Technology Transfer for Development
WASTE Consultants

Organic Waste

Urban Solid Waste Series 1

Options for small-scale Resource Recovery

Inge Lardinois
Arnold van de Klundert (eds.)

TOOL

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WASTE Consultants is a company for small-scale development projects in countries in the South and works with organizations that aim at sustainable improvement of the living conditions of the urban low-income population and of the urban environment in general. WASTE Consultants is active in four fields: solid waste management and resource recovery, low-cost sanitation and liquid waste management, bicycling as a means of urban transport, and community enablement for neighbourhood improvement. WASTE Consultants opts for a multidisciplinary and integrated approach in which various experts with different backgrounds and experiences both from the North and the South cooperate. The company operates under the corporate body of the WASTE Foundation to express its notfor- profit identity and to safeguard its development goals.

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Preface

A few years ago the Undugu Society of Kenya (USK), a non-governmental organization (NGO) working in the low-income areas of Nairobi, met with community members in the Kitui neighbourhood to discuss the opportunities they saw to improve their living conditions. Their major concern was employment, and the question was raised whether employment could be created from the waste lying around the city and industrial areas. Lacking the necessary knowledge and experience, USK asked WASTE Consultants to assist in setting up waste recycling activities. This was the starting point for the socalled WAREN project (WAste REcycling in Nairobi).

Rather than 'reinvent the wheel' and try to develop recycling activities, WASTE Consultants decided to involve local consultants from six other cities where resource recovery efforts are better developed than in Nairobi. General terms of reference were drafted to guide the research in these cities, adjusted to suit specific local conditions. The consultants investigated the technologies used, the products made and the markets covered by micro-entrepreneurs who recover urban solid waste materials in Cairo, Bamako, Accra, Manila and Calcutta. In Nairobi a similar research was done to inventorize the current state of recycling and to identify new implementation opportunities.

Ten major materials were identified: rubber, plastic, motor oil, cooking oil, tin cans, photochemicals, broken glass, bone and horn, household batteries and organic waste. Attention was also paid to issues such as the size of workforce and type of labour within enterprises, skills, government policies on recycling, and environmental legislation affecting resource recovery. These issues form the context within which resource recovery may form the basis of viable enterprises, and determine the extent to which recycling activities can be introduced in other cities.

A wealth of information was obtained from these six cities. The analysis and adaptation of the research reports into a coherent series of books, proved to be a difficult but challenging task. Additional data and literature gathered during the research were included. On the basis of this material, the present book on organic waste was written. Topics covered in future books are: plastics waste, rubber waste and hazardous waste (including photochemicals, household batteries and motor oil).

We hope that these books will not be the final product, however. New experience is continually being gained, new technologies developed and innovative solutions found. We would therefore greatly appreciate hearing of the experiences of readers of this book, so that the information can be updated and be made available to a wider audience. Comments on this publication would also be highly welcome.

Many colleagues and friends contributed to the preparation of this book. We are grateful to the more than hundred individuals and organizations who provided us with addresses, ideas and supporting literature at the start of the project. This book could not have been written without the contributions of experts from EQI (Cairo), AUC (Cairo), AB&P (Accra), GERAD (Bamako), CAPS (Manila), Ptr Services (Calcutta) and USK (Nairobi), who conducted the research in the six cities over a period of some months doing the painstaking work of visiting and interviewing micro-entrepreneurs, trying to obtain government documents and strolling over dumpsites in order to get a glimpse of what technically and commercially is being done by thousands of people in this informal field of work. We would also like to acknowledge the people in the recycling sector for describing their activities and sharing their experiences.

Research data as such do not make a book. Help with the analysis and interpretation of data was provided by Joris Oldewelt (economist) and Pam Minnigh (environmental engineer), while Hanns-Andre Pilot (environmental consultant) carried out the missions.

Many people offered their valuable knowledge and time to read the manuscript: Rehan Ahmed (sanitary engineer, APE, Karachi, Pakistan), Jos Frijns (environmental engineer, Agricultural University of Wageningen, the Netherlands) and Mounir Bushra Mina (solid waste expert, EQI, Cairo, Egypt). Others commented on parts of the text: Onno van Eijk (Research Institute for Pig Husbandry, Rosmalen, the Netherlands) and Maria Muller (urban sociologist, WASTE Consultants). Anne-Lies Risseeuw (WASTE Consultants) took care of the language corrections of the draft manuscript, while Valery Jones did the final editing of the whole manuscript.

Finally, we would like to thank the Dutch Ministry of Foreign Affairs, Directorate General of International Cooperation (DGIS) for financing the research and this series of publications.

Inge Lardinois (environmental engineer)
Arnold van de Klundert (project leader)
WASTE Consultants Gouda, September 1993

Contents

Introduction

Since the publication of the famous book *Work from Waste* (Jon Vogler, 1981), there has been silence in the field of small-scale resource recovery. No second edition or new books have appeared dealing specifically with micro-recycling businesses. Within that time, however, the scale of resource recovery in many economically less developed countries has increased at an impressive rate, and it is worthwhile documenting these experiences and disseminating ideas to other interested parties. This is the first book in a series that will deal with specific materials and their resource recovery.

Government authorities often regard informal waste recovery activities with disdain. It is usually the poorest people, often those at the margins of society, who roam the streets and waste dumps to find items that can be salvaged and sold, to earn their daily bread. Scavengers are often seen as social outcasts, their businesses as informal, and their work as a nuisance to modern urban life. Nevertheless, municipal authorities and urban elites everywhere are facing mounting problems in dealing with the growing volumes of solid waste. Conventional approaches have included the purchase of high-tech equipment such as compaction vehicles, incinerators and computerized routing programmes, usually with little regard for its potential impacts. In particular, potentially valuable components of the waste are destroyed, resulting in the loss of means of survival for the vast numbers of people who work in the informal waste trade. Although a great deal has been written about the need for appropriate technology, decision makers in less developed countries, as well as donor agencies, seem to have underestimated the complexity and thus the vulnerability of such high-tech waste technology, as well as its high maintenance costs and the need for skilled operators.

But the atmosphere is changing, and attention is now focusing on finding ways of dealing with the problem of waste in low-income cities that do not depend only on high-tech equipment. The most appropriate solutions are now regarded as those that take into account the needs of the people who are already involved in the (informal) recycling business, and the financial capabilities of municipalities and national governments. Waste technology that is feasible in high-income countries is usually inappropriate for the socioeconomic conditions in less industrialized countries. Whereas industrialized countries have often taken the road of capital-intensive development, in low-income countries the large labour surpluses and low salaries should favour the choice of labour-intensive options. Wider issues such as the availability of space, climatic factors, and the existence and enforcement of environmental legislation also influence the choice of the most appropriate approach adapted to local circumstances.

In many newly industrializing countries, various types of local machinery and equipment have been developed in the recycling sector. A wealth of valuable experience has been gained in adapting and upgrading resource recovery processes so far, even though the processes in use could still be improved. One way to achieve further innovation might be by providing the micro-entrepreneurs with scientific knowledge at no or low cost.

Innovation could also be stimulated through the exchange of information (knowledge and experience) between micro-entrepreneurs in various parts of the world: the so-called South-South technology transfer. In the research on which this series of publications is based, many different options were identified that could be helpful to entrepreneurs elsewhere. For example:

- Glass blowers in Cairo produce bowls from used glass. Their products, however, often contain air bubbles causing breakages, when it comes into contact with a hot liquid. In Manila, micro-entrepreneurs found a solution by changing the design of the furnace and putting an additive to the glass: the bubbles disappeared, and the glass became heat-resistant.

- Waste plastics are often smeared with sticky liquids and are mixed with organic matter. It makes the sorting of plastics a dirty job for the thousands of scavengers on road and dump sites in various cities. In India this problem has been tackled by washing the waste plastics in a large concrete basin with water pumped by a small electric engine before sorting. The washed plastics are then dried in a rotating mesh drum and are spread out on the ground to dry in the sun. This approach has helped to improve working conditions considerably: the waste plastics to be sorted are almost clean.

Such innovations in processes and technology found in Manila or Calcutta may be highly useful to micro-entrepreneurs elsewhere to improve the quality of their products or the working conditions. Though these changes will result in higher costs, they will also result in an increase in the monetary value of the waste products, and thus increase income and employment opportunities. This book therefore presents many different recycling activities set up by entrepreneurs and organizations, the technical and commercial problems involved and the solutions found.

A large proportion of the waste in less developed countries is recycled, and there are many success stories of the recycling trade, but little has been described in terms of micro-businesses. The experiences of individuals are passed on from parents to children and perhaps neighbouring entrepreneurs may benefit from innovations. But only rarely does information from Asia, for example, reach entrepreneurs in sub-Saharan Africa. Documentation of this locally adapted recycling knowledge and experience could assist many entrepreneurs in other less industrialized countries either to set up or to improve their businesses. It could also demonstrate to decision makers that feasible opportunities exist for removing and recovering solid waste.

There are, naturally, many differences in economic and industrial development between, for example, Asian and African countries. It may not always be possible for some experiences to be replicated. Asia, for example, has a longer (formal) industrial tradition than Africa, which has its spin-off to the informal micro-enterprises in the sense of availability of knowledge and of second-hand machinery and (locally made) spare parts. These larger and formal industries also provide a market for the semi-manufactured products produced by micro-enterprises. These differences in economic development, plus other differences such as in population size, influence the demand from the market and the waste materials produced.

This book is the first in a series on Urban Solid Waste Recovery, and represents an attempt to document the experiences of recycling activities in cities around the world. There are considerable differences between these cities and the recyclable materials investigated. Micro-enterprises are rarely engaged in organic waste recovery except where it is used for animal raising. In some cities individuals sell compost directly from waste dumps on an informal basis, or non-governmental organizations (NGOs) run compost plants as income-generating projects. Other waste materials such as plastics, rubber, glass and tin cans are processed in micro-enterprises and turned into either final products or semi-manufactured materials ready for use by formal industries. Future books in this series, *Rubber Waste* and *Plastics Waste,* will describe the products, markets and technologies for these materials, while *Hazardous Waste* will also pay specific attention to the recovery and safe storage of hazardous waste chemicals such as motor oil, photochemicals and household batteries. Handling such materials can affect the health of employees, and improper disposal may affect the surrounding environment.

The recovery of solid urban waste certainly has the potential to contribute to solutions of problems such as the need for waste removal and unemployment. There is scope for implementation on a much broader scale than has been the case so far. If the urban populations of less industrialized countries are to benefit, however, the range of small-scale, low-cost and environmentally sound options needs to be developed and improved. It is hoped that this book will make a contribution.

The scope of the book

The book is intended primarily for intermediate organizations who deal with communities in urban low-income areas and who seek opportunities either to create or to increase employment among their members. It is also intended for institutions that are concerned about the potential threat of solid waste to human health as one of the many environmental problems in fast-growing cities, and who try to promote solutions. Policy and decision makers in government institutions or municipal departments may also benefit from the alternatives and experiences described here. Hopefully, it may convince them of the many benefits of supporting rather than overlooking the work of thousands of people and their organizations in their attempts to create employment opportunities and at the same time keep cities clean. This book is not intended to provide a complete overview of the technical and economic options for waste recovery. Rather, it is hoped that it will serve as a guideline to the basic principles of small-scale and low-tech options available for the recovery of urban organic waste.

Attention is also paid to issues such as the problems involved in finding a market for the organic waste products, the feasibility of activities in this field of resource recovery and the effects upon the environment. It is important to know if, under what conditions, and how micro-enterprises can contribute to a sustainable solid waste system in cities. The Boxes within the text illustrate particular aspects of urban waste recovery, such as the technology used, the feasibility of an activity or the way an organization operates.

Chapter 1 gives a general introduction to urban organic waste recovery. This recovery requires particular systems of sorting and collection, which are described in Chapter 2. Chapters 3 and 4 describe economic and environmental feasibility, which are important parts of an integrated approach to waste recovery. The reader is urged to read these chapters. Chapters 5-10 cover the technical possibilities of organic waste recovery. In this book, organic waste primarily refers to the organic part of the waste generated by households, commerce and industry. The recovery of human or animal waste is dealt with only in relation to combined disposal with organic material in solid waste. Chapter 5 deals with animal raising as a direct method of reusing organic waste. Since compost is the end product of a number of treatment processes (composting, co-composting and anaerobic digestion) its composition and use are described in Chapter 6. The respective processes are explained in Chapters 7 to 9. The potential of briquetted organic waste as a fuel is examined in Chapter 10.

