and funding inadequate. Such leadership ensures good training and tight supervision. Without this kind of leadership the risks will remain high and waste-related infections will result, even if sophisticated treatment equipment is installed.

B4 Options for disposal of solid wastes

There are many different ways of disposing waste to land. The best method of disposal – sanitary landfilling – is more expensive in the short term than the common practice of dumping waste, but it avoids long-term environmental damage which can be very difficult and expensive to remedy. Direct disposal to land in a satisfactory way is always cheaper than any method of treatment that reduces the volume of the wastes or their potential for pollution, such as incineration or mechanical-biological treatment.

In general, municipal solid waste should never be disposed into water. This is because of the serious pollution that this can cause. If municipal waste is dumped in the sea, floating items will be spread by wind and current over large areas and other materials that do not float may be carried away by the tides and currents. The products of decomposition may cause chemical pollution of the water. Remote islands may have no option apart from dumping their waste into enclosed areas offshore, but this must be seen as a last resort. The dumping of waste into low-lying areas that are marshes or flooded at certain times should be avoided at all costs because the pollution leached from the waste is in direct contact with the water resources. The town where the author lives suffered the unpleasant and potentially hazardous bad-egg smell of hydrogen sulphide when seemingly inert gypsum plasterboard was dumped in a wet area. Clean, truly inert, demolition debris has been used successfully for building breakwaters at harbours and discarded vehicle tyres have been used to build reefs to be colonised by marine life.

It is important to understand that waste disposal is not so much a question of having a facility, but rather what matters is the way in which the facility is used. Waste disposal is an activity, not a site. It is better to think of the verb *landfilling* than the noun *landfill*. The way in which a site is operated is crucial to achieving the objectives of waste disposal. Many sites that have been constructed for sanitary landfilling have been operated in a way that is no better than crude dumping, and the potential for minimising pollution has not been achieved. Sites should be designed after careful consideration of local financial and human resources to ensure that their operation is affordable and sustainable, and that they satisfy the basic requirements of environmental protection and efficient operation.

The following sections describe the two extremes of waste disposal – sanitary landfilling and unplanned dumping. The waste disposal procedures of most large cities in middle- and low-income countries can be characterised as being in between these two extremes. In most cases it is difficult to transition in a short time from dumping to sanitary landfilling. Steady progress by means of step-wise improvements is a more sustainable strategy.

A valuable and innovative approach to setting standards for landfilling has been developed in the Republic of South Africa by the Department of Water Affairs and Forestry [DWAF, 1998]. These *minimum requirements* provide a framework of standards for the siting, design, construction, operation, closure and aftercare of landfills. The requirements are of particular interest because they take into account site-specific factors such as the size of the operation, the local climate and the risk of serious

pollution by leachate, as well as the type of waste to be handled. A guiding priority is to set standards that are realistic, achievable and effective. Landfills are classified according to pollution risk, and the requirements determined for each class of disposal operation are proportional to that risk.

After introductions to the two extremes of solid waste disposal, the subsequent section presents, with photographs and comments, the challenges posed by disposal and the ways that these challenges can be overcome by good practice.

B4.1 Sanitary landfilling

The best method for the disposal of any residues that cannot be reused or recycled is sanitary landfilling. In most situations, direct sanitary landfilling of solid waste is very much cheaper than using any method of treatment to be followed by the landfilling of the residues. If correctly sited, designed, constructed and operated, a sanitary landfill generates very low levels of pollution. Sanitary landfills are very flexible, being suitable for many different kinds of waste and able to accommodate wide ranges in quantities – such as the surges in daily tonnages that occur when treatment plants are closed for repair or maintenance or when there are large quantities of extra waste after festivals. Sanitary landfills are also reliable and can generally be expected to operate every day of the year.

Sanitary landfills are the optimum method of disposal to land. Their locations are carefully selected with regard to land use, distance from urban areas and natural features. They are designed, constructed and operated so that any pollution of water is kept to very low levels and gases that are generated by the decomposing wastes are collected and treated or utilised. Any nuisance to neighbours from windblown litter, birds, dust and odour is minimised. The movements of vehicles on the site are facilitated by good internal roads and moderate slopes, and the waste is laid down in a way that maximises the use of the available area. At the end of the working life of the site, the surface is restored and landscaped to blend in with the surrounding area, and ongoing environmental impacts are monitored and minimised.

B4.2 The other extreme – unplanned dumping

Unfortunately, in many countries, the most common method of waste disposal is open dumping. In complete contrast to a sanitary landfill, an unplanned dump is a major environmental problem. Trucks unload their waste at any convenient or accessible spot, so that the dump extends over a wide area. Piles of waste that have been dumped previously prevent access to much of the site. At times of heavy rain access to the site is often further restricted by mud and accumulations of water. Dogs, goats and other domestic and wild animals wander over the site, feeding on the waste. Waste pickers sort through the waste looking for anything they can sell. Often they set fire to the waste, causing polluting and toxic smoke from fires that often burn continuously. The

smoke from such fires is not only unpleasant, but a serious health hazard[17], particularly to communities downwind. Fires may be started in various ways: (i) deliberately by waste pickers in their search for metals, (ii) by the site watchman to reduce the volume of the waste, (iii) by accident (e.g. a dropped cigarette) or perhaps (iv) by natural processes (such as the spontaneous combustion of sawdust).

Children play among the waste piles, exposing themselves to serious health and safety risks. The wind scatters paper and plastic over a wide area. Polluted water seeps unseen into the ground. When the site can no longer be used, because all the space is occupied or because of protests or legal action by the owners or neighbours, it is simply abandoned as it is, remaining an eyesore and hazard for generations. Sometimes waste is tipped down slopes into gulleys or valleys, perhaps polluting or blocking water courses, and offering very little opportunity for rehabilitation at a later date.

The reasons for resorting to unplanned dumping are clear. It often requires no investment (since the land is rarely purchased for the purpose) and no direct operational expenditure is incurred. The few citizens who protest about this abuse of the land have insufficient influence to bring about any change. In addition, there may be no-one in the municipal workforce who knows how to dispose of waste in a better way. The actual costs to society, in terms of environmental damage, illness, injury and death, may be high, and the problems of vehicle access may add to the costs of the collection service.

B4.3 Challenges and solutions

B4.3.1 Problems with unplanned dumping

The following pages show photographs with brief comments to illustrate the main health, environmental and operational problems associated with open or unplanned dumping. Different problems are found in different countries. Some shortcomings are linked to socio-economic factors and some are made worse by the weather, particularly wind and rainfall. Some of these problems occur wherever waste is dumped without good management and environmental protection.

[17] When PVC plastic and other wastes containing chlorine are burned, dioxins are formed. Dioxin, in the form of "Agent Orange" was sprayed to kill vegetation during the Vietnam war, and it has caused birth defects and genetic damage that are still of great concern 40 years after its use.

↙ a) Burning piles of waste cover a wide area

↗ b) Waste from this dump is taken toward the adjacent town by the prevailing wind

↗ c) Environmental degradation at its worst

↗ d) Should the driver of this tractor be condemned to spend most of his working life in this smoke?

Photos B4.1 Smoke from burning waste on various dumpsites

a) Unloading waste creates a dust cloud

b) Driving over waste creates dust

c) Spraying to suppress dust

Photos B4.2 Waste disposal can generate a large amount of dust in dry weather.

The dust nuisance can be reduced by minimising the distances that vehicles must cover away from gravelled site roads. Regular spraying of the site roads with water reduces the dust coming from the site roads. Spraying the roads with leachate would seem to solve two problems at once, but the smell of the leachate might be more of a nuisance than the dust. A light spraying of used oil on the roads has also been used to control dust.

Photos B4.3 Children like to play on dumps and may be required to work on them

Often the children found on dumps have no protection for their hands and feet, and so are at risk of infected wounds as well as injury caused by the dangerous items that they find. Some potential hazards that they might find are shown below and on the next page.

↗ a) Condemned eggs, and
b) condemned canned food ➔

↗ c) This can exploded in the burning waste

Photos B4.4 Condemned food looks attractive but could be dangerous

↗ a) Used needles and syringes – dangerous toys, infectious if reused

↗ b) Sheep carcases – unfit for human consumption, but accessible

➔

c) Slaughterhouse waste being unloaded and left on open ground. It is likely to attract dogs and flies.

Photos B4.5 Wastes that should not be left in the open.

a) Each black dot on this dump bulldozer is a fly. Houseflies spread disease. Good disposal techniques result in fewer flies.

b) Different species of birds colonise disposal sites but all can spread disease.

Photos B4.6 Disease vectors proliferate on unplanned dumpsites

← a) Looking down from the highest point of a disposal site, we see many tyres but also black streams of polluting leachate infiltrating into the ground.

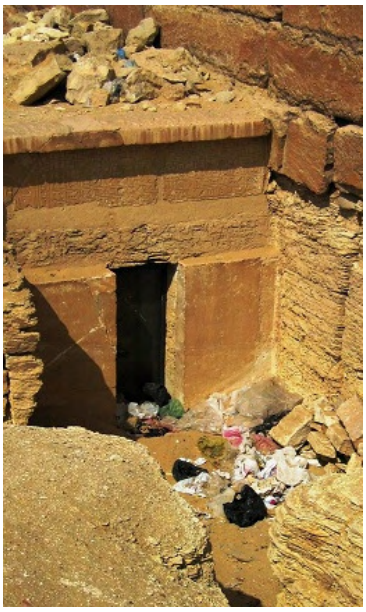
b) above At another site, the leachate flows a long way from the waste in which it originates.

➔ c) This channel carries not only a large amount of solid waste, but is also coloured black by the polluting leachate that flows from a nearby dump

Photos B4.7 Solid waste disposal sites produce highly polluting black leachate which must go somewhere

↗ a) The black specks in the sky are not birds but plastic bags escaping from an open dump.

↗ b) These bags have come to rest in an open field where they may be eaten by goats and cattle, with serious consequences.



↙ c) Windborne plastic bags accumulating at a site of exceptional archaeological and touristic significance.

↗ d) Plastic bags can block screens, reducing the flow of air or water, or even damaging equipment. This screen is on a train.

↙ e) and f) ↘

It sometimes seems that plastic bags grow on trees!

Photos B4.8 Plastics bags cause aesthetic pollution but can also be a nuisance or harmful in other ways

↗ a) If the access to the unloading area of the dump is like this, the vehicles bringing waste will experience many problems

↗ b) When vehicles dig their rear wheels into soft ground they may damage their transmissions and there will be delays, as well as obstruction of other vehicles.

↗ c) A wheeled loader is coming to assist this helpless truck and clear the blockage in the road that it is causing.

🡐 d) These trucks are unloading at the side of the internal road because they cannot drive on the waste. The piles of waste they leave behind will make it even more difficult to use the area away from the road.

🡓 e) The bulldozer is helping this truck to escape from the hole it has dug with its rear wheels

Photos B4.9 Soft ground on a dumpsite causes many problems.

↗ a) The dumping of scrap and waste has made this land unusable and a hazard to the children living in the nearby residential area. Because of its proximity to housing it is likely to be very valuable land.

↗ b) This waste has been tipped down this slope beside the road. Dumping it was easy, but it will be very difficult to clean it up.

↗ c) Nature can provide a thin cover of leaves over the waste, but the hazard posed by the rusty steel and the broken glass remains.

Photos B4.10 The legacy that we leave for the next generation – land that is now unusable and hazardous.

B4.3.2 A common problem with serious risks

Larger cities have huge amounts of waste to dispose of, and often they have a limited land area for its disposal. On sloping sites it is common to find that a horizontal platform

is formed at the upper end of the site and the waste is pushed over the edge at the far side of the platform. If the disposal site is on level ground, some of the waste is used to increase the height of the operating platform but often much of the waste is pushed over the edge. This method of working, known as *end tipping*, is very unsatisfactory because it results very steep cliffs of waste – cliffs which may be higher than a ten storey building. Photo B4.11 shows the edge of a dump built in this way. Steep slopes like this cannot be compacted, covered or finished in a satisfactory way, and prevent the control of fires. Much more serious than these drawbacks is the risk of slips or landslides, especially after heavy rain, when hundreds or even thousands of tons of saturated waste suddenly descend on the area in front of the face. Box B4.1 lists some catastrophic failures of steeply sloping dump faces – failures of slopes which are known to have caused the deaths of ten people or more. It is likely that during the period of this record there were many more smaller slips that were not reported.

Photo B4.11 The steeply-sloping edge of a huge dumpsite

Box B4.1 Serious slope failures of steep-sided dumps

Date	Location	Country	Death toll
10/07/2000	Manila	Philippines	287
14/06/2002	Chonqing	China	10
21/02 2005	Cimahi, Bandung	Indonesia	143
01/09/2005	Padang, Sumatra	Indonesia	25
07/10/2005	Shangluo City, Shaanxi Province	China	13
07/10/2005	Bello, Medellin	Colombia	43
20/06/2008	Guatemala City	Guatemala	50*

* Provisional death toll just after the disaster

Source: Dave Petley, The Landslide Blog
http://blogs.agu.org/landslideblog/2008/06/22/garbage-dump-landslides/

B4.3.3 Overcoming these difficulties at a sanitary landfill

a) Stability

The ability of the ground under the landfill to support the weight of the deposited waste will be discussed in connection with the drainage system that collects leachate. In general *landslides* of waste can be prevented by restricting the steepness of side slopes of waste that is deposited above ground level. The steepest slope is generally recommended to be 1 : 3 (vertical : horizontal), in order to avoid slip failures. This cannot be achieved by end tipping (pushing waste over the edge), but requires that the horizontal layers of wastes (or *lifts*) are terminated at a predetermined distance from the edge of the preceding lift, so that the required slope can be built. Additional precautions may be needed if waste is deposited on sloping ground. Relatively gentle slopes also allow machinery to work everywhere on the site (including around the edges) so that the waste can be covered with soil or an impervious cover, and so that erosion can be controlled.

b) Fires

In a waste disposal site there may be two kinds of fuel for fires. One kind of fuel is the combustible material in the waste, such as paper, plastic and unburned wood or charcoal. The other fuel is methane gas which is generated by bacteria that thrive in the absence of air. Very little methane may be generated within shallow layers of waste, but if the waste is deposited to a depth of several metres, it is likely that methane will be formed. Fires on the surface burn combustible waste or escaping methane, and fires below the surface burn methane, provided that there is enough oxygen for the combustion to take place. Fires deep within landfills can be discouraged by restricting the entrance of air. Air may penetrate deep into a landfill through drainage paths or if the gas pressure within the waste is lowered by excessive withdrawals of landfill gas or by changes in atmospheric pressure. Fires within the waste often burn very slowly, but they can continue burning for months or even years, leaving behind large underground cavities which may collapse when machinery is driven above them. Photos B4.12 illustrate these points. The only way to extinguish a deep fire is to carefully dig down to the seat of the fire and excavate the burning material, or expose it and smother the fire with sand.

↗ a) Charred soil and subsidence are the results of a deep fire.

↗ b) Whisps of smoke indicate that a deep fire is still burning.

↗ c) The gas burns at the surface because there is insufficient oxygen lower down.

Photos B4.12 Signs of fires in a deep landfill

Prevention is better than cure. Strict measures should be enforced to prevent the occurrence of fires. Staff at the entrance should be looking out for any incoming loads that seem to be hot or burning, and they should ensure that such loads are unloaded at a designated and isolated location where they will not set fire to the main body of deposited waste. There should be strict enforcement of a ban on cigarette smoking and the lighting of any kind of fire. The control of landfill gas is discussed below.

c) Dust

Dust is a particular problem in dry climates where the waste contains a large proportion of fine material or where the soil that is spread on the waste is fine and is broken into finer particles by the movements of vehicles. As suggested in the previous section, the problem of dust can be minimised by limiting the movements of vehicles, as much as possible, to routes that generate less dust because they have been sprayed or because they have been surfaced with coarse material that does not form dust when driven on.

Dust clouds that form when dry waste is tipped out of a truck can be minimised by a fine spray of water, but this is rarely done at landfill sites.

d) Access for children and animals

Larger animals such as cattle and goats can be kept out of waste disposal sites by robust fencing that is maintained in good order and by cattle grids across the roads at the site entrance. (Cattle grids are composed of bars at right angles to the direction of travel that are fixed at a spacing that is too large for the hooves of animals to bridge). If waste pickers are accustomed to gaining access to the site through damaged sections of the fence, it may be very difficult to keep the fence in good condition.

A waste disposal site can be made less attractive to children and animals by minimising the area of waste that is uncovered and by levelling and compacting the waste so that edible material is less accessible to the animals and there is little on the surface for children to play with or salvage.

e) Difficult wastes

There are some hazardous chemical wastes that should never be allowed onto a landfill site. There are other wastes which should be managed in a special way, but which may be safely disposed on a landfill. The decision as to which wastes should be accepted at a landfill should be made after considering potential risks to humans, animals and the environment, and considering what would be done with the wastes if they are not accepted at the landfill. Certain difficult wastes can be accepted at well operated disposal sites if they are deposited into trenches and immediately covered by at least one metre of domestic waste. In this way they can be inaccessible to dogs and other animals, and to waste pickers.

f) Disease vectors

Flies and rats are the carriers of disease that are commonly associated with waste disposal, but mosquitoes, birds and dogs can also spread communicable diseases.

The common housefly is of particular concern because it lays its eggs in waste that may be highly infectious and it frequents houses, particularly kitchens, where it may transfer to food the germs that it picks up on its hairy body and legs. The time taken for an egg, once laid, to develop into an adult that can fly depends on temperature, and can be as little as eight days. One way of reducing fly populations at landfill sites is to control the deposition of waste so that one day's waste is covered by the next day's waste, and so on, so that the intermediate development stages of the fly are buried by several days' waste before the adults are ready to emerge. The heat generated by decomposition of the buried waste may be sufficient to kill the pupae before they transform into young

adult flies. Spraying with insecticide is considered to be expensive, polluting, potentially hazardous to the labourers who are using it, and not very effective. Fly traps have been used in India to reduce numbers of flies at disposal sites.

The breeding of rats at disposal sites can be discouraged by compacting the waste and covering areas that are not being used with a uniform soil cover that makes it easy to detect rat holes and rat runs. The careful use of rat poisons may be needed if people are living close to the site (so that control of the rats is crucial). Bait boxes are used along the paths that rats frequent such that the rats have access to the poisoned bait, but dogs and other animals do not.

Mosquitoes breed in standing water; therefore open drains should be kept clean so that they do not impound puddles of water and surfaces above the deposited wastes should be kept free of depressions that hold water for more than two days. Discarded vehicle tyres can retain rainwater sufficient for mosquito breeding, so they should be buried or cut into pieces.

Aggressive dogs may frighten site workers and spread rabies. Their access to food on the site should be minimised by burying meat wastes. A control programme may be necessary.

g) Water pollution

Polluting leachate is not only the result of rainfall and surface water infiltrating into the waste, but is also generated when wastes containing moisture are compressed and when biodegradable materials decompose to form water, carbon dioxide and other products. Even if no black streams of leachate are seen on the surface of the ground or on the waste, it is likely that some leachate is infiltrating into the ground directly below the deposited waste. Some types of soil are able to purify this leachate to varying extents, by means of filtration, adsorption (molecules of pollutant adhering to the surface of soil grains) and microbiological processes. (These processes are collectively called *attenuation*.) It may take years for concentrated and polluting leachate to pass through layers of soil to the water table, and move through the ground to a water source, but when pollution is finally detected in the water supply it may be too late to prevent continuing contamination of the source for the next 20 years or more.

Four measures are needed to prevent leachate contamination.

- The volume of leachate that is produced should be minimised by minimising the infiltration of clean water (either rainfall or water flowing along or under the ground) into the waste. Water that is flowing over the ground should be diverted away from the waste by means of interceptor drains, which are usually in the form of ditches around the upslope perimeter of the deposited waste. (They intercept the water before it reaches the waste.) It is important that these drains are kept clean and in good condition. Contact between the waste and rainfall can be minimised by covering waste in areas that are not being used with an impermeable cover (such as clayey soil, or plastic sheet weighted down with sandbags – Photo B4.13). The slope of the top surface of the deposited waste should be sufficient to encourage most of the rainwater to run down the slope away from the waste rather than infiltrating into it. However, the slope must not be so steep that it hinders vehicle movements or

encourages erosion. The working area where waste is exposed should be kept as small as possible, especially during the rainy season.

Photo B4.13 Temporary impermeable cover.

The blue area on the right is a temporary plastic cover to keep the rain off a part of the landfill site that is not currently in use. The working area is in the distance.

There must be an impermeable barrier to prevent leachate within the waste from travelling downwards or sideways into the ground. Sometimes the natural ground provides a reasonably effective barrier – if it is composed of clayey soil or impermeable rock that has no interlinked fissures. If the ground does allow infiltration or in order to provide a greater degree of security, the base and sides of a new landfill site may be rendered impermeable by a layer of clay or a carpet of carefully joined plastic sheets, as shown in Photo B4.14. Rolled asphalt has also been used. Geosynthetic clay liners (GCL), which consist of clay material, usually bentonite, woven between two geotextiles layers, are now being used extensively as landfill liners, as they are effective, durable and easy to lay.

(The case study in Section C6 provides an example of an asphalt liner). More information about these impermeable layers can be found in Section C4.3.

Photo B4.14 Construction of an impermeable liner.

A black carpet of high grade polyethylene plastic is being laid during the construction of a new landfill site so that leachate will not be able to infiltrate into the soil.

- It is not sufficient just to stop the leachate from moving down into the soil. The leachate must go somewhere. If it cannot infiltrate into the soil below it will stay within the waste, getting deeper and deeper (and so putting more pressure on the impermeable layer below) until it finds a way to escape, perhaps escaping from the side of the waste mass. A drainage system, usually composed of coarse stones and perforated plastic pipes, is needed to conduct the leachate to a collection pond.
- The leachate cannot be allowed to accumulate for years. In dry climates it may be possible to lose it by evaporation, either from the collection pond itself or by pumping onto the landfilled waste where some may infiltrate and be recirculated through the waste and the rest may evaporate. Sometimes the leachate is taken by tanker truck or pipeline to a nearby municipal wastewater treatment plant. Leachate is much more difficult to purify than domestic wastewater, so special care may be needed in the operation of the treatment plant, or it may be necessary to pretreat the leachate before it is mixed with the municipal wastewater. The remaining alternative is to purify the leachate at the landfill site so that it can be discharged into the environment without causing environmental damage. Successful on-site treatment plants tend to be very sophisticated, requiring considerable skill and expenditure to achieve the required levels of purification.

h) Landfill gas

In the middle of the twentieth century, waste disposal operators and environmental officers were concerned about landfill gas for two reasons. One concern was that it could cause explosions when it migrated into buildings. The other concern was to prevent underground fires which resulted in air pollution and formed large underground cavities in waste disposal sites, leading to the risk of dangerous collapses when vehicles were driven above them. They were also concerned about the ongoing generation of methane at disposal sites, which continues long after the closure of a site, with the potential to cause fires and to damage impermeable layers laid over the top of completed sites. More recently, the concern about climate change has been added to this list, because the methane in landfill gas is a potent greenhouse gas, having an impact on global climate that is more than twenty times that of the most common greenhouse gas, carbon dioxide.

Apart from these negative effects, methane is a useful fuel which can be used to provide heat, generate electricity or drive vehicles. Methane from anaerobic digesters at wastewater treatment plants has been used as a fuel for heating or generating electricity for many decades.

The simplest way of reducing the harmful effects of methane is to construct collection wells for collecting the gas and burning it at the top of each well in a flare. No pumping is needed, so this method is known as *passive* venting. In daylight the flame cannot be seen and there is the risk that wind and fluctuating atmospheric pressures may extinguish the flame, so the individual flares must be checked regularly.

Alternatively, the wells may be connected by pipes so that the gas is extracted and brought to a central flare by means of the pipe network and a vacuum pump. In this way the quantity of gas can be measured and the flare can be monitored more

effectively. The establishment of a network of pipes on a landfill that is still receiving waste presents some challenges – if buried, the pipes must be able to withstand settlement and the load of passing vehicles, and if on the surface they must be protected from damage by vehicles and carried high above roads.

On large sanitary landfill sites where the waste is well compacted and the completed sections are enclosed in an impermeable cover, it may be economical to install additional equipment that enables the use of the gas as a fuel. The most common use is for generating electricity, but alternatively the gas can be used as a vehicle fuel or for providing heating for greenhouses or industries if there is a demand for heat nearby. Combining electricity generation and the sale of heat is the most efficient arrangement. It is often necessary to remove the water vapour from the gas, and other treatment may be necessary for some purposes. Sometimes exaggerated claims appear to be made regarding the quantity of gas that can be collected or the financial benefits of collecting and using the gas.

New projects for burning or utilising landfill gas may be eligible for financial support under the Clean Development Mechanism that is discussed in Section B5

Photos B4.15 show various aspects of gas management systems.

↑a) Vertical gas wells that are raised as filling proceeds

↑ b) Connected gas wells on a completed section of a large landfill

↗ c) Vacuum pumps that draw the gas from the wells

↑ d) Central flare burning landfill gas

↗ e) Generating station on a large landfill, fuelled by landfill gas

Photos B4.15 Collection, burning and utilisation of landfill gas

i) Windblown litter

There are ways of minimising the escape of paper and plastic bags from waste disposal sites. The first step is to level and compact the waste. On large landfills where the waste has a low density, special, large landfill compactor machines (Photo B4.22) are used. Elsewhere the passage of site machines or rubber-tyred vehicles can provide a degree of compaction for levelled waste.

The next stage is to catch any windblown litter while it is still on the landfill site. Examples of how this can be done are shown in Photos B4.16. Permanent fences or portable netting screens may be used, and earth bunds can also be effective. Temporary netting can be erected close to the working area and on the downwind side. It is not sufficient to catch the litter – labourers must collect the paper and plastic on a regular basis to reduce the chances that it is once more picked up by the wind, and to prevent litter accumulating on the fences to the extent that the wind can push them over.

↗ a) This small fence has caught a large amount of plastic and needs cleaning

↗ b) These nets can be moved so that they are always downwind of working areas

↗ c) The tall poles in the foreground and in the distance are supporting nets for catching litter

↗ d) Paper and plastic have collected in the hollow downwind of this cell wall.

Photos B4.16 Catching paper and plastic before they are blown off the site.

Because of the benefits of limiting the working area on a landfill at any particular time, landfills are divided into cells. Embankments are built to define the boundaries of a cell and to form a wall against which the waste is laid. These embankments also trap windblown plastic and paper, which collect in the relatively sheltered area downwind of the embankment, as shown in Photo B4.16d.

There are several advantages in having a belt of trees around a landfill. Trees can hide the site from view, and reduce the noise that is heard outside the site. They can also serve as a final barrier to prevent windblown litter from escaping from the site.

Certain weather conditions can lift paper and plastic to a considerable height, well above all the barriers that have been suggested. In such cases, residents and landowners who find paper and plastic in their neighbourhood or on their land should be able to make a complaint to the landfill operator, and the landfill operator should endeavour to arrange for landfill employees or local casual labour to collect the litter and take it back to the landfill. A landfill operator should take every opportunity to be a good neighbour and to value and promote good relationships with people living near the disposal site.

j) Vehicle movements

There are convincing reasons for ensuring that vehicles have good access to the landfill site and spend the least possible time on the site at each visit. Among these reasons are the following:

- Operators of waste collection vehicles should aim to achieve high levels of productivity for these vehicles because of the costs involved in operating them. If vehicles are delayed, waiting to enter the site (Photo B4.17), their opportunity for collecting waste is reduced. Similarly, if there are delays within the site, collection costs are increased.
- Vehicles should unload their waste as near as possible to the final resting place of the waste, so that bulldozers or other machines that are intended to level and compact the waste do not spend much time moving the waste from the place where it is unloaded to the working face where it is to be finally located. There should be space where the vehicles can turn safely, and the slope and surface conditions of the waste on which they must drive should allow them to reverse close to the working face without problem. This will enable the landfill machinery to operate more productively.
- It is important that the vehicles driving on the site do not lose traction and dig their driving wheels into soft ground. Not only do bogged vehicles suffer delays and obstruct the movements of other trucks, but they also may damage their transmissions and overheat their engines in their attempt to move off under their own power. Some mechanics have observed that a high proportion of tyre damage occurs when tyres are spinning in waste. Further damage may be caused if a bulldozer or similar machine is used to push the vehicle out of the hole it is in. It is quicker to push a truck than to attach chains and pull it. It is understandable that bulldozer operators prefer the easier approach. Unless considerable care is taken, the rear of the truck may be damaged. (The author is familiar with a case in which the large bulk transport vehicles have tailgates that have been damaged when bulldozers have pushed them. Since the tailgates do not close properly, the vehicles

cannot be fully loaded.) Trucks are particularly vulnerable to losing traction when they are empty.

Photo B4.17 Waste collection vehicles waiting to unload the waste they have collected

- In order to avoid long waits or difficult driving conditions, some drivers may prefer to unload their waste at an unauthorised – but more convenient – location, perhaps causing serious pollution and nuisance, and involving considerable expenditure for cleaning up. If private sector landfill operators are in competition with each other, the collection agencies may prefer the landfill where there are fewer delays and difficulties.

When designing the entrance area of a landfill, a sufficient length of internal road between the public road and the weighbridge should be allowed so that trucks arriving at peak times are not forced to queue on the public road and obstruct traffic there.