Appendix 1 lists the 1991 exchange rates, on which the cost calculations are based. Note, however, that the calculations in this book have been taken from real life 11 situations and adapted. They should be used with caution and seen as practical illustrations. Appendix 2 provides a classification of urban solid waste materials.

Appendix 3 lists the addresses of consultants and organizations which can provide additional information on process details, feasibility and equipment. They may also be able to refer the reader to local project experience and experiments. Relevant magazines are also mentioned.

At the end of the book the reader will find a list of references and a glossary of the technical terms used.

1 Organic Waste Recovery in Urban Areas

Solid waste is often disposed of without the expectation of compensation for its inherent value. However, it is increasingly being recognized that some of the value of refuse could and should be recovered.

The scale of resource recovery is much wider in economically less developed countries than in the industrialized countries of Western Europe and North America, largely due to their very different economic circumstances. In the industrialized countries, the lack of suitable waste disposal sites, stricter environmental legislation and controls and increasing amounts of hazardous waste, have all contributed to a rapid increase in the cost of disposal services. Consequently, policy has shifted away from the acceptance of simply throwing away waste, towards the prevention of waste generation on the one hand, and the minimization of waste, including the need for recovery, on the other.

In economically less developed countries, poverty is the major reason why thousands of people are involved in the (informal) collection, sorting and processing of solid waste. Rapid urbanization and related problems such as the steadily decreasing employment opportunities contribute to the extended scale of resource recovery.

This Chapter provides a broad introduction into the subject. The importance of resource recovery in general and the magnitude of the waste problem as well as sociocultural and gender aspects are described. Also, an overview of possible uses of organic waste as described in this book is given.

1.1 The importance of resource recovery

In 1988, the city of Jakarta, Indonesia, produced more than 21,000 m3 of waste daily, 25% of which was recovered by an estimated 37,000 scavengers who earn $ 0.75 - 3.50 per day. Today, at least 78 factories use recovered material from waste for plastics, paper, glass and metal production. The recycling rates for .glass and paper are as high as 60 - 80%. The waste paper collected by scavengers or *pemulung* makes up to 90% of the secondary raw material in this sector. In delivering 378,000 tonnes of waste paper per year to paper factories for recycling, the *pemulung* save 6 million trees from being cut down. Some $ 48.5 million per year are extracted from solid waste recycling, compared with the $ 0.5 million paid in garbage collection fees. Jakarta produces 711,180 tonnes of garbage per month, which costs the sanitation department $ 8.50 per 13 tonne for collection, transportation and disposal. The 25% of the waste recycled by the scavengers saves the city $ 270,000 - 300,000 per month.

This example illustrates some of the many benefits of resource recovery, which are often undervalued: the creation of employment, reducing the volume of waste to be disposed of by municipal authorities, savings on foreign currency, and conservation of natural resources.

Resource recovery in the economically less developed countries is managed predominantly by informal sector entrepreneurs and provides many jobs in this sector. In Kathmandu, Nepal, for example, road sweepers are hired privately by residents to clean courtyards and streets. The edible portion of the wastes collected is fed to pigs and the pig manure is sold to farmers. Scavengers work door-to-door in the wealthier neighbourhoods of Kathmandu, returning home with laden carts that the women and children sort into piles of organic and non-organic materials. The valuable items are sold to middlemen.

For many people, working in the informal waste sector is the last resort in the daily struggle for survival. Incomes are usually minimal, and working conditions are often appalling. Nevertheless, some traders and reprocessors have managed to set up a feasible business that can earn reasonable profits. All these people provide a valuable service to society as a whole; in many cities the municipal refuse collection and disposal services are woefully inadequate, particularly in low-income areas, where waste accumulates in the streets. Improved recovery processes could therefore reduce the amounts of waste that need to be collected, and thus the costs of municipal waste disposal, and could help to reduce the risk to human health.

For example, Cairo is renowned for its extensive informal waste recycling system. In the Cairo metropolitan area, 6000 tonnes of municipal solid waste are generated daily. The municipality collects about 2400 tonnes per day, while informal workers collect about 2700 tonnes of household waste per day using a fleet of some 700 donkey carts.15 The balance of 900 tonnes remains on the city streets, vacant lots and the peripheries of poorly serviced low-income areas of the city.

Resource recovery reduces the quantity of raw materials needed in production processes. It may therefore reduce dependency on imports and save foreign currency. Reused rubber and plastics, for example, reduce the need for imported raw materials, and the reuse of organic waste as compost reduces the dependence on imported chemical fertilizers.

Resource recovery saves natural resources, particularly in the form of raw materials and energy. The recycling of aluminium, for example, results in energy savings 14 of up to 96%. An environmentally sound waste disposal system should therefore involve resource recovery as much as possible.

However, waste recovery also creates employment opportunities that can conflict with environmental and health criteria. Although the reuse of organic waste helps to prevent environmental degradation and pollution, the recovery methods themselves are often not environmentally sound and may pose health hazards for workers. Within solid waste disposal systems environmental, socio-economic and health costs are rarely considered. The total costs of safe and environmentally acceptable solid waste disposal are poorly documented and are therefore underestimated. However, it is against this background that resource recovery needs to be valued and supported in order to use the potential of recovery to its full extent and to improve existing practices.

1.2 Quantity and composition of solid waste

Many materials are categorized under the broad heading of solid waste. Urban solid waste can be considered to incorporate domestic or household refuse, institutional waste (from schools, hospitals, universities and offices) and commercial waste (from restaurants, hotels, markets and industry). For an overview of the categories of waste materials, see Appendix 2.

Municipal refuse can be divided into two parts: organic or biodegradable waste, and non-organic or non-biodegradable waste. Organic waste includes kitchen waste, food leftovers, rotten fruit and vegetables and peelings, straw and hay, leaves and garden trimmings, crop residues, rags, paper, animal excreta, bones and leather. Typical industrial organic waste includes coffee husks, coconut waste and sawdust. The non-organic components of solid waste include earth, including ash, stone and bricks, coal and cinders, glass, plastics, rubber, and ferrous and non-ferrous metals.

Most household, and some commercial and industrial refuse, is organic, whereas hardly any organic waste can be found in institutional waste. In the AccraTema metropolitan area in Ghana, for example, 75% of urban solid waste comes from domestic sources, 15% from commercial and industrial sources and the rest from institutional sources.2 The bulk of organic waste is generated by households. Table 1-1 shows that hotels, restaurants and markets in Accra generate about 600,000 m3 of organic waste each year. This waste forms a valuable source for recovery because of the quantity, its easy collection (since it is stored in bins at particular locations), and because it is unlikely to be contaminated with non-organic material. For the same reasons, some types of industrial waste, such as sawdust, can be reused relatively easily.

Household organic waste includes raw kitchen waste generated in the preparation of food, and cooked food leftovers from the dining table, which are sometimes fed to 15 domestic animals. However, the largest proportion of organic waste is usually disposed of together with other non-organic materials. The quantity and composition of the generated solid waste in urban areas provide a mirror of the society that reflects among others cultural and religious habits of the population. The composition of waste is also closely related to the overall economic levels of the population from which it originates. Comparative data for low-, middle- and high-income countries are presented in Table 1-2. An important difference between the urban waste generated by low-income and industrialized countries is the percentage of organic material. In industrialized countries some 20-50% of the urban waste is organic, compared with about 40-85% in low-income countries. The abundant organic waste in less developed countries could therefore form an important source for recovery

Table 1-1: Organic wastes in hotels, restaurants and markets in Accra. *Source:* AB&P2

Name of the hotel/restaurant	*Number of bins positioned*	*Volume in m^3 of waste/day*	*Estimated quantities in m3 per 30 days, 11 months /year*
Selected hotels			
Golden Tulip	3	6.84	2,257.2
Labadi Beach Hotel	4	9.12	3,009.6
Novotel	5	13.68	4,514.4
All other hotel estimates	100	228.0	75,240.0
Restaurants		2.28	
Edoy	1	2.28	752.4
Ghana Airways Catering	1	2.28	752.4
Bus Stop	1	2.28	752.4
Stopover	1	22.8	752.4
Chinese restaurants	10		7,524.0
Chop bars			
All chop bars	400	912	300,960.0
Markets			
Makola market	40	91.2	30,096.0

31st December market	35	79.8	26,334.0
Malata market	20	45.6	15,048.0
Kaneshie market	35	79.8	26,334.0
Agboloshie market	30	68.4	22,572.0
All other markets	100	228.0	75,240.0
Truck, metal containers	50		
Total	787	1,787.52	592,896.43

Table 1-2: Patterns of municipal refuse quantities and characteristics for low-, middle- and high-income countries. *Source:* Cointreau .

	Low-income Countries	*Middle-income countries*	*Industrialized countries*
Waste generation (kg/capita/day)	0.4-0.6	0.5-0.9	0.7- 1.8
Waste density (wet weight basis kg/m3	250 - 500	1 70 - 330	1 00 - 1 70
Moisture content (% weight at point of generation)	40-80	40-60	20-30
Composition (% by wet weight)			
Paper	1 -10	15-40	15-40
Glass, ceramics	1 - 10	1 - 10	4- 10
Metals	1 -5	1 -5	3- 13
Plastics	1 -5	2 - 6	2 - 1 0
Leather, rubber	1 -5	-	-
Wood, bones, straw	1 -5	-	-
Textiles	1 -5	2 - 10	2- 10
Vegetables / putrescible	40-85	20-65	20-50
Miscellaneous inert materials	1 -40	1 -30	1 -20
Particle size (mm)	5 - 3 5	-	10-85

Low-income countries: those with per capita incomes of less than US$ 360.
Middle-income countries: those with per capita incomes of more than US$ 360 and less than US$ 3500.

It can be seen from Table 1-2 that the municipal refuse generated in the three groups of countries differs in physical terms. The (mostly organic) waste generated in low-income countries has a higher moisture content and waste density, making it heavy and unsuitable for incineration or long-distance transport, and it contains substantial amounts of dust and dirt, giving relatively small particle sizes. In choosing appropriate methods of treatment, the composition and characteristics of waste must be taken into account, as well as factors such as population density, climate, access to households, traffic Q conditions and land availability.

In economically less developed countries the amount of waste generated also varies according to the income group from which it originates. The richer the citizens, the 2 more waste is generated, as the case of Accra illustrates :

- high-income groups: 0.6 kg/capita/day
- middle-income groups: 0.4 kg/capita/day
- ow-income groups: 0.3 kg/capita/day.

An increase in wealth not only creates an increase in the volume of waste, but also in the value of the waste. The higher-income groups produce higher amounts of easily retrievable and valuable items such as paper, metals and plastics.

1.3 Overview of organic waste recovery options

Since organic material forms a large proportion of urban refuse, ways can be sought as to use this resource more effectively. Organic material can be reused in three ways:

1. to feed animals (fodder),
2. to improve the soil (compost),
3. to produce energy (biogas or briquettes).

The first two options are already very common in economically less developed countries. In Lahore, Pakistan, for example, 40% of urban refuse is collected by farmers and used as animal feed and soil amendment. The various processes and the end products they yield are shown in Figure 1-1.

Raising animals is the easiest possibility; in most cases organic waste can be fed directly to domestic animals without pretreatment, but cooking or the addition of nutrients may sometimes be necessary.