Some types of vehicles cause more problems on landfill sites than others. Articulated trucks (semi-trailers) can be particularly problematic in two ways. (They are used because they can carry large volumes of waste and because a trailer can be left for loading at a transfer station while the tractor unit is taking another trailer to the disposal site.) Long vehicles that tip to unload can be very unstable on soft ground and fall over sideways when the loaded body is raised for unloading. Articulated trucks often lose traction when they are empty because the small proportion of weight on the driving axle of the tractor unit does not provide enough traction to pull the trailer, even on level ground (Photo B4.18a).

Trucks that have no unloading mechanism (tipping bodies or ejector plates) need more time for unloading, so that there may be a large number of trucks unloading together at peak times, expanding the working area and requiring landfill machinery to travel greater distances (Photo B4.18b). Compactor trucks with low ground clearance are not suited to driving on soft or uneven ground.

↗ a) This long articulated truck needs help from the tracked loader to move off the site because it has insufficient traction when it is empty.

↗ b) These trucks are unloaded manually, and so are in the unloading area much longer than trucks that unload more quickly, by mechanical means. As a result, many are there at peak times, occupying a large area.

Photo B4.18 Types of truck that cause problems at landfills

There are some simple measures that can be taken to minimise delays and problems.

- Site roads should be maintained in good condition, avoiding humps and depressions and maintaining a surface that allows good traction. Hardcore rubble (broken bricks and broken concrete – provided it has no reinforcing bars or glass in it that would damage tyres) can be used to build and repair site roads (Photo B4.19). Graders and road rollers may be purchased or hired for this work (Photo B4.20).

Photo B4.19 Broken concrete used to make a site road

Photo B4.20 Road roller used to build a site road

- Operators of landfill machines should look out for patches of soft ground or depressions which might cause problems for collection vehicles, and fill the holes with rubble so that the driving surface remains relatively uniform.
- Site roads should be built up higher than the surrounding ground in areas of the site where trucks should not leave the road (because they will damage the surface or generate a large amount of dust). If the road is on an embankment that is about 0.5 m above the surrounding ground, this should be enough to discourage drivers from leaving the road.
- Clear direction signs should be provided so that drivers know where to unload the particular kind of waste that they are carrying. On busy sites it is useful to have a one-way traffic routing system to keep the traffic moving freely.
- Operators of landfill machinery should have radios so that they can report cases of careless or dangerous driving and the offending driver can be warned or penalised before leaving the site.

k) Legacy

A large landfill becomes a geographic feature which will remain indefinitely. It should, as much as possible, be an asset to the surrounding area, not a nuisance or an embarrassment. The final contours and use of the site should be given careful consideration during all stages of design and operation. When a landfill is closed to incoming waste it is not ready to be used for other purposes for some years, because the microbial decomposition processes and the settlement continue for years after closure – perhaps for twenty years or more. There is some indication that landfills that are located in areas of high ambient temperatures and that comprise waste with a high moisture content may stabilise more quickly than the landfills in cooler climates that have been studied intensively. Monitoring of gas generation and settlement is necessary to determine when no further significant changes can be anticipated.

Stabilised landfills have been successfully used for parks and outdoor recreation areas. Erecting buildings on former landfills is not recommended, because of the low load-carrying capacity of the ground and the uneven settlement which can cause damage to foundations and buried pipes. In poorly ventilated buildings there is also the risk of explosions caused by residual methane. Well-ventilated, low-rise constructions on raft foundations may be satisfactory in some situations. Piled foundations may also be used if the section within the waste is covered with a low-friction layer which prevents them from being dragged down unevenly by the settling waste. All possible measures should be taken to ensure that future generations of planning officials are aware that the site is a former landfill that should not be used for certain purposes. Much stricter controls should be applied to sites that might have received hazardous industrial waste.

B4.3.4 Selection and maintenance of machinery

Small landfills (that receive less than 25 tonnes of waste each day) can be operated using manual methods and animal carts, with occasional visits by bulldozers or other earthmoving machinery. Any bulky items can be flattened, broken up or filled with waste before being placed with the deposited waste. Larger landfills need machinery on a more regular or continuous basis. The selection of types and sizes, as well as the

specifications for the machines, should be carefully prepared by experienced staff to suit the local needs and conditions.

The first step in selecting machinery is to list the tasks that need to be carried out when operating a landfill. It is also important to estimate the number of hours each week when this function must be performed, or the tonnage of waste that is involved each day. These estimates are needed to determine the size or capacity of the machinery, and whether it is more economical to hire a machine when it is needed or share it with another facility rather than to have it available on the site all the time. The main tasks are likely to include the following (the construction of subsequent phases of the site is excluded from this list):

a) placing, levelling and compacting the incoming waste

b) excavating, transporting and placing soil for covering the waste

c) constructing and maintaining temporary internal site roads

d) constructing cell walls

e) helping vehicles that are unable to get off the waste because of insufficient traction

f) digging trenches for difficult waste and covering it with fresh waste

g) pumping and transporting leachate

h) transport for the site manager.

For smaller sites it is economical to have one machine that can perform several functions reasonably well. An example is the tracked loader with the multipurpose bucket shown in Photo B4.21 This type of machine is specially designed for working on landfills but it is not specifically designed for one task, but can perform several tasks reasonably well. The front attachment can be used as a bulldozer blade or as a bucket for excavating and placing soil. The bucket can also be used for transporting other materials.

Photo B4.21 Small tracked loader with multipurpose bucket

A machine that is often found on big landfills, especially in industrialised countries, is the landfill compactor. It may weigh 30 tonnes or more, and has large steel wheels fitted with teeth or blades that push the waste down, creating high pressures to compact and bind the waste so that paper and plastic are less likely to escape. An example of this type of machine is shown in Photo B4.22. These machines are usually fitted with a large

bulldozer blade (with a top section fabricated from bars so that the driver can see better in front). They are specifically designed for low-density wastes, which they compact by going forwards and back over thin layers of waste several times.

Photo B4.22 Landfill compactor fitted with a bucket instead of a bulldozer blade.

The two types of machine shown in Photos B4.21 and B4.22 are specially designed for working with waste. They require more power than machines used for earthmoving. They have underbody protection and their radiators are at the rear to reduce the problems of clogging. Because they are often working in a very dusty environment it is advisable to provide air-conditioned cabs.

It is a mistake to believe that every landfill needs a landfill compactor of the type shown in Photo B4.22. Dense waste with a high proportion of inert and biodegradable material quickly settles to a high density so that good use is made of the available void or landfill volume without the necessity of intensive compacting. Windblown litter can be controlled using fences, netting and manual labour. Because large landfill compactors are very rare in many low- and middle-income countries, maintenance presents many problems, and it may not be possible to hire a replacement machine to cover for downtime necessitated by maintenance and repair. Spare parts may take a long time to arrive. Fuel costs are also very high for these heavy machines.

The most important machine for landfilling in developing countries is the bulldozer. Bulldozers are robust and versatile, being able to perform a variety of landfilling tasks. Because they are widely used and relatively common, it is usually easy find a good service agent (depending on make chosen). The blades of bulldozers designed for landfilling have a larger area than blades used for earthmoving. In general, caterpillar tracks are designed to produce a low ground pressure, but tracked machines designed for landfills sometimes have tracks that are narrower than the tracks fitted to the more common earthmoving machines, in order to increase the ground pressure that they exert.

Other types of machine that are often seen on landfill sites are, wheeled loaders, 360° tracked excavators, off-road trucks, tractors and trailers and standard tipper trucks.

Arrangements should be made for maintaining good standards of landfill operation when any of the machines is out of action because of breakdown or if undergoing maintenance or repair. In large sites this may involve having a spare machine or contingency arrangements for using only one machine when two are normally in use. In other cases it may be possible to hire a replacement machine of satisfactory specification, or to borrow one from a local government department.

Stationary plant that may be needed on landfill sites includes

- a weighbridge at the entrance, with electronic data processing (This can provide operational data that benefits all aspects of solid waste management, not just disposal);
- a wheel cleaner, for trucks leaving the site, if they are depositing mud on the public road (This is often simply a set of transverse bars that shake the vehicle as it passes over them, releasing much of the mud on the wheels.)
- an electricity supply, which may require a transformer, a diesel generator, or solar panels if the demands for electricity are not high;
- lighting if the site is open at night;
- pumps for recirculating leachate, or pumping leachate to a wastewater treatment plant;
- a gas collection system and a flare or electricity generator if landfill gas is to be collected;
- a security system perhaps including lighting, closed-circuit cameras and alarms.

Preventive maintenance, incorporating the monitoring of the condition of each item, the routine replacement of consumable spares (such as oil filters) and parts that are showing signs of failing, should be carried out faithfully on all machinery, to ensure the maximum working life for each machine. A clean workshop area should be provided so that this work can be done conveniently and to a high standard on-site. It may also be appropriate to carry out routine checks on collection vehicles when they are visiting the landfill site. Maintenance contracts may be the best means of ensuring satisfactory maintenance for some items of equipment.

B4.4 The process of upgrading

As already stated, there is a wide range of approaches to waste disposal between the unplanned dump and the sanitary landfill. In industrialised countries the process of upgrading from unplanned dumping to sanitary landfilling probably took half a century. Each site was developed according to local understanding and conditions, but the process of evolution of the sanitary landfill has often advanced by the following steps:

- The first step may have involved appointing a responsible watchman or foreman to work on the site, and the occasional levelling (by manual methods for small sites) of the waste piles to increase the access for vehicles bringing waste.

- Fences were erected in an attempt to restrict access by animals and unauthorised people. Vehicle access began to be controlled and monitored.
- Internal site roads were developed to provide all-weather access.
- Attempts were made to extinguish the fires and prevent further burning.
- The practice of covering the levelled wastes with soil or inert waste was introduced; the purpose was to reduce the spread of litter and discourage fly breeding and birds.
- Plans were developed to determine how the site should be used, and drivers were instructed to unload waste in certain areas, according to the site plan.
- Areas of the site that were no longer to be used were covered with topsoil and planted with vegetation that would discourage erosion of this soil and improve the appearance and usefulness of the former disposal site.
- Earthmoving machinery was stationed on site to level the waste and the cover material, and later, as the density of municipal waste decreased, special machines – landfill compactors - were developed to compact the waste to make better use of the available volume, to make a firmer base for vehicle operations and to reduce the scattering of paper.
- If the site was located on impervious soil so that the flow of polluting leachate was obvious, attempts may have been made to collect the leachate flowing from the site and spray it over the waste or transport it to a nearby wastewater treatment plant.
- Waste was used to fill abandoned quarries and depressions in order to improve the appearance and usefulness of the land. Such sites were still considered the appropriate locations for waste disposal. Problems of water pollution led to the introduction of drainage systems to prevent clean groundwater from coming into contact with the waste and to extract the leachate for treatment in municipal wastewater treatment plants.
- A small number of incidents of explosions in houses located near to quarry landfills led to a concern to prevent the underground migration of gas and to monitor gas levels. The impact of the ongoing generation of landfill gas on the growth of vegetation and on the covering layer of soil led to attempts to vent the gas.
- Problems associated with water pollution led to a gradual move from the use of depressions and former quarries for waste disposal towards above-ground disposal, which is often referred to as *landraise*.
- Cases of pollution of groundwater resources motivated a more thorough approach to the control of leachate – initially the siting of disposal sites on impervious soil, and later the construction of impermeable clay linings on the bases and sides of disposal sites. As treatment of leachate with municipal wastewater was found to be problematic, methods of on-site pre-treatment or full treatment of leachate were introduced at large disposal sites. Research into decomposition processes in the mass of the waste and into leachate treatment gathered momentum. The monitoring of water quality in boreholes around landfill sites became common.
- Gradually, legislation was developed, leading to the need for operators to get site licences which specified how the site should be operated and which types of waste could be accepted. Independent inspection arrangements became more effective,

particularly when the monitoring of landfills was made institutionally independent of operations.

- Permeable synthetic geotextiles became available and were used for the construction of site roads and drainage systems. Impermeable plastic sheeting (known as geomembranes) began to be used for isolating the waste from water resources.
- Completed landfills were covered with impermeable soil, and later plastic liners, to reduce the production of leachate when filling had been completed. Later it was discovered that the lack of moisture in the waste resulting from this "dry tomb" approach stopped the processes of biodegradation. This led to the fear that an inflow of water many years after the closure of the site, resulting from the failure of this impermeable cover, would result in massive decomposition, generating huge quantities of methane gas and leachate when there would be no measures in place to control them. Opponents of this total sealing of a landfill argued that it is better for the decomposition to take place quickly - as much as possible during the time when the landfill is operational and experienced staff are on site. Some landfills were designed and operated as *flushing bioreactors*, in which the decomposition of the waste was accelerated by recirculating water downwards through the waste.
- Concern about the risks posed by hazardous wastes led to the development of new techniques for the management and disposal of these wastes, and special landfills for hazardous wastes. Operators were required to monitor the nature of incoming wastes.
- Concern about the risks of fire and explosion caused by methane generated in landfills led to more stringent requirements regarding the location of landfills and improved gas venting. On larger sites, trials were set up to collect and use the methane in landfill gas to drive electricity generators and for local heating. Financing mechanisms that favoured non-fossil fuels improved the economics of these energy recovery schemes.
- More comprehensive regulations, accompanied by increased inspection and enforcement, obliged operators to upgrade their disposal operations. As a result, smaller disposal operations were closed and wastes from smaller communities were transported to large, central landfills. Monitoring of closed disposal sites was required by law. Opportunities for training in landfilling techniques and new institutional arrangements were introduced. Safety standards affecting site workers were upgraded.

It has taken industrialised countries decades to upgrade standards of waste disposal. This experience suggests that, in developing countries, it may be wise to formulate a policy of progressive upgrading over a decade or more, rather than expecting to change waste disposal practice from dumping to sanitary landfilling overnight.

It took a long time to upgrade waste disposal in industrialised countries, and the many developing countries have found it difficult to make rapid changes in their waste disposal practices. Are there general lessons that can be drawn from these experiences? Why did it take so long to develop the sanitary landfilling techniques that are used today? Might the same factors delay implementation of improvements in low- and middle-

income countries in the coming years? The following factors are considered to be at least part of the answer to these questions:

- Technology: One factor clearly was the time taken to develop and refine new technological approaches – observing the need for improvements in materials, design, treatment processes and working methods; devising improvements and implementing them on a commercial scale, observing the need for further improvements and so on. This delaying factor is not the reason why upgrading of waste disposal in developing countries can be expected to take some years, since these practices and equipment are available and documented. However, practices must be modified to suit local conditions, particularly waste characteristics, climate, geology and local recycling practices; time must be allowed for locally appropriate methods to be developed
- Institutions and politics: Another factor is the speed at which institutions operate. Political leaders sometimes give waste disposal a very low priority. Developments in legislation are not always effective in motivating attempts to make reasonable and sustainable improvements. Municipal and regulating agencies take time to respond to shortcomings and adopt innovations, and time must be allowed for operators to adapt to the new requirements, particularly if new disposal sites must be identified and acquired – a process that can take years. Effective means of monitoring and enforcement may take even longer to develop, partly because of the need to persuade decision-makers of their importance. The process of developing good sanitary landfills will be retarded if there is no free exchange of information – especially regarding disappointments and costs – between decision-makers and site managers.
- Resources: Another important delaying factor is the time needed for building the capacity of waste management organisations so that they are ready to pay the extra costs of improvements and can recruit and train the needed staff. Training of staff will be discussed in more detail in Section B7. To be successful, the training process should generally include site experience as well as classroom training, and if disposal sites that use improved methods are not available as a location for work experience, capacity building will take longer. Effective capacity building is needed both for site managers and for agencies involved in inspection and monitoring.
- Attitudes and practices: There may be opposition to any changes from the staff. Perhaps no engineer is willing to spend most of her/his time working on the disposal site, because of a cultural dislike of working in waste management or the working conditions and working hours. Perhaps the drivers have been receiving unofficial payments from waste pickers for delivering their loads in places specified by the pickers, and they are reluctant to lose this additional income in a controlled landfill where they are told to unload in a specified working area and where waste picking is controlled or even forbidden. Attitudes and practices may take time to change.

B4.5 Intermediate options

The various steps along the way from unplanned dumping to sanitary landfilling have been given labels such as controlled dumping, controlled landfilling, and engineered

landfilling. However, there is no fixed way of upgrading disposal operations from dump to landfill, because innovations and improvements may be implemented in different sequences. The World Bank has published an excellent manual that advocates stepwise upgrading of waste disposal practice [Rushbrook and Pugh, 1999].

In a paper linked with the South African *Minimum Requirements* document, Ball and Bredenhann [2003] divided the process of upgrading into defined steps or stages, each stage having targets for improvements in operation to be achieved within an agreed time frame. Progress should be audited regularly by means of check lists. The milestones in the upgrading process are clearly defined.

As a first step, a vital decision must be made about whether an existing dump should be upgraded, or whether it is necessary to find a new site and close all existing dumps. The factors to be considered when deciding whether an existing site should continue to be used or whether a new site should be found are discussed briefly in Section B4.8.

There are distinct advantages in using an existing site. The long process of finding and acquiring a new site is avoided. Local opposition is likely to be less than for a new site. There are also operational advantages because the landfilling machinery and site staff are needed at only one location. If a separate new site is being developed, but much needs to be done to clean up and close the existing site, resources will be divided between the two locations, hindering work in both places.

If action is taken to upgrade a disposal site from an uncontrolled dump to a controlled landfill, this may attract the attention of the environment ministry, which may require improvements up to full sanitary landfilling standards. If the disposal site is not improved, but continues to be used in a polluting way, the environment ministry may pay no attention. In this way, by opposing stepwise upgrading and insisting on the highest standards, an environment ministry may actually prevent sustainable improvements being made. By insisting that any improvements must match the highest standards of design, they may encourage waste management agencies to avoid unaffordable expenditure by continuing to use their disposal sites as they are, without attracting the attention of the environment ministry. Donor and lending agencies may have the same effect by insisting on constructing sophisticated and complex sites that are too expensive or difficult to operate, without paying sufficient attention to the institutional context and the need for capacity building.

A key aspect is water pollution. The leachate emanating from a disposal site may not be visible because it disappears into ground that is covered by waste, and there may be large quantities of leachate even in a semi-arid climate (as in the case described in Section C6). In dry climates, where the waste contains little biodegradable material and little moisture, the amount of leachate generated by a disposal site may be very small. If a disposal site is designed on the basis that no significant leachate will be generated, no liquid wastes – such as septage, nightsoil or sludges – should be deposited there. As with all sites, it is essential to prevent clean water from outside the site from coming into contact with the deposited waste, so open drains must be constructed and maintained to intercept all overland flows.

Unfortunately, collecting the leachate without treating it properly can be worse than doing nothing, because the environmental impact of untreated leachate can be more if it is discharged at one point than if it is spread over a wide area. The reason for this is that a clay soil can improve the quality of the leachate to a limited extent by natural mechanisms such as filtration, if the leachate is spread over a wide area. However, if the flow of polluting liquid is concentrated in one place, the natural purifying mechanisms may have a negligible effect. This consideration is not a reason for avoiding the installation of under-drainage systems, but emphasises that it is not enough to bring the leachate to a treatment facility if the pollution potential of the leachate is not effectively reduced. In this case the intermediate option of leachate collection without effective treatment is not recommended.

B4.6 Strategic planning

This section discusses some basic considerations related to developing a strategy for waste disposal in landfills. For a more detailed coverage of this topic the reader is urged to download from the World Bank website and read the *Strategic Planning Guide for Municipal Solid Waste Management* [Wilson et al., 2001].

B4.6.1 Setting a realistic time frame

When formulating a policy and a strategy, realistic consideration must be given to the time that is needed to implement the steps of the process of upgrading disposal operations. Changes in practices and improvements in standards take time to achieve, and if they are pushed through in too short a time they may not be sustained. Experience has shown that it is not sufficient to pass laws and develop standards if the capacity for implementing them is not widely available.

Policies and strategies should be realistic and achievable, taking into consideration the time needed to find, approve and establish new sites, the time required to train site managers and, crucially, the financial capacity of the responsible administrations not only to fund the construction of the sites but also to meet the recurrent financial commitments involved in operating the site in an acceptable way. The lack of resources in smaller cities and towns might rule out the possibility of successfully operating sanitary landfills, at least in the medium term, and for such communities a more modest target would be appropriate – a controlled tip or an engineered landfill. Policies should indicate priorities and criteria for deciding on the most appropriate standards to be achieved in each urban area, and strategies should be based on realistic phasing of improvements and allow for revisions to schedules according to experience.

Commitment to following such a strategy may be tested if an international development agency offers finance and expertise for the establishment of a number of sanitary landfills. Difficulties may arise if the proposals and requirements of the external agency conflict with the provisions of the national strategy, because the external agency is likely to insist on sanitary landfills that meet the highest standards and the national strategy may be setting more modest and realistic standards in some of the cases and in the medium-term. The phasing of improved standards should take account of the availability of the human and financial resources that are essential to ensure that

appropriate standards of operation can be achieved and maintained. .If not, a sophisticated disposal facility may soon become a dump and an environmental hazard.

B4.6.2 A model landfill and data collection

A national waste management strategy may include the setting up of one or more model[18] sanitary landfills of the highest standards for demonstrating the technology and training landfill managers. The selection of the locations of such facilities should take into consideration transport links and the interest and commitment of local politicians and officials. If properly operated, such facilities could be used to show to political leaders and municipal officials what a good sanitary landfill looks like, because many decision-makers may consider that all disposal sites are similar to the unplanned dumps with which they are familiar. Video presentations could be made at such sites to show the benefits of sanitary landfilling and to be used for training future site managers. In such cases there may be a need for support at national government level, to ensure that sufficient resources are allocated and that the potential of the site for awareness raising and training is fully used.

The value of a model landfill could be further enhanced if it is used for collecting operational data on factors such as the density of waste when placed and after certain intervals and the generation of landfill gas and leachate. These factors are expected to vary with climate, type of waste and method of landfill operation, and so data from other countries and conditions may not be a reliable guide. Data on leachate and gas generation that are collected after the site is closed could provide a basis for deciding the number of years after site closure during which the operator is responsible for the site.

Methods that are developed at a model landfill of this kind for the collection, analysis and dissemination of data could be used to monitor other sites. Benchmark values or norms could be established and revised on the basis of data from landfills that are operated well. Sites for which the data are far from benchmark values could be identified for special attention.

B4.6.3 Phased construction

Landfills are often developed in several phases and each phase may comprise a number of individual cells[19]. Several cells or more than one phase may be constructed at one time, or the cells or phases may be constructed in stages, ready for when they are needed. Clearly, constructing many cells at one time requires a higher initial investment, but the advantages of constructing all the cells that may be needed for a long period of operation (such as ten years) include:

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[18] In this book the word "model" is used in two senses. Here the meaning of "model" is *exemplary*, *ideal, demonstration* or *pioneering.* The model landfill referred to here would be full-size, and designed and operated in such a way as to set the standard for landfills elsewhere. (Elsewhere the word *model,* used as a noun, refers to a small-scale replica.)

[19] A cell is an area surrounded by an earth embankment, which is usually filled with waste before operations move on to the next cell. Specialised cells may also be constructed for particular types of waste or for use at night or during difficult weather conditions.

- Finance may be available (perhaps in the form of a grant or a loan from an international agency) for construction of more than one phase, and there is no guarantee that financing would be available at a later date, if the envisaged work were divided into two or more stages. For this reason it may be decided to build as much as possible using the finance that is currently available.
- The construction of an impermeable liner or membrane under each cell requires special skills and special equipment. If the capacity to lay a particular kind of liner does not exist within the country, it may be considered advisable to build as much as possible when the international experts are present.
- The current municipal leadership may be convinced of the benefits of environmentally acceptable waste disposal, but there is concern that subsequent administrations may not be prepared to invest in landfills, and so it is decided to build as much as possible before the next election.

However, there are non-financial benefits in constructing cells for when they are needed, rather than years in advance. One consideration is that the impermeable linings may deteriorate if they are left unused for several years. Polyethylene liners may degrade if exposed to strong sunlight or be damaged if trucks or landfill machinery drive over them. They may also be dislodged by strong winds. Clay layers may crack if they become dry. Another benefit of building a landfill in stages is that lessons may be learned from the experience of operating the first cells, and these lessons can be incorporated into subsequent stages so that designs are improved, operation standards are upgraded or costs are reduced.

B4.6.4 Final use

The strategy for sanitary landfilling should include the planning of the closure and on-going monitoring of the site. Considerations should include the plan for the sequencing of the filling of the various parts of the site, the final elevations and contours, the provisions for monitoring emissions and settlement after the site is closed, and proposals for the final use of the site. Arrangements should be made, including the enactment of any necessary legislation, to ensure effective control of any construction on or near the completed site, to ensure that any structure is compatible with the ground conditions, the possibility of gas accumulation and the protection of the cover soil.

B4.6.5 Useful tests

Ball and Bredenhann [2003] summarised the requirements for any strategy for upgrading disposal operations with the following words "... a major challenge is to ensure that the proposed upgrading standards are in fact acceptable, appropriate, practicable, affordable, attainable and sustainable." It is worthwhile to reflect briefly on these tests for upgrading proposals.

- Acceptable – Are the proposals acceptable to the local administration that is responsible for solid waste management, to residents living near the site, to the environmental authorities, and to other stakeholders? Has their acceptance been stated, or is it merely anticipated?

- Appropriate – Are the measures that are proposed commensurate with the local needs and also with the skills and resources that can be expected to be made available?
- Practicable – Can the proposed goal be achieved with the available human, physical and financial resources? It is realistic?
- Affordable – Given the availability of financial resources and the competing demands for funding, is it realistic to expect that the required finance will be made available for the capital and recurrent costs associated with the proposed improvements?
- Attainable – If the required measures are undertaken, is it reasonable to expect that the stated improvement will be achieved? What are the grounds for believing the outcome will be as expected?
- Sustainable – Will the desired outcome continue have the expected benefits for the expected lifetime of the measure? Are the measures themselves robust? Is there a sufficient revenue base to cover recurrent costs? Is there a human resources management regime in place that will ensure that appropriately skilled staff are appointed to operate or ensure the proposed improvement? Is there public and political support for the proposed measure? Will the proposal result in environmental degradation?

B4.7 Motivation for improving and maintaining disposal standards

A further aspect for inclusion in the national policy and strategy is how to motivate municipal authorities and site managers to maintain high standards. The passing of laws and the promulgation of standards is rarely enough. Information, persuasion, public pressure, inspection and penalties may also be needed. If legal requirements for waste recycling and disposal are considered to be too difficult or expensive to implement, municipal authorities are likely to try to dump their waste in the cheapest way possible, without any environmental precautions. If penalties cannot be effectively imposed on municipal administrations that operate disposal sites, it may be necessary to engage private sector operators who can be penalised – if willing and capable operators can be found.

Even if a high quality landfill is constructed, municipal administrations may be unwilling to allocate the necessary funds and senior staff to ensure that the site is operated as intended. If municipal decision-makers are aware of the importance to the environment of good standards of disposal operations, they will make available the necessary funds and provide the necessary support to the manager of the landfill site. If the disposal site is operated by a private company it is possible to include provisions in the contract or agreement that allow enforcement of good operating standards by means of fines or other penalties, provided that the public sector client organisation fulfils its responsibilities and takes the action necessary to ensure good operating standards. Some international landfill operators may maintain good standards without external coercion because of their concern for the environment or their international reputation, but this motivation cannot always be relied upon.

The best motivation is based on the understanding of the importance of protecting the environment and an awareness of the link between good operational standards and environmental protection. The administration that is responsible for a disposal site should be well informed on these issues and the general public – as individuals and through NGOs – should provide encouragement and support, and, if necessary, pressure, to keep environmental protection high on the list of municipal priorities. However, this is not enough. When new political leaders take office there may be a different set of priorities and municipal funding may be switched to other tasks.

Legislation is also required to set standards, establish a monitoring system, provide a system of incentives and penalties and institute a mechanism for enforcing legal requirements on operators of disposal sites. Each of these issues needs careful consideration:

- Standards must be necessary, achievable, objectively verifiable and enforceable. Standards should not be copied from nations that are much further advanced in waste management, but rather reflect the requirement for a stepwise upgrading of operational performance.

  Standards and requirements that are too high can result in no significant improvements, and wasted expenditure. Such standards may be set by legislation or requirements of the environment ministry, or by the provider of financial assistance. Requirements that are considered to be unrealistically high may deter local authorities from attempting any improvement, if they can continue current practices without attracting the attention of any enforcement bodies.

  Monitoring should be the responsibility of an organisation that is independent of the organisation that operates the site. If landfills are operated by municipal agencies, it may be appropriate for a regional environmental agency to take on the task of monitoring. It is generally ineffective for a municipal administration to monitor its own operations and enforce standards on itself. In some cases effective monitoring may be assisted by an NGO or a university, especially if they have links to citizens who live close to the disposal site and are anxious that good operating standards are maintained.

  Individuals who are responsible for monitoring landfill operations must be motivated, trained, equipped and supported. Their motivation should be based on a concern for a healthy environment so that they are able to withstand pressure or inducements that are intended to encourage them to ignore failures and problems. It can be very intimidating for a young, lone inspector to be on a remote site surrounded by site workers.

  Inspectors should be trained in landfill operations to the same level as the operators, so that they are confident in their knowledge of how disposal operations should be carried out and so that they understand whether any deviations from normal practice are significant or not.

  Monitoring staff should be sufficiently equipped. They need transport to take them to landfills (which are usually in remote locations). They need equipment that enables them to take any necessary measurements (such as for sampling water quality or particular types of waste) and a camera to record any observations. If

they are required to enter confined spaces they should have the necessary safety equipment to check that the air in the shaft or chamber that they are to enter is safe to breathe.

Inspectors need support. They need support from their superiors, based on a similar motivation to protect the environment which is not spoiled by pressure or inducements coming from the operators. They may need laboratory support, for the testing of samples and the calibration and maintenance of field measuring equipment. They also need support from the judiciary in the form of access to law courts where the judges are familiar with environmental issues and aware of their importance.

In some countries the ministry responsible for environmental issues is relatively new and weak, and it may not have the political power to enforce standards and insist on penalties, particularly if the offender is a major city or a more powerful ministry. This is one reason for engaging contractors to operate landfills – penalties can be imposed according to contract conditions rather than by struggling with a powerful ministry or municipality. If, however, the contractor is headed by a person with powerful friends, it may be difficult to implement the penalties that are written into the contract.

- If a landfill is operated by a municipal administration, what incentives or penalties can be used to ensure compliance with legal requirements? Options will vary, depending on legislation regarding local government. If significant subsidies are provided by national or provincial government, it may be possible to motivate city administrations to comply with waste disposal standards by threatening to withdraw or reduce these subsidies. In some cases it may be possible to arrange for remedial work to be organised by the monitoring agency and charged to the operating organisation. Alternatively, it may be possible to impose fines on administrations or individuals; the amounts of such fines must be high enough to have a significant effect, and any related court cases should not be subject to long delays.

This brief discussion of monitoring suggests why it is not sufficient for law-makers simply to pass laws and set standards, but it is necessary to ensure that there is an effective system for determining when operators are not complying with the laws and standards that are established, and that the monitoring system is sufficiently resourced.

There have been cases in which failures to maintain adequate operating standards for landfills have made front-page headlines in national newspapers, with calls for the chief executive of the responsible organisation to resign. Publicity of this kind may be effective in discouraging cases of gross pollution, such as serious odour nuisance and major fires. However, other operational failures are less dramatic – and so may not be noticed by the public - but, in the long term, they may be potentially more serious.

In some countries there are non-governmental organisations that have a strong concern for environmental issues and sufficient resources and numbers of active supporters to be able to influence public and political opinion. Unfortunately, sometimes their understanding of waste disposal issues is based on ideals and concepts rather than realities, and so they may promote an extreme interpretation of "zero waste" or an unrealistic expectation of what can be achieved by composting. On the other hand,

great benefits arise from the work of environmental NGOs in increasing public awareness and changing the waste-related habits of citizens.

Enforcement may also be required to prevent industries and other generators of large quantities of waste from dumping their waste in unauthorised places. This need for enforcement will be more critical if waste must be transported a long distance to the disposal site or if there is a gate fee to be paid for each truckload of waste. In this case the first step in ensuring compliance is the accurate recording of all loads received at the disposal site, coupled with regular and detailed analysis of these records. The next step may be to introduce a small gate so that users become accustomed to paying a fee for disposal, but the fee is not so large that it discourages users from coming to the site.

Industries that generate hazardous waste should be monitored to ensure that hazardous wastes are not disposed of in such a way that they are accessible to the public (especially children) and waste pickers.

Countries where landfilling standards are more advanced often operate a permit system. Before a landfill site can be operated, a permit must be obtained. The permit may specify required construction features and also include detailed and specific operational requirements. New arrangements for permits should include existing sites and sites that are to be closed. The permit may also specify the professional qualifications that must be held by the site manager. The permit can be revoked and operations suspended if conditions are not met. (The revoking of a permit should not lead to the situation in which there is no alternative waste disposal option of an acceptable standard in the locality. If there is no alternative site, it may be possible to provide new management for the site, or a different regime of monitoring.) This method of control is successful only if there is effective enforcement of both the requirement to obtain a permit before any waste is brought for disposal and adherence to operating standards. A further requirement is that the government department that is responsible for granting permits should have experts in landfilling on its staff or be able to hire consultants with sufficient experience of sanitary landfill operation as well as design. An example of a permit system that meets many of these requirements is described in [DWAF, 1998].

B4.8 Selecting and developing a landfill site

B4.8.1 Selection

When there is the political will or motivation to upgrade standards of waste disposal, the next challenge is very often to identify the site that can be developed into a landfill. It may be that site investigations indicate that an existing disposal site is satisfactory and large enough for upgrading to the proposed standard. Alternatively, it may be that land adjacent to an existing disposal site is available and so must be assessed to determine if it is acceptable for an extension to the existing site. The third alternative is that a new site is required.

If a new area is being considered for waste disposal, there are many considerations that must be taken into account – some scientific, some socio-political and some economic. The scientific investigations relate to the geology and hydrogeology of the immediate and surrounding area, distances to sensitive sites (Box B4.2) and a range of

environmental factors. The socio-political aspects relate to opposition to the use of the site from neighbouring residents and land owners, the relocation of any residents or activities and the willingness of the authority with jurisdiction over the site to allow it to be used for waste disposal. Future residential development should be considered because it is undesirable for many reasons that new houses are built close to a landfill site. Economic considerations include both capital investments and recurrent operational costs. .

Box B4.2 Determining the suitability of a site for waste disposal

Factors to be considered when reviewing the suitability of an existing disposal site or selecting a new site include the following:

- Its proximity to housing, water sources, airports and other sensitive locations such as touristic sites, land belonging to senior government officials and sites of special scientific interest (because of their geology, flora and fauna, etc.), and whether a landfill on that site would be, a conspicuous feature of the landscape. Wind directions and other meteorological considerations which affect the movement of odours, dust and litter should be taken into consideration when determining necessary distances.
- The underlying geology and the likelihood that use of the site will result in contamination of drinking water resources. Geological fault lines and areas of fractured rock should be avoided because they may offer a rapid flow route for polluted water. Furthermore, in areas of possible seismic activity any movement along a fault could destroy the leachate collection system of the landfill. The bearing strength and the stability of the underlying soil should also be considered. Areas above mining tunnels or subject to sink holes should be avoided because of the need for a stable base for the landfill. The depth to the water table, the flow direction of the groundwater and the quality of the groundwater should be investigated. The presence of any surface water drainage paths must also be taken into account. Rainfall and evaporation data are also needed for design.
- The capacity of the site for receiving waste. If an existing site is to be upgraded, it is necessary to take into account the need to reduce steep side slopes (if the waste has been placed in this way) and the possibility of acquiring adjacent land for extending the site. In the case of a new site, the shape of the site (in plan) and the topography will influence the volume of waste that can be deposited there and hence the useful life of the site.
- Access to electricity and water supplies, and the possibility of sending leachate for treatment at a wastewater treatment plant.
- Other general considerations include the strength and reasons for local opposition to the use of the site, ownership of the site and its surroundings, local land use practices and official land use designations, access to the site, including the time taken to bring waste from the urban areas that are to be served, and the need for constructing or upgrading all-weather roads to the site.
- Costs of acquiring or leasing the site, the costs of developing the site and upgrading access roads, the availability and cost of the various types of soil and rock needed

for construction and operation, costs associated with compensation for the relocation of housing and agricultural or industrial activities. The cost of transporting the waste to the site each day must also be factored in.

In the early days of controlled landfilling, preference was given to quarries and depressions when selecting new sites for landfills. In those days the concern was to fill voids so that the area could be safer, more useful or more attractive. Whilst quarries and similar voids are still sometimes used for waste disposal, they are less popular now because the base of the site may be close to or even below the water table (greatly increasing the risk of polluting water resources) and extra pumping is needed to collect leachate. (When measuring the vertical distance to the water table it is important to remember that the elevation of the water table can vary according to rainfall and recharge and that there may be localised depression of the water table caused by nearby wells and boreholes.) Flood plains should be avoided.

The identification of possible sites involves firstly an extensive review of land use and hydrogeology over a wide area, in order to exclude unsuitable areas and identify favourable areas. The investigations then adopt a smaller scale, investigating particular sites in detail. Before a preferred site is declared suitable, there should be a detailed environmental impact assessment (EIA) which considers a wide range of potential impacts of the landfilling operation on the local area, on its people and their activities, and on the local resources, flora and fauna. Regulations governing the conduct of EIAs and the involvement of stakeholders may exist in national legislation or be defined by a funding agency. An EIA usually includes necessary or recommended measures that should be taken in design and construction or in operation and aftercare to minimise or avoid potential impacts that are identified in the study. It may also include risk assessment, based on an evaluation of the environmental consequences of a failure in any of the environmental protection measures. Annex 1 provides a checklist of information that might be needed for assessment of environmental impact and the determination of necessary design features and operational practices.

Before or after the EIA is carried out, it is necessary to engage the neighbouring communities in an effort to win their support (or even reluctant agreement) for the project, as discussed in Section B6 below. Because the process of identifying and obtaining suitable sites can take such a long time, donors and lending agencies may be reluctant to become involved in financing the construction of a landfill until a site has been identified, shown to be satisfactory, and approved by local residents and political leaders. The time allowed for establishing a new landfill must take account of the time needed for these studies and processes. Box B4.3 suggests possible sources of necessary information and indicates the scope of the information needs when investigating possible sites.

Box B4.3 Some possible sources of information on site selection

When looking for a new site for a landfill, it is advisable to contact the government authorities with responsibility for

- pollution control and environmental impact
- environmental conservation
- planning and transport
- land ownership
- water resources
- military affairs
- electricity transmission and distribution
- telecommunications
- aviation
- mining
- agriculture
- tourism and cultural heritage

Information on local conditions may be available from

- government ministries
- geology and seismology institutes
- water resources agencies
- mining and petroleum companies
- hydrology and meteorology institutes
- water supply authorities, and
- universities

Because of the costs and delays inherent in the site selection process, it is important to select a site that is large enough so that it will last for many years (at least 20 if possible) so that the site selection process does not need to be repeated often. When estimating the area required for a landfill it is preferable to allow space for a buffer zone around the periphery of the site so that the site can be hidden from view and the noise of landfill operations attenuated. In some cases it may be necessary to have a wide buffer zone around the site to prevent the construction of houses close to the landfill.

The process of selecting a landfill site is often not only long but also complex. It requires expertise and knowledge of local politics and customs as well as the inputs of geologists, civil engineers, waste managers and accountants. There are differing views about the use of a scoring system for taking account of the many factors to be considered. Experts who oppose the use of giving a score to each of the factors argue that some factors are much more important than others. They also warn that one negative factor may be so important that it outweighs all the other positive factors and must lead to the rejection the particular proposal. (A negative factor of this kind is often referred to as a *fatal flaw*.) These objections to the scoring system suggest that, if scores for each option are to be used in the selection process, the weightings given to the various factors must be carefully decided according to their importance. Furthermore, the comparison of scores should only be considered when all sites with serious drawbacks have been excluded.

This Section provides only a brief scoping of the issues. For a more detailed coverage of the process the reader is referred to a World Bank publication by Rushbrook and Pugh [1999]. Some further points regarding the anticipated lifetime of a site can be found in Section C4.2 below.

B4.8.2 Developing a landfill site

The design and construction of a landfill site is a specialised and complex task which should be undertaken by experts with proven experience. The expenditure is too large and the costs of failure are too high for the work to be done by engineers who do not have the specialist knowledge required. Designs should be checked by a competent and independent consultant and construction should be supervised by an independent and experienced engineer who has the authority to order that unsatisfactory work is redone. It is particularly important that any impermeable barrier that is installed meets the required specifications in terms of materials and water tightness, and that it is sufficiently protected from damage by weathering, by vehicles and by the loading that it must support. The bearing capacity and stability of the ground should be sufficient so that the weight of the waste or other factors do not cause settlement which reduces the effectiveness of the drainage system by modifying the gradients of drain pipes.

Plans should be provided for the operation of the site, showing the sequencing of cells, the suggested layout of temporary site roads, and the final dimensions and profiles of the mound or hill that is to be created. In most cases it is appropriate that the final shape of the landfill is like a natural hill, without straight lines or symmetry. The designer should be familiar with all aspects of operation so that the operating plans are realistic and feasible; if this is not the case a person with experience of operations should join the designer in preparing operational plans.

Some more detailed technical information regarding the design and construction of sanitary landfills can be found in Section C4.3.

B4.8.3 Interim measures

If an existing disposal site is being upgraded, it may be possible to continue waste disposal operations at the site while the upgrading work is being carried out.

If a completely new site is being developed, it would be appropriate to implement minor modifications and operational improvements on the existing site since it may take a considerable time to prepare the new site for receiving waste, and experience gained at the existing site during this interim period can be applied beneficially to the operation of the new site. Planning and preparations for the closure of the site should also be initiated if such plans have not already been made. It is clearly preferable that plans for closure are drawn up at a much earlier stage so that they influence the way the site is operated, but if no such plans exist, planning for closure should be a priority.

Of particular concern is the case in which an existing site is being developed in a fairly radical way, such as the installation of an impermeable liner on the base of the whole site. In this case a satisfactory arrangement should be made for disposal of each day's waste while the disposal site is being modified. One way of making provision for interim

disposal of the waste is to lay the base liner in two stages so that half of the site is available at any time for receiving waste.

B4.8.4 Closing dumpsites

In many cases the upgrading of waste disposal practice involves the closure of small, perhaps unofficial, dumpsites and the transport of all waste to one upgraded disposal facility. In such situations there is the likelihood that some waste collectors will continue to dump waste at the old, more convenient, sites. Measures that can be taken to prevent this include

- tidying up and covering the closed sites, together with prompt removal of any waste that is subsequently dumped, so that they no longer look like places to dump waste;
- fencing off the old dumpsites (but this may result in waste being dumped just outside the fence);
- stationing police officers or municipal officials at the old sites either to prevent illegal dumping at the closed sites or to impose a penalty on any who attempt to dump waste there.

In some cases it is sufficient to bulldoze the waste into a mound with a shape that blends with the surroundings, but if there is a particular risk of water pollution or the site is to be developed for housing, it may be necessary to remove the waste altogether.

B4.9 Operating a landfill

Some specific aspects of landfill operation have been mentioned in Section B4.3.3. The purpose of this section is to offer some general principles and a few particular points that can lead to the satisfactory operation of a landfill.

The aim of the site manager and the supporting administration should be to continually improve both the standards of operation and the service provided to users of the landfill. This involves investigating problems and learning from mistakes, and a willingness to experiment with new approaches and to take reasonable risks. The sharing of experiences and ideas with other landfill managers may be very useful. Site staff should be encouraged to share with the site manager any suggestions they have of how operations could be improved.

Technical experts should be involved when specifications are being prepared for machinery and other equipment that is to be purchased for transporting waste and operating the landfill. Inadequate machinery represents a waste of money and results in poor operational standards.

A motivated and conscientious site manager can have a very positive impact on the costs and standards of landfilling. Therefore, a good manager should be provided with facilities (such as transport and a site office) that enhance the status of this post and reflect the value of the manager's work. This issue is discussed more in Section B7.

Staffing of the landfill should be organised so that there is always a responsible supervisor on the site. The site manager should be on the site for most of his/her official working hours, but if the landfill is open to receive waste for more than the official

working week (typically 40 hours) there should be a trained deputy on site with sufficient authority to organise operations and penalise infringements. This is particularly important if the site is open at night.

There are many types of waste that require disposal, but the location, design or size of a particular landfill may oblige the operator to refuse to accept certain types of waste. For example, if a landfill does not have an impermeable liner because very little leachate is anticipated, it would be appropriate to refuse to accept wastes with high water contents such as septage from septic tanks and sludges from wastewater treatment or industry. Without a dependable liner and a functioning leachate treatment system it would be wise to refuse to accept any industrial wastes that are judged to be more hazardous than domestic waste. If the size of a landfill is barely enough to accommodate municipal waste until a new landfill is ready, it would be appropriate to refuse to accept inert wastes such as construction and demolition debris unless they are needed for the construction of site roads or cell walls. If a waste is not accepted at the landfill there should be an alternative disposal route and a means of ensuring that the particular waste is disposed of in the required way. Septage can be disposed of in a lagoon or wastewater treatment plant. It may be possible to dewater industrial sludges so that they are dry enough to be disposed on the landfill. Inert wastes could be used as fill or taken to an inert waste disposal site (which would not need all the pollution control features that are found on a sanitary landfill). Some industrial wastes could be disposed of at a sanitary landfill elsewhere or sent for incineration or co-processing.

In order to enforce these restrictions on the types of waste that are accepted, the weighbridge clerk should have the training and the authority to demand information about any load and know whether it can be accepted at the site. Drivers of municipal trucks should be informed about the restrictions on the types of waste that cannot be accepted, and instructed not to mix restricted waste with normal municipal waste. Drivers of vehicles that are turned away should be informed as to where they may unload their waste and, if possible, action should be taken to verify that the waste has been taken to the correct disposal location. The weighbridge clerk should also look for any signs of fire in the incoming loads, and should direct the driver of a truck with a burning load to dump the load in a designated and isolated place from which the fire cannot spread. At the same time the site foreman should also be informed so that (s)he can check that the burning load is disposed of as instructed. Some types of waste, such as healthcare waste, slaughterhouse waste and dead animals should be disposed of in special ways, and it is the responsibility of the disposal site staff to ensure that the correct procedures are followed.

The operation of a landfill site does not stop when the last load of waste has been received. The waste must be covered with a thick layer of soil and topsoil, and planted with indigenous vegetation to improve the appearance of the site and protect the soil. The condition of this top layer must be monitored and maintained. The surface water drainage system and leachate drains (if any) should be monitored, and cleaned or repaired when necessary. Environmental monitoring, especially of groundwater quality, should continue. These tasks that must be carried out after a landfill site is closed are often referred to as *aftercare*.

More information about the operation and aftercare of landfills are provided in Section C4.

B4.10 Picking at disposal sites

At many disposal sites around the world there are large numbers of informal waste pickers who sort through deposited wastes and take out items that they can use or sell. Being informal, they are not employees of any organisation and there is no direct line of control or co-ordination with the manager of the disposal site. It is common for men, women and children all to be involved, and very small children may be left to play on the waste by mothers who are picking through the waste. It is often the case that a picker specialises in one material, such as plastic, cardboard or metal.

Photo B4.23 Women, men and children picking close to a bulldozer

Working so close to a moving bulldozer presents serious risks of fatal accidents.

B4.10.1 Arguments for and against picking at disposal sites

Landfill managers and other officials are often opposed to allowing waste pickers on their disposal sites, and try, often unsuccessfully, to prevent these people from entering. Others, particularly those who work with the informal sector community, argue that these waste pickers perform a useful service and should be allowed to work on waste disposal sites. The arguments of the two sides are often based on one or more of the following points.

a) <u>In favour</u>

- The benefits of recycling in general apply to waste picking at disposal sites. Material is returned to the economy, conserving both raw materials and energy. Livelihoods are provided for people who have no formal skills and no capital, and might otherwise be destitute and forced to turn to begging, crime or prostitution. The volume required for the disposal of waste is reduced.
- There are advantages for waste pickers who might otherwise be forced to look for recyclable materials on city streets and in communal waste containers. Pickers at disposal sites often live close to or on the site, so it is convenient for them to work close to where they live. In many cases they are not harassed by officials, as they might be if they worked alone within the urban area. There is a regular and

relatively predictable supply of waste to sort through. There may be scrap dealers nearby to whom salvaged materials can be sold, so there is no need to transport these materials a long distance.

b) Against

- Remembering the value of an integrated approach to solid waste management, one can ask if picking at the disposal site is the best stage or location for this activity. In many ways it is not. It is generally preferable that recyclable materials are removed from the waste at the earliest opportunity, by means of at-source segregation or during primary collection, if possible. At these early stages the desired materials and items are less contaminated by the other wastes, and the reduced volume of the unusable waste means that costs of handling, transporting and disposing of the remaining waste are less.
- Waste disposal sites can be unhealthy places to live and work, particularly if the waste is burning, because of the smoke and toxic gases that result from fires. Illness is the likely consequence of working without protective clothing (Box B4.4) and the lack of handwashing and sanitation facilities, as well as of a poor knowledge of the importance of hygiene. Some wastes from industries and hospitals can cause serious illness. Rats, insects and birds spread disease. Water supplies for people living near the site are likely to be inadequate. Access to medical care is difficult. These risks are not serious for a trained municipal team that runs a well-managed landfill site, but they may pose serious threats for informal waste pickers.

Box B4.4 Providing protective equipment

It is often suggested that protective clothing – particularly gloves, boots and face masks – should be provided to informal sector waste pickers. This proposal is not realistic if the pickers are not registered and carrying identification and if they are not accountable in any way to the site management. If such personal protective equipment (PPE) is provided free of charge, many individuals (whether actual waste pickers or others posing as waste pickers) are likely to ask for the equipment and then sell it rather than using it. Furthermore, it is often noted that formal sector waste workers do not use the gloves that are provided if they are uncomfortable to wear for long periods or if they make it more difficult to pick up bags or other items. Some face masks should be replaced each day to provide effective protection against dust. A considerable expenditure on these items might be difficult to justify when cash is in short supply.

The situation is very different for waste pickers who are members of a co-operative or employees of a recycling company. They should be provided with basic safety equipment including a high-visibility waistcoat or jacket, and be accountable for its use and condition. It is important that official waste pickers are distinguishable, identifiable and protected.

- Waste pickers also are at risk of being injured or killed by accidents involving trucks and machinery. Pickers like to work as close as possible to vehicles while they

unload their waste, in order to be the first to pick the best items of waste. They are therefore at risk of being crushed by reversing vehicles or the heavy machinery that is used on a landfill site. In some cultures the drivers and operators fear that they themselves might be killed on the spot if they are blamed for causing a fatal accident. (Photo B4.23)

- Waste pickers can seriously hinder the operation of a landfill. Plant operators may take such care to avoid accidents with waste pickers that they do not use their machines as intensively as they otherwise would, and drivers of trucks delivering waste may fear to unload their waste at the correct location because of the crowd of pickers that is there. The result of this obstruction is either a lower standard of operation or a higher expenditure on fuel, wages and machinery. The author knows of a case where waste pickers use threats and violence to control the operation of the disposal site, and tell the truck drivers to unload the waste at places that suit the waste pickers; they also steal items (such as batteries) from the trucks that are unloading on the site.
- Waste pickers sometimes set fire to the waste in order to expose metallic items, using magnets to collect small items of iron or steel. (At one large site where this was taking place many magnets were confiscated and the army had been called in to force the waste pickers to leave the site, but neither of these measures had proved effective.) Fires started in this way may go deep into the waste and be very difficult to extinguish. Air pollution is another consequence of open burning. Pickers also sometimes burn the PVC insulation off wires producing smoke that is particularly harmful. At a disposal site that was operated at night, waste pickers were seen to burn discarded vehicle tyres to provide light to work by. Because of the very serious environmental, health and operational problems that are caused by fires on landfill sites, such practices of some waste pickers can be of great concern.
- The storage of recovered materials may spoil the tidy appearance of a landfill site and may also be a fire hazard.

B4.10.2 Options for integrating waste picking at disposal sites

Faced with the problems that might be caused by waste picking at disposal sites, and considering the advantages of recycling, managers of disposal sites have developed several approaches to the issue of informal sector picking.

a) Preventing access

Attempts have been made to prevent waste picking on disposal sites altogether. Fences around sites are not generally effective in deterring waste pickers. There are cases of disposal sites that have been moved far from population centres with the expectation that the long journey will deter pickers from travelling to the site. Police action and military force have also been tried. None of these measures guarantees success.

b) Organising picking activities

The disposal authorities may decide to allow pickers to work on the disposal site, provided that the authorities have some control over them. In order that the landfill operator can have some influence over how the pickers do their work, it is helpful if they have some sort of organisational structure. If the pickers have leaders, it is possible to

negotiate with the leaders. If the pickers can be encouraged to form a co-operative, there are opportunities for negotiation and co-ordination. There are cases where a private operator has been given a contract for picking, and the operator has recruited the existing waste pickers as employees, and given them a distinctive uniform and identity cards.

Whenever informal sector workers are formalised in any way, there is the possibility that other workers will wish to work as waste pickers on a completely informal basis, outside the formal arrangements. If there is a co-operative, pickers who do not wish to join the co-operative, or who have been excluded or are not eligible to join, may continue to work alongside, and in competition with, the members of the co-operative. The same situation may apply where there is a contractor if waste pickers who are not employees continue to work on the site. These informal pickers may wish to work in this way for financial reasons, to benefit from the lack of restrictions on the way that they work, or because they have been excluded from the formal arrangements. If these unauthorised individuals form a small minority it may be possible for the more formal majority or the site staff to control access to the site, so that workers who do not carry an identity card or wear the contractor's uniform are prevented from working there.

If waste picking activities can be controlled by one of these mechanisms, there are opportunities for training the workers in hygiene and safe working practices, and for controlling the way in which they work to minimise the obstructions caused by the waste pickers to site operations.

- One way of doing this is to divide the working area of the site into two separate sectors. Waste is unloaded in the first sector during the first part of the working day, but the waste is not spread or compacted. In the second part of the working day the waste is unloaded in the second sector and waste pickers are allowed to pick waste in the first sector. When no more waste is to be delivered, the pickers are moved to the second sector and the wastes in the first sector a levelled and compacted. Later the pickers are told to leave the site and the waste in the second sector is levelled and compacted. In this way the waste pickers are kept separate from the trucks and machinery. This method of site management can also be used when waste is being delivered day and night. One disadvantage is that it requires a considerably larger open working area, and there is likely to be more litter on a windy day because the waste is not quickly levelled and compacted, but for some hours is exposed and scattered.
- Another option that is often suggested is that a sorting station or materials recovery facility (MRF) should be established near the entrance to a landfill so that items that can be recycled are separated from the waste before the remaining waste is taken to another part of the site for disposal. This arrangement involves additional operating costs because the waste that remains after sorting must be loaded into a truck and transported to the working area for final disposal. Also, if there are any conveyor belts and magnetic separators in the sorting station, they will not only significantly increase the capital cost but also add to the operation and maintenance expenditures. Facilities of this kind have often been installed at composting plants

that were designed to received mixed waste, where there was the need to remove materials that would harm the quality of the compost.

It has sometimes been suggested that informal sector waste pickers should be allowed to work in such sorting stations since they would no longer be attracted to picking waste at the working areas of the landfill and they would be working in improved conditions, reducing the volume of the waste without adding to the wages bill of the disposal operation. It has also been suggested that the waste pickers could show their gratitude for the opportunities provided to them by loading the residual waste into vehicles which would carry it away for disposal. It could be said that the suggestion that informal sector workers would work in this way is typical of a technological approach because it does not take account of various human factors. A key consideration is how the workers would receive their income - Would the waste pickers be paid a wage or would they continue to work independently, being paid according to how much they (and their families) collect?

- If they are paid a fixed wage instead of keeping the materials that they pick, would they still be motivated to work hard, or would their efficiency be similar to that of formal sector workers? (In many cases, informal sector workers manage to earn a livelihood from recycling by working long hours and using the unpaid labour of family members.) If the wages were less than the income they received from working independently, would they be interested in participating?
- If the waste pickers in the sorting plant are able to keep what they find, so that their income depends on the amount of recyclables that they can sell, there would be fierce competition for the best places in the sorting lines and for the loads of waste that contain the most recyclables. The same would apply if a co-operative was paying them according to what they collect. The sorting station would quickly become very dirty, and perhaps a place of conflict. There would also be problems of storing material that is collected, and, probably, accusations of theft.
- One possible mode of operation would be to rent sorting areas to small teams which bid for truckloads of waste, in order to avoid conflicts over priority of access and access to loads considered to be more valuable. Access to a sorting table would only be granted to teams that left their sorting area clean on the previous day. This would require close management and could result in delays.

The author has often read proposals for sorting stations of this kind to be installed at the entrance to landfills, but has only heard of one that was actually established. Unfortunately it was not successful and was not being used, according to the report that was received. The apparent reason was unresolved conflicts over access to the most profitable waste.

B4.10.3 Key points

- It is clear that waste pickers on disposal sites can cause problems, but it must always be remembered that they may see no other option for earning enough to support themselves and their families. After debating the issue and coming to a decision to deny access to pickers, it may prove impossible to keep them out.

- There are distinct advantages in removing recyclables from the waste as early as possible in the waste management chain.
- Improvements in this field are not just a matter of technology, but require a comprehensive approach which should include listening to the waste pickers themselves.

B5 Carbon credits

Following the adoption of the Kyoto Protocol on climate change by 37 countries in 1997, the Clean Development Mechanism (CDM) was set up to encourage projects and measures that would reduce the quantities of greenhouse gases (GHG) that are exhausted into the atmosphere by industries, aircraft and other human activities. Financial contributions, known as *Carbon Credits*, are payable to support projects that have been approved under the CDM scheme. The CDM has been operational since 2006, and since then over 1,650 projects have been registered, equivalent to a reduction in emissions of 2.9 billion tonnes of carbon dioxide by 2012[20]. The United Nations body responsible for this scheme is the United Nations Framework Convention on Climate Change (UNFCCC).

Carbon funding can provide the motivation for improving solid waste management standards. Box B5.1 explains why money is made available by agencies concerned with global climate change to support solid waste treatment processes and sanitary landfilling in certain conditions.

Box B5.1 The reason for carbon credits

Industries and airlines that exhaust large quantities of carbon dioxide gas into the atmosphere are under pressure to reduce these emissions because of the link between carbon dioxide and climate change. (The term *climate change* is preferred to *global warming* because increased quantities of carbon dioxide in the atmosphere could lead to some countries becoming colder if ocean currents are affected, and other modifications of climate could include increased or diminished rainfall.) If these organisations are not able to reduce their own emissions, they may provide financial support for organisations elsewhere in the world to enable them to operate new projects that reduce their emissions of carbon dioxide or methane, so that the global result is reduced quantities of greenhouse gases in the atmosphere.