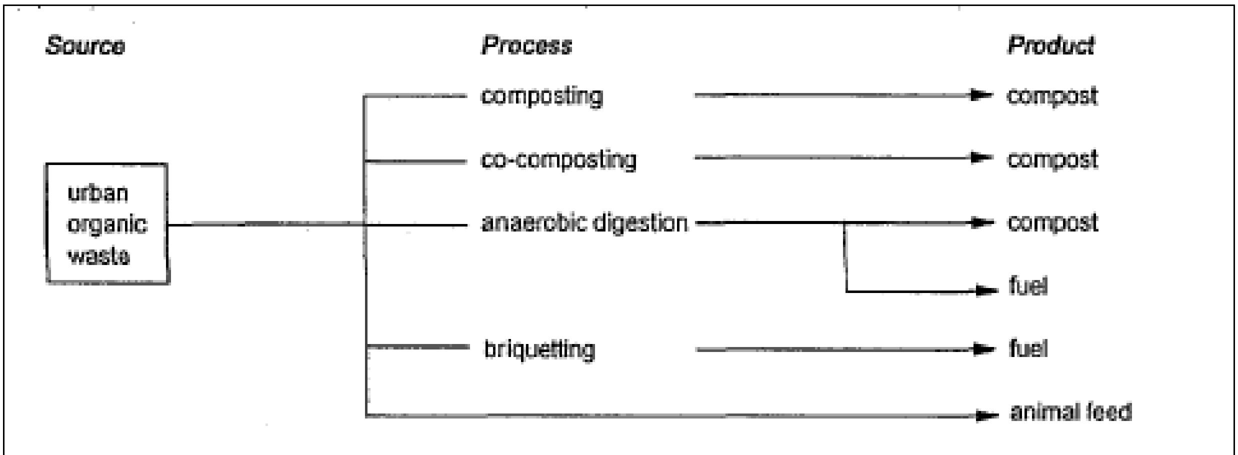

Figure 1-1: Processes and products from organic waste

Compost is the end product of basically two processes: composting and anaerobic digestion. Both refer to the biological degradation of organic material, but via different processes. Composting, which is probably the oldest method of waste treatment, occurs in the presence of oxygen, whereas anaerobic digestion occurs in the absence of oxygen. The last treatment method produces as well compost as combustible gas, which is known as 'biogas'. Co-composting refers to the combined degradation of organic household waste and animal and human excreta. In principle, the process is the same as composting, in that it occurs in the presence of oxygen. The borderline between these processes is not very strict.

Combustible organic materials can also be converted to usable fuel by compressing them into briquettes that can be used in cooking stoves. All of these processes can be carried out at different levels of technology and scale. Also, they can be applied in combination. Box 1.1 gives an example of the situation at a dumpsite in Calcutta, where the organic material is used for several purposes.

Box 1.1 Multiple uses of organic waste in Calcutta

Most of the waste collected by the municipal waste services in Calcutta, India, is taken to a landfill next to a large fishery located in the Eastern Wetlands of the city. Numerous scavengers search through the material for paper, plastic, rubber, fuel, rags, etc. In addition, a large number of pigs and cows are raised on the organic waste of the landfill, and fish farmers use the city's sewage in their ponds.

As they are filled, the older sections of the landfill are flattened and the excess waste *is* removed and used as a fertilizer. About 800 hectares of the flattened, mature dump land are leased by the municipal corporation for use as plots for vegetable farms. The city's refuse is therefore a productive substrate: in addition to vegetable matter and coal ash, it contains quantities of animal dung, sewage sludge, bones and other organic materials. An estimated 20,000 people find work in this intensive farming system, growing 25 varieties of vegetables throughout the year, with an average yield of 150 - 300 tonnes per day, without the need for additional chemical fertilizers. The city derives several indirect benefits from the utilization of the natural compost. On the markets of Calcutta, the vegetables from the landfill are considered to be of a high quality. In this system of garbage farming there are few marketing and transportation costs, which have been bottlenecks in other resource recovery systems.

Sources: Furedy20, 1989; PTR Services47, 1992.

Despite the obvious positive spin-offs of the system in Calcutta, such as the employment generated and the nutrients recovered, little attention has been paid to the possible negative environmental and health effects. The reclaimed areas are visibly contaminated with plastics and paper. Since the waste is not separated before it is dumped, it may contain quantities of hazardous materials, and so the quality of the fish and vegetables cannot be guaranteed. The more waste materials are mixed, the more difficult it is to recover items for reuse. Thus, the nearer to the origin the waste is recovered, the lower will be the transportation costs, the higher the quality and the price of the product (e.g. compost), and the higher the environmental compatibility of the system (see section 2.1).

1.4 Socio-cultural aspects

Human behavioural patterns are a key factor in determining the extent to which organic waste can be reused. Human societies have developed very different sociocultural attitudes to the use of organic waste and untreated excreta. In Europe, North America and Africa, waste is regarded as dirty, so that people naturally avoid contact with it.

In sub-Saharan Africa, which has a history of land abundance, shifting cultivation and low population pressure, agricultural practices have developed in which the reuse of nutrients is rarely maximized. In contrast, in China, Indonesia and India, organic waste, especially human and animal waste, has been used in agriculture for thousands of years. This practice reflects an ecological as well as economic understanding of the relations between man, excreta, soil fertility, and food production. In these societies intensive cultivation practices have evolved in response to the need to feed the large numbers of people living in an area of limited land availability, and this has necessitated the careful use of all available resources.

Religious practices have also influenced the extent to which organic waste is reused. In Islamic societies contact with or consumption of dogs, pigs or other animals that feed on carrion or waste matter is forbidden, so that raising animals on organic waste 12 is not a viable option.

Muslims also profess to avoid all contact with human excreta, although in some Islamic cultures such as in Indonesia, the use of human excreta in agriculture or in fish ponds is common. Sometimes religious restrictions prevent women from engaging in activities outside the home. In Kano, Nigeria, for example, the population is predominantly Muslim; most women are in *purdah* and are confined to their homes except for special occasions, so that children are responsible for transporting household refuse to municipal collection points, communal dumps, or open waste heaps. In many less industrialized countries, employment in waste collection and reuse has very low status. It is therefore not surprising that religious or ethnic minorities, low castes or rural immigrants are often involved in this type of work. Examples include the Zabbaleen in Cairo, the Tamils in Colombo and the Harijan in Calcutta. Despite the vital services they provide, which contribute to both the economy and the urban environment, their work is rarely highly valued.

1.5 The gender-based division of labour

Waste recovery may provide an important source of income for many housef y \ holds, especially in times of economic hardship. The management of household waste is usually the responsibility of women. The disposal of household waste is just one of the many routine duties of housewives, and so it is to women that appeals to reduce waste or to make more effective use of available resources should be made. Sometimes, children take over part of these duties, such as by bringing household waste to communal bins.

Within the informal solid waste recovery system, the tasks that fall to men and women vary according to socio-cultural and economic circumstances. The men are usually involved in the selling of valuable items and the recycling of waste materials, whereas the women tend to be involved in collecting waste from the streets and dumps, and in sorting the material, sometimes in their backyards.

Figure 1-2: Women picking waste at a dump in Calcutta

Photo: WASTE Consultants, 1991

The gender division of labour within a waste system in many societies reflects a picture in which the women and children are responsible for running the household and for domestic food production, while the men earn incomes outside the home. Cultural or religious considerations often prevent women's participation in income-generating activities outside the home, whereas men have easier access to the starting capital required to purchase machinery and means of transportation. As soon as mechanization is introduced into a production process, men are usually responsible for handling the machines. Thus, the introduction of new technologies may have negative impacts on the position of women by removing employment opportunities. Sometimes changes within a solid waste management system may have negative impacts on the position of women. For example, as soon as informal activities become formalized, men become interested because of the status they derive from the work and the equipment. If no preventive measures are taken, women may lose access to certain jobs and areas. When jobs are formalized and carts and uniforms are supplied, men often take over the jobs previously done by women and children. Women's work is often undervalued and is thus not taken into account. But, because of survival objectives and the essential role of women, however marginalized, alterations in solid waste management should aim to improve and strengthen their positions.

2 Waste Collection and Sorting

In low-income countries municipal waste consists predominantly of organic material (see Chapter 1). Because of its bulk, the transportation of municipal waste to landfills is expensive, so that recovery activities that reduce the volume of organic urban refuse represent attractive alternatives.

Before organic waste can be reused, it needs to be collected and sorted out. There are several points within a solid waste management system where waste could be retrieved for recovery: at source, i.e. at the point of waste generation; at designated pickup points (usually along the street); from refuse collection vehicles; at interim transfer stations or waste-processing facilities; and at the ultimate disposal site.10

Figure 2-1: Waste collection system in Calcutta.

Photo: WASTE Consultants, 1991

In many countries waste is collected from all of these points either by the municipality (formalized) or by informal scavengers. Informal solid waste management systems are usually complex, consisting of several strongly interrelated activities. Micro-enterprises, dealers or middlemen, pickers at the dump site, as well as municipal workers and itinerant scavengers, all play indispensable roles in the collection, treatment and disposal of waste. More and more, approaches to the development of sustainable solid waste management systems are attempting to include the informal sector and to focus on the community level.

This Chapter deals with some sociological and organizational aspects of collection and treatment at neighbourhood level. Attention is paid to separation at source as a means to improve the quality of end products and working conditions of the labourers.

2.1 Separation at source

The growing amounts of non-organic material in waste have led many farmers to reject urban wastes for use as a soil improver. In many parts of Asia, for example, the 20 presence of thin plastic bags in waste has reduced the quality of compost. The use of these bags for packaging has exploded over the last few years. Although a large proportion of plastic is recycled, waste pickers prefer hard plastic in large pieces, since they receive only low prices for dirty, low-grade plastic. In mechanical composting systems the plastic bags frequently cause operating problems and reduce the quality of the compost. Other non-degradable materials in compost may also cause problems: broken glass can injure farmers, for example, and hazardous wastes may introduce toxins to the soil.

The separation of waste at source has been defined as 'setting aside recyclable waste materials at their point of generation for segregated collection and transport to the secondary materials dealer, or to specialized waste processing sites for recycling or final o^ manufacturing markets'. In economically less developed countries, the major benefit of waste separation at source would be the retrieval of valuable items such as bottles and plastic from the valueless fraction before they enter the mixed waste stream. Scarcity of these products and marginal incomes encourage reprocessing activities and direct reuse. The practice of retrieving valuable items from waste is actually widespread in low-income countries. The separation of waste into organic and non-organic fractions is much less common.

In many industrialized countries the separation of household waste into organic and non-organic fractions is gaining ground - for environmental and health reasons, and in particular to improve the quality of compost. Systems are now being introduced to this purpose. After separation into organic and non-organic, the waste can be further which can be further sorted to retrieve items such as glass and paper. From an environmental and health point of view, hazardous wastes also need to be further separated for appropriate disposal. When hazardous wastes are concentrated, they are safer to collect, to dispose of and (possibly) to treat.

As stated in section 1.1, a large proportion of the urban waste in Cairo is collected and reprocessed by informal entrepreneurs according to a traditional system involving Zabbaleen (Coptic Christian) and Wahi (Muslim) communities. The Zabbaleen collect household garbage, while the Wahi, as contractors, control the collection routes, and assign blocks of households to particular Zabbaleen for a fee. The Zabbaleen derive most of their income from the sale of recyclable items to local industries via a network of specialized dealers, and from the sale of animals, especially pigs, raised on the organic component of the garbage collected. Another part of the organic waste, together with the pig manure, goes to a composting plant, as described in Box 8.1. In 1991, however, a chemical analysis of the compost produced at the plant showed that it fell well below European safety standards; it contained high levels of zinc and lead, and even dangerous levels of cadmium.7 It was assumed that the organic waste was being contaminated by mixing with non-organic, sometimes even hazardous waste (such as batteries) during storage and collection.

In order to avoid contamination, efforts are now being made to convince Cairo households of the benefits of separating their waste into two fractions. In a limited experimental project, 600 households are separating their organic and non-organic refuse before collection by the Zabbaleen. The resulting health and efficiency effects on the participating Zabbaleen community as well as the quality of the compost are being monitored. The simple sorting of refuse into dry (non-organic) and wet (organic) fractions makes the Zabbaleens' job easier and less dirty.

The collectors and reprocessors benefit from the separation of waste at source in a number of ways:

1. the incidence of injuries and waste-related diseases is reduced;
2. the recyclable materials are cleaner and so fetch higher prices;
3. it takes very little time to sort the various materials; and
4. the quality of end products such as compost, meat and vegetables is improved.

At the municipal level, the waste management system also benefits:

1. less waste has to be collected, which means lower transportation costs and less material that needs to be disposed of; and
2. when the wet (organic) part is kept separate, the heat value of the remaining fraction increases, which makes incineration a more interesting option for further treatment.

Organic or biodegradable materials that can be kept separate, include fruit and vegetable peelings, leftovers (including meat and fish), egg and nutshells, coffee grounds, tea leaves, husks and seeds, flowers, manure, grass, straw, leaves and garden trimmings. Ash and charcoal should not be included, since these are not biodegradable, although small amounts may increase the nutrient value of compost. Only small amounts of paper should be included, since it does not biodegrade easily, and the ink may contain hazardous chemicals.