There are three main ways in which greenhouse gas emissions can be reduced by improved solid waste management:

1. Reduced methane from waste disposal sites.

   As has already been mentioned, methane (which is produced by the decomposition of organic waste in landfills) has over 20 times the impact on global warming compared with the same amount of carbon dioxide, so if the methane that is

[20] http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

produced in landfills is converted into carbon dioxide by burning it, the global effect on climate is reduced. Methane is only one component of landfill gas but it is more potent as a greenhouse gas than the other main constituents. If a landfill is constructed and operated to a reasonably high standard, it is possible to draw the gas into pipes and transfer it to one location where it is burned in a flare or put to good use as a source of energy. Landfills that are planning a project that will burn or use landfill gas in this way can apply for financial assistance (credits) that will be assessed according to the reduction in greenhouse gas emissions that is anticipated. Payments are made according to the actual reductions that are achieved. If standards of operation fall, the amount of gas that is collected is likely to drop, and therefore the carbon credit income is reduced. In this way carbon credits can motivate landfill managers to operate their disposal sites in a good way. Gas collection systems are considered to be uneconomical on small sites.

As with other technologies there is the risk that enthusiastic and persistent salesmen will quote overly optimistic estimates of the gas yield from a landfill and the potential income from carbon credits. The amount of gas that can be collected from any particular landfill depends on many factors. It may be prudent to proceed cautiously, beginning by collecting and monitoring the gas on a relatively small scale before committing to a landfill gas utilisation project.

2. Treatment methods that reduce the amount of waste going to waste disposal sites.

   If solid waste is diverted away from landfill sites to be treated in a way that produces less greenhouse gas, carbon credits can be paid according to the reduction of greenhouse gas. As discussed in earlier sections, composting is the only method of treating biodegradable municipal solid wastes that, at the time of writing, has proved to be suitable for treating municipal solid waste in low- and middle-income countries. If waste is composted under aerobic conditions it does not produce methane, and so this process has a lower impact on climate change than landfilling without gas collection.

3. Recycling methods that use less energy than the production of material from virgin raw materials.

   In a recent development, a methodology has been developed to provide for the payment of carbon credits for projects that recycle certain plastics according to the amount of energy saved by recycling used material when compared to the amount of energy that is used in producing plastic from virgin raw materials.

Applications for carbon credits cannot be made for existing arrangements that reduce greenhouse gas emissions, but only for new projects that are designed to reduce GHG (greenhouse gas) emissions below current levels. Data must be provided to show the existing or *baseline* levels for the greenhouse gases of concern, usually for the past three years. The aim of the Clean Development Mechanism is to facilitate new projects that would not otherwise be attempted. If, for example, a law is being enforced to oblige waste disposal operators to reduce their GHG emissions in a particular way, any project that aims to comply with this law is not eligible for CDM funding.

The accreditation process for CDM funding includes an application accompanied by specified data, and on-site assessment. If accreditation is granted, on-site surveillance and possible spot checks are used to verify performance. Accreditation is renewable every three years.

More details about the Clean Development Mechanism can be found in Annex 3. Extensive information on opportunities and procedures is available on the UNFCCC website

B6 Involving the citizens

B6.1 Public opposition

The involvement of the general public can be one of the greatest causes of headaches for the solid waste management planner, and so often planners and decision-makers try to implement strategies and develop sites without informing people in the neighbourhood. Although there may be short-term benefits in avoiding the involvement of the general public, this approach usually creates opposition at a later stage and causes significant disruption and additional expenditure. The attitude of the public towards waste treatment and disposal schemes is summarised well by the following two sayings:

Everyone wants the garbage to be picked up, but no-one wants it to be put down

and

Not in my back yard (NIMBY)

It is common (and understandable) that residents agree that waste treatment and disposal sites must be established somewhere, but they generally oppose any move to establish them close to where they live or work or go for recreation. This opposition applies not only to disposal sites but also to facilities where waste is treated or recycled. Even in countries where there is strong centralised control there can be strong opposition (Box B6.1).

Box B6.1 Some examples of opposition to waste disposal activities

- In a country with a centrally planned economy and an authoritarian government, farmers whose land was near an unsatisfactory disposal site blocked the road leading to the site in protest at the polluted water that was flowing from the waste.
- When unusually high rainfall caused an escape of leachate from a generally well-operated landfill, farmers in the neighbourhood set fire to the earthmoving machine that was used to operate the site.
- Farmers who claimed ownership of land that was adjacent to a large existing landfill refused to give access to borehole drilling machines that were deployed to investigate the suitability of the site for development as an extension to the existing disposal operation.
- In an island nation where fish was a major part of the diet, deposited waste in a

landfill was partially excavated to enable the construction of an internal site road. The resulting smell (made worse by the high content of fish waste) caused a national outcry, was front page news and led to the resignation of the responsible official.

- Citizens who accept the presence of a landfill for disposal of wastes from the local community may resist attempts to bring in solid waste from other communities for disposal on the landfill.

Acquiring a site for a landfill or treatment plant can be a long process. It is not uncommon in UK for it to take several years to find a site for establishing an incinerator. Increasingly, international development agencies do not wish to be involved in the process of site acquisition, but will only come in with technical and financial assistance when a site has been identified and approved, and satisfactory arrangements have been made for the relocation of people living on the site or its immediate surroundings.

It is clear that any operation involving the processing of waste should not be in an urban area, but be located as far as possible from homes, schools, factories and other areas where people congregate. It is also important to ensure the highest possible standards of operation and cleanliness so that the impact on the local environment is as small as possible and so that waste management operations gain a better reputation than they currently have in many places.

If the only experience of waste disposal sites is of large areas of smoking waste piles from which large quantities of plastic bags are disseminated to accompany the choking smoke, dust and the unpleasant smell, it is understandable that there is opposition. A sanitary landfill is very different from a burning dump, but people who have never seen one may not believe this. Seeing is believing.

There have been unfortunate cases of public opposition to the ongoing operation of certain waste disposal sites that were located far from any dwellings when operations began. In the subsequent years areas adjacent to these sites were developed for housing. Before long the residents in these recent developments petitioned for the closure of the sites, even though these sites were active before the nearby houses were built and the residents knew of the existence of the sites before moving to their current houses. Such experiences provide a strong reason for effective land use planning and restrictions on the uses of the land around any waste management site so that formal or informal housing is not built close to a disposal or treatment facility.

B6.2 Overcoming public opposition

Unfortunately there seems to be no universal formula for avoiding public opposition to proposals for siting waste treatment and disposal facilities. The most effective approach probably depends on local politics, both formal and informal, and good local knowledge of the people and their activities and priorities.

The scientific factors to be considered in the selection of suitable sites have been presented in Section B4.8. The tendency for planners and engineers is often to try to avoid informing and involving the public. In the issue of landfill siting as well as in many others it is important for engineers and managers to work together with experienced

social scientists in order to find ways of working with the community to find sustainable solutions to waste treatment and disposal needs. Failure to face this challenge may lead to lasting opposition, conflict and delays. Methods that have proved effective in the open societies of some industrialised countries may not be acceptable or successful in other parts of the world.

The following suggestions, based on experiences in different places, are offered in the hope that they may be of assistance in this difficult task of gaining acceptance for the use of a particular piece of land for a solid waste management facility:

- Be transparent. If concerned citizens think that decisions have already been made without their knowledge, or that relevant information is being hidden from them, this will undermine any trust that they may have in the officials responsible for selecting the site to be used. Avoid making promises that will not be honoured.
- Identify at least three possible sites and present the advantages and disadvantages of each to the stakeholders who will be affected by the selection. If the concerned citizens can follow the processes that are involved in making the selection, they may understand the reasoning being used and, to some extent, sympathise with the officials who are looking for a site.
- Reassure the potential neighbours that the facility will not be an unsightly and hazardous smoking dump. They may be reassured by learning about the plans for the site and the standards to be maintained in its operation. Showing photographs or videos of well-run sites of a similar nature may persuade them that the site will be less of a problem than they anticipate. It may be helpful to make a model of the site (Photo B6.1) or produce artist's impressions showing how the site will appear during operation and after restoration.

Photo B6.1 Model of a proposed sanitary landfill. This model was made to show political leaders and the public how the site would appear. It can also be used for training site staff and inspectors.

- Propose a monitoring committee (to oversee the operations at the site) that will include representatives of local residents and, if possible, at least one member of a

trusted environmental NGO. Offer also a means of making complaints and delegate a senior local official who will have responsibility for handling any complaints.

- Convince any local people who will need to move their homes or who will lose some or all of their farmland that compensation will be generous and that satisfactory relocation arrangements will be made.
- Offer employment on the site to local residents. (This will encourage some feeling of community ownership of the site and give the residents a representative within the operating organisation through whom they can make informal complaints and receive information. Providing employment in this way will also be seen as an economic benefit to the local community.)
- Include improvements to the local infrastructure as part of the development of the site, if it is selected. Such improvements might include upgrading a road or providing a better water supply or connection to the electricity distribution grid.
- Listen to the concerns and objections of the concerned residents and try to find ways of minimising the inconveniences that they anticipate. For example, if they are worried about large numbers of trucks using a road in their village, it may be possible to develop another route which causes less nuisance to the residents. If they are worried about the noise of operations at night, it may be possible to schedule the working hours so that little or no work is done on the site at night. If they are concerned about the appearance of the site, it may be possible to screen it with an earth bank and plant trees to hide the operations. Such an approach not only addresses specific objections but also would be appreciated because of the willingness of the developers to listen to the citizens and to respond to what they hear.
- The planting of flowers or trees along the boundary of the site next to a public road is recommended. Such measures can show that the operating authority is concerned to take care of the appearance and environmental impact of the disposal facility. It may even be possible to rent out some land in front of the site to market gardeners or flower growers, or to use the area between a public road and the landfill as a nursery for growing plants and flowers for public parks.
- The landfill site and any treatment facilities should each have a clear and attractive signboard that states the purpose of the site and explains how to contact the person responsible to ask for information or to make complaints. An artist's impression of how the site will appear when it is completed could also be shown on the signboard.

B6.3 Providing information and encouraging participation

B6.3.1 Providing information to the general public

Most solid waste management organisations do not have a public relations officer. They may have a somewhat defensive attitude, waiting for attacks from the public and politicians and hoping to survive them, rather than taking the initiative and presenting a positive image of their work.

Waste management organisations often make the mistake of not providing sufficient information. The results of this neglect may be that the only news that reaches the

public is unfavourable newspaper reporting about the waste management system. If local residents are not kept informed, this may lead to a feeling of suspicion regarding the actions and intentions of the solid waste management agency. As a result they may be reluctant to pay fees or taxes for waste management services. The information that is provided should not be limited to instructions, but should include explanations and presentations of what is being done and being planned, reminders of the benefits resulting from good solid waste management, and positive news items such as the purchase of new equipment, the achievement of targets, the extension or improvement of services, as well as news about distinguished visitors, awards and promotions.

There are many ways of communicating with the public, including:

- Public open meetings, at which relevant issues are presented and there is ample time for the citizens to raise issues and ask questions.
- News releases in the media, including social networking media if appropriate.
- Leaflets and small booklets, with information and pictures, and a telephone number to contact for more information. Technical drawings should generally not be used since most of the public may not be able to understand them. The contents of printed materials should be tested on a sample of the general public before final editing and mass printing to ensure that the messages are communicated clearly and without causing confusion or misunderstanding.
- Visits to schools
- Participation in fairs and exhibitions.
- Site visits. Site visits could be offered to schoolchildren and other members of the general public, so that they can see the work and facilities involved in local solid waste management. If well run, such site visits can be a very useful means of developing helpful links with the public and fostering popular support. They also encourage the maintenance of good operating standards. Some landfill sites have viewing platforms and training rooms so that students and other citizens can learn about what happens to the waste they generate. Such visits may also help to motivate citizens to become more involved in the recycling of their waste.
- Advertisements in papers and magazines and on hoardings and signboards.

B6.3.2 Encouraging public participation

An important aspect of waste management, for which widespread public participation is essential, is at-source segregation, both in the home and in businesses. Some cultures have a tradition of segregating their waste so that they can sell or reuse as much as possible, and some people are reluctant to discard something if there is a possibility that it might have a use. Others, however, are content to discard freely with no thought of reclaiming any value or minimising the amount of material that is discarded.

Changes in attitudes and practices generally take time to achieve. Apart from the need to convince citizens of the value of the requested change in behaviour, there is also the need to show them how the change can be achieved in their own home, shop or office.

In cities and larger towns it may be appropriate to focus on one part of the urban area for the initial campaign for encouraging participation. This part of the city may be

selected on the basis of its socio-economic profile or on the basis of the results of a city-wide questionnaire survey. Visits to homes and schools, as well as public meetings, can be concentrated in one area for maximum impact. When the required behaviour change – usually at-source segregation – has been largely achieved, interviews with enthusiastic residents can be broadcast on television and radio and featured in printed media. Comments from residents can be used to encourage participation in other areas and explain to others how the segregation can be achieved by means of two or more bins in the home. Feedback on results, such as the tonnage of waste recycled or the reduction in quantities of waste going to the landfill, should be provided to the public to encourage continuation. Competition between different parts of the city or between different schools can provide additional interest and encouragement.

Visits to schools can be an effective way of introducing change because when the children are convinced they can encourage their parents to participate. It is useful not only to provide information but also to start campaigns within the schools for collection of items that can be reused or recycled [Obarcanin, 2008], taking care to select items, such as plastic bottles, that do not present a significant risk of causing injury or infection to the schoolchildren. Animal characters that are somehow linked to resource management are sometimes used in cartoons or by means of costumes to remind children especially of the campaign.

B7 Human Resources

Whilst there are many approaches to the management and motivation of professional and middle-management staff, two extremes can be characterised as follows:

- The *master-slave* relationship: Subordinate staff are given instructions and moved from post to post by managers who neither listen to, nor take into account, their juniors' viewpoints, insights, wishes and concerns. The objective is to control the junior professionals and middle management. It is unlikely that this approach will make use of the full potential of the subordinate staff, who will probably be concerned to avoid taking risks of any kind. Improvements in the performance of the organisation are unlikely.
- The listening and explaining manager: The objective here is development rather than control. The superior officer takes time to listen to the concerns and ideas of the subordinate officers, and keeps the subordinates informed about developments in the organisation that might affect them. The manager is concerned to develop the potential of each subordinate by giving them increasing responsibility, but under supervision. Such a manager realises the value of career prospects and opportunities of promotion or job enhancement. This model of human resources management is likely to lead to higher degrees of motivation and loyalty, and improvements in the performance of the organisation.

The issue of the status and public image of professional staff working in waste treatment and disposal has already been mentioned in Section A5.1.2. In order to improve the status of waste management staff, the job title of the manager of a treatment or disposal facility should be given careful consideration, taking into account the

suggestions of the individual concerned. The names given to the facilities should also be selected with care, so that it is clear to all concerned that the facilities are not open dumps – unless, of course, that is what they are! Waste management professionals should be given every encouragement to develop their interest and skills in their work, by providing opportunities for them to upgrade their knowledge and understanding and offering interesting career prospects. Too often, municipal engineers are moved from one department to another at short or unpredictable intervals so that there is little motivation for personal development related to the current responsibility.

Training courses are often seen as the main way of developing the abilities of technical staff, but courses in solid waste management are not widely available. Many courses in solid waste management are designed for students from industrialised countries. If a course is recommending solutions and approaches that are not suitable in the country that the student comes from, the training could do more harm than good by persuading the student that problems can only be solved in the ways that have been effective in prosperous, industrialised countries. (The reasons why different solutions are required in different locations have been discussed in Section A6).

Relevant training that involves gaining experience and growing in confidence is an essential requirement for improved performance, and it can be cost-effective in the medium and long term. Consideration should be given to co-ordination of training at the national level, so that relevant training courses can be provided. Support from central government could enable national experts to travel so that they can provide guidance and mentoring to landfill managers, and suggest solutions to operational and design problems. More on capacity building can be found in [Coad, 2011].

Long-term mentoring support from experienced practitioners can be very beneficial for local managers, heads of maintenance, laboratory technicians and inspectors. Whenever possible, more than one person should be trained for each position to provide continuity in case any staff move to the private sector or another job, or retire. If the movement of trained staff to the private sector is proving to be a problem, ways should be found to make remaining with local government more attractive – higher salaries or better working conditions can certainly be cost-efficient if they are effective in retaining staff who are performing well.

Managers are urged to discuss with technical staff the problems that they face in gaining access to information and opinions, and to take steps to make information and experience more widely available.

B8 Partnerships

Effective partnerships can be of great benefit in waste recycling and disposal. In this Section partnerships between the public and private sector, between neighbouring public sector bodies and across international boundaries will be discussed.

B8.1 Links with the informal sector.

Links with the informal sector have already been discussed in Sections B2.5 and B4.10. In this Section, partnerships are considered to mean formal, legal arrangements that are defined by contracts or agreements. Since, by definition, informal sector enterprises are not legal entities, government agencies are usually not entitled to sign binding contracts or agreements with them.

Whilst in many countries the informal sector is taking the lead in recycling, there is no obvious role for the informal sector in the treatment and disposal of waste. Waste treatment and disposal facilities must normally operate on a large scale to be economically viable, and large-scale operations need costly measures to minimise pollution. Treatment processes that aim to reduce the environmental impact of disposal operations must also be carried out on a scale commensurate with the landfilling operation. (Biogas or anaerobic digestion plants can operate successfully on a small scale and are the exception to the requirement that energy-recovery plants must be large. Consequently small biogas plants are generally not implemented in partnership with the public sector.)

Waste treatment and disposal by the private sector requires government clients (which must retain overall responsibility for waste management) to establish formal relationships by means of contracts or agreements with registered entities. The construction of treatment and disposal facilities requires considerable investment. Because of the possibility that serious environmental damage could be caused by poorly-run operations, there is the need for clear definition of responsibility in case it is necessary to impose penalties or take legal action. Finance must also be available to remedy any pollution incidents. Treatment and disposal involve a long-term commitment and access to large amounts of capital, as well as the arranging of adequate insurance cover. Any service provider interested in entering the field of waste treatment and disposal is normally required to provide documentary and verifiable evidence of relevant experience. For all these reasons the informal sector is not able to undertake treatment and disposal operations. Therefore, the discussion of private sector involvement in treatment and disposal in the next Section is concerned only with the formal private sector.

B8.2 Private sector involvement

For more than two decades, international development agencies have been promoting the involvement of private companies in the provision of public services, including water supply, public transport, electricity distribution and solid waste management. Each type of public service has its own particular features, and experience in one service does not necessarily transfer usefully to another. A key feature of waste management is that it is largely a *public good* (benefitting the whole population in a general way) rather than a *private good* (such as water supply or public transport for which individuals pay the supplier to satisfy their own personal needs).

In a country where waste disposal standards are low, the private sector may be invited to participate in order to provide expertise that is not available within the public sector.

In other situations private sector involvement may be of interest in order to reduce costs or to enable more effective monitoring of disposal standards (since operational standards can be defined in the contract or agreement and – if there is no corruption – monitoring of an external organisation is likely to be more objective than the monitoring of work done by colleagues within the public sector). Private sector operation may also offer more stability in a situation where there is a high turnover of senior municipal staff. In some cases it may be possible to ensure that regular financial allocations are made to pay an external supplier whereas it would be more difficult for a local government agency to ensure that sufficient funds are made available for in-house operation and large capital investments.

a) Wide range of options

There are many ways in which the private sector may be involved in solid waste treatment and disposal. Consultants provide advisory, design, monitoring and training services. Private sector service providers might provide the management skills for day-to-day operation under a *management contract*, or provide all the resources needed for operation as they deliver a service under a *service contract*. For the construction and operation of a facility such as a treatment plant or a landfill, a private sector company might sign a lease or concession agreement for designing, constructing and operating the facility, and, at some stage, transferring the ownership of the property to the public sector client. Private enterprises may establish and operate landfills as private initiatives, perhaps in competition with other companies. Contracts and agreements could be in connection with only one aspect of solid waste management (such as disposal), or for any combination of stages from provision of storage containers to disposal. Other aspects such as vehicle maintenance or fee collection might be involved. The contract or agreement might be limited to municipal solid waste, or it may include other types of waste such as industrial wastes or healthcare wastes. There is a very wide range of possible options, so it is important to consider carefully each aspect of any proposal for private sector involvement so that the arrangements are beneficial to the local government client and attractive to private sector bidders. Some service providers may not wish to limit their work only to disposal because they would expect to make most of their profit from collection of waste. Cointreau-Levine [2000] provides very useful information about private sector participation.

b) Preparation for involving the private sector

Kirke (1991) has suggested that local government bodies should have the capacity to provide the particular service themselves before considering whether to request proposals for the private sector to provide a service. At first this may seem surprising, but further consideration shows the convincing logic behind this statement. If a public body does not know how to provide a service (such as constructing and operating a landfill) it is not able to define the requirements effectively in the contract documents, assess what is a fair price for the work or monitor the on-going provision of the service in an effective way. It appears that many contracts for solid waste management services are seriously inadequate. There are examples of inspectors who are not capable of adequately monitoring disposal operations. These observations support Kirke's statement regarding the importance of public sector capacity. What can local

administrations do if they do not have the capacity to operate disposal sites themselves and do not have the capacity to engage a private sector operator?

A partial solution to this dilemma is to engage an experienced consultant who has experience of achieving satisfactory landfilling standards in similar conditions, as well as successful experience of private sector operation of landfills. There could be various objectives for such a consultancy, including

- to propose contractual arrangements,
- to write tender documents and contracts,
- to train public sector staff to monitor the private sector operator,
- to supervise and approve the construction of the landfill site and
- to assist the public body to monitor the work of the private sector service provider for a defined period – perhaps one year.

In some cases international donors are prepared to finance this kind of support.

Some potential private sector partners do not wish to become involved in the acquisition of a landfill site, because of the uncertainty regarding how long the process of acquisition will take and because the process often depends on local politics. Firms that assist with site selection may wish to keep the contract for this work separate from the agreement for the construction of the site, because of the uncertainly regarding timing and the risks of starting design work before all aspects of site selection have been finalised.

A well-written contract has, among others, the following features:

- It defines the work to be done in a precise way and so prevents misunderstandings and conflicts regarding the duties of the contractor and the responsibilities of the client;
- It awards payment to the service provider according to actual performance. For instance, if recycling and treatment plants are not operating at the desired diversion or production rates, the payment due to the operator should be reduced, at least proportionately, provided that a sufficient input of waste is available.
- It allocates the risks between client and contractor in a reasonable way. (If all the risks are borne by the contractor, the contract price is likely to be higher than if the risks are shared, or there is an increased possibility that the contractor will default.)
- If defines the penalties and additional payments that may be imposed as a consequence of inadequate performance in a precise and objective way so that the consequences of shortcomings are clear and not the subject of disputes.
- The terms of the contract are based on reliable data.
- The requirements of the contract do not impede the development of initiatives that encourage reduction, reuse and recycling of waste.
- In the case of sanitary landfills, emissions (of leachate and gas) and settlement continue after landfilling ceases and the site has been closed, so the responsibility for monitoring the site and correcting any problems during this post-closure stage (which may last 20 to 30 years, as discussed in Section C4.6) should be defined. If private sector landfill operators are involved, it is important to consider at the tendering stage what arrangements will be made for ensuring aftercare for the site.

Potential private sector service providers may be reluctant to commit themselves to such a long-term and open-ended responsibility, or may charge heavily for accepting this risk. A bond may be required, but the length of time from the start of operation until the end of the aftercare period, coupled with inflation and financial uncertainties, may make the posting of such a bond ineffective as well as a major deterrent for potential private sector partners. Some form of insurance policy may be an alternative. In the end, the public sector client may take on this risk, even if it is questionable whether there is a way of compelling the client agency to take this responsibility seriously.

Contracts for the treatment of waste may set limits for the range of composition or characteristics of the waste. Contracts that specify the composition of the waste should be very carefully reviewed because they may cause many disputes and extra costs because of the difficulty of assessing the composition accurately, and because the composition varies with season and according to the quantities of recyclables that are removed before the waste reaches the treatment plant.

Proposals to introduce private sector provision of public services often attract political or ideological opposition which may focus on the anticipated redundancies of local government labourers. In the case of waste disposal this may not be so much of a problem because the number of staff involved is small (in comparison with the waste collection service), and citizens are less aware of waste disposal compared to other public services. Opposition may be based on the concern that increased fees paid by poor residents will be used to make the owners of large contracting companies unreasonably wealthy, so it is necessary to inform the public about the measures that have been taken to ensure good value for money. Transparency helps to allay fears of corruption.

The beginning of the involvement of the private sector may be used as an opportunity to introduce other changes, such as measures that favour recycling, changes in the waste collection system or the introduction of a direct charge for solid waste management (to be paid by each household and business). It is also an opportunity for raising public awareness regarding hygiene, the environment and solid waste management.

c) Potential private sector providers

Promoters of systems for processing and treating waste are usually very active in making contact with municipal administrations in developing countries and preparing proposals. It is often more difficult to make contact with companies that are able and willing to construct and operate landfills, particularly if there is a preference for companies based within the nation. If there are no landfills of the desired standard within the nation or region, there may be no national engineer with the required professional experience. (The experience that is required should go beyond the academic knowledge to include experience of supervising the construction and of actual operation.) If this is the case it is necessary to look abroad for construction firms that can build landfills, though this may result in considerably higher fees and language problems. Partnerships between local and international firms are discussed in Section B8.4 below.

The competence of any private sector operator should be carefully checked. Even if the company has significant collective experience, the individuals designated for designing or operating a particular site may not have the experience that is promised in the tender bid. The field experience of leading staff should be verified and substitution of staff after the award of the work should only be allowed with the agreement of the client.

If more than one contractual partner is responsible for the design, construction and operation stages, it may be very difficult to allocate liability for any shortcomings that become apparent during the operation phase. The designer may blame poor construction or materials, the constructor may say that the problems were caused by an unsatisfactory design or poor operation, and so on. Such disputes can be avoided if one organisation is responsible for all aspects.

d) Financial considerations

When evaluating tenders, the responsible public sector body needs to know what price range is reasonable. Low prices for the work may indicate that the particular bidder has little experience and does not understand what the work involves. There may be few bidders for the work, making the risk of price fixing higher than if there is considerable competition. Each landfill site is different so the assessment of an experienced consultant may be needed to determine reasonable costs for construction and operation.

If the private sector service provider is expected to finance its landfilling activities from gate fees charged to incoming trucks, increases in gate fees may encourage drivers to unload their waste elsewhere at unauthorised locations, in order to avoid paying the gate fee at the official landfill. Not only would this cause financial difficulties for the landfill operator, but it would also cause widespread environmental pollution and heavy remediation costs.

If a contractor who is collecting waste and operating a disposal site is paid by the client according to the tonnage of waste received, there are incentives to maximise the quantity of waste to be landfilled, rather than to minimise it. Not only does this arrangement discourage reduction, reuse and recycling, but it also encourages the contractor to increase the tonnage figure for each month by collecting soil and rocks and additional dense wastes, or by falsifying the weighbridge data. (One operator was seen to add water to loads of solid waste before they were weighed at the landfill, in order to increase the weight.) The best way to minimise such fraud is to have accurate data on waste quantities (from before the start of the contract) and effective inspection and monitoring.

If the service provider is to be paid by the client, it is important that payments are made on time (and that the client pays a penalty if payment is delayed) and that any penalty deductions are made in a transparent way and strictly in accordance with conditions found in the contract or agreement.

e) Key points

- There is a wide range of possible arrangements so decisions about the nature of the partnership with the private sector should be considered carefully.

- Many waste management contracts are seriously inadequate and so it is recommended that experienced consultants are engaged to assist in developing contract documents.
- Inspectors must be well trained and closely supervised.

B8.3 Inter-municipality partnerships

This section is about partnerships between neighbouring cities. Such partnerships are also called *intercommunal*. They may involve only two communities, or as many as 20. Examples of inter-municipality partnerships is given in Box B8.1 The discussion here concerns mainly landfills that receive the waste from several cities, but such partnerships could also be used for collection, recycling and treatment operations. Landfills that are used by several towns and cities are often called regional landfills, but because a region is often understood to mean a group of nations, the term *district landfills* will be used here in connection with this type of partnership.

Box B8.1 Examples of inter-municipality partnerships

a) Eleven communities share one landfill

- Until the 1990s, eleven towns and villages in the middle area of the Gaza Strip each had their own dumping sites, which were all unplanned and very unsatisfactory. When a new landfill was proposed for this area, these communities were persuaded to close their dumps and form a joint Council in the form of an autonomous, commercialised public utility which would provide secondary collection and disposal services to all eleven communities. The constitution of the Council was developed using the experience both of bodies working in other sectors in the Palestinian Territories and of waste management utilities in Germany. The operations of the Council are supervised by a board consisting of the mayors of each community. Each community is responsible for collecting revenue and paying the Council according to the quantities of waste collected and disposed of. More information has been provided by Scheu and Borno [2000].

b) Co-operating communities in Chile

- Sixteen communes in Santiago joined together informally for the purpose of waste disposal. The construction and operation of a district landfill was granted as a concession, and each of the mayors involved signed a concession agreement with the concessionaire. The administrative expenses and duties of the association were the responsibility of each member in turn.
- In another association in Chile, comprising eleven municipalities, the concession for waste disposal was signed only by the leading organisation, which was the largest municipality in the group. [Coad, 2005]

The organisational and administrative arrangements for such partnerships need careful consideration. Sometimes the municipality with the largest population takes responsibility for administration and finance, but in other cases all the partners have more or less an equal status. The district landfill may be operated by one of the

partners, by an autonomous public sector body established for this purpose, or by a private sector company.