However, in home composting units greater care needs to be taken in the selection of materials used than in centralized units. Food leftovers, bones, yard waste and orange peel, for example, can cause problems because they do not degrade easily and attract flies and rats. Composting at a larger scale does not have these problems, because the larger quantity of waste means that the various organic materials can be more thoroughly mixed.

Figure 2-2: Separation of waste into organic and non-organic fractions in Manila

Photo: WASTE Consultants, 1991

Separation of waste at source is an environmentally sound option and a technically simple and cheap procedure. However, a number of logistical problems need to be addressed, both at the household level and the municipal level.

In hot climates the storage of waste can be a problem within the households. As the organic fraction rots, it can cause unpleasant odours and attract insects and rats. The problems are more evident in areas with high population densities. Special attention needs to be paid to cleaning the storage bins and collection should be frequent. Other precautions include wrapping food leftovers in paper, recycling only dry organic material, and the rejection of meat and fish leftovers. The amount of organic material may vary according to the season.

Different urban areas (low-, middle- and high-income; one-storey and multistorey buildings) each have their own specific problems. In lower-income areas, the limited space between multi-storey buildings can cause cleaning and collection problems for refuse collection vehicles. Intensive collection systems are therefore needed, which are facilitated by the short distances between houses. In high-income areas there are few storage problems because there is usually no lack of space. Large quantities of organic material in the form of yard waste may be generated depending on the season. Collection may be less efficient, however, because of the greater distances between houses. For these reasons, it may be easier to introduce a system of waste separation at source in the highincome areas, and to extend it gradually to middle- and low-income areas.

2.2 Government versus private waste collection

From the viewpoint of environmental health management, the collection and disposal of waste is usually considered to be the responsibility of the government or municipal institutions. However, municipalities in many low-income countries are often unable to cope with the ever-growing volumes of waste due to inadequate public funds, increasing populations, the lack of equipment and spare parts, and often poorly trained staff.

To deal with these problems, municipalities often choose capital-intensive waste recovery options, and thus overlook the usually strong informal waste collection and recovery sector. The introduction of expensive compaction vehicles is an example of an inappropriate technology that usually has a negative impact on the informal system. In low-income countries compaction does not reduce the volume of waste very much (waste densities are already high because of the high proportion of organic material), but merely crushes the waste and mixes it thoroughly, so that scavenging, separation and recovery become more difficult.

In some countries the contribution of the informal sector to formal waste management systems is slowly being recognized and valued, and ways are being sought to integrate public and private systems in order to avoid competition. Private companies or community-based organizations are increasingly taking over part of the responsibilities of the municipalities by forming public-private partnerships, sometimes under pressure of structural adjustment programmes.

In Manila in the Philippines, in 1978, for example, the Balikatan Women's Movement presented to the Ministry of Human Settlements a proposal for a solid waste separation and resource recovery programme called *Pera sa Basura* (Cash for Trash). Their original plan envisaged that the existing informal resource recovery system could be used as the cornerstone of the proposed scheme. During implementation, however, the plan was changed by the Ministry, who recruited 'eco-aides' as collectors, and set up 'eco-centres' to replace the informal junk shop dealers. Thus a parallel system was created that competed directly with the informal sector. By 1980, all eco-centres had been closed, primarily because of the negative reaction from the existing informal system, most notably from the junk shop dealers. Learning from these mistakes, Balikatan refor- 27 mulated the original idea as an innovative programme called *Linis*

Ganda (Clean and Beautiful) that also involved households and junk shop dealers. Now, more than 18,000 households separate their waste into wet (animal and food wastes) and dry fractions. A government agency collects the wet garbage daily, and the dry garbage is bought by more than 100 collectors who sort it and sell the valuable components. The success of the programme can be attributed to its integration of the informal sector who benefit financially, an education campaign focusing on environmental issues, and the support and participation of the junk shop dealers, the community and local government.

In Mali, the political changes in the early 1990s encouraged the formation of several private initiatives to help solve the growing waste problem. In Box 2.1 two examples of successful initiatives are described.

Box 2.1 Private waste collection in Bamako

It is estimated that the capital Bamako produces 1 500 m waste per day, whereas only 700 m3 is collected. One private waste collection initiative in Bamako, COFESFA (Cooperative des Femmes pour ('Education, la Sante' Familiale et I'Assainissement), provides a health education and garbage collection service. In the late 1980s, the government had slashed public sector jobs in accordance with the structural adjustment programme worked out with the World Bank and the International Monetary Fund, making it difficult for young graduates to find work. The head of the African division of PROWWESS (Promotion of the Role of Women in Water and Environmental Sanitation) then had the idea of addressing simultaneously the problems of the increasing quantities of waste, high unemployment among graduates, and the family health situation. A group of female graduates were given training in environmental health, and sent to *a* Bamako neighbourhood to encourage residents to change their hygiene practices. Once families realized the importance of hygiene, they would be willing to pay for daily rubbish collections, and thus the organization would become financially independent. The initial idea of charging the families failed, however, because the majority of families could not afford it, so the women approached the municipality. Impressed with the their work, the municipality awarded them daily collection contracts for one year, worth $ 34,000. This was enough to cover the running costs, but not to pay salaries, so as an additional source of income, COFESFA is selling dustbins made from used vehicles. As a result, 16 women have set up their own enterprise, and the environmental health standards of the neighbourhood have greatly improved. The enthusiastic response of the local authorities has stimulated further efforts to improve the solid waste collection services.

Figure 2-3: Transportation with carts and donkeys at GIE BESEYA transfer station

Photo: WASTE Consultants, 1993

GIE BESEYA, an initiative similar to COFESFA, was formed in February 1992, and employs young unemployed graduates (male and female). This enterprise also collects garbage from a neighbourhood chosen by the municipality. GIE BESEYA differs from COFESFA, however, as it makes compost from the organic waste fraction. At the transfer station near the office the recyclable items are sorted out by scavengers. The waste is placed in pits, which are covered with soil, and is left to decompose for several months. Experiments are being carried out to mix the organic waste material with animal manure. The compost is then sieved to separate the non-organic items, and is sold. GIE BESEYA has also set up a tree nursery, where the compost is used.

Sources: GERAD23, 1992; Robson51, 1990.

2.3 Neighbourhood resource recovery centres

As a city grows, so do the distances between the areas where waste is generated and the dumping sites. Transport costs are increasing, and land for new dumping sites is becoming more difficult and more expensive to obtain. The subsidies needed to maintain effective services are often beyond the financial capacities of most local governments. New approaches point to the need for decentralized and privatized, autonomous systems. Besides supporting private companies, one alternative could be to set up resource recovery centres that can be operated and managed by community members, where workers sort garbage into primary components and sell them to reprocessors, factories and workshops. Additional activities could include compost making and marketing, thus generating employment opportunities.

Such a system has been introduced in Bandung, Indonesia. The preliminary design for low-cost 'integrated resource recovery modules' was developed as an alternative waste management system that aims at recovering wastes economically. The system is socially and politically acceptable, and finances its own operation. Such modules are economically viable enterprises, owned jointly by a local scavengers' cooperatives, local communities and the Bandung municipal cleaning department, and operated by the scavengers. Each module needs a land area of around 1000 m and produces compost from organic waste, while also retrieving glass, paper, metal cans and other valuable items. The concept of the module was based on studies of the activities of scavenging communities conducted with the support of several research institutions. Project activities undertaken include waste sorting and the sale of recovered materials, seed farming, rabbit raising and primary health care. In cooperation with the Development Technology Centre in Bandung, the following low-cost waste processing techniques have been developed:

1. A composting system with piles of 1.5 x 2.0 x 2.5 m, manually formed and turned over for aeration.
2. A composting system using bamboo pipes to allow water and air circulation within the composting piles, so that no turning over is necessary (see also the Chinese covered pile system described in Box 7.1).
3. A multipurpose shredder to produce plastic pieces and finer compost in order to increase the value of the products.
4. A composting system using a ferris wheel or carousel to minimize the need for land is still being developed.

This alternative system contributes to the implementation of sustainable urban waste management. It is a concept that avoids some of the mistakes made in the past, where centralized waste recovery necessitated bulk production and bulk marketing, and was highly capital-intensive . Integrated resource recovery modules are more adaptive to market fluctuations since they rely on manual labour, which makes a shift towards collecting more or other types of waste easier.

Another experiment with a neighbourhood resource recovery activity is described in Box 2.2. This case shows the possible organizational set-up and describes some employment opportunities.

Box 2.2 Experimenting with resource recovery centres in Kampala

In Kampala, Uganda, an experimental resource recovery centre was set up by a consultant in cooperation with the Senior Women's Advisory Group for the Environment (SWAG), who were responsible for operating the project, hiring labourers for sorting, and selling the marketable components. The consultant provided technical assistance and advice, as well as protective clothing (gloves, boots) and sorting tools (forks, shovels, etc.).

In a trial of the system, six labourers were hired to sort waste six days a week. A woman was hired as a cook, and the labourers stored their tools in her home. The garbage was delivered to the site by the Kampala City Council. Two labourers spread out the garbage using two forks, while the other four sorted the organic and non-organic waste materials. Also, 18 drums were bought and cut into two and the 36 smaller drums were set up in 18 marketplaces. At each market a woman was appointed to take care of the drums and to instruct other women to dump organic waste in one drum and non-organic waste in the other. The organic waste was sorted into fresh material, which was sold to pig farmers, and rotten and secondary materials, which were sent to the centre for sorting and recovery.

Based on this experiment, an assessment of ongoing recovery activities and of the existing and potential markets for recycled items, the resource recovery centres were designed, but not yet actually implemented. The centres are to be administered by private companies or community-based organizations, supported by SWAG, the municipality and international organizations. The capacity of a typical centre will be 20 - 50 tonnes of garbage per day (centres with capacities of less than 10 tonnes of waste per day would not be cost-effective). Each centre occupies an area of 20,000 - 50,000 m2 and operates for a calendar month, since at least 10 tonnes of waste are collected per day, although the area required could be reduced to 10,000 - 25,000 m2 if an efficient system for selling recyclable material immediately after sorting could be established. One labourer can manually sort at least one tonne of household waste in an eight-hour shift, compared with more than 5 tonnes if the centre were equipped with a conveyor belt. Thus an average centre without a conveyor belt needs 20 - 50 labourers for sorting alone, compared with only 4 - 1 0 labourers with a conveyor belt, excluding management, marketing and administrative personnel.

Source: EO.l16, 1991.

2.4 Community participation

Waste disposal is not the sole responsibility of the municipality. Those generating the waste also have a contribution to make. For the smooth functioning of a waste collection and disposal system, it is first essential that the understanding and cooperation of citizens are obtained. They should be encouraged not only to dispose of their waste in the proper way, but also to cooperate by separating waste at home.

In low-income countries examples of separation at source on a large scale are scarce, and the few attempts that have been made have shown that it is often difficult to obtain community cooperation. One successful example is the Balikatan Women's Movement in the Philippines (see section 2.2). I

n Calcutta, efforts have been made to separate organic materials at source, particularly in municipal markets. The feasibility of setting up a pilot plant to extract oil from household waste such as vegetable peelings, leaves and vegetable waste was examined, but for this households would have to separate their refuse before collection. Unfortunately, neither households nor markets could be convinced to do so. The success of any effort in this direction needs the cooperation of the people, and much energy has to be invested in raising public awareness of the importance and benefits of participation. It is often difficult to motivate urban populations to work voluntarily, especially if modern services are offered to the more wealthy. Changes in behaviour that involve extra effort can only be achieved with long-term and strategic information campaigns or with the introduction of incentives such as reduced prices for collection services.

In the village of Villa Giardino in Argentina, a preliminary experiment was set up to collect organic waste separately in two streets. This first experiment was not a success, due to the lack of waste processing know-how, and because the scheme was not accompanied by a systematic public relations campaign. With the help of an expert, however, the TROU (Treatment of Urban Organic Waste) project was set up, involving a citizens' action group, the municipality and external advisers. With the help of 10 volunteers, and, in particular, a group of motivated teenagers, an intensive education campaign was mounted prior to the implementation of the project to raise public awareness of the need for separate waste collection. The campaign was effective, and the residents were motivated to participate. The organizational problems were solved next: lockable dustbins were distributed to households, locations for composting were found, staff were trained to run the composting facility, the collection area was defined and the collection schedules decided upon. The pilot project was a great success, and neighbouring communities are now becoming interested in adopting the idea themselves.