B8.3.1 Reasons for sharing disposal facilities

a) Economies of scale

A major investment is required to establish a sanitary landfill. Disposal facilities of this type demonstrate considerable economies of scale – that is, the cost of disposing of one tonne of solid waste is generally less in larger landfills than in small ones. This is because some costs (such as the reception area and weighbridge) are similar whatever the size of the site, so dividing these costs by a greater tonnage results in a lower cost per tonne. Large sites can often accommodate greater heights of waste, so the cost of constructing one square metre of impermeable base lining is divided by the greater volume of waste that can be deposited above it, resulting in a lower cost per tonne. Since the ratio of perimeter to surface area is lower for a large site, the proportional spending on perimeter fencing and buffer zones is less for a large site.

Equipment (such as bulldozers and other specialised plant) can be used more intensively on a large site, and the greater workload allows specialised machines to be employed on larger sites. The use of specialised machines allows greater efficiency. For example, a small site might be operated by a small tracked vehicle with a combination bucket that allows it to bulldoze waste and spread cover soil, but it does not compact the waste very significantly and moves slowly.. A large site might have a landfill compactor that compacts the waste to a higher density, a bulldozer for earthmoving and a wheeled loader that can load and distribute cover material very efficiently.

There are other factors that also contribute to the general trend that larger landfills are cheaper to construct and operate on a per tonne basis. It follows that cost saving is one reason why neighbouring urban communities should share one large disposal site rather than each having a small site of their own. Box B8.2 shows how the numbers of waste disposal sites in the USA decreased, as increasing numbers of towns and cities opted for the financial and environmental benefits of district landfills.

Box B8.2 Experience of reducing the number of sites in USA

In 1978 USEPA's national open dump survey showed more than 8500 dumps in the USA, each usually serving only one town or city. This was when the Environmental Protection Agency ordered the closure of open dumps.

By 2002, the number of disposal sites had dropped to 1767.

By 2007, 200 of the nation's sanitary landfills were receiving 75% of the nation's solid waste, and the biggest 250 sanitary landfills were large enough to take all the waste of the USA. (Bhatnagar and Vasuki, 2007)

b) Selecting a site

It has already been stated that finding a suitable site for a landfill and obtaining agreement for it to be used for this purpose is often a very challenging task. It is likely to be easier to acquire one site than to acquire many. In intensively developed urban

areas there may be no available space for a landfill within the boundaries of the jurisdiction of a large municipal authority. For these reasons it may often be necessary or advantageous to form an alliance with neighbouring administrations in order to find a site that is suitable and acceptable.

c) Experienced management

The management of disposal operations requires skill and experience. No particular skills are needed for supervising an open dump, but as disposal standards are improved the need for well-trained and capable managers becomes critical to success. It is easier to find one effective site manager for one large site than to find several effective site managers for several small sites.

B8.3.2 Challenges facing inter-municipal partnerships

a) Continuity

Changes in political leadership of the participating communities may threaten the cohesion of such partnerships. The leader of one of the communities may believe that a satisfactory disposal service can be provided by the municipality alone at a lower cost (perhaps by disposing of waste in an open dump with no environmental controls) and therefore wish to withdraw from the collective operation. Reverting to small, polluting dumps can be prevented by robust enforcement of environmental standards.

It has been suggested that municipal administrations might be reluctant to relinquish control of waste disposal, but since waste disposal is such a low priority for many cities, this will probably not be a major challenge. There may be a greater reluctance to lose control of the land that is selected for a district landfill.

There is also the risk that some mayors may not wish to work with mayors of other communities for political or personal reasons.

The failure to honour financial commitments to the partnership adds strain to the relationship, and procedures must the agreed for dealing with any member administration which does not contribute its share.

b) Perceptions of fairness

Residents of the community which has the disposal site within its boundaries may resent the fact that waste from other towns and cities is being deposited on their land. For this reason some schemes pay a *host fee* in the form of a regular payment to the community where the disposal site is located to compensate for the inconvenience or perceived insult of receiving the waste of others.

Small communities may consider that they are paying charges that are too high for transport of the waste, and so in some cases it may be decided to cross-subsidise the smaller partners.

c) Transport costs

When selecting the disposal site and considering which communities should be included in the partnership, it is important to include in the feasibility study the costs of transporting the waste to the disposal site. Towns that have been using low-cost means of transportation (such as carts pulled by animals) to carry their waste to a nearby

dumpsite may be reluctant to pay the extra costs of transporting waste a much longer distance to a district landfill. (In such cases it should be pointed out that the costs of upgrading the local waste disposal site to meet the required standards could be much more.) There may be benefits in including the transporting of waste from small communities, or from all, within the activities of the partnership, in order to minimise transport costs. Transfer stations may be needed.

d) External initiatives

If one member of an inter-municipality partnership receives financial assistance or equipment from a donor or other external source, it might wish to leave the partnership in order to operate alone. This might happen if vehicles or a composting plant are provided. (If a composting plant is set up, there would still be significant quantities of residues requiring disposal, but if there is no control over disposal standards, the city concerned might use the new plant as an excuse for reverting to unplanned dumping.) It would be preferable for any such donations to be redirected from the individual partner to the collective partnership.

B8.3.3 Key points

- There are compelling technical and financial reasons for towns and cities that are close together to consider sharing one landfill.
- The institutional arrangements for such partnerships must be carefully developed, so that they can survive through challenges and changes.

B8.4 International links

B8.4.1 International partnerships involving the public sector

It is understandable that municipal and government officials in low- and middle-income countries should seek financial and technical assistance from nations that are more prosperous and have a more modern waste management sector. Financial support is usually provided in the form of equipment that is considered by the sending nation to be necessary or beneficial, or as advice regarding how to improve operations. Unfortunately, in some cases, such assistance can bring more problems than benefits, as will be discussed below.

In Section A6 some of the differences in the solid waste management conditions and needs between different countries have been listed. Because of these differences, methods and equipment that are successful in one country may fail completely in another. If the administrators and consultants who are deciding on the nature of the assistance are not aware of the impacts of these differences, the advice or equipment that is given may take waste management in the receiving country in the wrong direction. Unwise decisions may be made by officials of the receiving country, as well as by those working with the donor. This can happen in many ways.

- Unsuitable equipment may be supplied for the following reasons:
  - Equipment may be selected according to what is used in the donor country. This equipment may not be useful in the receiving country because of differences in the nature of the waste, or other differences as listed in Section

A6. It may be that the equipment cannot be maintained satisfactorily in the receiving country because spare parts or the necessary skills, tools or facilities are not available.

- Normal procurement processes may be by-passed in the case of development aid so that officials in the receiving country are free to request and obtain equipment that is not effective, and that would have been rejected if the normal tendering and selection processes had been followed. This is illustrated by the case described in Box B8.3.

Box B8.3 Another useless bulldozer

A particular make and model of bulldozer had been supplied to a large landfill. Unfortunately this machine was not able to work effectively on the site because it was not sufficiently powerful and so was overheating. (A bulldozer working on a landfill site needs more power than one working on road construction or general earthmoving.) As a result this machine was rarely used. The records for the landfill showed that two bulldozers were available at the site so no other could be purchased from local funds. Later a donor offered more financial assistance. In response the senior official in charge requested another bulldozer of the same specification as the unsatisfactory machine that was already on the site, but not being used. It is likely that the selection of the machine was not made according to the normal procedure, and no technical advice was sought. It may be relevant to mention that the new bulldozer was supplied through the dealership that was owned by the official who selected it. If the site manager had complained about this decision, he would have run the risk of being accused of not being able to operate the landfill properly. Fortunately, in this case he is able to hire a useful bulldozer at least some of the time.

- Senior politicians and officials are invited to visit a donor country, and, while they are there, they are shown the best examples of that country's waste management technology. They are naturally impressed by the technology and by the sophistication and effectiveness of the aspects of waste management that they are shown. Without consideration of the international differences, financial aspects and necessary enforcement mechanisms, and without consulting technical experts in their own countries, they decide to order the advanced technology that they have seen, thinking that this will transform the appearance of their city or nation, and solve all their waste management problems. Unfortunately the equipment, when purchased and installed, does not perform as expected, because it is not suited to the particular local conditions. There are monuments that tell this unfortunate story all over the developing world – incinerators, composting plants and anaerobic digestion plants that are operating at a fraction of their design outputs – or not operating at all.

- Training may give the wrong messages. It can be argued that the gaps between the best and worst examples of solid waste and resource management are growing

wider. Legislation, financial instruments and public demand are causing rapid development of waste management in some European countries, whereas waste collection and disposal in some of the poorer countries show little sign of improvement (partly because of the increasing demands of rapidly growing urban areas). It is therefore necessary that the training that is provided to waste management professionals is suited to the conditions that the trainee will work in. There are some courses in industrialised countries that teach the importance of considering the international differences and approaches that take account of local conditions and potentials, but many of the courses that are available are designed for the most advanced situations. Financial assistance may be provided for engineers and managers from developing countries to attend these courses with no consideration of the relevance and usefulness of the subject matter. University teachers in developing countries may teach the same material that they received when they were students in industrialised countries, out of concern that anything else would not be academically respectable. Fortunately there have been some excellent new initiatives in training, such as a World Bank program in Africa [Ball and Cisse, 2008].

In many situations knowledge from the classroom is not enough – there is also a need for building confidence so that young professionals can effectively argue their case against enthusiastic foreign salesman and arrogant consultants who advocate measures that are not appropriate.

- Undermining agreed national strategies. Donors and consultants should respect strategies that have been developed to guide the upgrading of waste management standards. For example, if a national strategy states that recycling should be left for the informal sector and that public investment should focus on progressive upgrading of waste disposal standards, it would be unhelpful for a donor to provide a large recycling or treatment plant or insist that any landfill that the donor helps to fund should be constructed according to the best standards found in Europe. Donor contributions should be in accordance with the agreed national policy and strategy. Most donor initiatives involve a national contribution, and recycling and treatment plants tend to draw the best waste management experts away from the less glamorous work that is required by the national strategy. Even if sophisticated equipment is provided by means of a grant rather than a loan, precious local resources will be taken from the work of implementing the national strategy.

There can be real benefits from partnerships between developing countries and industrialised countries, if partners from the former can maintain their focus on realistic targets and partners from the latter can listen to local experts and go back to first principles rather than assuming that they have all the answers. Good relationships take time to develop, and the timescale for many donor-led projects seems to be too short. Good relationships are characterised by mutual respect, listening and learning. The twinning of a city in the North with a city in the South can last for many years and be beneficial to both sides, provided that both parties are well prepared. The Government of the Netherlands has set up a programme to improve the effectiveness of twinning arrangements; it is described by Scheinberg [2008].

Sometimes the most effective input from a consultant may be to tell senior managers what the local technical staff already know but are not allowed to say. Perhaps some kinds of advice and recommendations are not accepted or believed unless they come from an expensive foreign consultant.

B8.4.2 International partnerships between private companies

In countries where local engineering and project management firms have no experience of the required level of waste disposal technology and management, the best way of providing the required services, transferring technology and building the capacity of local firms is often to engage a consortium that involves at least one local firm and one international firm with the required experience. The local partner can provide important local information and be the interface with the client organisation, as well as collecting data and undertaking general engineering work. The international partner can undertake much of the site investigation, design work and construction management, and provide intermittent support of operations. One of the objectives of the partnership should be to upgrade the technical skills of the local partner.

Many international waste management construction companies and service providers would maintain high professional and engineering standards because they are concerned for their reputation, but it is likely that there are some which would give low priority to such work, assign less competent staff and seek to cut corners to maximise their profits. Therefore an independent and experienced consultant should be engaged to review designs and supervise construction. In particular, construction of the impermeable base and drainage system of a sanitary landfill must be of a high standard, so careful site supervision is required.

The requirements for a successful working relationship include:

- Clear definition of the responsibilities of each partner and the products that each is responsible for;
- Good relationships between individuals and a level of trust that leads to transparency and full and open communication between the partners
- Both partners having the goal of developing a long-term relationship that outlasts the current job.

B8.4.3 Key points

- Assistance from donors and lending agencies can have unforeseen negative consequences if it is not based on an understanding of the local situation.
- Training should equip young professionals for the situations in which they are working.
- Relationships that extend over a long period can be much more effective than short-term inputs.

B9 Important general conclusions

Social scientists and engineers should work closely together to develop sustainable approaches to the challenges posed by solid waste management in low- and middle-

income countries. Solid waste management is a complex sphere of activity; it is not purely technical in scope, neither is it purely social.

From one country to another, and even between cities and regions within one country, there are many important differences in factors that affect the sustainability of approaches to solid waste management. Measures that are effective in one country should not be attempted in a different socio-economic setting without careful investigation and well-designed pilot trials.

Recycling and waste disposal are not alternatives. The benefits of recycling are great, though they differ according to socio-economic factors. Even when there are successful and extensive recycling projects, there are still residues (that cannot be recycled) that should be disposed of in an environmentally acceptable way.

The minimisation of waste quantities is an important goal, but it requires changes in habits, customs, work practices, manufacturing, infrastructure and other aspects of daily life. Plans for waste disposal should be based on existing waste quantities and trends rather than on hopes and wished-for reductions in waste quantities.

The component in municipal solid waste that causes the most pollution is the biodegradable organic fraction, which is the largest proportion of domestic waste in many countries. The main constituent of this organic fraction is usually food and garden waste. Composting appears to be the ideal way of managing this organic waste, but the experience of large-scale composting plants has generally been very disappointing. It is important to learn from these experiences, to have realistic expectations, to develop a strong marketing approach and to work closely with the agricultural sector, in order to have a brighter future for this ecologically ideal method of managing biodegradable waste.

Unplanned, open dumping causes serious environmental damage. Sanitary landfilling is effective in minimising the environmental pollution associated with waste disposal. In industrialised countries the transition from open dumping to sanitary landfilling has taken many decades, and has required not only financial resources and technical innovation, but also the development of new institutional structures and considerable capacity building. It is reasonable to expect that the process of upgrading disposal standards in developing countries will take time. Lending agencies and environmental authorities should accept this fact and support incremental upgrading. National policies should set targets for stepwise improvements rather than expecting that the highest disposal standards can be achieved in one giant leap.

Waste disposal needs enthusiastic, trained, confident and motivated waste managers. A new approach is needed to capacity building, especially with regard to the development of successful landfill managers. Training courses are not enough – there is a need for operational experience, increased organisational responsibility and well-conceived career paths. Mechanisms are needed for the open and honest sharing of experience, of failures and disappointments as well as of successes.

In many cities there is no motivation for improving standards of waste disposal. In some cases there are relevant laws, but the enforcing agencies are weak and inspectors are untrained and inadequately supported by superiors and the public.

The involvement of the private sector is not necessarily a cure for these ills. In many cases local government authorities are not able to engage and manage contractors in an effective way. Satisfactory operational standards may not be achieved without effective monitoring by trained and motivated inspectors - operators cannot be expected to police themselves. Unrealistically low prices, overzealous imposition of penalties or delayed payments often lead to difficult relationships and cancelled contracts. Private sector involvement can be the best way to improve standards, but success cannot always be guaranteed.

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PART C SELECTED TECHNICAL INFORMATION

C1 Data collection and utilisation

Data on various aspects of solid waste management may be required for a range of purposes. The effort needed to collect data of the required quality, as well as the parameters to be measured, depend on the purpose to which the data will be put. Before a data collection exercise is designed, it is important to define the way in which the data will be used so that the data reflect the most relevant aspects and are in the most suitable form. Some of the reasons for collecting data are listed below:

- For selecting the most appropriate recycling and treatment options;
- For determining the required capacities for treatment and disposal facilities, and for estimating site life of landfills;
- For designing installations and planning their use and replacement;
- For setting targets (such as the reduction of waste quantities) and measuring success in meeting these targets,
- For setting benchmarks for performance and cost, and for comparison with benchmarks to indicate where to focus efforts to improve performance or reduce costs.

C1.1 Waste composition studies

It is very common for waste management studies to involve an extensive survey to determine the composition of the waste – the percentage by weight of various categories of the many materials in the waste. In many cases the results are hardly used. If accurate data are required, this can involve a large amount of work, so before initiating a programme of studies to determine waste compositions it is important to assess the degree of reliability and level of detail that are actually required.

It is also important to consider the use to which the information will be put, because this will determine how the study will be executed. The purpose of the study will determine at which point the waste should be sampled (for example at the household or after waste pickers have removed items that they can sell) and the required level of reliability. These aspects, together with other points to consider when planning a composition study, are discussed in the following Section.

C1.1.1 Planning a composition study

If it is considered necessary to determine the composition of the waste, there are a number of factors to consider when planning the investigation. Among them are the following:

- The purpose of the study: It is important to consider the use to which the data will be put, because this will determine when and how the samples should be collected for analysis. The purpose of the study also determines the categories into which the

waste must be sorted. For example, for investigations relating to recycling it might be appropriate to have eight or more categories of plastic, whereas for other studies one category for all types and forms of plastic would be sufficient. The purpose of the study might also influence the degree of accuracy required.

- The point of sampling: The purpose of the composition study will determine at which point the samples of solid waste should be taken. In many cases it is necessary to make allowance for the recovery of material by waste pickers and the grazing of animals. Since the removal of selected materials can occur at several points along the waste management chain (from generation to disposal), the point at which samples are taken should be carefully chosen, so that the results suit the purpose. For example, if it is planned to establish a materials recovery facility at a landfill, the samples that are analysed should be taken from trucks arriving at the landfill, not directly from households and businesses.
- The time of year: Since the waste is being sampled for short periods rather than continuously, the times for undertaking the sampling exercise must be selected so that they represent the various seasons and weather conditions of the year. Consideration should be given to seasonal effects such as the weather, the availability and consumption of fruits and vegetables, school holidays, public holidays and festivals, and seasonal waste from gardens and trees. These factors may also influence the number of times in the year when samples are taken for analysis.
- The sources of the samples: The solid waste arising in a town or city comes from a variety of generators. If it is decided to determine the composition of the waste as it is initially discarded (before any recycling by others), to get an accurate picture of the waste from the whole community it is necessary to classify the sources and to determine the relative importance of each. Households may be classified according to size or socio-economic factors such as type of housing, location, household income and lifestyle. Allowance must be made for the various types and sizes of institutions, shops, offices and industries, as well as street and drain wastes. If the waste is to be sampled at another point, such as a transfer station or at the entrance to a disposal site, it will be necessary to select truckloads that, together, give a reasonable representation of the city as a whole.
- The method of collecting the samples: If waste is to be collected from the sources, a common method is to give plastic bags to each of the selected households each day for 8 days, and to analyse the contents for each day except the first. In some cases the contents of the bags may not be typical of a day's waste if residents are reluctant to put certain items in the bags because they know that the contents of the bags will be opened and studied by strangers. Alternatively, they may use the opportunity of a more convenient collection service to clean out the hen house or clean the yard. If the waste is normally collected by handcart it might be satisfactory to analyse the complete loads collected in selected handcarts. If samples are taken from truckloads it is unlikely that the whole load can be analysed, so a representative sample of the load must be prepared; this is commonly done by dividing the load into four, remixing it and dividing it again – a process known as

quartering. When his has been done several times, one of the quarters can be taken for analysis or further quartering.

It is strongly recommended that the advice of an expert in applied statistics is sought, for guidance in designing the sampling programme and for help in analysing and interpreting the results that are produced. Statistical considerations can indicate the level of confidence that can be placed in the results and whether observed trends are significant.

A common method for determining waste composition is provided in Appendix 2A of [Rushbrook and Pugh, 1999].

C1.1.2 Considerations for particular composition studies

a) Informal sector recycling

If the effects on the composition of the informal recycling system are being investigated, it may be necessary to first understand how the recycling system is structured and working, so that it is possible to forecast the impact of changes in the system on composition. It is usually misleading to assume that all of the recyclable material that is found in the samples would actually be of interest to waste pickers. If the material is dirty or joined with another material, it may be of no interest to experienced recycling workers. Some items made of recyclable material may be too small to be of value. If contaminants such as food waste are adhering to recyclable materials it may be necessary to clean off the contaminants before weighing in order to obtain the true weight of recyclable material.

a) Incineration

A good example of the need to consider the purpose of the study before starting to collect samples is provided by incineration. If incineration with heat recovery is being considered, it is essential to undertake a detailed study of the composition and moisture content of the waste as it would be received at the treatment unit, taking into consideration that informal waste picking might remove materials such as the paper and plastic that could provide most of the energy during combustion. There are well-documented cases of incinerators that have been used very little, if at all, because the waste material that was received had such a low energy value that unaffordable quantities of fuel were required to make it burn. Analyses of the waste must be performed several times during the year because rainfall or seasonal fruit (especially water melons) may add large quantities of moisture to the waste at certain times of the year. The moisture content of waste has a major influence on the energy that can be derived from the waste.

c) Composition and composting

One of the misconceptions discussed in Section A2 is that a high proportion of biodegradable matter in the waste indicates that composting is the best method of treating and disposing of the waste. Whilst there appears to be some logic in this conclusion, it has been found to be false time and time again. In most cases the factors that determine the success of large-scale composting operations are the demand for the product, the quality of the feedstock, and the ability of the operator to control the

microbiological processes and maintain the equipment. In many cases the demand for compost might be satisfied by the relatively small quantity of waste that is almost entirely biodegradable, such as wastes from restaurants, markets, parks and food processing industries. The much larger quantity of biodegradable waste in mixed municipal solid waste may be of no interest or no use because of its contamination with other wastes.

When undertaking a study of the feasibility of composting, it might be appropriate to limit the study of waste composition to waste from sources that generate very little waste that is not biodegradable, such as markets. These sources might provide enough biodegradable waste to satisfy the existing demand for compost. Alternatively, the biodegradable waste could be divided into two categories – one being biodegradable waste that can be collected separately from other wastes, and the other being biodegradable waste in mixed refuse that is thereby contaminated by other types of waste material and is thereby less suitable.

A common mistake is to classify fine material (that passes through a sieve or screen) as biodegradable; often it is largely inorganic.

d) At-source segregation

Successful programmes to promote at-source segregation do not usually achieve complete success overnight. It generally takes time for residents and employees to develop the habit of segregation and to understand the criteria to be used in segregating the waste. As with any programme, it is useful to be able to measure the level of achievement. One way of doing this is to ask citizens, using a scientifically designed social survey, about their attitudes to waste reduction and whether they are segregating their wastes. The results of such a survey could be linked with random sampling of waste that should have been segregated at source, and measuring the amount of waste that has been correctly segregated. The results may be different for different socio-economic groups.

e) Moisture content

Determinations of moisture content may be used to estimate the potential of the waste for producing leachate in a landfill as well as for determinations of energy value as mentioned in (b) above in connection with incineration. Moisture content is normally determined by drying representative samples of the waste in an oven at 105C. The size of the oven determines the maximum size of the sample. Estimates of composition are used to put together representative samples of appropriate size.

f) Alternatives to conventional investigations

Because of the large amount of work required to obtain reliable and precise composition data, it may be advisable to consider alternative ways of achieving the desired purpose. Examples are presented in Box C1.1.

Box C1.1 Examples of alternatives to extensive conventional studies to determine waste composition

If it is desired to estimate the potential reduction in waste quantities that can be achieved by recycling, it may be helpful to involve informal sector waste pickers and dealers in recyclables, since they know what kinds of objects and which materials can be sold for recycling. Instead of splitting the waste into the usual categories, wastes that are of no interest to recyclers could be considered as one category. The categories used by recyclers could be used in the analysis. Not all plastic items, for example, are suitable for recycling in particular locations. Some polymers (types of plastic) may not be suitable. Some forms, such as plastic film (whether contaminated or clean) may not be usable. It is also important to decide at which point the samples to be tested are taken – whether at the point of generation or after the waste has been partially picked over by waste collectors. The waste pickers engaged for the sorting could be paid for their work and allowed to keep material that they select, after it has been weighed. Operators of factories that recycle wastes and exporters of recyclable materials should also be involved in defining precisely the description of each category.

If it is desired to determine the potential leachate generation from a sample of waste, one option would be to determine the percentage of biodegradable material and the moisture content of the waste, and use factors developed from experience to estimate the volume of leachate that would be expected. Alternatively, it might be sufficient and less expensive to place representative samples of waste in tanks or vertical pipes and observe the quantities of liquid generated after some time as a result of anaerobic decomposition and applied pressure. (A practical experiment of this kind would also give some information about the characteristics of the leachate that would be produced during the early stages of landfill operation.)

C1.2 The density of the waste

As discussed by Coffey and Coad [2010], the density[21] of solid waste varies considerably (sometimes increasing and sometimes decreasing) from the time when it is discarded into a container until when it is fully decomposed in a landfill. Therefore, if it is desired to measure the density of the waste, the reason for requiring this information must be clear so that the measurement can be made at an appropriate point in the waste management chain. When measuring the volume of the waste, care must be taken neither to compact the waste artificially nor to increase its volume by entraining more air.

[21] It is the bulk density of the waste that is of interest (that is, the weight divided by the volume of the waste itself together with the volume of its interstitial spaces in the waste that are filled with air) The density is determined by weighing a known volume of the waste (usually in a drum or box having a volume of 200 to 500 litres), or the occupied volume in a container or truck body).

C1.3 The quantity of the waste

The amount of waste is clearly an important parameter in the design of treatment and disposal systems, as it is also for the design of the collection system.

Because the density of a sample of waste can vary considerably, and because of difficulties in making accurate estimates of the volume of irregular shapes of waste, the normal way to express the amount of waste is in terms of its weight.

The best way to measure and monitor the weight of waste that is received at a landfill or treatment plant is to install a weighbridge and ensure that every vehicle that is carrying waste is weighed full, so that, by subtracting its empty weight, the weight of waste received can be computed. If there is only one weighbridge at the treatment or disposal facility, it may not be possible to always weigh the vehicles as they leave the site without causing delays and congestion. However, all vehicles should be weighed empty from time to time, to minimise errors.

The times of arrival and weights of loaded vehicles should be entered into a database automatically, with minimum manual data entries. Often it may be necessary for the weighbridge clerk to enter the code number of the vehicle, the source of its load and the name of the driver, but transponders can be fitted to vehicles so that the weighbridge computer automatically records the code number of the vehicle. The three main reasons for favouring automatic recording of weights and times are (i) to avoid human error – misreading weights or times or omitting to record them, (ii) to prevent fraudulent entries that might be made for financial gain or to hide absenteeism, and (iii) to enter data in digital form immediately into a database so that it can be used to calculate totals, monitor vehicle utilisation and prepare invoices.

If a weighbridge is not available at the treatment or disposal facility, it may be possible to use a weighbridge belonging to a highways agency or local private company on an occasional or random basis. If they are available, portable truck scales (Photo C1.1) can be used to measure the weight on each axle separately. If the weighing is carried out by someone who understands the process, these sample weights can be used in the estimation of daily quantities.

The loads carried in collection trucks may vary significantly from day to day, so, if daily weighing is not practicable, the load brought to the disposal site each day can be estimated in the following way: When the loaded vehicle is weighed, the volume of waste in each vehicle (based on the dimensions of the load-carrying body and the degree to which it is filled) is estimated, and the weight and volume are used to estimate the density of the waste. When it is not possible to weigh the vehicles, the volume of each load can be assessed visually and multiplied by the appropriate density estimate to obtain an estimate of the weight of the load. (It is very important to note that the nominal carrying capacity or gross vehicle weight of a truck is not used to indicate the weight of the waste that it carries, since open trucks carrying waste generally carry a load significantly less than their rated payload capacity.) If a compactor truck is operated as intended – the ejector plate gradually being pushed forwards as the truck is loaded – an estimate of the load that it is carrying can be made by noting the position of the ejector plate.

Photo C1.1 Portable truck scales or weighing pads

Every disposal site should have some form of control at the entrance, even if a weighbridge is not installed. A small hut that provides a reasonable degree of shelter and comfort should be located at the entrance so that records can be kept of each vehicle entering the site, and loads can be checked to ensure that no prohibited waste is brought onto the site. The person at this gatehouse can also give instructions to new drivers.

C1.4 Financial data

Managers must have reliable financial data in order to make appropriate decisions about a range of aspects of waste management. Information on current expenditures and expected costs can provide justification for making improvements and changes to the balance of expenditures – for example spending more on maintenance may generate overall savings by reducing expenditure on new equipment. Spending more on salaries of key technical staff may reduce wastage. Good financial data can be used to determine target contract prices for private sector involvement and indicate whether contracting out is a beneficial option.

Unit costs – the expenditure for each tonne of waste or for each household served – are very useful for comparing methods and suggesting where efficiency improvements are needed. The calculation of unit costs should include capital costs, interest payments, salaries, overheads and other labour costs, fuel and maintenance costs, and all other operation costs. In many municipal authorities the various expenditures are scattered between departments and even between different levels of government. It is often the case that employment costs are in the budget of one department, fuel and maintenance are in another whilst some capital costs are paid by central government. To make rational decisions it is necessary to bring all these costs together when calculating unit costs and comparing alternatives. Senior technical staff should be encouraged to consider a range of alternatives and decide between satisfactory options using objective criteria.

Financial and economic data are needed for preparing feasibility studies, particularly when international lending agencies are involved and comparisons between alternatives must be made. Shadow pricing modifies financial data to take into account costs and

benefits in the way that is most appropriate to the needs and situation in a particular country.

If compost or recyclable material is being sold, it is important to keep a record of prices and quantities bought by customers, and to monitor the impact on sales of advertising and promotional campaigns.

C1.5 Operational data

Operational data include measurements of outputs and productivity, timing of operations and information from pilot projects. Such data can be used for design and cost estimation, for benchmarking and indicating which activities could offer the biggest efficiency gains, and scheduling of operations. Examples of operational data include:

- quantities of recyclable materials collected per hour at sorting facilities and the productivity of individual workers involved in such sorting (that is the average quantity collected by one person in one hour or one day);
- the output of a recycling plant, such as a composting facility;
- chemical analyses for incoming waste and mature compost at a composting plant;
- the time of arrival of trucks bringing waste to a treatment or disposal facility. This information can be used to determine the hours when the facility should be open, and to design reception procedures and space for unloading so that delays at peak times are minimised. In some cases such data could indicate if it might be beneficial to provide some storage capacity at transfer stations so that the number of hours that the landfill is operational in a 24 hour period could be reduced. Monitoring of truck movements can also have many benefits for the collection operations.
- the total weight of waste received at a facility each day;
- the number of waste pickers working at a disposal site
- the density of the waste in the landfill when it is placed and at intervals thereafter;
- the volume of soil or inert material that is used to cover waste each day, and the area covered;
- the amount of waste that can be placed and compacted by one machine of a particular type at a landfill – this information is useful in choosing the type and size of a machine for a particular landfill;
- The volume occupied by the deposited waste (and cover) at a landfill

This list does not include all the data that should be collected, but indicates the range of types of information that are needed for effective management. The value of operational data of this kind is greatly increased if the data are accurate and made feely available to all organisations that might benefit from them.

C2 Composting processes

This section should be seen as an introduction to some technical aspects of composting, and not as a manual on designing or operating a compost plant. For more detailed information other sources should be referred to; a study of the manual authored by

Rothenburger et al, [2006] would be a useful next step for the reader who is seriously considering setting up a composting operation.

C2.1 Objectives

The objectives of the composting process depend on whether it is viewed as a disposal process or a production process. If composting is considered to be part of a disposal process then the objectives are to produce a stable material that does not cause problems when buried in a landfill. If composting is viewed as a production process, the objectives are to produce a material that customers value and that meets the following criteria:

- it should be stable, meaning that it does not decompose and consume oxygen or generate methane in the presence of water and the absence of oxygen. (Immature compost that is not stable may take nitrogen out of the soil rather than adding it.);
- it should benefit the soil by adding organic matter – which makes heavy, clayey soils easier to dig and improves water retention in light, sandy soils;
- it should contain other constituents that benefit plant growth, such as nitrogen, phosphorus and potassium (NPK) and micronutrients that promote healthy growth;
- it should not contain significant amounts of harmful constituents, such as weed seeds and heavy metals. (Many countries have standards for compost which set limits for concentrations of harmful metals and for pH.)
- it should not contain fragments of glass, plastic or other materials that are not found in natural soils;
- it should be visually and aesthetically acceptable and easy to handle. (Mature compost has a pleasant, earthy smell and is grey-brown in colour. Its moisture content should be low enough that it does not form clumps, but high enough to prevent it from blowing away like dust in moderate winds.)
- for some purposes it should not include large pieces, but have a uniform and relatively small particle size.

In many places farmers and gardeners have other possible sources of organic soil improver, so that refuse-derived compost must be competitive in price, quality and consistency.

C2.2 Process requirements

The input material must have approximately the right balance of carbon to nitrogen so that the microbiological processes advance at a near optimal rate and produce a good quality compost. The balance in municipal solid waste is usually within the acceptable range, but if it animal manure is to be composted, its high nitrogen content should be balanced with the high carbon content of straw or similar crop residues.

Experience has shown that the nature of the input waste has an important impact on the marketability of the product. Mixed municipal solid waste has proved to be unsuitable as the feedstock for good quality compost because it is difficult to remove all the glass, plastic and other unwanted materials. (This is particularly the case when certain

processing technologies shatter any glass into small shards.) In some cases the heavy metal content of municipal solid waste has led to the rejection of compost produced from it. Most modern composting plants use waste from markets, green waste from parks and gardens, and – perhaps – source segregated domestic waste.

During the composting process, three parameters deep within the mass of the waste should be controlled for effective aerobic composting – they are moisture, oxygen and temperature.

The first stage of the composting process depends on thermophilic aerobic bacteria which, given oxygen and moisture, rapidly develop and generate considerable heat as they metabolise the waste. If there is sufficient insulation, the high temperatures that result increase the rate at which the composting process takes place, and kill any weed seeds and pathogenic micro-organisms that are present. However, if the temperature rises above about 75C the process slows down because the bacteria do not operate effectively at high temperatures and may be killed off.

If the moisture content is too high, the voids between the particles of material are filled with water instead of air and there is not enough oxygen for the bacteria. If this happens the aerobic bacteria give way to anaerobic bacteria and unpleasant smells are generated as the stabilising process slows down. If the moisture level is too low, the rate of metabolism and multiplication of the bacteria reduces and the process slows down.

After the initial high-temperature phase there is a long maturation phase that is needed to complete the composting process. During this phase the cellulose in wood is broken down by fungi. The uptake of oxygen is minimal during the maturation phase and so no special measures are needed – the maturing compost is simply left in windrows.

The final stage of maturation often takes place under cover to ensure that the moisture content of the product is not so high that it causes problems with the final screening and renders the product less attractive. Final screening is needed if there is a market demand for fine compost that is free of large particles. Coarse compost costs less and is suitable for large-scale application, such as tree planting and land reclamation.

Since the production of mature compost takes a long time – at least ten weeks – there is considerable interest in possible ways of reducing this time. If the time can be reduced less space is required for making the compost. There may also be times of the year when demand may exceed supply, and at such times the operator may be tempted to sell immature compost to meet the demand. Proponents of some processes claim that they are able to make compost in a shorter time; in such cases it is necessary to check that the compost has fully matured. Many composting experts claim that certain enzymes or microbiological agents can shorten the process time and suppress odours, but other experts are not convinced by these claims. One method of accelerating the process that all agree to is the size reduction of the input because smaller particles of waste have a bigger surface area per kilogram and so offer more opportunities for microorganisms to metabolise the waste.

In order to monitor the conditions within the composting waste and to make adjustments as required, it is necessary to have equipment for measuring temperature,

and moisture content, and laboratory equipment for determining other parameters that influence the composting process or indicate its status.

C2.3 Process categories – composting and other processes

C2.3.1 Anaerobic decomposition

Anaerobic decomposition in pits is not a composting process, but it is sometimes referred to as composting. This process is the same as burial in a landfill, except that the pits that are used are relatively small and the material that is buried may have been segregated so that it is largely biodegradable organic material. The process may take several years to achieve a relatively stable product so a larger area of land is needed in comparison with more rapid processes. The quality of the product is not as good as the compost produced by aerobic processes. The major advantage of this method is that no work input is needed until it is time to excavate a pit to remove the decomposed material.

C2.3.2 Anaerobic digestion

Anaerobic digestion also is not composting, but because it treats biodegradable waste and produces a soil improver from solid waste it is mentioned here. The liquid residue from anaerobic digestion (including biogas plants) is considered to be a natural soil improver. The residue from continuous-flow anaerobic digestion plants is not fully stabilised because fresh waste is mixed with digested waste in the digester, and so the slurry that leaves the digester contains some waste that has not been fully digested. The slurry contains a high percentage of water so it requires special equipment to transport and spread it. The liquid contains a useful amount of nitrogen which can benefit plant growth if applied correctly. The smell can be a significant problem.

C2.3.3 Windrow composting

Windrow composting has been practised for many years and in many locations. A windrow is a long pile of decomposing material which may be up to 2.5 m high and 100m long, though often windrows are much smaller. A larger windrow cross-section provides more insulation, allowing higher temperatures to be attained in the core of the windrow. The sloping sides shed much of the rain that falls on the windrow, but in some climates it is preferred to keep windrows under cover.

Oxygen can be provided to the bacteria in two ways. One is to "turn" the windrow by moving it and relaying it, ideally so that the material that was on the outside is relaid as the core, and the waste that has been pasteurised in the high-temperature core is relaid on the outside. In this way most or all of the weed seeds are deactivated and all of the waste receives a similar degree of treatment. In practice, most machines used for this purpose mix the material in the windrows rather than deliberately moving material from the core to the outside, but after this mixing is done several times the effect is almost the same and virtually all of the waste has been in the warmer core. Windrows may also be turned to prevent the temperature in the core from reaching levels that are harmful to the bacteria. Water can also be added at this stage so that it is dispersed throughout the material. In small composting plants the windrows may be turned manually, but in

larger operations front-end loaders or purpose-built turning machines may be used, as shown in Photos C2.1, for mixing and aerating the material in a windrow.

	
a) Turning machine in action	b) The horizontal rotor mixes and aerates

Photos C2.1 Windrow turning machine for mixing and aerating windrows in the early stages of composting

The second way of controlling conditions in a windrow is to build the windrow on a pipe or, alternatively, on a grating or porous base under which are ducts. The pipes or ducts are connected to a blower so that air can be drawn down into the windrow or blown up into it from underneath. This movement of air can also be used to control the temperature in the core and have an effect on the moisture level within the windrow.

In spite of these modern methods of controlling the conditions within a windrow, there may still be occasions when the composting plant emits odours which cause complaints from neighbours.

C2.3.4 In-vessel composting

In order to ensure that odours are virtually eliminated, there are modern processes, known collectively as *in-vessel* composting, in which the waste is composted in a vat, tube or tower. This arrangement allows precise control of the supply of air and moisture. The air that has been in contact with the material being treated can be passed through an odour filter to remove any odours before this air is released into the atmosphere.

C3 Technologies for treating waste

C3.1 Size reduction

The purposes for which size reduction may be used have been listed in Section B3.3.2. This section introduces three basic types of machines that are used for cutting lumps or particles of solid waste into smaller pieces. There are many variations of the three classes that are introduced here, but these are the most common types.

C3.1.1 Trommels

Trommels are large open-ended cylinders that rotate slowly about a horizontal (or slightly sloping) axis, and have blades that gradually move the waste from the inlet end to the outlet end. (Photo C3.1) The waste is broken up by the tumbling action, particularly if the waste contains glass, metal items and stones which cut or break up the softer materials. Knives may be fitted inside the cylinder to cut open any bags and assist in the size reduction process. Trommels are often fitted with a screened section so that they also operate as a rotating screen. Trommels require less maintenance than other technologies used for size reduction.

Photo C3.1 View inside a trommel

C3.1.2 Shredders

The most common type of shredder has two parallel shafts which rotate relatively slowly in the opposite directions. Each shaft is fitted with a row of discs into which teeth have been cut. (Photos C3.2) The teeth pull the waste down so that it passes between the two shafts and the teeth also cut it or shear it so that it can pass through the narrow spaces between the discs and drop down below them. The teeth must be very sharp to cut some materials (such as pieces of carpet) but may be blunted by other materials (such as bricks or metal castings). The motor must be fitted with a cut-out or clutch that stops the rotors when they engage an object that the teeth are unable to cut. The amount of maintenance required depends of the types of waste that are processed and how quickly the teeth are blunted or damaged.

b) Close-up of cutting discs ↑

← a) Two shafts fitted with cutting discs (Photo: Monomuncher)

Photos C3.2 Rotary shredder

C3.1.3 Hammermills

A hammermill has a shaft that rotates at very high speed and therefore requires considerable power. Hammers (which are often heavy rectangular pieces of hardened steel) are fixed or pivoted to the shaft, and as they rotate at high speed they smash the waste into small pieces. Hammermills are very noisy and should be installed in strong but ventilated enclosures in case they explode. The hammers need frequent maintenance because they are worn down by the wastes and so extra metal needs to be welded onto them. (Photos C3.3)

a) View inside a hammermill

b) A reconditioned hammer element among many worn elements

Photo C3.3 A hammermill

C3.2 Screening

Compared to other methods of processing solid waste, screening is relatively simple and robust, but problems can still occur. The most common problems are incomplete separation of the size fractions and clogging of the screen. If a screen is overloaded some of the fine material is carried over with the coarse fraction; the solution may be simply to slow the rate of feed or to make the rate of feed more uniform. Screens may become clogged if some of the material adheres to the screen rather than passing through it or along it. This may occur only at certain times of the year or at certain moisture contents. In the case of rotating drum screens, the problem of clogging may be alleviated by means of a rotating brush that forces its bristles into the mesh holes as the drum rotates (Photo C3.4). The clogging of vibrating screens used for processing compost has been cured by heating the screens.

Photo C3.4 A rotating brush is used to keep the apertures clear on a rotating screen.

The required size of the apertures in a screen is best determined by pilot testing using a simple sloping screen which can be fitted with meshes of various sizes, and choosing the mesh size that gives the desired result.

The mesh in a screen, and its supporting framework, must be strong enough to withstand the impacts of heavy or sharp items that may be found within the waste. Inclined screens used for demolition waste normally use bars instead of mesh, in order to provide sufficient strength to resist the impact of large pieces of masonry or concrete.

Corrosion may be a problem with some types of waste. It may be necessary to fit dust extraction hoods in certain situations.

More complex screens may be used for particular purposes. A screen composed of interlocking wheels (all rotating in the same sense) may be used to separate strips of cloth from granular materials – the cloth rides on the rotating wheels while the granular material falls though the spaces between the wheels. Some vibrating screens are designed so that some materials that do not pass the screen migrate to the top of the screen while other oversize materials move to the bottom.

C3.3 Other treatment methods

Text books written for university students in industrialised countries mention other methods of treatment for solid waste, in addition to those introduced in Section B3. Their inclusion in such books should not be taken as evidence that these technologies have proved effective, reliable, or affordable. It is commendable that research is being done to find ways to reduce the environmental impact of waste management and to gain value from waste, but the conditions that can be maintained in a laboratory or in the pilot plant of a research institute are very different from the conditions that apply in the waste management systems of developing countries.

Methods have been devised for converting solid waste into alcohol, vehicle fuel and other organic chemicals. None has proved to be effective and economic on a large scale. The method of treatment that has not been mentioned so far and that has found limited commercial application on a small scale is pyrolysis. When solid waste is heated in the absence of air it forms various products which burn and which may have some applications as feedstock for chemical processes or as fuel. This process has been used in a few instances for processing discarded tyres. Pyrolysing incinerators have two stages – the first is a pyrolysing chamber which converts the waste to inflammable gases and the second burns these gases.

The situation regarding these experimental technologies may change in the coming years, and new technologies may be developed, but the author's recommendation remains unchanged: no investment of money, people or land should be made to adopt any new technology unless it there is trustworthy evidence that the particular technology has proved to be reliable and economical in similar circumstances and with similar waste. If a city cannot operate a sanitary landfill to a high standard it should not consider investing resources in unproven technologies.

C4 Disposal of solid waste

This book is not a design manual, but aims to provide information that can

- assist in the preparation of project documents,
- suggest issues and questions to be put to designers, and
- highlight points to check when monitoring construction and operation.

Valuable practical information on site selection, environmental impact assessment, and all other aspects of landfill siting, design, construction, operation and closure can be found in [Rushbrook and Pugh, 1999], which can be downloaded from the World Bank website (details of which are in the list of references at the end of this book).

C4.1 Selecting standards for disposal

A comprehensive framework of minimum requirements has been developed in South Africa [DWAF, 1998]. The reader is referred to this publication for a thorough review of appropriate standards that have been established for a country which has a considerable body of legislation relating to waste disposal and has made considerable strides in

upgrading waste disposal practice. The report provides a comprehensive review of the large range of aspects that are of concern with regard to waste disposal

When selecting the standards for a particular waste disposal operation it is important to consider objectives and how they can be achieved in each situation.

C4.1.1 Water quality

a) Leachate generation

An important consideration is the prevention of water pollution. In the past it was often assumed that the volume of polluting leachate that is produced depends only on the rainfall in the area, since it was assumed that most of the leachate is produced when rainfall or other water infiltrates into the mass of deposited waste. The South African *Minimum Requirements* document [DWAF 1998] accounts for the potential for generating leachate by estimating the "climatic water balance". In addition to rainfall, it also considers leachate generation caused by waste deposition in water, (*wet tipping*), poor site drainage, allowing up-slope runoff to enter the waste body, and the concept of "superimposed hydraulic loading", which is the leachate generation caused by the disposal and compaction of waste that has a high moisture content.

Investigations in Gaza (Section C6) have clearly shown that in some cases almost all of the leachate comes from the waste itself, as a result of decomposition and progressive compression of the waste. This indicates that significant quantities of leachate may be produced in areas of minimal rainfall, and that the nature of the waste, not only the climate, may be of great significance when estimating leachate flows. In arid climates it may not be necessary to build interceptor drains for surface water, but it may still be necessary to take measures to prevent pollution of groundwater by leachate. If, however, the waste is dry and contains little biodegradable material, it may not be necessary to be concerned about leachate, especially if the groundwater is at a considerable depth and the underlying ground provides some attenuation capacity (removing some of the pollutants), thereby providing some protection of water resources.

In locations where only small amounts of leachate are expected, where there is a thick layer of clayey soil under the waste and where there is low probability of any persistent organic pollutants ("POPs") being deposited with the waste, it may be decided that natural purification mechanisms in this soil provide enough protection of the groundwater resources in the medium term, until a more effective means of pollution prevention can be afforded and operated satisfactorily. (It is likely that officials in environmental organisations will be very reluctant to accept this reliance on natural purification mechanisms, even if the proposed improvements represent a significant upgrading of landfill standards. However, to rely on leachate collection and treatment before a good standard of treatment plant operation can be expected may represent a greater environmental threat in such cases.)

In developing countries there are many examples of leachate treatment plants that are not working satisfactorily. In such cases untreated leachate is discharged in a large quantity from the outfall of the ineffective treatment plant, as a *point source* of pollution. It can be argued that such a point source discharge may cause more pollution than the

diffuse infiltration of leachate over a wide area (under an unlined site), because the latter case gives more opportunity for natural purification (or attenuation) mechanisms to improve the quality of the polluted discharge. Alternatives to on-site treatment have been introduced in Section B4.3.3g.

In some geological conditions, pollution of groundwater by landfill leachate may take many years to appear, because of the slow rate at which water moves downwards through unsaturated soil. Nevertheless it is important to monitor the impact of a landfill on groundwater quality from the start of operation. This is done by regular sampling of groundwater from boreholes drilled upstream and downstream of the site. If pollution by leachate is occurring, the plume of leachate may be relatively narrow close to the site, so care must be taken in siting the downstream boreholes. Water quality should be tested regularly, especially if there are any wells or boreholes providing drinking water in the vicinity. An increase in electrical conductivity is a quick test for indicating leachate pollution. This should be followed up by monitoring of other parameters, and if any of these in water taken from a supply well exceed the WHO drinking water standards, the drinking water source should be replaced.

In areas where the groundwater is brackish or saline, or if it is unusable for any purpose for some other reason, some pollution of this water may be considered acceptable.

b) Leachate collection

Leachate collection systems consist of two basic parts – a impermeable layer that prevents the leachate from moving downwards and infiltrating into the ground, and a system of drains surrounded by a drainage layer of coarse stones to convey the leachate to a storage pond or treatment plant. Standards specify the minimum slope of the impermeable layer so that leachate flows to the pipes, and the minimum slopes for the pipes themselves. Leachate can be very corrosive to steel pipes, so polyethylene pipes are generally used, perforated to allow leachate to enter. It is advisable to install rodding points at the ends of these pipes so that any obstructions in the pipes can be rodded out and the internal condition of the pipes can be inspected by CCTV cameras.

The various types of impermeable liner that are discussed in Section C4.3 all require careful construction. Clay liners must be well compacted in thin layers. Plastic liners must be laid so that they are not punctured and joints must be welded and tested to ensure that they do not leak. Asphalt must be of the right mix and laid and rolled to achieve the correct density

There may be alternative "low-technology", low cost alternatives to these liners – alternative designs that can collect a high percentage of leachate, perhaps relying on the low vertical permeability of some types of waste, relatively steep slopes and the high permeability of coarse stones, but the author is not aware of systems of this kind. A system that collects a considerable proportion of the leachate is clearly preferable to the situation in which no leachate is collected.

c) Leachate treatment

If a leachate collection system and leachate treatment plant are required, it is important to consider the quality standard to which the leachate must be treated, and what action must be taken if the quality standard is not achieved. It sometimes appears that

designers and clients are satisfied if there is an area of the site labelled "leachate treatment plant" even if the performance of the plant is totally inadequate. Poorly designed reed beds have proved ineffective, and treatment ponds that have no mechanical aeration are likely to achieve very little. The fact that a plant has been constructed is not sufficient to protect groundwater resources; what matters is the quality of the water that leaves the site. Further consideration of leachate treatment follows in Section C4.3.2.

C4.1.2 Site roads

Internal roads on a landfill site can be divided into two categories – (i) roads that are expected to last for the lifetime of the site and (ii) temporary roads that are covered by deposited waste as the landfill height increases. Standards may include the width of the roads (or the spacing between passing places on single track roads in the case of low traffic volumes), surfacing and gradients. All the roads should be passable by trucks in all weathers.

C4.1.3 Standby capacity

Provision of standby equipment should be made for times when mechanical equipment is awaiting repair, being repaired or undergoing routine maintenance. It is likely that the fixed plant on most landfill sites is limited to a weighbridge, pumps for leachate and gas and machines used in leachate treatment. Generators and lighting may also be required. On all but the largest landfills only one weighbridge is normally provided, and so when it is not functioning incoming vehicles cannot be weighed. There should be backup pumps for leachate and gas. Standby earthmoving machines should be provided unless adequate substitutes can be hired and brought on site quickly and at short notice.

C4.1.4 Daily cover

The covering of deposited waste at the end of each working day is often quoted as a basic requirement of sanitary landfilling. However, because of the costs involved[22] and the volume of the landfill that would be occupied by cover soil, it may be decided that the benefits of covering each day do not merit the expenditure that it would involve. In that case other operational techniques should be tried to achieve the some of the benefits of daily cover (which are mainly control of windblown litter, control of fly breeding, discouraging birds, reducing the risk of fires and providing a satisfactory surface for trucks to drive on). The need for daily soil cover may depend on the nature of the waste, the climate, and the type of machinery that is used to level and compact the waste. If soil cover is not applied at the end of each day, care must be taken to ensure that each day's waste is covered by the next day's waste, so that the heat of decomposition is conserved within the waste to kill fly larvae before they can mature. This will require sizing of the operational cells and control of the depth to which the waste is placed so that the whole operating area is covered by waste each day.

[22] The cost of providing and placing daily cover soil may be as much as 50% of the operating cost of a landfill. (Gerd Burkhardt, Personal communication, 2010)

C4.1.5 Accommodation and facilities

Consideration should be given to the standard of accommodation that is provided for the weighbridge clerk, the landfill manager, and other site employees. Provision should also be made for garaging the landfill machinery and, if maintenance of these machines is to be carried out on site, there should be a clean workshop where mechanics can work.

The gatehouse where the weighbridge clerk monitors the incoming loads should be a comfortable working environment. On busy sites it may the useful to reduce delays at the entrance by locating the weighbridge office so that truck drivers do not need to leave their cabs to get documents stamped by the clerk, but can simply hand documents across to the clerk from their cabs. On some landfill sites a mirror is mounted at the entrance so that the weighbridge clerk can monitor the loads in open trucks and containers.

Landfill offices should include an office for the site manager that reflects the importance of the work of the site manager. A training room may be provided. It may be appropriate to include a shower and changing room in addition to the washing and toilet facilities. In some situations a ventilated room may be provided where staff can smoke cigarettes, in order to reduce the temptation of smoking outside and possibly starting a fire. There should be toilets and washing facilities for truck crews. If waste pickers are working on site, sanitary facilities should be provided for them also.

C4.2 Selecting sites

The technical aspects of site selection have been outlined briefly in Section B4.8.1. It is not the intention of the author to provide detailed information about the process of site selection here, because of the need to involve experts in the identification and investigations of the particular potential sites, and the importance of local politics and procedures. Additional general guidance on site selection procedures can be found in Rushbrook and Pugh [1999] and Wilson et al. [2001].

C4.2.1 The lifetime of the site

An important consideration in selecting a site is the lifetime of the landfill that can be constructed on the site. The lifetime of a landfill is determined principally by the volume of waste that can be accommodated on the site and the daily inflow of waste.

a) The volumetric capacity of the site.

The volume of waste that can be accommodated on the site is estimated by considering the area that can be covered by waste, the height to which the waste can be filled, and the shape of the site. The height of the waste is determined by the side slope (usually 1 vertical : 3 horizontal) and the minimum horizontal dimension[23] at each part of the site. Not all of the area of the site can be covered by waste, because space must be allowed for the entrance, parking, administration buildings and weighbridge, for site roads, for the collection and treatment of leachate and facilities for landfill gas, for storage of cover

[23] A circular or square plan area allows a greater height than a long, narrow rectangle having the same plan area.

materials and for a perimeter or buffer zone around the site. The perimeter may be occupied only by a boundary wall and a perimeter access road. Alternatively there may be a buffer zone consisting of a belt of trees and perhaps an earth bank around the site. A buffer zone of this kind may be needed to screen the site from view from the outside or to prevent the construction of houses near the site (if land use planning law cannot be relied upon to prevent construction close to the site). Parts of the site may not be usable because of the topography or because of electricity transmission lines (unless they are rerouted).

b) The daily inflow of waste

It is desirable that the lifetime of a landfill is at least 20 years. There are many uncertainties about the volume of waste that will be brought to the landfill each day over such a long period. Among these uncertainties are the following factors:

- If there is no weighbridge or not all of the waste loads are weighed, estimates of the current waste flow may be uncertain and so any projections of future waste flows will be affected by this uncertainty.
- There may be expectations that the proportion of generated waste that is taken to the landfill may be reduced in future because of laws and programmes to reduce waste generation and increase recycling. Proposals for composting or treating the waste may be expected to reduce quantities going to landfill. It is clearly preferable that a landfill is operational for a longer period than a shorter one, so it is recommended that it is assumed that the current proportion of waste going to landfill is maintained, rather than basing projections of waste flows on anticipated reductions. Experience in the cities of most developing countries supports this conservative assumption. If the quantities of waste requiring landfilling do reduce considerably and part of the acquired land is no longer required, the land can later be sold off or used for some other purpose.
- There is a general trend of closing small dumpsites and developing smaller numbers of larger landfills. District landfills that serve a number of cities and towns benefit from economies of scale. When forecasting future waste flows it may be wise to take into account the possibility that additional waste will be brought to the site from nearby towns and cities that currently operate their own disposal facilities.
- Forecasts of population growth provide another element of uncertainty.
- Per capita waste generation rates are generally assumed to rise in line with economic growth, and changes in the nature of the waste affect the volume that will be occupied by a given weight of waste in a landfill. Lack of current data on final waste densities in a landfill may be another reason for uncertainty.

If the deposited waste is covered with soil each day, the volume of soil used each day must be added to the daily inflow of waste when determining the volume requirement. Municipal waste in a landfill can be compacted to a density approaching one tonne per cubic metre, and the decomposition process will further reduce the volume of each tonne of waste that is deposited. The volume occupied by the cover soil will not reduce in this way.

C4.3 Design and construction of sanitary landfills

C4.3.1 Sealing

As already mentioned, modern specifications for sanitary landfills require an impermeable liner covering the area on which the waste is deposited, with a drainage system above it to collect the leachate and minimise the hydrostatic pressure exerted by the leachate on the liner. Clay soils, plastic (high-density polyethylene – HDPE) and asphalt are used to provide a barrier to the movement of leachate so that the leachate is retained within the landfill until it flows out of the leachate collection drains. Certain organic liquids can gradually diffuse through barriers that retain water-based liquids; clays are particularly effective in arresting the movement of such liquids. Organic liquids of this kind are found in industrial wastes; although they are present in small amounts in domestic solid waste, they are not considered to be a significant problem in municipal wastes.

Mineral liners come in three forms[24]. If it can be demonstrated that the natural soil consists of a layer of clay[25] at least one metre thick with a coefficient of permeability k of less than 1×10^{-9} m/s, this is referred to as a *geological barrier* and is considered acceptable as a mineral liner. If such a layer is not found, and artificial mineral liner can be formed by compacting clayey soil with the correct moisture content in thin layers by means of a roller, so that there is a layer at least 0.5 m thick with a coefficient of permeability k less than 5×10^{-10} m/s. This is known as a *compacted clay liner*. If necessary, it may be possible to reduce the permeability of the natural soil by adding a small proportion (typically 5%) of purified bentonite (a clay which swells in the presence of moisture). Instead of natural clay an artificial mixture that has a very low permeability can be used. An example is TRISOPLAST® which is an innovative mineral sealing material which was developed in the Netherlands and has been used since 1992. It is a mixture of sand (about 89%), bentonite (about 10%) and a polymer (1%) – a mixture that is protected by patent. A layer of 100 to 200 mm is sufficient because it has a permeability coefficient k of less than 5×10^{-11} m/s. The third type of mineral liner – the geosynthetic clay liner (GCL) - consists of a thin layer of artificial soil which has a very low permeability and is able to adsorb[26] organic molecules; the mineral material is sandwiched between two layers of geosynthetic textile

Synthetic liners or geomembranes usually consist of a layer of HDPE plastic. The sheets of such a geomembrane are supplied in rolls and, when unrolled on the ground, are joined together by a welding process that is carefully checked for water tightness. The sheets may be up to 2.5 mm thick. They are usually combined with a compacted clay liner for extra security, forming a *composite* liner.

The third type of barrier, which has been used in some European countries for some time, is asphalt. The material has the same components as the asphalt used for road surfacing, but the mix of the constituents may be different. The asphalt is laid on a 250

[24] This discussion of liners is based on information provided by Burkhardt [2010]

[25] Clay that contains particles that are larger than clay grains (such as silt) may be suitable; the important parameter is the coefficient of permeability.