Another project in Curitiba, Brazil, has also succeeded in overcoming initial problems, and demonstrates the importance of municipal support. Curitiba has an innovative environmental policy that is largely due to the efforts of the current mayor. A citywide environmental education programme called 'Garbage that is not garbage' encourages households to separate their organic and non-organic waste, and over 70% of the community now participate. The 'Purchase of Garbage' programme is run in *the favelas,* the squatter settlements of Curitiba where household garbage was not collected because there are no access roads for garbage trucks. In the programme the residents could 'sell' their bags of garbage in return for agricultural and dairy products, as well as bus tickets. For the local government, the costs of the programme are the same as they would have been if a private company had been hired to collect the garbage.

Changes in behaviour regarding the disposal of waste can only be achieved if clear instructions are first provided. Participating citizens need to know: the objectives and benefits, and what to do, i.e. how to store the waste appropriately, the method of collection and the collection schedule, and how to separate various types of waste. The value of their cooperation needs to be emphasized. Information should be given about the programme and the results, for example in terms of the quantity of collected waste and the quality of the end products (e.g. compost). The participants are not the only ones who need information; policy makers, private organizations and the press also need to be informed. Schools could be involved as well.

For the residents of low-income areas, waste removal is rarely a priority. Their lives are dictated by survival economics and so are their reasons for taking any action. Therefore, the information presented and the approach taken should emphasize the economic benefits. The increasing economic value of waste materials could provide an incentive for individual families to separate and save or sell certain items from their garbage. Although urban communities are already reusing valuable waste items, this practice could be extended to separation in more and other waste fractions. Enterprises involved in resource recovery hold the double promise of improving the level of services provided and community health conditions, as well as offering potential economic returns. Organized on a cooperative basis, such schemes allow the community to retain control over the profits generated. These benefits could be particularly important for women, who are most likely to participate in community waste recovery activities due to their responsibilities within the household. As was shown in the case of COFESFA in Mali (Box 2.1), the health of the family and especially of the children could also form an entry point for the introduction of a community-based waste collection service.

One of the most important requirements for successful community improvements is the parallel provision of other (municipal) services as well as infrastructure. For example, the provision of regular and reliable waste collection services is indispensable for public cooperation in waste collection schemes. Also, if the waste is brought by members of the household to transfer points, the removal of the waste to the dump site needs to be guaranteed.

Another precondition for neighbourhood upgrading is the political organization of the community. Improvements at this level require the active involvement and cooperation of men, women and children. The participation of women in waste management can improve their influence in community affairs. This is clearly showed in Box 2.3, which describes a community-based waste recovery system in Mexico. From the outset, the majority of members of the scheme have been women and young people, although some husbands regularly help with specific tasks. The new cooperative structure gave the women a strong sense of solidarity, and increased their independence and their confidence in dealing with their husbands and families.

Box 2.3 Community-based waste recovery in Mexico

In 1978 the Alternative Technology Group (GTA) in Mexico set up the Integrated System for Waste Recycling (SIRDO). SIRDO was designed to manage urban waste, as well as to provide income- and employment-generating opportunities. The system is based on intensive community labour inputs in all phases, from construction through to maintenance and production, as well as cooperative management of day-to-day operations.

In the SIRDO system, each house is connected to a community waste disposal system by two pipes that separate the 'grey water', containing detergents from the bathroom, kitchen and laundry, and the 'black water' from the toilet. After filtering, 80% of the grey water can be reused for irrigation. The black water is channelled into accelerated sedimentation tanks where the sludge is separated out. The sludge is placed in an aerobic decomposition chamber and mixed with household garbage (this process is called co-composting). In the chamber solar dryers evaporate the water, and within a year the sludge is transformed into a nutrient-rich, dry powder fertilizer that resembles coffee grounds and is free from pathogens. The' chamber's dual compartments yield fertilizer harvests every six months. In the meantime, the treated black water is used to irrigate vegetable and flower gardens.

The key innovative feature of the system is its intermediate scale. It would be too expensive to be installed in individual households, but it requires careful management and is thus ideal for community-level operation. The precise technical design of the system and its management are determined by the ecological and socio-economic aspects of each community. During its initial phase SIRDO encountered considerable opposition. Community-based projects often threaten existing power relations, in that the position of community leaders may be challenged. Some government officials may resist such projects if they believe the urban population will be less dependent on state support and thus become increasingly politically independent. Private firms may resent the loss of profits from large-scale public works contracts. There is also a natural resistance to any new technology; many people are simply more comfortable with systems they know, and those that 'everyone else' has.

SIRDO also encountered problems at the operational level. Users complained of flies, unpleasant odours, and leakages. Women had to change their domestic cleaning routines, and some chemical cleaning products could no longer be used because they would damage the chemical balance in the decomposition chamber. The system also requires the separation of organic garbage and non-organic materials such as plastic, glass and metals, which cannot be placed into the chamber. The odours soon disappeared, however, and various other problems were resolved. The children were the first to help with maintenance, such as separating the waste and filling the chamber. Following their example, women in the community now allocate tasks on a cooperative basis.

Attitudes to the system improved when the first harvest yielded nearly a tonne of fertilizer, and a cooperative of 18 members, 14 of them women, was set up to sell it. The quality was tested and initially some remaining micro-organisms were found due to improper operation; this was corrected by increasing the drying time and adding more organic matter. The men carry out the heavier, periodic cleaning jobs for which they receive a nominal payment. Simple day-to-day operations that are not too time-consuming are done by women in the neighbourhood who do not have jobs outside the home. The system is maintained by members on a voluntary, rotating basis. Most of the earnings from the sale of the fertilizer (mostly to middle-class residents who use it in their gardens) are reinvested in production enterprises, although small amounts have been distributed among members based on the amount of labour they contribute.

The first SIRDO was not designed to be managed by women and young people, but because they traditionally deal with household waste disposal and sanitation, and because they are less likely to have jobs outside the home, they have the time to operate and maintain the system. In the design of any system the roles of women and children need to be anticipated so that they can carry out day-to-day maintenance without external assistance. In the case of SIRDO, for example, the weight of some components of the original system had to be reduced so that women and children could handle them.

Source: Monasterio and Schmink , 1986.

3 The Economics of Organic Waste Processing

This chapter is meant to provide some insight into economic considerations relevant to the question whether it is feasible to start an organic waste reprocessing activity. Costs and benefits of the activity as well as external influences such as government subsidies will be dealt with. On the cost side of the equation there are four main categories: raw material costs, production costs, distribution costs, and hidden costs. The benefits include the market value of the recovered products, the by-products generated in the process, the opportunity savings, and the hidden benefits. It is by no means simple to assess the economic feasibility of an organic waste resource recovery system. It cannot be assessed solely on a commercial basis, since other positive or negative effects, for example on the environment, also need to be taken into account. However, there is no agreed methodology for quantifying these effects, so economic comparisons of different recovery processes and treatment and disposal methods are difficult. Thus, the objectives (in terms of either management, financial or environmental issues) of starting an organic waste processing system need to be clearly defined at the outset.

3.1 Costs

3.1.1 Raw material costs

Organic household waste can often be obtained for free, but organic waste from markets, hotels and restaurants may sometimes have to be paid for, as shown in the case study of animal raising in Manila (see Box 5.1). Transportation costs, which vary with distance, have to be added to the raw material costs. Since organic waste is bulky, transportation costs may be high, so that the locations of collection points and processing plants should be carefully selected.

3.1.2 Production costs

The costs of processing organic waste are determined largely by the choice of technology. With simple hand tools and locally made equipment the production capacity is limited (2 - 3 tonnes/day) and investment and processing costs are low. More capitalintensive options will substantially increase the production capacity (to, say, 10 - 100 tonnes/ day), but require more advanced mechanized equipment (such as shredders, front loaders, rotating drums, tippers) and more energy, but fewer personnel and less space. The initial unit costs of production will be high, but they will gradually decrease as the capacity is more optimally utilized.

A comparison of the cost effectiveness of different composting methods in India has shown that the unit production costs of manual composting methods vary from $ 1 - 5 per tonne organic material, compared with about $ 11 per tonne for mechanical treatment, so that at the small-scale level manual composting methods can be cost effective, whereas mechanized ones cannot. *41* A similar conclusion is drawn in Box 7.3, which compares a labour- and capital-intensive composting system in Kathmandu, Nepal.

Another important component is the cost of transporting rejects (inert non-organic materials such as plastics and metals) from processing sites to a (sanitary) landfill. Rejects can constitute up to 50% of solid waste inputs, so that these transportation costs should again be an important consideration in the siting of the plant. This is also an argument for the prior separation of the different waste fractions and the recovery of as many valuable items as possible, which can be sold to provide an extra source of income.

In Calcutta, for example, a composting unit was set up in 1976 under government control and with state assistance. The processing capacity of the plant was about 40,000 tonnes of garbage, yielding 16,550 tonnes of compost per year. Although the demand for the compost produced by the plant was high, the price was too high. Taking into account the initial capital investment, working capital, depreciation, interest charges, and operating costs (including wages and electricity), the production costs were 1.5 times 2 the price the farmers were willing to pay. In addition, the removal of non-organic rejects and transferral to the dump (about 50% of the volume of the input material) posed an additional expenditure. For these reasons, the plant closed down shortly after it was commissioned in 1977, and no private entrepreneurs have since shown interest in reviving it.

This example is typical of many mechanized composting plants in low-income countries. Due to the high costs of investment, maintenance and transportation, and the low prices farmers are prepared to pay, such plants are rarely feasible enterprises. An important argument for a more labour-intensive strategy is the ample supply of cheap labour in most low-income countries.

3.1.3 Distribution costs

Distance to the market is an important criterion in the selection of a suitable site for a processing plant. The final product has to be transported from the point of processing to selling points or directly to consumers. Normally, transportation costs are added to the market price and so are borne directly by the consumers.
For many compost-producing systems transportation costs are an enormous bottleneck. Since the urban market for compost is often limited, the compost has to be 38 transported out of town, often over long distances. Transportation charges may increase the market price of the compost to a level that rural farmers cannot afford. Thus, in most cases markets for the compost have to be found within a limited radius from the point of production. Examples from Asia suggest that the market radius of compost is limited to about 25 km from the plant, beyond which the price is no longer competitive. The situation in Egypt is an exception, however, largely because of land reclamation schemes in the desert, where compost is transported distances of up to 140 km.

3.1.4 Hidden costs

The hidden environmental costs associated with the pollution that may be caused by waste processing systems, including odours, contaminated drainage water, air pollution and improper disposal of rejects, are seldom accounted for. For example, livestock raising in residential areas generates large quantities of manure, for which appropriate disposal solutions are not always found, and may seriously affect environmental conditions in the neighbourhood and the health of residents. These hidden costs of processing organic waste are difficult to quantify, but it is essential that they are included in the equation.

3.2 Benefits

3.2.1 Market value

The clearest benefit of a waste processing system for the entrepeneur is the income generated by the sale of the end products (compost, meat or fuel). The market value of the product is, besides the production costs, determined by factors such as the demand for the product and the price of competing products.

If non-organic materials such as plastics, rubber, glass, and tins are separated from the solid waste input by, for example, the entrepeneur of a composting unit, the salvaged materials can be sold to provide additional income. If the waste is separated at source, materials such as plastic and paper are likely to be cleaner and thus will fetch higher prices. The Zabbaleen system in Cairo (see Box 8.1), and the neighbourhood resource recovery centres described in section 2.3 are both based on the integration of different recovery methods.

3.2.2 Opportunity savings

The costs of resource recovery systems have to be compared with those of alternative waste treatment and disposal methods such as incineration or landfills. Resource recovery reduces the overall volume of solid waste that needs to be disposed of in sanitary landfills, thus reducing transportation and disposal costs. However, these so-called opportunity savings enter the equation only in the case where a government agency, for/ example, has to choose between a resource recovery system and a sanitary landfill; they do not improve the actual operating performance. Thus, a composting operation that costs, say, $ 20/tonne of product and realizes $ 15/tonne in revenue, may be considered economic only if the cost of proper disposal that would otherwise be necessary exceeds $ 5/tonne.

In the case of a private operator who wishes to set up a composting unit, a comparison of the alternative costs of using a landfill are irrelevant, and so are the savings involved. In the above example, the composting unit would be an uneconomic proposition since it would have an operating loss of $ 5/tonne. Producers themselves usually do not receive any direct reward for reducing the negative environmental effects of their work.

In the example of the composting activities in Kathmandu described in Box 7.3, the production of compost from municipal waste could only be enhanced if it is subsidized to bridge the gap between production costs and market prices.

3.2.3 Hidden benefits

Enhanced resource recovery results in a number of other wider benefits that are difficult to quantify, but which should be taken into account by governments when considering the value of a waste processing system:

- resource recovery will reduce the demand for imported raw materials and fossil fuels, thus saving foreign exchange;
- the reduction in the volume of solid waste will have a positive impacts on the natural environment by reducing pollution, and will improve standards of public health and safety;
- reprocessing enterprises create income- and employment-generating opportunities;
- compost produced from organic waste will improve soil texture and soil productivity; and
- the fuel derived from waste (either as briquettes or in the form of biogas), will reduce the demand for fuelwood and thus help reduce the rate of deforestation.

3.3 External influences

The viability of resource recovery systems depends upon a number of important technical, socio-economic and political relationships. Macro-economic influences such as international price and trading policies, government policies such as import regulations, and municipal policies also affect the level of resource recovery that will be feasible. For example, the reuse of organic material as an organic fertilizer can reduce the country's dependence on imported fertilizers. However, if chemical fertilizers are cheaper because of government subsidies, farmers are likely to be less interested in using locally produced organic waste as a soil conditioner.

In the past, many municipalities have opted for capital-intensive solutions to the problem of waste, such as buying large-scale mechanical composting plants rather than developing small-scale, low-tech and low-cost approaches. This is not surprising, since to install a plant is an easy decision for a city council, especially if it is offered as a gift or on low-interest financing under a bilateral aid agreement. Also, a people-centred approach requires much more elaborate and decentralized decision-making and coordination. Donor agencies may also play an important role in this process in that they often push certain technologies developed in their own countries, for example compaction vehicles or mechanical composting systems.

For various reasons, informal resource recovery, either by micro-entrepreneurs or by communities, has not received the support it deserves. In low-income countries in particular, where unregulated dumping is usually the cheapest means of disposing of waste, activities in this field are poorly stimulated and supported by local and national governments. Sometimes municipal policies (deliberately or accidentally) undermine small-scale recovery activities. In Calcutta, for example, the city council wished to convert a landfill site into residential and industrial areas, but this threatened the livelihoods of the informal users of the refuse. The farmers organized themselves to form a Waste Recycling Region Development Committee to work for the preservation of their vegetable gardens and fish farms. 20

The support of local governments is vitally important for the success of resource recovery activities, as is clearly demonstrated in the case of Curitiba in Brazil (see section 2.4). What strong government support and advocacy can achieve has also been demonstrated in China, where government programs increased the number of biogas digesters from only 1700 in 1972 to approximately 7 million just ten years later. The programs included financial support for the installation of new biogas units, training, extension officers to provide technical and administrative assistance, publicity, and research and development to improve biogas production techniques.

Governments can have enormous influence on the promotion of resource recovery. Different methods of waste treatment and disposal have to be compared, not only in terms of their economic output, but also of their impact on the less privileged.

4 Environment and Health

The most important environmental and health hazards are due to pathogens and heavy metals. Other environmental effects include water, soil and air pollution. In this chapter, the environmental and health effects of the recovery of organic waste are discussed. They refer mainly to those arising from the biological treatment of waste through processes such as composting.

4.1 Waste: a potential health threat

Over the last decade, public awareness of environmental issues has grown considerably, especially in the industrialized countries of Western Europe and North America. Measures to clean up water, soil and air pollution have become so expensive, however, that priority is now being given to the minimization and avoidance of pollution. Rising transport and disposal costs, as well as the lack of land for waste dumps, have clearly demonstrated the need to minimize the amount of waste generated, and to develop alternative treatment systems. The prevention of waste is the ultimate aim, but this is only possible in a few areas. Although the importance of environmental protection has now been recognized, the implementation of legislation is often rather slow due to economic constraints, the lack of political will, and because the change to cleaner production processes needs time.

In many economically less developed countries awareness of the environment is also increasing, especially within government institutions and non-governmental organizations. However, in these countries it is even more difficult to change policies and to take appropriate measures than in industrialized countries. Protection of the environment is not a priority in these countries, where survival economics dominate and where foreign currency is badly needed.

Waste treatment systems themselves may also pollute the environment. Assessments of both the environmental and health effects of a system should therefore be integrated in any choice of technology. Although ideally the same standards and criteria used in Western Europe and North America should be applied in less developed countries, the health and pollution risks should also be seen in relation to the exposure to and contamination from other sources. Environmental impact assessments are not easy to carry out. For example, it is often difficult to determine the exact cause of a human health problem, since this is likely to be influenced by a number of factors, and disease transmission routes may be long and complex. However, since it is known that waste collection and recovery activities also pose environmental and health risks, ways should be sought to minimize these dangers as far as possible.

4.2 Pathogens

Urban solid waste may contain large quantities of pathogenic micro-organisms. This is especially important when organic waste is used as compost or animal feed. The sewage sludge or human excreta that is sometimes added to increase the nutrient value of the compost generally contains more pathogens (particularly of faecal origin) than solid waste.

There are two groups of micro-organisms that may cause disease.42 *Primary pathogens,* which are normally present in raw waste and can cause infections in healthy individuals, include bacteria, viruses, protozoa and helminths eggs. Most of the infections they cause (such as diarrhoea and dysentery) are spread via faecal-oral transmission routes. The micro-organisms that are the causative agents of these diseases pass from infected persons in excreta, eventually reaching other people either orally (by drinking water contaminated with faeces) or through the skin. The micro-organisms (fungi and acid-producing bacteria) that grow during biological decomposition are called *secondary pathogens.* These pathogens are less important than the first group, however, they can cause primary infections or respiratory diseases, usually in people with weakened immune systems. Contact with or inhalation of air containing a high density of secondary pathogens (which may occur when a compost heap is being turned, for example) may cause health problems for both compost workers and users. Examples of some common primary and secondary pathogens are listed in Table 4-1.

Waste can also encourage rats, and the diseases they carry, such as plague, endemic typhus and rat-bite fever. Flies and other insects are also responsible for the transmission of pathogens.

Table 4-1: Examples of pathogens spread during the composting of sewage sludge, and the associated human diseases. *Source:* EPA 1981, quoted in Polprasert46.

Group	*Example*	*Disease*
Primary pathogens		
Bacteria	*Salmonella enteritidis*	Salmonellosis (food poisoning)
Protozoa	*Entamoeba histolytica*	Amoebic dysenetry (bloody diarrhea)
Helminths	*Ascaris lumbricoides*	Ascariasis (worms infecting the intestines)
Viruses	*Hepatitis* virus	Infectious hepatitis (jaundice)
Secondary pathogens		
Fungi	*Aspergillus fumigatus*	Aspergillosis (growth in lungs and other organs)
Actinomycetes	*Micromonospora* spp	Farmer's lung (allergic response in lung tissue)

4.3 Positive effects of waste treatment

The treatment of waste using methods such as biological degradation can greatly reduce the numbers of pathogenic organisms and should result in hygienically safe products such as compost, or in hygienic methods of disposing of non-reusable waste. One of the major benefits of waste treatment is its positive effects on public health. Biologically degraded waste does not attract insects as is the case with fresh waste, and it is free of odour.

The spread of disease caused by pathogens depends on a variety of factors, including the number of pathogens present, transmission routes, level of immunity, multiplication rate and the infective dose. The key conditions that determine the survival of pathogens are temperature and time. The higher the temperature, the shorter is the time required to destroy the pathogens, and vice versa. High temperature is the most effective method of killing pathogens, since these organisms consist of proteins that are usually denatured at temperatures of 50 - 70 °C. Each group of pathogens has a different ability for survival. The following recommended timetemperature interactions will destroy practically all pathogens: heating for 1 hour at more than 62 °C, 1 day at more than 50 °C, or 1 week at less than 46 °C. These conditions should also deactivate weed seeds and pests. In a system of windrow composting (see Chapter 7), where the piles of compost are regularly turned, heat treatment at 55 °C for an extended period (18 - 21 days) is necessary. If temperatures are increased to 60 - 70 °C, the pathogens will be destroyed more rapidly.

Since human and animal waste may be used in co-composting or anaerobic digestion systems, the effects of treatment are briefly described here. Faecal material normally contains higher concentrations of pathogens than other organic waste material. Anaerobic treatment of sewage sludge or human excreta also reduces pathogens, but since the temperatures reached are normally lower than during aerobic processes, pathogen dieoff is not complete. Digested sludge should be handled with care, since it may still contain some pathogens, especially helminth eggs. Further treatment of the sludge (by air drying or co-composting, for example) reduces the pathogen content still further and in the latter case, if properly operated, it produces a pathogen-free product. Dried sludge may still contain some pathogens, but if it is applied properly (by being ploughed under, for example) they present no health risks.

Before being applied to the land, excreta should be stored for at least a year at ambient temperatures. This period of storage refers to the entire time interval between excretion and application, and includes any time spent in a pit latrine or in a treatment process such as an anaerobic digester or a composting plant. However, since there is no way of differentiating between freshly added and already digested excreta within a sanitation system, the entire contents of single-pit latrines, septic tanks, single-vault compost toilets and wastewater sludge should be stored for at least a year after removal. This storage period should only be reduced if the material is treated by aerobic composting at higher temperatures or co-composting.

The complete deactivation of pathogens in a compost heap is rarely achieved, for a number of reasons:46

1. Due to the heterogenous nature of the compost materials, clumps may form with the pathogens and protect them from being fully exposed to high temperatures.
2. The temperature distribution within a compost heap is usually uneven; unless the heap is completely and continuously mixed, the temperature near the outer surface will remain lower than on the inside, reducing the overall efficiency of pathogen die-off throughout the heap.
3. Many pathogens (such as spore-producing bacteria, cysts and helminth eggs) are only partially deactivated during composting. They can regrow and may become infective again if exposed to a favourable environment, such as the moist conditions in crop fields.

4.4 Heavy metals

Small amounts of metals such as zinc and manganese are necessary elements for the growth of living organisms. However, when inhaled or when present in excessive amounts, they may cause acute and sometimes chronic effects. Other metals, like mercury and cadmium, are non-essential and toxic elements. The presence of these heavy metals may affect the quality and suitability of the end products of organic waste recovery processes such as compost and meat from animals fed on contaminated material. They present a high pollution risk for the environment. When present at or above specific concentrations, heavy metals interfere with processes in the soil and in plants, and if they enter the food chain, they may form a health hazard for human beings and animals. The health effects of the various metals differ, and depend upon the concentrations34.

Many countries have established legal maximum levels for individual metals; as an example, Table 4-2 gives the currently accepted levels of metals in compost in the Netherlands. Because the criteria used to determine safe levels have been tightened, a number of grades of compost are distinguished, i.e. 'compost', 'clean compost' and 'very clean compost'. To achieve these stricter criteria, the Dutch government is now actively promoting the separation of all waste at source (see Chapter 2). By 1994, in principle all Dutch households will be required to separate the organic from other waste fractions.

The amounts of metals that remain in end products can fluctuate strongly, depending on the origin of the raw material. Organic waste material may contain high concentrations of heavy metals due to contact with, for example, batteries or newspaper ink, during storage and transportation. If they are not biodegradable, other hazardous chemicals that are present in organic waste, such as pesticides, may also appear in the end products.

Table 4-2: The maximum allowed amounts of metals in the three grades of compost in the Netherlands. *Source:* Van Lierop *etal.35*

	Compost		*Clean compost*	*Very clean compost from 1991*
	A	*B*	*A*	*B*

Organic material (% d.s.)	. > = 20	. > = 20	. > = 20	. > = 20
Cd (cadmium)	< = 2	< = 1	< = 1	< =0.7
Cr (chromium)	< = 200	< = 50	< = 70	< = 50
Cu (copper)	< = 300	< = 60	< = 90	< = 25
Hg (mercury)	< = 2	< = 0.3	< = 0.7	< = 0.2
Ni (nickel)	< = 50	< = 20	< = 20	< = 10
Pb (lead)	< = 200	< = 100	< = 120	< = 65
Zn (zinc)	< = 900	< = 200	< = 280	< = 75
As (arsenic)	< = 25	< = 15	< = 15	< = 5

1 until December 1994
2 with effect from January 1995

4.5 Precautions

A number of precautionary measures can be taken to improve general standards of hygiene and safety in waste treatment systems. These measures are strongly recommended for use in all composting and co-composting systems:

1. Workers should be encouraged to maintain high standards of personal hygiene. Washing facilities should be provided.
2. During hot, dry weather the composting area should be periodically sprinkled with water in order to reduce dust dispersal.
3. Workers should protect themselves by wearing gloves, masks and boots during processes such as sieving or (mechanical) turning, when the spores can be dispersed.
4. During bad weather, workers should be encouraged to wear masks, respirators or some other material to cover mouths and noses in order to avoid dust inhalation.
5. Skin contact with biologically degrading materials should be avoided.
6. Waste treatment plants should be located well away from hospitals and residential areas. The distances will vary from plant to plant, but in general should be at least 1 km.