[26] To adsorb means to retain the organic molecules on the surface of the grain.

to 300 mm thick layer of crushed stone, to form a base course, in the same way as for road construction. The first layer of asphalt is a bearing (or supporting) layer and the upper layer is the asphalt liner. The percentage of voids in top layer should be less than 3% so that the lining system has a very low permeability. Asphalt liners can be laid using the same machinery as is used for road construction provided that the slopes are not steeper than 1:3 (or 1:4 in the case of old equipment).

Other components found in lining systems are

- geotextiles, which are made of plastic fibres and allow liquids to pass through them but prevent the movement of soil grains and resist puncturing by sharp stones. Geotextiles are laid above geomembranes to protect them from being damaged by the drainage material above, with an additional protective layer of sand between the drainage layer and the geotextile. (Geotextiles are also used for the construction of temporary roads on soft, wet ground. Another type of geotextile can be used as a drainage material to transport water laterally to a drain pipe.)
- drainage layers, which are composed of 10/40 mm gravel in a layer 500 mm thick, with a permeability coefficient k of greater than 1 x 10^{-3} m/s, so that the leachate can easily flow to the nearest drain pipe.

The simplest form of landfill liner is the single liner having just one impermeable layer to prevent the flow of pollutants. These single liner systems are used for landfills for inert wastes in Europe, but are considered as a cost-effective measure in countries where waste disposal standards are progressively being upgraded.

Landfills for municipal waste in Europe are required to have composite liners, which are made of two types of liner - a mineral liner and a synthetic liner or asphalt liner.

Double liner systems are used in the USA for hazardous waste landfills. They have two layers of drain and liner combinations so that any leachate that penetrates the top liner is collected by the lower drainage system, providing increased protection and a warning of any failure of the top liner.

Since asphalt liners are not as well known as mineral and plastic liners, it is useful to consider the advantages and disadvantages of asphalt.

<u>Advantages of asphalt liners</u>

- Asphalt is a well known construction material. Its constituents – bitumen and mineral aggregates – are available in most countries of the world, and so is the equipment and know-how for processing, placing and compacting asphalt.
- Asphalt liners are robust. The material is ductile and can accommodate differential settlement without rupture.
- If laid correctly, asphalt liners are impermeable to leachate, comparable in sealing performance to geomembranes.
- Asphalt liners can be constructed in hot and dry climates, whereas satisfactory construction of clay liners is very difficult because of rapid loss of moisture from the clay.

<u>Disadvantages of asphalt liners</u>

- Unlike clay, asphalt has no capacity for purifying leachate (by adsorption of organic molecules onto the surfaces of grains). Therefore, if there is a hole in the asphalt layer, leachate will escape unchanged.
- Asphalt liners should not be used for landfills in which the wastes contain petroleum products and organic solvents.
- The properties of asphalt change with time to some extent.

Comparative costs

The costs of alternative systems vary with time and from place to place, but the cost comparison in Box C4.1 gives an indication of how the costs compare for three liner systems. In particular the cost of clay would vary according to the availability of good quality clay near to the site. These estimates are similar for all three options, indicating that cost may not be a primary consideration when choosing a lining system. The costs of laying geosynthetic clay liners should also be compared before a decision is made.

Box C4.1 Cost comparisons for three liner systems

Option A is the conventional composite liner consisting of a compacted clay liner (CCL) and a plastic geomembrane. Option B uses TRISOPLAST® - a patented mixture of sand clay and polymer. Option C is an asphalt liner.

The order of the layers in the table below is as they appear when the complete liner system has been constructed. The sequence of construction starts from the bottom of the table.

Layer	Costs US$/m^2		
	Option A	Option B	Option C
Drainage layer – gravel 10/40 mm: 300 mm	8.00	8.00	7.50
Protection layer (2) – sand bedding	5.00	5.00	
Protection layer (1) – geotextile: 1,000 g/m^2	6.00	6.00	
Asphalt sealing layer: 80 mm			18.75
Asphalt bearing layer: 100 mm			12.50
Geomembrane (thickness 2.5 mm)	15.00	15.00	
TRISOPLAST®: 150 mm		18.75	
Compacted clay liner: 500 mm	12.50		
Base course: 300 mm			5.20
Ground preparation – removing topsoil and loose rocks and smoothing the surface.	Same for all options		
Total cost US$/m^2	46.50	52.75	43.95

Apart from cost, the other factors that need to be considered include

- Chemical resistance, considering the likelihood of the presence of organic solvents and petroleum products in the waste;
- Resistance to loads (trucks and landfill machinery) and ground deformation (settlement)
- Resistance to environmental factors, especially temperature, heavy rainfall and evaporation (evaporation causes desiccation [drying] of clay, often resulting in cracking and increased permeability);
- Access to the necessary expertise, equipment and quality control – especially important if the construction of the site will take place in stages over the lifetime of the landfill.

Sealing the sides of a sanitary landfill site may present additional challenges, particularly if the site is a deep quarry or has steep sides. The placing of clay and asphalt linings on slopes steeper than 1:3 may require equipment that is pulled up the slope by cables. Photo C4.1 shows a 360° excavator lining the side of a quarry landfill by placing clay on white geotextile.

Photo C4.1 Lining the side of a landfill

If a plastic geomembrane is used on slopes, precautions must be taken to ensure that it is not dislodged by wind or water pressure, and there is the risk that the downwards drag of the covering material or the waste (which settles downwards as it decomposes) will tend to stretch and tear the liner.

On very steep side slopes the layers of the liner must be built up progressively, just ahead of the level of the deposited waste. The clay layer must be wide enough to allow the compacting roller to work on top of it. A sanitary landfill should never have any part below the level of the groundwater table. As already mentioned surface water flowing towards the area reserved for deposited waste should be intercepted by open drains. If water tends to flow into the side of the landfill void after rainfall (from the unsaturated zone above the water table) two separate drainage systems are needed – one to collect the incoming clean water and one to collect the polluted leachate. These difficulties provide additional reasons for siting a landfill above ground rather than in a quarry.

C4.3.2 Leachate treatment

There is no benefit in collecting leachate if it is discharged untreated into the environment. Because of the difficulties and cost of treating leachate, every effort should be made to minimise the quantities that require treatment. Quantities can be minimised by

- preventing clean water from mixing with leachate. This can be done by constructing and maintaining drainage ditches around the perimeter of the site and diverting the collected water away from the site;
- diverting rain falling on parts of the site that have not yet been used away from the site. If the leachate collection drains are all constructed before the site becomes operational, there should be some way of separating the water collected in the unused area from the leachate collected in the operational area, unless the annual rainfall is virtually insignificant;
- covering deposited waste in areas that are not operational with a temporary or permanent cover, and collecting the water that runs off these areas separately from the leachate;
- In locations where evaporation exceeds rainfall, leachate volumes should be reduced by evaporation, either in an evaporation basin or by recirculation – spraying the leachate over the waste. Some of the leachate will infiltrate into the waste, with the beneficial effect of promoting microbial decomposition of the waste, so that the landfill is stabilised within a shorter time.
- spraying leachate on roads and working areas to suppress dust in the dry season; if partially treated leachate is not available there may be problems from the odour of raw leachate;
- encouraging rainwater to run off the waste without infiltrating by providing a gentle fall or slope on the surface, and preventing the ponding of rainwater by filling any depressions.

(Clearly, some of these measures are more connected with operation rather than design, but it is important to consider operational requirements at the design stage.)

Having taken all possible measures to minimise the volume of leachate, there may still be a significant quantity of leachate requiring treatment. Aside from its unpleasant smell and black, oily appearance, leachate is a cause for concern because of its very high organic content (expressed as chemical oxygen demand – COD). Difficulty is often experienced in reducing the high concentrations of COD and ammonia found in leachate, using common microbiological treatment methods. Depending on the nature of the waste, leachate may also contain high concentrations of iron and significant concentrations of heavy metals and chloride salts. The pH of leachate (low at first and increasing with age) and its composition change with the age of the waste in the landfill, and leachate continues to flow out of a site for some years after the site is closed.

Extensive research has been undertaken on the subject of leachate treatment, and much has been written on the subject. It is beyond the scope of this book to recommend how leachate treatment plants should be designed. It is very important to understand that the methods that are used to treat municipal wastewater are inadequate for treating

landfill leachate alone. If there is a nearby municipal wastewater treatment plant it may be possible to transfer the leachate to this plant by tanker or pipeline. Leachate can be very corrosive so iron pipes and steel tanks may have a short life. For treatment in municipal plants to succeed there should balancing tank so that leachate is mixed with the municipal wastewater at a constant rate with a high dilution. Because of the high concentration of ammonia in leachate, it may be necessary to remove most of the ammonia by air stripping (raising the pH of the leachate to at least 10 and aerating it) or by aerating the water in a lagoon to encourage microbiological oxidation of the ammonia.

If the leachate is to be treated on-site, aeration in lagoons can be effective, and physical-chemical treatment – coagulation, flocculation and sedimentation – can be used to remove some of inorganic pollutants, as well as some of the organics. To obtain an effluent that meets discharge standards it may be necessary to use sophisticated membrane treatment technologies in addition.

If evaporation is not sufficient to cope with the expected volumes of leachate, the need for long-term treatment of leachate must be faced, and the resource challenges met, if lining and leachate collection are proposed.

C4.3.3 Landfill gas

Perforated pipes for collecting landfill gas may be horizontal or vertical. Horizontal wells are constructed as filling progresses. Vertical wells can be constructed progressively as the height of the landfill increases, or boreholes can be drilled when the waste has reached its final height. Wells constructed in stages may be damaged by trucks and earthmoving machines that are depositing the waste. Drilling boreholes in landfilled waste requires special techniques to cope with the wide range of materials that may be encountered when drilling down through the waste. Borehole linings should be telescopic and flexible so that they can reduce their length as the waste settles because the volume of the waste is reduced by decomposition which converts some components of the solid waste to landfill gas and leachate.

A simple way of constructing gas vents as landfilling proceeds is shown in Photos C4.2. A cylindrical casing, about 2 metres long, is fitted with a loop or chain or with a flange so that it can be lifted. It is placed into the waste and coarse stones are put inside the casing. When the level of the waste has risen to near the top of the casing, the casing is lifted up using an excavator or similar machine until about 0.5 metre remains embedded in the ground. Most of the stones that were in the casing fill the void that was left by the casing, forming a column of loose stones which allow the gas to move upwards freely. When the waste reaches the final level the top of the stone column can be capped with a metre of clay through which a pipe passes. Alternatively, as shown in Photo B4.15a, a slotted or perforated pipe can be introduced in the centre of the stone column and sections added to it as the level of the waste rises.

↗ a) The casing is partially buried in the waste

↗ b) Stones are placed in the casing to approximately the same level as the waste

Photos C4.2 A simple way of constructing a gas vent

As with any fuel gas, precautions must be taken to prevent the flame moving down the pipe and causing an explosion. If there is no oxygen in the pipe and the flow velocity of the gas is sufficient, no problem need be anticipated. To maintain safe conditions in landfills where many wells are connected to one vacuum pump, care must be exercised not to apply too great a suction on any well, especially to those near the periphery of the site, because this could result in air being drawn into the waste and adversely affecting some the methane-producing bacteria. Also if oxygen enters the pipe system, the mixture of air and methane could cause a fire or explosion. Air might also be drawn in through the drainage pipes. To prevent such an occurrence the oxygen content of the gas should be monitored regularly and flows reduced if oxygen is detected.

A common use for landfill gas is to power electricity generators. Gas turbines have been used for this purpose, but the most common type of engine is a dual fuel engine that looks like a diesel engine but operates using a conventional fuel (diesel oil or natural gas) and landfill gas. Usually these engines are started on the conventional fuel and then the landfill gas is introduced. It may be necessary to purify the landfill gas by removing the moisture it contains, and possibly other unwanted constituents. Clearly the generation of electricity in this way is only economically feasible if there is a customer for the electricity willing to pay a price that will cover the amortised capital costs and running costs, after subsidies and other income have been taken into consideration. The economics are improved if the waste heat can also be sold.

C4.4 Operation of large sanitary landfills

Many principles of good waste disposal practice have already been discussed in Section B4.3.3.

C4.4.1 Components of an operational landfill

At most stages during the operation of a landfill, the site will comprise at least five different areas. A small part of the site will be active, where waste is being unloaded, placed and compacted. Another part of the site will have been used for depositing waste until a certain height is reached, and then it is covered with a temporary cover (if this area will be active again later, perhaps when the level of waste in adjoining areas reaches a certain height) or with a final cover if no more waste will be deposited there later. In general, there will be another part of the site that has been prepared, but is not yet being used. In areas of significant rainfall the water drained from this area should not be mixed with leachate (in order to minimise the volume of leachate). There will probably also be another part of the site which will be used for depositing waste in the future, but is still in its natural state because it has not yet been developed for receiving waste. Finally there will be areas of the site that will not be covered with waste because they are used for site roads, for storage of soil or other materials, for site offices and parking, for managing leachate and landfill gas, and there may be a buffer area around the perimeter of the site for environmental or aesthetic reasons.

C4.4.2 General principles of landfilling

Perhaps the most important guide for good operation of a landfill is

Never push waste over the edge.

There should be no place where the slope of deposited waste is so steep that it cannot be driven over by the machinery that is used on the site. If waste is pushed over the edge of the platform of compacted waste where waste is being unloaded it will form a very steep slope which may be unstable and will be impossible to cover effectively. Steep slopes formed in this way are more likely to have fires. To close the landfill in an acceptable way it will be necessary to convert the slope to a more gentle gradient and that will be a very expensive and difficult operation.

It has been said that the three 'C's of good landfill operation are *Confine, Compact* and *Cover*.

1. Confine

   The working area on which waste is being deposited on a particular day should be confined so that it is as small as possible. The reasons for this requirement include the following:

   - Whenever possible the waste deposited on one day should be covered by the waste deposited on the next day. This will help to control fly breeding. This practice is especially important if the waste is not covered by soil each day.
   - In humid regions or at times of significant rainfall, most of the deposits of waste on the landfill site should be covered with a temporary or permanent cover so

that the amount of leachate to be treated is kept to the minimum. The working area that is exposed to the rain should therefore be as small as possible.

- Activities taking place within a small area can be supervised more effectively than activities (such as unloading and placing waste) that are taking place over a large area or in scattered locations around the site.
- If waste is being unloaded in several different places, the machinery that is used to level and compact the waste will spend time and fuel travelling between these various parts of the site, or additional machines will be needed.
- Landfill compactors and bulldozers that are used to place, level and compact the waste should not be required to push the waste over a long distance, because this would result in them having less time for their primary functions of levelling and compacting. Trucks should unload their waste as near as possible to the working face where the waste will be finally put.

It is clear that delays will result if the working area is too small. Accidents may also be caused. The site should be large enough so that trucks have enough space to manoeuvre to get to the unloading location. Provision must be made for vehicles with trailers, if such vehicles are bringing waste to the site. Allowance must also be made for the maximum number of vehicles arriving in any 15 minute period during the working day, so that there is space to manoeuvre and space to unload even at the most congested times. If many of the vehicles on the site are being unloaded manually, more space will be needed than for vehicles that have mechanical unloading systems because trucks that are unloaded manually will be at the unloading point for at least three times as long.

The area being used at any one time is called a cell, and the boundaries of a cell are usually marked by embankments made of soil, rock or inert waste, known as cell walls. Initially, the waste is placed against the cell wall that is furthest from the entrance to the cell, and the line of freshly deposited waste gradually moves back towards the entrance to the cell.

Waste is compacted more effectively in thin layers. If compaction is achieved by the to-and fro movement of bulldozers and trucks, it may be advisable to place the waste such that each layer is about half a metre thick. If a landfill compactor is used, a greater depth is satisfactory. If no daily cover is applied, it is necessary to cover the previous day's waste each day. Therefore the cell should not be so big that the whole area of the cell cannot be covered with waste each day.

2. Compact

Solid waste in a landfill should be compacted or compressed into the smallest possible volume for the following reasons:

- To provide the firmest possible and most uniform surface for trucks to drive on so that they do not sink into depressions, lose traction or damage their transmissions because their wheels sink into the waste.
- To minimise the volume occupied by each tonne of waste so that more waste can be accommodated on the site, thereby increasing the life of the landfill and reducing the unit cost of disposal.

- To minimise the volume of voids within the waste, because the voids retain air; minimising the volume of the voids minimises the amount of air within the waste thereby reducing the risk of fires.
- To minimise the settlement that occurs as a result of decomposition for perhaps 20 years after the waste is placed. Less settlement requires less maintenance work on the site after it is closed (i.e. less aftercare).
- To ensure that the settlement is as uniform as possible. If there are bulky items in the waste, such as furniture and appliances, drums and other large containers, and car bodies, they will eventually collapse, resulting in larger settlement above them than above the surrounding, more uniform, waste. It is therefore important that such bulky items are broken up or flattened when they are placed in the waste. If drums cannot be flattened they should be filled with waste. It is desirable that waste should be mixed, placed and compacted in a uniform way so that the final settlement is as uniform as possible.

Compaction is most effective if done in thin layers. The waste is compacted as vehicles drive backwards and forwards over it. The waste may be compacted in horizontal layers or placed uniformly on the working face (a 1:3 slope with freshly deposited waste behind it as shown in Figure C4.1) and compacted by machines driving up and down the slope (Photo C4.3). If the waste is covered with soil each day it is preferable to compact on the working face so that a deeper lift of waste can be placed each day, in order to keep the ratio of cover soil to waste is as low as possible. (This ratio should be low to save expenditure on daily covering and to minimise the proportion of the volume of the landfill that is occupied by daily cover soil.)

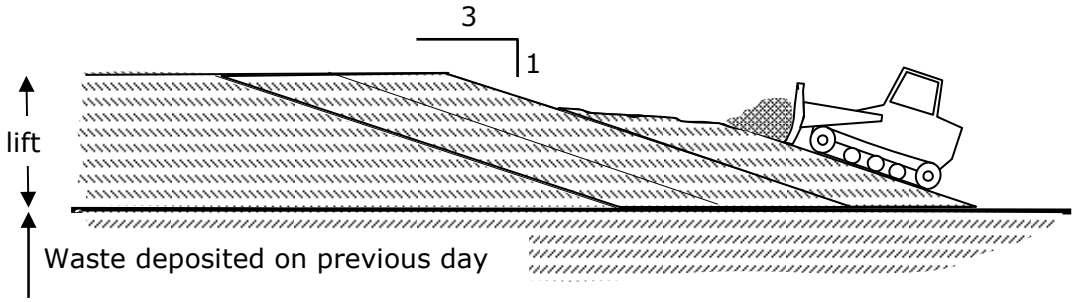

Figure C4.1 Placing and compacting waste up the working face. (No daily cover shown.)

Photo C4.3 A landfill compactor at the working face, moving up and down the slope to compact the waste.

The machinery used for placing and compacting waste on a landfill has been introduced in Section 4.3.4. Large landfill compactors are clearly effective in compacting waste, but they have a high fuel consumption and maintenance can be expensive. The projecting teeth on the wheels of landfill compactors are worn down surprisingly quickly by the waste. The tracks of tracked vehicles can be damaged by items of waste getting between the tracks and the guide wheels. The rubber tyres of wheeled vehicles are also damaged by the waste; punctures can be avoided by filling the tyres with foam instead of air.

Compaction is more critical with some types of waste than others. Estimates of the densities of waste in the landfill described in Section C6 show that high values can be achieved for some types of waste without intensive compaction. Compaction may also reduce the scattering of plastic bags and paper by the wind, and this may be a reason for ensuring that the deposited waste is well compacted. In every situation vigilance is necessary to ensure that bulky items are flattened so that settlement is as uniform as possible and cavities do not form within the waste.

3. Cover

Daily cover

As has already been discussed in Section C4.1.4, there are different opinions regarding the need to cover the deposited and compacted waste with soil each day. There is greater agreement that waste should be covered with 24 hours of arriving at the disposal site, either by soil or by the next day's waste. Some wastes, such as slaughterhouse waste and some types of healthcare waste, should be covered immediately, either by municipal waste or inert material. In some situations in which daily soil cover is considered necessary, it may be wise to operate without soil cover for a short period (two to three weeks) to assess whether daily soil cover is really essential. In some places there may be inert wastes from industry that can be used for daily cover – suitable wastes should not be carried away by the wind, should be suitable for driving on – whether wet or dry – and should not have large voids (because gaps in the cover would favour fly breeding and encourage birds and dogs). Demolition waste may be unsuitable for daily cover if it contains reinforcing

bars, nails and glass which can damage vehicle tyres and be a hazard for people working on the site.

To avoid high transport costs, cover soil should be available close to the site, or from the site itself. On-site excavation of cover soil may have the advantage of increasing the volume available for waste deposition, but care should be taken to ensure that the excavation does not approach within several metres of the water table or penetrate to fractured rock which would provide no protection for the groundwater. Additional plant might be needed for extracting, transporting and placing the cover soil. Clayey soil should not be used for daily cover, because, when wet, it adheres to the wheels of the machinery and vehicles, and because it forms internal barriers to the downwards movement of water within the mass of the waste. The thickness of the daily cover soil layer is usually specified as at least 150mm, but it is difficult to be precise about the actual thickness when it is laid. By monitoring the volumes of soil cover that are used for a known area is it possible to estimate the average thickness of the layer of cover soil that is being laid.

Temporary or interim cover

Temporary cover is laid over areas that are not in current use but will be opened up later for further placing of waste. The depth of soil for temporary cover should be more than for daily cover. In areas of significant rainfall such areas may also be covered with impermeable sheeting, weighed down with bags of soil. Used tyres should not be used for this purpose if there is the possibility that rainwater caught in the tyres will allow mosquito breeding. Temporary cover soil can be stripped off and stockpiled when the area is once more to be used for depositing waste.

Final cover

The cap or final cover may be one metre thick or even more, and may include an impermeable layer to prevent the escape of landfill gas and also to prevent the infiltration of rainwater into the waste. Moisture and a slow downwards flow of water are needed to sustain the microbiological processes that eventually stabilise the waste so that it produces no more gas and does not subside further. If the final cap is impermeable it is recommended that leachate is recirculated to the waste below this cap so that the decomposition of waste can continue until the waste is stabilised. If this is not done and the waste is kept in a dry condition, gas generation, leachate flow and settlement will stop, but the waste will not be stabilised. If, perhaps many years later, the impermeable cap is damaged, allowing water to come into contact with the waste, microbial decomposition processes will restart and cause serious environmental pollution because the means of treating leachate and controlling the gas will have long since been abandoned. In order to minimise the time required for aftercare (until the waste is stabilised) it is recommended that some water or leachate continues to percolate down through the waste until the settlement of the waste and generation of gas are hardly detectable. The measures used to allow this movement of moisture will depend on the climate and the permeability of the top layer of waste.

The final cover should be very flexible so that it is not damaged by the differential settlement of the waste beneath it. The cap should also include a layer of topsoil to

encourage the growth of plants that will improve the appearance of the completed landfill and stabilise the soil against wind and water erosion. If the topsoil does not contain the seeds of native plants it will be necessary to sow seeds that will provide a vegetative cover. Compost is useful in improving soil fertility and retaining moisture for the plants. (There is also some evidence that moist compost assists the oxidation of the methane in landfill gas to carbon dioxide.) It is not advisable to plant trees in the cap layer of a closed landfill because the roots of the trees may increase the permeability of the cap and their growth may be stunted by the landfill gas in the soil and waste. If trees are to be planted it is advisable to increase the thickness of the final cover so that there is enough soil for the roots.

C4.4.3 Cells for special purposes

In municipal landfills most of the waste is put together into the same cell, and only one cell is used for municipal waste until it is full, by which time the next cell should have been prepared. However, there may also be special cells for particular purposes, such as:

- There may be a cell near the entrance for use during or after periods of heavy rain, when it would be difficult for trucks to reach the cell that is in current use.
- There may be a cell for hazardous industrial wastes that has a more secure base lining and leachate management system than the rest of the site.
- There may be a cell for healthcare wastes which is more secure than the rest of the landfill site, so that waste pickers cannot get access to waste from hospitals which is infectious but also attractive for recycling.
- If it considered possible that the decomposed waste will be excavated after some years for use as soil conditioner, there may be a separate cell for wastes that should not be excavated, such as asbestos, medical waste and industrial sludges. The area of this cell should be clearly marked when the site is closed so that it is not excavated.

C4.5 Operation of small landfills

Small landfills present a number of challenges because of the need to minimise costs – including the input of experts and the use of machinery – while minimising pollution. When it is economically feasible to do so, solid wastes from small communities should be transported to the nearest municipal or district landfill. However, this is not possible in many cases, such as for wastes from construction camps and towns and villages in remote areas, and so a small local landfill must be established and operated.

As with all solid waste management planning, the primary objectives should be to minimise the amount of waste and recycle as much as possible. Quantities of packaging are likely to be lower per capita than in a larger community; recyclable packaging could be cleaned and segregated by the households and stored for occasional transport to the nearest dealers or to recycling factories. It is likely that food waste is already used as animal feed, if this is an option, and it may be possible to encourage the composting of biodegradable material for improving the soil.

Because it is not possible to employ the methods of site development and operation that have been discussed here in connection with large landfills, much depends on the siting of the waste disposal facility. It should be located on soil with a low permeability so that some natural attenuation of the leachate can take place. It should be downwind of any houses and the flow of groundwater should be such that any polluted water is taken away from any water sources and well dispersed before reaching any other community. The water table at the site should be of sufficient depth so that it never comes within two metres of the deposited waste – though a greater depth is much to be preferred. There should be sufficient soil on or near the site for covering the waste.

The key to satisfactory operation of small sites is to allocate the responsibility for operating the site to a person with sufficient training and motivation to ensure that the basic operational requirements are adhered to. Affordable methods of operation should be devised to meet the basic objectives of landfilling. Suitable methods vary according to the size of the operation, the nature of the waste and the features of the site.

Ideally, the site should be surrounded by a fence or wall to keep animals out, to warn unauthorised people that they are not supposed to be on the site, and to catch windblown paper and plastic. Fences should be made of chainlink mesh or local materials that are sufficiently porous so that the wind can pass through it but plastic bags and paper cannot. However, it is common for fences to be broken either by waste pickers to allow access or where they cross customary paths, and materials may be taken from them for use elsewhere. Regarding this issue, as well as many others, it is useful to learn from the experiences at other sites.

Appropriate measures should be taken to minimise the amount of rainfall and surface runoff that comes into contact with the waste. These measures should include intercepting ditches to catch surface runoff and laying the waste so that there is a slope on the top surface of the deposited waste to encourage the shedding of water and to prevent ponding in surface depressions that would otherwise form as a result of uneven settlement.

A common method of land disposal for small site is to dig a trench at least two metres wide at the base and with sloping sides so that the waste can be deposited in the trench and to a convenient height above it. The excavated soil is used as cover on the top and sides. On small sites this would require the visit of a small excavator or wheeled loader when it is needed to dig a new length of trench and undertake other necessary site maintenance. The daily use of a means of transporting the cover material – such as a small tractor and trailer or a donkey cart – would also be required. For sites receiving less than 25 tonnes of solid waste per day the waste can be levelled manually using long-handled rakes. The soil can also be spread on the waste manually, using appropriate tools. Depending on the nature of the waste, without much compaction, the surface of the deposited waste may be too soft for trucks to drive on. Since it is essential that the waste is unloaded as near as possible to its final resting place it may be necessary to improve the driving conditions on the waste by placing railway sleepers or metal plates for the trucks to drive on or by making a temporary road using a geotextile covered with crushed stones or hardcore.

An interesting proposal for operating a small site is to use an agricultural tractor fitted with a *push-off buckrake* at the rear, as described in Annex A5.4 of [Coffey and Coad, 2010]. The buckrake is widely used in farming for carrying and distributing various materials and it could be used for spreading solid waste at a small landfill. The passage of the tractor backwards and forwards would help to compact the waste. The tractor could also be fitted with a front-end bucket for excavating and spreading cover soil.

As already mentioned, bulky items should be flattened or filled with waste.

Few references to small landfills can be found in the literature, so experiences of operating small sites should be pooled and discussed so that improvements can be made and operators trained.

C4.6 Closure and aftercare

C4.6.1 Closure

After the last load of waste has been brought to a landfill, it is time to prepare the site for the next phase of its life. The initial plan for the landfill should have included proposals for the final contours and for the ongoing use of the site, but experience develops during the years of operation and planning considerations change, so the final plans may differ from those originally proposed. Nevertheless, the landfill must be constructed according to a sound plan at all stages of its development.

The closure of a landfill should not involve reshaping of the landfill. It is very important that the side slopes are constructed at the required gradients because reducing the slopes at the closure stage is a major and expensive undertaking and may result in considerable odour nuisance. Parts of the landfill that reach the planned final elevations should be completed and covered immediately, rather than waiting until the placing of waste in the entire site is concluded.

The objectives of the closure stage are

- to ensure that all drainage systems are in place and functioning,
- to minimise or control the infiltration of water into the mass of the waste, by means of the final cover, in order to control the production of leachate,
- to finalise the gas collection or venting system for continuing flaring or utilisation of the gas,
- to complete the placing of the final cover soil and to spread topsoil so that the site no longer looks like a landfill but blends in with the surrounding topography and vegetation,
- to take all possible administrative and physical action to ensure that the site is not used for unsuitable purposes. (For example, there should be effective restrictions governing building on the site to ensure that the design of any structure to be built in the future takes account of the low bearing capacity of the landfilled waste and the generation of methane),
- to discourage the dumping of waste at the former entrance or in the vicinity of the site,

- to remove any equipment, buildings or infrastructure that are no longer needed.