Composting processes that do not require the piles to be turned, such as the Chinese composting system and the forced aeration system (see Box 7.1), pose fewer health risks to workers.

Before applying compost to the land, its quality should be checked by measuring the amounts of metals and pathogens. Livestock fed on organic waste should also be kept in accordance with local health and safety regulations to ensure the production of good quality meat (see section 5.3).

4.6 Other environmental effects of waste treatment

4.6.1 Odour

In general, the anaerobic conversion of organic waste produces far more odour than aerobic processes. If a closed system is used, the inconvenience of odours is also limited. However, the aerobic process in an open system should be odourless if carried out correctly. This method can this be used as an index of the efficiency of the composting process. Odour affects public acceptance of treatment systems, especially in densely populated areas. There are various effective methods of controlling or removing foul odours from composting materials unless the process is completely anaerobic. One method is to use some previously composted material as a filter. The organisms in the compost readily absorb and decompose the malodorous compounds. Simple filters consist of a small pile of compost through which air is blown.

4.6.2 Emissions into water

Aerobic treatment systems release less liquid than anaerobic treatment systems because most of the moisture evaporates into the air. However, leachate water may pollute the soil and eventually may threaten groundwater supplies. The amount of water that will leach from the system depends on a number of factors, including weather conditions. When large amounts of leachate are discharged, the water should be collected. Part of the leachate water may be used to dampen the composting material during processing.

4.6.3 Air pollution

Air pollution caused by biological treatment systems such as composting is usually limited, but when organic waste is burned as a fuel (see Chapter 10) the levels of air pollution caused by the smoke could be considerable. The composition of the waste is important; it should be processed and burned in such a way that smoke is avoided as far as possible. Organic waste that is burned should not contain materials such as plastics, because the smoke may contain hazardous chemical compounds. The smoke may also affect human health, especially if the organic fuel is used for cooking indoors. Some of the additives, for example the ones that are used to improve the binding characteristics of briquettes, may cause considerable levels of pollution, and so should be avoided. Suitable binders include starch and molasses.

5 Animal Raising

One of the simplest ways of recovering the value of domestic and some industrial wastes is to feed it to animals. In situations where it is culturally acceptable, such use of organic waste can increase nutrient levels, and reduce dependence on imported feed.

Backyard animal raising is a common practice in many cities in low- and middle- income countries, and provides a source of income for many small-scale enterpreneurs. Goats, hens, cows, donkeys and especially pigs can be raised on garbage. The two most common types of pig are the heat-tolerant breeds kept in cities such as Cairo and Calcutta, and the less heat-tolerant Western breeds raised in Manila, which need to be cooled down on hot days. The manure of Southern breeds tends to be solid, while that of the Western breeds is more liquid, so that more water is needed to keep the pens of Western breeds clean.

This chapter discusses some technical, financial and environmental health aspects of animal raising.

Figure 5-1: Animal raising in Muquattam, Cairo.

Photo: WASTE Consultants, 1990.

5.1 Organic waste as animal feed

Organic household waste provides a cheap source of animal feed, since it is usually abundant, freely available, and transportation costs can be kept low. Markets also provide useful organic materials such as fruit and vegetable waste. Only completely rotten items cannot be used and are thrown away. In Nairobi, for example, market traders have organized the collection of waste for their own use or for sale as animal feed. While awaiting collection, the waste is generally stored in sisal bags and straw baskets. Many hotels and restaurants have arrangements with traders to collect food remains for use as poultry and pig feed. Stale bread from bakeries is sold to livestock farmers and to animal feed companies. Industries are also important sources of organic waste. Breweries, for example, produce substantial amounts of organic waste by-products (wet malting, sieving), which are sold either as animal feed or as raw materials for animal feed manufacturers.

Figure 5-2: Feeding animals with organic waste in Cairo..

Photo: WASTE Consultants, 1993

Animal feed should contain:65

- carbohydrates for energy to keep the animal alive and to increase its weight;
- protein for energy and amino acids necessary for survival and growth;
- minerals, vitamins and other essential nutrients for a healthy condition of the blood, bones, teeth, etc.,
- fibre or roughage to assist the animal's digestion;
- fats to provide energy and increase weight; and
- water, which may also be provided separately.

Free-range animals obtain these elements independently, but penned animals must be fed carefully blended diets that include all the necessary nutrients. Organic wastes usually provide most of the bulk feed elements, but additives are sometimes necessary. Pig fodder, for example, is often supplemented with an iron preparation.

In Manila, pigs are not fed on a constant diet of organic waste. One month before delivery, pregnant sows are given commercial feed instead of organic waste, since experience has shown that this helps to build the sow's resistance to infection and increases the likelihood of a healthy litter. Commercial feed is continued for 45 days after delivery, when the piglets are weaned from their mothers. Feeding organic waste to the sows or piglets before that time will result in diarrhoea.

Some animals such as cows have complex digestive systems that can digest materials containing mainly cellulose, such as straw, whereas pigs have simple systems that cannot digest straw or low-quality fodder. However, pigs have powerful appetites and eat almost any food waste materials. All organic waste used as animal feed should be carefully examined to ensure that it contains no harmful or poisonous substances. In general, the taste of meat and diary products such as milk and eggs is not affected.

5.2 Pretreatment

Some organic waste needs to be treated before use. Crop residues such as rice straw or bran can provide the necessary nutrients for livestock without processing, but if 1 "5 soaked in an alkali bath, the digestibility of these materials can be almost doubled. This can greatly increase the nutrient availability, enabling the animals to produce more milk or to gain weight more quickly.

In Manila, as soon as the organic waste is obtained, it is fed directly to the pigs; uncooked waste is preferred because the pigs grow better. Cooking is needed only if there are enough leftovers for the following day, by which time micro-organisms in the o material will have multiplied rapidly, giving it a sour taste. The leftovers are heated to kill the harmful micro-organisms, although in the process the beneficial micro-organisms are also eradicated.

In Ghana, cacao waste has been used as animal feed following the favourable results of trials carried out by the Cacao Research Institute (CRAIG). On a dry matter basis, cacao husks contain about 43% soluble carbohydrates, 6.5% crude protein, 27% *fj* crude fibre and 8% ash (half of which is potash). CRAIG has now developed a technology for processing fresh cacao pods into dry pellets that can be fed to animals. The husks are partially sun-dried, sliced into small pieces, mixed with corn and other ingredients such as fish, and then milled in a mincer equipped with a pelleting device.

5.3 Health problems

Animals are sometimes fed on urban refuse that contains slaughterhouse waste. This practice can pose grave dangers. Waste products containing meat or other animal products may help to transmit serious diseases to other animals (e.g. swine fever), as well as to humans (e.g. salmonellosis), and should not be used. Food waste that contains meat, or has been in contact with meat or any part of an animal carcass, should always be batch-sterilized by boiling in water for at least an hour. Sterile and raw waste should always be handled and transported separately, preferably using different containers and vehicles. High standards of cleanliness are required throughout the operation. Eggs produced by hens raised on garbage should be cooked for at least six minutes to kill all pathogens.

In urban areas, livestock rearing presents a number of health risks, however, not only because human diseases can be spread through the waste, but also because of the unsanitary conditions created within residential areas. For these reasons, and because of the foul odours that are often generated, the practice of animal raising is sometimes forbidden in city centres. In Manila, for example, backyard pig raising was once widespread, but as the population grew and space became scarcer, the practice was prohibited. [8] The activity has now been displaced from the centre to surrounding neighbourhoods, and the number of backyard pig breeders increases with distance from the centre of Manila.

Animal raising as carried out in urban areas such as Manila generates new waste, since the untreated manure is usually allowed to drain into the environment. In Cairo, the Zabbaleen take solid pig manure to the nearby composting plant, and the health of the animals is checked at the veterinary clinic of the GAMEYA (Association of Garbage Collectors). Animal raising brings many benefits, yet ways should be sought to prevent or reduce the risk of environmental and health problems, as in Cairo (co-composting, see also Box 8.1) or in Manila (cooking raw waste when necessary).

5.4 Cost savings

The economic feasibility of raising animals is increased considerably if organic waste can be used as feed. However, the number of animals that can be raised depends largely on the amount of cheap waste that is available. Any increase in the number of animals beyond the supply of waste will mean that the rearers will be forced to depend 54 on commercial feed, which will necessarily result in higher production costs. An example of the cost savings possible within a backyard animal raising activity in Manila is given in Box 5.1.

Box 5.1 Backyard pig raising in Manila

In the outskirts of Manila pig raising is a popular backyard operation. Commercial animal feed, which accounts for roughly 60% of production costs, is substituted with organic waste. Backyard pig raisers collect the organic waste on a daily basis from restaurants in the city centre at a cost of $ 1.48 per 20 kg container of leftovers. Delivery of the waste to the backyard farmers costs another $ 0.70 per container. The total cost of the organic waste feed (including delivery) amounts to S 0.11/kg, compared with $ 0.22/kg for commercial feed bought in local shops.

The organic waste is fed to piglets when they are six weeks old, and continues for 3.5 months when the fattened pigs are ready for sale. In this case study, a cost comparison was made for five pigs raised on commercial feed (15 kg/day) and organic waste (20 kg/day). The use of organic waste entails additional transport costs, and fuel costs for heating the leftovers that are not used on the day of delivery ($ 5.50/month). The costs of the piglets, veterinary care and equipment were assumed to be the same in both options. The use of organic waste as pig feed reduces production costs by almost $ 100 per production cycle of 3.5 months (=105 days), or by 17%, thus more than doubling the net profit per cycle from $ 82 to $ 181. With the organic waste option, the average profit amounts to $ 51.70 per month, or $ 1.72 per day. Given that pig raising is a part-time activity, the earnings per day are reasonable compared to the minimum wage level of $ 2.78/day. The relatively small investment in equipment and pig-shed ($ 370) is earned back after two production cycles.

	A - Commercial feeds $	*B - Organic waste $*
Costs		
5 piglets (1.5 months old @ $ 37	185	185
Feeds: 105 days© $ 3.30	347	
Feeds: 1 05 days @ $ 1 .48		155
Transport: 105 days @ $ 0.70		74
Fuel: 3.5 months @ $ 5.50		19
Medicine: 3.5 months @ $ 7.40	26	26
Depreciation: tools and shed ($ 370/60) x 3.5 months	22	22
Total production costs	580	481

	A - Commercial	*B - Organic waste*

	feeds $	$
Gross sales		
5 fatteners at 55kg each @ $ 2.41/kg	662	662
Net profit per production cycle of 3.5 months	82	181
Average profit per month	23.50	51.70
Average profit per day	0.78	1.72
Official minimum wage per day	2.78	2.78

The production cycle lasts 3.5 months or 105 days. Labour input is unknown in this case study. So the remuneration of the pigowner is included in the net profit. Capital investment in tools, equipment and pigshed is $ 370, depreciated in five years (60 months).

Source: CAPS8, 1992.

This case study clearly shows that animal raising is a cost-effective activity and that profits can be increased by using organic waste, which costs less than 50% of commercial feed. On the other hand, the costs of transportation are higher, because it is assumed that a backyard pig raiser can buy commercial feed in a local shop near his place. Another difference between commercial feed and organic waste is that only organic waste needs fuel to treat it.

6 Compost

Compost is the end product of a number of biological degradation processes (composting, co-composting and anaerobic digestion) which will be dealt with in Chapters 7, 8 and 9 respectively. In this chapter, the general benefits and some technical and marketing aspects of compost will be explained. Also, some traditional and modern uses of organic material will be described.