It is recommended that the plans for the closure of the site and the execution of the work are approved by the responsible government department. When the closure works are completed and approved, the aftercare phase can begin.

C4.6.2 Aftercare

Microbiological processes in biodegradable waste in a landfill can continue for decades after closure of the site. The ongoing microbial activity is evidenced by the generation of gas and the reduction in volume of the solid material, which results in uneven lowering of the surface. Polluting leachate may continue to flow out of the site even after microbial activity has effectively ceased. *Aftercare* is the name given to the monitoring and remediation work that is required after a landfill has been closed.

The theoretical end of the aftercare period is signalled by the complete stability of the site, meaning that no more leachate or gas are being produced and the surface of the site has stopped sinking. Estimates of the time needed for the waste to stabilise are difficult to make; an initial aftercare period of 30 years is not uncommon.

Aftercare involves some or all of the following tasks:

- ensuring that the drainage systems keep working satisfactorily,
- preventing pollution of the water resources. The systems for collecting and treating leachate must be monitored and kept in good operating condition. This may include inspecting and cleaning the leachate collection pipes. The quality of water in the monitoring wells must be tested regularly and any necessary action taken.
- maintaining the landfill gas management systems in good working order. Flares should be kept burning and all control and utilisation systems monitored and maintained. On large sanitary landfills where the landfill gas is used for electricity generation, it may be necessary to flare residual gas when the yield is too low to be utilised economically for electricity generation.
- monitoring the surface of the landfill. The cover of the landfill should be checked for the following problems:
    - cracks in the surface which may allow water to infiltrate into the waste and increase the chance of fires,
    - indications of subsurface fires, such as smoke, charred soil, warm areas and depressions caused by the collapse of voids that have been formed by fires. If the fires cannot be extinguished by sealing any cracks in the cap, it will be necessary to dig down to the seat of the fire and remove the burning material. When the fire has been extinguished, it may also be necessary to fill any voids that have been created by the fire.
    - settlement that results in depressions that collect surface water. Water that is ponded in this way may increase infiltration into the waste and allow the breeding of mosquitoes.
    - erosion of the cover soil by rainfall runoff flowing down the sloping sides. If this is occurring it may be necessary to fill the gullies so caused, improve the vegetative cover or construct contour ridges that prevent downwards flow.

  - wind erosion of the cover soil may occur if a vegetative cover has not developed.
- Preventing the dumping of waste near the site. Occasional transporters of waste may not know that the site has been closed and continue to bring their waste to the site, dumping it near the former site entrance. Some drivers may dump waste near the entrance because it is easier and cheaper. Preventive measures may include signs informing transporters of the location of the new site and of penalties for dumping, fencing, closed circuit television surveillance and police involvement. Any dumped waste should be cleared quickly so that it does not encourage others to dump there.
- Preventing unauthorised access. Fencing and gates should be kept in good condition so that livestock are not allowed to damage the vegetation and cover of the landfill, unauthorised structures are not built and the waste is not excavated for any unauthorised purpose. If access for authorised purposes is not required, entrances can be blocked by ditches or barriers of soil or debris.

C4.7 A final comment on landfilling

The tasks involved in establishing, operating and providing on-going maintenance of a sanitary landfill may seem complex and onerous, and it may seem that incineration or composting are more straightforward and less demanding. This perception is not valid in most low- and middle-income countries, for the following reasons:

- It must be remembered that costs of incineration are very significantly more than the costs of landfilling. After the recovery of recyclables the waste will generally not burn without the addition of unaffordable quantities of fuel.
- Incineration produces residues that must be landfilled and composting cannot treat all of the waste for various reasons. Landfilling is therefore necessary after these methods of treatment.
- The machinery that is used in landfilling is simpler and more robust that the machinery required for incineration or large-scale composting, so landfilling is more reliable and does not require specialist mechanical engineering expertise.

Investments and challenges are involved in upgrading dumps into sanitary landfills, but success is achievable. Sanitary landfilling, in conjunction with reduction, reuse and recycling, has been shown to be environmentally acceptable, affordable and sustainable.

C5 Inert, difficult and hazardous wastes

Inert, difficult and hazardous waste have almost nothing in common except that they all require treatment and disposal that is different from the requirements of municipal solid waste.

C5.1 Inert wastes

Inert wastes are not subject to microbial decomposition and do not have constituents that dissolve in water, so they can be disposed of without the need for measures to prevent water pollution or to manage gas. It is therefore much easier to find a site for the disposal of inert waste, and the construction, operation and closure of such sites are all much simpler. No aftercare is needed. Unfortunately, it can be very difficult to prevent the dumping of types of waste that are not inert at these sites, and loads of waste which are mostly inert may contain significant amounts of biodegradable material. This mixing often arises when containers for inert waste are accessible to the public and so are used for household and garden waste. Paper, which is biodegradable, is often found in construction and demolition waste. If strict control of incoming waste (to ensure that only inert waste is accepted) cannot be guaranteed, it may be advisable to take all waste to the municipal waste landfill.

If control of the incoming waste is ensured, inert wastes should not be sent for disposal to sanitary landfills where the cost of disposal of one cubic metre is considerably more than the cost of disposal of the same volume in a disposal site intended only for inert waste. The exception to this rule is that sanitary landfills need inert waste for building temporary site roads, for building cell walls and perhaps for daily cover. For this reason sanitary landfills accept a controlled quantity of selected inert waste than can usefully serve these purposes.

According to the definition of *inert* given above, asbestos is inert. However, asbestos is classed as a hazardous waste because inhalation of fibres in asbestos dust can lead to asbestosis, a fatal lung disease, and other problems. Asbestos waste should be handled only by people wearing protective clothing and using the appropriate type of respirator. It should be placed in a plastic bag which is then enclosed in another plastic bag and buried in a landfill where it will not be excavated at a later date. If a landfill containing asbestos waste catches fire, there is a serious risk of air pollution if the fibres are liberated from their bags and carried into the air by the fire. Glass fibres – released from weathered fibreglass when it is bent – are also inert, but of concern because of possible health risks.

C5.2 Difficult wastes

Difficult wastes are generally not specified by legislation, but require separate treatment in some way because of difficulties in handling or disposing of them. To some extent the designation of a waste as "difficult" depends on the methods of treatment and disposal that are used for the majority of the municipal solid waste.

The following list suggests some types of waste that might be classed as difficult and explains why this categorisation might be justified.

- Slaughterhouse waste, dead animals and fish waste are objectionable in appearance and smell, and attract dogs and flies. They should therefore be buried under fresh municipal waste, either by dumping them at the bottom of the lift and then covering them with at least a metre of municipal waste, or by digging a trench in the waste,

putting the difficult waste in the trench, and then covering it with municipal waste. Such wastes increase the concentration of ammonia in the leachate.

- Sludge and septage. Inorganic sludges are generated by chemical industries and drinking water treatment plants, often as a result of the precipitation of metals to form the sludge. Organic, biodegradable sludge is generated in wastewater treatment plants. There are processes to dewater and dry sludge, but usually the dried material still contains about 30% water. Many sludges have much higher water contents. Septage is the liquid that is pumped out of septic tanks, and because of the difficulties of pumping septic tank sludge that has a high solids content, the septage that arrives at disposal sites may be more than 95% water. The liquid pumped out of cess pits and pit latrines is similar in composition. The primary problem caused by sludges is the addition of significant quantities of water to the deposited waste, increasing the volume of leachate to be treated and sometimes making the surface of the landfill difficult or unpleasant to walk or drive on. For this reason many landfills will not accept wastes with a high water content, and alternative treatment facilities such as lagoons may be used. When the climate and the nature of the sludge permit, sludge drying beds may be used to reduce the moisture content of the sludge so that it is accepted for landfilling. Because of the offensive smell of sanitary sludges, they should be buried under municipal waste as soon as they are deposited. The high bacterial content of sanitary sludges is not usually a problem because of the need to treat or attenuate the high pollution potential of the leachate from the general municipal waste.
- Vehicle tyres. The life of vehicle tyres can often be lengthened by retreading or regrooving them, but eventually every tyre becomes unsuitable for further use on a vehicle. Tyres can be recycled as shoe soles or buckets, or partly buried to mark pathways or to stabilise slopes. Tyres can be used as fuel if combustion conditions are carefully controlled. In spite of these options, large numbers of tyres remain to be disposed of as solid waste. Because of their size, elasticity and resistance to decomposition they cause problems in landfills and tend to rise to the surface of the waste. Tyres burn fiercely in the open air, producing thick clouds of noxious black smoke, and a fire in a stockpile of tyres can be virtually impossible to extinguish. Left in the open, tyres collect rainwater in which mosquitoes can breed. If tyres are shredded or cut into pieces they cause fewer problems in landfills, but they are difficult to cut because of the combination of tough, flexible rubber with high-tensile steel wires. Powerful shredders can rip them apart. If the tyres must be landfilled whole, they should be distributed over the area of the cell and placed near the bottom of the waste in each cell.
- Abandoned vehicles should be taken to scarp yards so that oil and fuels can be removed and as many components as possible salvaged for resale or recycling. If possible the remaining hulks should be compacted into bales for recycling, but the presence of copper wires reduces the value of this scrap because it impairs the properties of the remelted steel. Car bodies (whole or part) should be flattened before they are covered with waste in a landfill so that they do not form voids which later collapse. If possible, such large items should not be placed in landfills.

- Waste electrical and electronic equipment (WEEE or e-waste) There is increasing concern about discarded computers, mobile phones, television sets and other electronic goods because the rapid development of the technology of these items leads to short useful lives and increasingly large numbers being discarded each day. The resale value of such items is low so reuse is not an effective option. There are companies and other organisations that claim to recondition or upgrade used items for resale and reuse, but some of them are using this claim as a means of exporting these items to a low-income country where they are broken up to reclaim small amounts of valuable and rare metals. When some of these metals are handled and processed without sufficient care there is a risk to the health of the people involved.

  Electrical appliances such as refrigerators and washing machines (often referred to as *white goods*) may be repaired and reconditioned for reuse. Old refrigerators, freezers and air conditioners use chlorofluorocarbons (CFCs) as a refrigerant, and when this liquid is released into the atmosphere it contributes to the damage of the ozone layer[27]. If an appliance is sent for disposal or recycling, any CFC refrigerant should be removed before the shell is baled for recycling or flattened for landfilling. Refrigerators and freezers can be dangerous on disposal sites because children may become trapped inside them. If large appliances are dumped at disposal sites they cause uneven settlement.

C5.3 Hazardous industrial wastes

Key points for decision-makers regarding the management of hazardous industrial wastes have been discussed in Section B3.6. The body of information regarding hazardous waste management is extensive and it is beyond the scope of this book to give more than a brief introduction. Much has been learned since the middle of the twentieth century regarding safe technologies for treating hazardous waste and means of ensuring that at least most of the hazardous waste generated by industry is managed in a satisfactory way.

The challenges facing a government agency that is responsible for ensuring safe management of hazardous industrial wastes include:

- defining which wastes are classed as hazardous and setting up laboratories that are able to test wastes accordingly;
- determining the scope of the problem – the kinds of waste being produced, the locations of the industries that produce them, the quantities of each type;
- developing legislation and regulations that can be implemented and an effective system of documentation, inspection and jurisprudence for enforcing the legislation;
- informing industrialists of the seriousness of the issue, the requirements of the legislation and the acceptable means of treatment and disposal for each type of waste

[27] The ozone layer in the upper atmosphere is very important because it protects the surface of the earth from harmful radiation.

- developing, or encouraging the private sector to develop, the infrastructure and facilities needed for treatment and disposal of the types of hazardous waste that are being generated.

The methods that can be used for treating hazardous industrial waste depend on the properties of the waste. Organic materials can usually be broken down into simple, harmless substances by incineration in purpose-built incinerators that provide the right combustion conditions (time, temperature and turbulence) and have elaborate treatment processes for cleaning the exhaust gas. However, wastes containing mercury or other toxic heavy metals should never be incinerated because this would disseminate these toxic elements into the atmosphere. Such wastes should be buried in secure landfills. Inorganic wastes that might be dissolved may need to be encased in a concrete container or mixed with a type of cement that sets hard and prevents soluble materials from being dissolved. Whenever possible, hazardous wastes should be treated to make them less hazardous – a simple example is the neutralising of acid wastes before disposal. Great benefits can be derived from reducing the quantities of hazardous wastes or from using raw materials that produce wastes with a lower impact on the environment, and from reusing or recycling hazardous materials that would otherwise need expensive treatment and disposal.

Great care is needed when disposing of hazardous wastes in landfills. The landfills should be secure in the way that unauthorised people are kept out and in the way that leachate is collected and treated. Certain wastes should never be mixed – for example, acid wastes and sulphide wastes since they react to form lethal hydrogen sulphide. Cyanide wastes must be treated with similar care. Acid wastes can also dissolve toxic metals from hydroxide sludges. Landfills that receive hazardous wastes should therefore have several active cells, clear signs and very strict supervision, in order to protect drivers, site staff and the environment.

Industries should regard the full costs of safe disposal of their hazardous wastes as part of the costs of the processes that they employ. In many cases industries are unwilling to accept this responsibility and so it is necessary for government bodies to develop realistic strategies for both creating an acceptance of this responsibility by industries and ensuring that the environment and public health are protected.

C5.4 Hazardous household wastes

Small quantities of a range of hazardous wastes may be discarded with general municipal wastes by households. The most common types are fluorescent tubes and compact fluorescent lamps (which contain mercury), certain cleaning liquids, paints and solvents and some types of dry cell batteries. Syringes and needles may also be discarded after self-treatment, drug abuse or a house visit by a medical practitioner.

In addition, some cottage industries and small businesses may discard more significant quantities of hazardous wastes in waste that is mixed with household waste. Paints, varnishes and solvents from furniture finishing and car body repairs are of particular concern. Used dry cleaning fluids may also find their way into municipal waste.

C5.5 Healthcare wastes

Perhaps the two most important actions that can be taken to minimise risks from healthcare waste are to prevent handling of used sharps (needles and blades) and to ensure that toxic chemicals and cytotoxic[28] wastes are not discarded carelessly but are treated as industrial hazardous wastes. For some people the main concern may be to ensure that blood and recognisable body parts are not exposed to public view.

Used *sharps* (needles and blades) discarded after any form of medical treatment should be put immediately into a strong one-trip (disposable) container which should be sealed before it is full and sent for treatment and disposal. The container should not be opened, but destroyed with its contents. Satisfactory exceptions to this practice include sharps containers that are emptied and disinfected by a machine at a central plant, and some of the devices that cut or burn needles. In some places needles are bent before being discarded to that they cannot be reused by unscrupulous practitioners. Unfortunately, some hospitals and clinics decide that they cannot afford to buy a regular supply of such containers and so alternative methods are developed, some involving high risk to staff or waste handlers. Depositing needles into a pit which is sealed with concrete when full can be a satisfactory alternative if there is no possibility of skin contact with the needles and blades when they are being taken to the pit.

Waste body fluids may splash onto waste handlers if the waste is not handled correctly – for example if waste is being compressed into a bin. Such splashes can transmit hepatitis, as well as being very unpleasant. Personal protective equipment – such as gloves and goggles – is essential.

As mentioned in Section B, the two main methods of treating infectious healthcare waste are incineration and autoclaving. Each method has its advocates, but there is a trend in favour of autoclaving. Autoclaves do not radically change the appearance of the waste, and some processes are effective only if the waste is cut up and bags are torn open. For these reasons shredders may be used before or after the waste has been autoclaved. Although it is common for autoclaved waste to be shredded, there are some very convincing reasons for not shredding such waste[29].

Another method of disinfecting healthcare waste uses microwaves. The waste must be shredded before it is processed in this way.

Chemical disinfection is another option. Some of the chemicals that are used in this way require careful disposal to avoid environmental pollution. Inadequate chemical disinfection can be dangerous if it is believed that the waste has been effectively disinfected when, in fact, it is still infectious. This situation may arise if wastes are soaked in a solution of bleaching powder or sodium hypochlorite that has lost by evaporation most of its chlorine. (The author has observed cases when used sharps have been soaked in a hypochlorite solution which had no detectable smell of chlorine.)

[28] Cytotoxic medicines are used in chemotherapy for treating cancer and are very dangerous if not administered by experts.

[29] See, for example, http://www.sanipak.com/pdf/mwm-november_05.pdf

In many cases, the key to safe disposal of healthcare waste is supervision, not technology. Training and supervision are needed to ensure that sharps waste is segregated from other types of waste and stored, handled and disposed of in a careful way. Hazardous chemicals and pharmaceuticals should not be poured into the drainage system, but stored until a safe means of disposal can be found. Until a means of effective disinfection is available, other healthcare wastes should be dumped into a pit and covered, or landfilled in a trench and immediately covered with at least a metre of municipal waste. It is unlikely that healthcare wastes will be disposed of in this way unless there is close supervision of the procedure. Without segregation and supervision it is very probable that healthcare wastes will be landfilled like any other municipal waste or recycled by waste pickers – at considerable risk to themselves and to the public.

C6 Case study: Gaza Middle Area landfill

C6.1 Introduction

This final section presents a case study of a landfill. There is no intention to suggest that the design and method of operation of this particular landfill is a pattern that should be followed everywhere, because, around the world, there are so many variations in geographical conditions, waste characteristics, institutional capacity and other factors. It is included here because it illustrates a thoughtful and successful approach to sanitary landfilling and provides some very interesting operational data.

This case study is of a fairly small landfill in the Gaza Strip in the Middle East. It included some innovative features and provided some interesting insights. It was designed and built in the late 1990s, served a population of around 370,000 and received about 240 tonnes of waste per day. The climate of the Gaza Strip can be described as semi-arid and the waste – as received at the site – was about 70% biodegradable organic matter.

The landfill was developed with technical and financial assistance from GTZ of the German Federal Government. Inputs from German experts consisted of a long-term technical advisor and short-term specialist inputs.

This landfill was used to generate a considerable amount of useful data and demonstrates an excellent approach to data collection, both in the careful monitoring of operations and also from some experimental observations. More information on this site and the solid waste management system that included it can be found in Scheu (2000) and Skat (2001).

C6.2 Site selection

The Gaza Strip is one of the most densely inhabited territories on Earth, and land ownership is complicated by the fact that some of the owners are overseas and hard to contact. In view of these difficulties and since there was some capacity remaining in the existing dumping site, it was decided to rehabilitate this site rather than to look for a

new site. This site was at a convenient location in relation to the communities it served, but it was in an area with relatively few inhabitants.

C6.3 Rehabilitation of the site

A major decision that had to be made concerned the issue of water pollution. At that time the Gaza Strip obtained all its water from boreholes, and all the aquifers that were available to the Palestinian residents were of poor quality. It was therefore determined that protection of groundwater quality was of prime importance. The next question to consider was whether the landfill would pose a significant threat to groundwater quality if no measures were taken to prevent leachate from infiltrating into the ground.

Pollution by leachate is often considered to be a result of heavy rainfall, and the rainfall in Gaza was low – between 200 mm and 450 mm per year – with evaporation rates that were more than 1200 mm per year. Two boreholes were drilled to investigate the underlying soils and to determine the depth to groundwater. In some situations in such a climate it would be considered that leachate quantities would be insignificant. In this case it was decided that measures would be needed to protect this groundwater, even though this entailed considerable expense. Operational experience showed this to have been the correct decision, and an important one.

Protecting the groundwater involved building an impermeable layer underneath the waste, and so it was necessary to move all the existing waste into one half of the site to lay the impermeable base on natural ground, and then move the waste to the lined half in order to complete the lining of the site. This was clearly an expensive operation that presented the risk of generating considerable smell.

The next issue was to decide how the impermeable base lining should be constructed. As has been discussed in Section C4.3, the most common materials are clay and plastic sheets, but in this case it was decided to use asphalt, because of anticipated difficulties in importing lining materials and bringing in the necessary expertise, and because the capacity for laying large quantities of asphalt already existed in Gaza, following the completion of the airport. The asphalt was laid in two layers, with a thin layer of bitumen between the layers. The properties of the layers were checked by taking and testing core samples. Photos C6.1 a, b & c show the asphalt being laid. Some difficulty was experienced in laying the asphalt on the side slopes of the site using ordinary road-making equipment, but these difficulties were overcome. Leachate collection was by means of a layer of gravel over the asphalt that led the leachate to a central drain. The leachate flowed over a Vee notch measuring device into lined storage tanks, from where it would be evaporated and recirculated to be sprayed over the waste.

a) The site is prepared for the asphalt

b) The asphalt is laid on the base (Note the waste piled up on the other part of the site)

c) Laying the asphalt on the sides

Figure C6.1 Laying the impermeable asphalt layers[30]

A site access road 1.4 km long was constructed. To save money and because the number of trucks using it was relatively small, it was made as a single track road with passing places. The site was fenced to discourage unauthorised access and the spread of windblown litter. A weighbridge (Photo C6.2) was constructed at the entrance with a computerised recording system in an office (which was made from a shipping container). Power for the computer was supplied by solar panels. The weighbridge station was not only important for determining what each community should be charged for collection and disposal, but also enabled monitoring of the collection crews and the calculation of useful operational data.

Photo C6.2 Weighbridge at site entrance

C6.3 Operations

The site was operated in the daytime only and for six days each week. One tracked loader (gross weight 19 tonnes) was used to operate the site, and a bulldozer was hired to replace it when it was being maintained or repaired. Other plant was hired in or earthmoving work was contracted out, as required.

Some of the decomposed waste was screened to determine whether it could be used as a soil improver. Laboratory tests showed that its organic content was lower than for normal composts, but higher than the organic content of the natural soil. The content of heavy metals and salt was found to be low. It was therefore decided to install a rotary screen (20mm mesh size) so that large quantities of decomposed waste could be used as a soil improver and for the final cover on the landfill. The rejects could not be recycled and so were returned to the landfill. Photo C6.3 shows the fine decomposed material and the rotary screen.

[30] All the photographs in this Section have been kindly provided by Manfred Scheu.

Figure C6.3 Fine material coming from the screening machine

The quantities of leachate that were produced were much higher than anticipated, necessitating the construction of a second storage tank that increased the volume of leachate that could be accommodated to five times the requirement that was initially estimated. High flowrates of highly polluting leachate were observed even during the dry season when there was no rain. This clearly showed the correctness of the decision to build an impermeable liner and drainage system. Pumps recirculated some of this leachate to the accumulated waste, to increase evaporation and in an attempt to accelerate the process of decomposition of the deposited waste. Data on leachate flows and recirculation are provided in Section C6.5. Attempts to recirculate the leachate during the rainy season were not successful, so sufficient capacity was needed to store the leachate until the start of the dry season. Leachate samples were obtained and analysed. Results indicated that the COD was about 40,000 mg/l and that the BOD about 11,000 mg/l. These results are quite similar to those obtained for young landfill sites in western Europe.

No measures were incorporated to collect or vent the landfill gas. The site was considered too small the merit the installation of a gas control system.

No daily cover was used. Operations were limited to a particular working area so that one day's waste covered the previous days'. When an area was filled or was not being used for a time, and before the rainy season, it was covered by a layer of sand and plastic sheeting weighed down by bags of soil, in order to reduce the infiltration of rainwater and so minimise the production of leachate.

C6.4 Reinstatement

When a section of landfill was completed it was covered with a 50 cm layer of screened decomposed waste before being seeded with indigenous varieties of plant to stabilise the cover, reduce leachate by evapotranspiration and improve the final appearance of the site. Local soil was not used for the final cover because it was very sandy and therefore

unsuitable for supporting vegetation. Photo C6.4 shows the vegetation that was established on the final cover of decomposed waste.

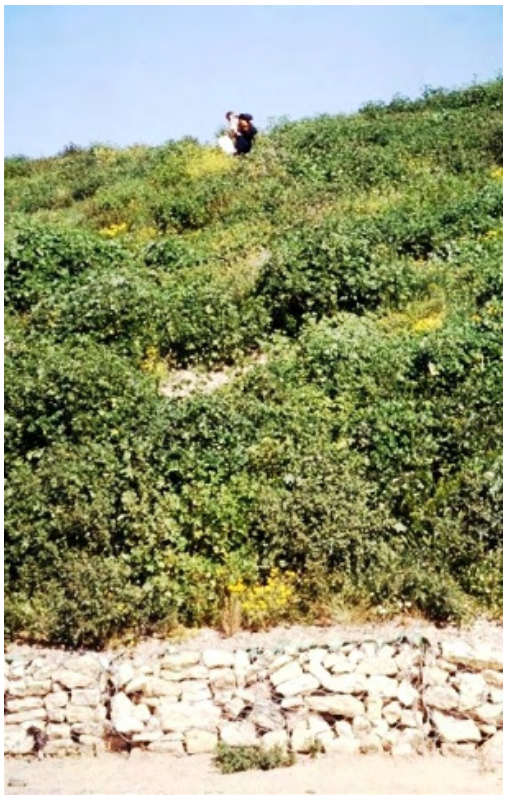

Photo C6.4 Vegetation on the final cover of the landfill.

It was decided that it would not be necessary to provide an impermeable cap to the site. Most of the leachate flow would cease when fresh waste was no longer being added (as discussed in the next section) and the smaller quantities of leachate that continued to flow could probably be evaporated from the collection ponds. In addition, the waste itself was found to be surprisingly impermeable, as discussed in the next section. The addition of small quantities of rainwater would also help to complete the decomposition process and stabilise the waste. Photo C6.5 shows aspects of the landfill.

In the foreground is the first leachate storage pond and the pumping station for recirculation. In the background are plastic sheets providing temporary cover and, beyond them, an area that has been given the final cover and seeded.

Photo C6.5 General view

C6.5 Some interesting observations

a) Leachate flows

There was relatively little difference in the average flows of leachate between the wet and the dry seasons. The average daily flow in the winter (the rainy season) of 1999/2000 was 27.4 m^3/day and during the summer this reduced to 25.4 m^3/day. In one year, when the total weight of waste received was 88,900 tonnes, the total flow of leachate was 9,600 m^3, suggesting that the weight of leachate was a little over 10% of the weight of waste deposited. The flow of leachate can also be expected to increase as the total volume of deposited waste increases. These observations suggest that most of the liquid collected was coming from the waste itself and not the result of rainfall. Water is produced as waste decomposes and is also released from the waste as the pressure on it is increased by the growing amounts of waste above. The nature and initial moisture content of the waste clearly has a major influence on the quantities of leachate that are produced.

b) Bulk waste densities

The density of the material in a landfill can be estimated in two ways. One is to log the weight of waste received in a landfill and survey the site to determine the increase in total volume of the accumulations. This can be called the "virtual density" and enables an estimation of the life of a site based on the incoming tonnage and the total available volume of the site. The other is to dig out waste, measure the volume of the void thus created and weigh the waste that is removed. This is called the "in-situ" density. Results that were obtained at the site are shown in Table C6.1.

Table C6.1 Density estimates for the Middle Area of Gaza

Point of measurement	Average value tonnes/m^3	Range tonnes/m^3
In 1m^3 storage container before collection	0.35	0.27 - 0.43
In 16m^3 truck body (no mechanical compaction)	0.50	0.41 – 0.60
Virtual density in landfill	1.9	1.87 – 1.93
In-situ density in landfill.		1.3 – 1.4

The values for the virtual density were much higher than the anticipated value of 0.9 tonnes/m^3, with the result that the life of the landfill turned out to be much longer than initially expected. The fact that material is lost from the landfill in the forms of leachate and gas explains why the virtual density is higher than the in-situ density. It should be remembered that no heavy compacting machinery was used on the site – the only artificial compaction was provided by the trucks moving over the waste and the tracked loader (which would have exerted a relatively low pressure on the waste).

c) Volume of the screening rejects

It was found that excavating and screening the waste did not result in a significant reduction in the landfill volume, because the rejects occupied almost the same volume as the total amount of waste that had been excavated for screening. In this case the

use of a heavy landfill compactor might have been useful to compact the reject material, but for this particular site the purchase and use of such a machine could not in any way have been justified. The reject material would have burned satisfactorily in an incinerator, but the costs of incineration excluded this option.

d) Low infiltration into waste

The mechanisms of recirculation were investigated by forming a pond of leachate on top of the landfill. It appeared that very little of the leachate actually infiltrated into the waste because the gradual disappearance of this ponded water appeared to be simply the result of evaporation. This low permeability of the waste may have been the result of the high density achieved and the homogeneity of the waste, so that there were no layers of more porous material which would allow the water to infiltrate and percolate downwards. This result suggests that some types of waste might be so impervious that, if the surfaces are sloped, there is little benefit in adding an impervious cap to the top of a completed landfill.

e) Rapid stabilisation of the waste

The waste that was dug up for the initial screening trials showed a remarkable degree of stabilisation – that is it seemed that the decomposition processes had largely been completed in a remarkably short period of time. This suggests that the higher ambient temperatures in the Mediterranean region or the high content of organic matter or moisture may result in much faster rates of decomposition than have been observed in industrialised countries. More investigation is needed regarding this possibility.

f) Costs

The total investment for the site, including the screening plant and an estimate for final cover and closure of the site, amounted to US$ 4.8 per cubic metre of capacity. The annual running costs in 1999, including salaries and operation and depreciation of the machinery were US$ 1.8 per tonne of waste delivered.

C6.6 Key points

- In some situations an asphalt liner may be preferable to conventional lining systems.
- Municipal waste with a high content of biodegradable matter can generate high volumes of leachate, even in the absence of rainfall.
- Some types of municipal waste reach high virtual densities, even if landfill compactors are not used.
- Infiltration into landfilled waste may be very low for some types of waste.
- There is much to be learned about landfilling outside industrialised countries, so it is important to collect as much data as possible from landfills in such places. A mechanism is needed for disseminating such information to landfill operators and designers.

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