6.1 Traditional uses of organic material

Farmers do not need to be told of the value of adding organic matter to the soil. From centuries of experience they know that soil rich in organic matter is usually the easiest to work and is most likely to give good harvests. Wherever there is settled agriculture, organic materials are reused to some degree. In Europe, manuring techniques were well developed by the first century BC. Roman farmers were well aware of the value of dung as a fertilizer, and distinguished between various types of dung. Ploughing back green plant materials (generally referred to as 'green manure') was also mentioned by Roman historians.

Together with extensive terracing and irrigation works, the recovery of organic material was one of the foundations of the highly productive agricultural system practised by the Incas in the Andes of South America. The Incas were among the first to discover the value of dead fish as manure, and they made extensive use of *guano,* the accumulated droppings of the large colonies of seabirds that inhabit the islands off the Peruvian and Chilean coasts. The *guano* is high in nitrates and phosphates and therefore serves as an excellent fertilizer.

Traditions of reusing organic material are extremely strong in many parts of the world, especially where population density is high. Throughout India, Bangladesh, and many other parts of Asia, compost pits can be found in villages. Even where chemical fertilizers have taken over as the main source of plant nutrients, farmers still place a high value on organic manure. Outside Asia, organic recycling traditions are generally less well developed, yet there is ample evidence that most farmers appreciate the beneficial effects of organic matter. In parts of the African Sahel, for instance, settled farmers encourage nomadic herdsmen to pen their animals on their fields at night, to obtain the dung they produce.

6.2 What is compost

Compost is the stable end product derived from the biological degradation of organic material, which can vary from dead leaves and roots to kitchen waste and vegetable remains. If well decomposed, the odourless and pathogen-free blackbrown mixture can be used as a soil conditioner.

Organic fertilizers such as compost serve a quite different function from that of chemical fertilizers. The main reason for using chemical fertilizers is to enrich the soil with the elements nitrogen (N), phosphorus (P) and potassium (K), nutrients that are vital for crop growth. Compost also contains these elements, but in much smaller amounts. In contrast with chemical fertilizers, compost plays a complex role in maintaining the humus balance in the soil. Humus is the result of natural processes of breaking down and composting of leaves and roots in the ground by micro-organisms, which need air and water to survive. Humus improves the structure of the soil, ensuring the proper circulation of air and water, and is thus indispensable for the growth of healthy crops.

Compost has many interrelated positive effects, depending on the kind of soil (i.e. clay or sand) to which it is applied:

- enlarges the air spaces in the soil, improving its permeability for air and water circulation;
- enhances the clumping of soil particles and thus improves the texture;
- lowers the degree of acidity (pH);
- helps to retain moisture; facilitates the mechanical treatment of heavy clay soils;
- adds nutrients and trace minerals to the soil,
- stimulating biological activity and encouraging vigorous plant rooting systems;
- helps to bind nutrients, preventing them from being leached out of the soil;
- if applied around plants, it will smother small weeds and prevent the surface soil from drying out; and
- helping to reduce soil erosion.

Compost is especially useful because of its humification characteristics and its long-lasting effects. The addition of compost to soil helps to compensate for the losses of organic material that result from intensive agriculture, and helps to maintain or restore soil fertility.

6.3 Some misunderstandings

The biological degradation of organic material can take place in two ways. Aerobic decomposition, which occurs in the presence of oxygen, is called 'composting', 58 while anaerobic decomposition, which occurs in the absence of oxygen, is called 'digestion' or 'fermentation'. Often the term composting is also used to refer to anaerobic processes, but this is incorrect. However, the end product of both aerobic and anaerobic conversion processes is called compost. If efficiently carried out, composting can rapidly produce a pathogen-free end product, whereas digestion requires much longer decomposition times and is seldom free of pathogens and odour problems.

Another mistake that is frequently made, is to underestimate the length of time required for biological degradation. The process is a microbial reaction, and the length of time it takes to complete depends on the state of the raw material. It is very difficult to reduce the length of this process; complete degradation cannot take place in a couple of days, as is sometimes claimed. The time required for degradation also depends on the biological cycles of the micro-organisms involved. Their replication times are conditioned by their genetic constitution and environmental factors; although the environmental factors may be improved upon, the genetic limits nevertheless remain.

6.4 The quality of compost

The main requirement for compost is that it should be suitable for use as an organic soil conditioner. Physical, chemical and biological stability, non-toxicity and a balanced mineral element content are therefore the essential elements for compost to be useful. The amount of organic material or, more specifically, the quantity of humus, can be used as indicators to determine the quality of the compost. The quality of the compost obtained from aerobic and anaerobic degradation are more or less the same, and both depend on the quality of the original organic waste material. The best quality compost will be produced from stable organic material with low levels of visible contamination, micro contaminations and heavy metals.

6.4.1 Stability

Compost should be stable, which means that the organic fractions of the degrading matter should have been sufficiently decomposed. Also, mature compost is free of odour and is easy to handle, store and transport. It is well known that the direct use of 'green manure' and ploughing-in crop residues inhibits plant growth until these materials have undergone a process of decomposition in the soil. Between two and four weeks are necessary for organic matter to be degraded in the soil and only at this stage can the organic residue have a positive effect on crops.

The degradation of organic matter in the soil results in the production of intermediate products of metabolic processes, which are toxic to crops. Other disadvantages are competition between micro-organisms and roots, a high carbon/nitrogen ratio (C/N), shortages of oxygen in the soil and the production of ammonia (see also Chapter 7). In economically less developed countries there are few official standards for compost quality. In Jakarta, Indonesia, the only condition is that compost needs to have a C/N ratio of less than 20, such that it will not damage the plants.4

In addition to sensory perceptions such as smell and visible appearance, temperature can also be used an indicator of whether the process of degradation is complete. During the process, temperature is high (on the average 50 - 60 °C), but when the compost is mature, it falls sharply to 30 - 40 °C. However, a fall in temperature may occur due to other factors, such as turning the contents of the compost heap.

At present, there are no reliable methods for measuring the maturity or stability of compost. This problem requires further and better study, to find an unambiguous, generally accepted indicator. Good methods of measuring the maturity of compost are urgently needed because of the frequent appearance of insufficiently stabilized compost on the market.

6.4.2 Nutrients

Although the nutrient value of chemical fertilizer may be much higher than that of compost, these nutrients usually dissolve and easily leach away from plant root zones. Organic fertilizers hold their nutrients in colloidal forms which are slowly released as the organic materials decompose in the soil. The low nitrogen and phosphorus contents of compost can be an advantage, because this makes dosages of these nutrients controllable. Compost may contain lime, which is useful for neutralizing acid soils. Compared with animal manure, compost derived from municipal waste has a low salt content; a high 35 salt content can inhibit the growth of rooting systems.

Table 6-1 shows the organic matter and nutrient contents of various soil conditioners used in Egypt. The table indicates that the nitrogen content of compost is lower than those of manure and sewage sludge. This is a result of the aerobic decomposition of waste during composting, which allows some of the nitrogen to be released as ammonia. Manure, peat moss and sewage sludge decompose anaerobically and therefore retain nitrogen.

Table 6-1: Organic matter and nutrient contents of various soil conditioners. *Source:* EQI 4.

Soil conditioner	*Percent weight*					
	Moisture content	*Organic matter*	*Nitrogen N*	*Phosphate P*	*Potassium K*	*C/N Ratio*
Cattle manure	0.8	36.0	1.7	0.6	1.2	18:1
Chicken manure from egg production	8.6	4.92	1.1	-	-	26:1

Soil conditioner	*Percent weight*					
	Moisture content	*Organic matter*	*Nitrogen N*	*Phosphate P*	*Potassium K*	*C/N Ratio*
from meat production	16.08	86.1	2.5	-	-	20:1
Sewage sludge	43.0	34.0	2-5	1-2	0.2	9-11:1
Peat moss *	45- 50	40- 45	1.3	-	-	-
Municipal waste compost	6.5	22-25		0.8	0.9	18:1

6.5 Modern applications of compost

The most important use of compost is its application to the soil. This can take several forms: it can be applied as a fertilizer, as a soil conditioner, as mulch and can also be used as a means of land reclamation. Compost may be added to soil for many purposes: urban agriculture, horticulture, home gardening, vegetable gardening, viticulture, landscaping, landfills, forestry or commercial farming.42 Thus the uses of compost can range from domestic applications by gardeners to large-scale applications by commercial farmers on cropland, or by municipal gardeners on parks and gardens. Other consumers are vegetable and fruit farmers, shops selling ornamental plants, golf course operators, city parks departments and housewives.

Apart from the traditional soil applications, compost can be used for a number of other purposes. Compost derived from night soil and vegetable matter can be used in fish farms as a nutrient for both the growth of algae and as fish feed. It has also been used to increase the porosity of bricks by incorporating it into the bricking material before firing. The organic matter burns during firing, leaving the bricks porous. Compost from horse manure has been used as a substrate for growing mushrooms for more than 200 years, but compost from urban organic waste could also be used for this purpose.

Sawdust from industrial sources may be used in its natural condition as soil conditioner or as a mulch. Wood contains several components (cellulose, lignin and pentosan) that are of agricultural interest, but lignin is regarded as the most valuable. Lignin, its degradable products and the residues of micro-organisms, tend to remain in the soil for a considerable time as constituents of humus, thus improving the physical condition of the soil. Lignin also reduces leaching and acts as a storehouse of several nutrients. Sawdust lacks nitrogen and thus, farmers add proportional amounts of ammonium nitrate in order to maintain the nitrogen balance of the soil.

6.6 Marketing of compost

The marketing of compost has many potential applications, but is sometimes problematic. As described in Chapter 3, in terms of price and quality, compost cannot compete with chemical fertilizers, which are often subsidized by governments. Besides technical problems, the failure to market the compost adequately has been cited as another important reason for the failure of some types of composting systems. The market value of compost is determined by local conditions, such as:

- the condition and fertility of local soils;
- government policies towards import substitution (such as import restrictions on chemical fertilizers);
- the availability and cost of other soil conditioners (livestock wastes, crop residues);
- the availability and cost of other agricultural inputs (including chemical fertilizers);
- cropping patterns, i.e. which crops and vegetables are grown during what time of the year (depending on seasonal rainfall patterns);
- the quality of the compost (nutrients, particle size, maturity);
- seasonal variations in the waste stream, particularly in terms of the volume of organic waste and its composition (moisture and ash contents in particular).

All of these factors determine whether the level of local demand and supply for compost will be sufficient, and thus determine the price that consumers will be prepared to pay (including transportation costs, as described in section 3.1).

In Egypt, for example, because large expanses of the desert are being brought into cultivation, the use of soil improvers has been widely promoted. Imported peat moss is now widely used for soil amelioration and for the production of nursery plants. The demand has increased to such an extent that in 1989 10,000 tonnes were imported, at a cost of $ 500/tonne. Because of the high cost of these imports, the private sector is now developing peat moss substitutes. One of these substitutes is compost, which is produced by combining the rich organic material in municipal solid waste and/or agricultural waste with animal waste. The Egyptian government is still subsidizing imported fertilizers, but due to the hard currency problems, it may be forced to change this policy. Table 6-2 illustrates the average prices of various organic fertilizers in Egypt per cubic meter.

Many reports in the literature have repeatedly stressed the need for well thought out and well executed compost marketing programs. In urban areas, compost users will need to have its uses and value demonstrated to them. The many benefits of compost could be promoted through advertisements in specialist magazines (e.g. gardening) and in newspapers. Guidelines on the use of compost could be prepared and widely 62 publicized. Another promotional measure could be to disseminate information through agricultural programmes on the radio.60

Table 6-2: Market prices in 1991 of organic fertilizers in Egypt. *Source:* Adapted from EQI. 14

Type of organic fertilizer	*Average price ($/m3)*
Cattle manure	6 - 7
Chicken manure	15-16.5
Sewage sludge	2.25
Compost	5-7.5

Imported peat moss*	0.5 $/kg

* Imported from Ireland in 60 kg packages

7 Composting

Composting is probably the most well-known system for treatment of organic material. This chapter describes various different systems that function on small or on large scale. Because of the importance of composting, the process is described in detail.

7.1 The principle of composting

Composting is similar to the natural process of biological degradation, such as the breakdown of leaf litter in forests or the ageing of cow manure. A scientific definition of composting would describe it as the biological decomposition of organic wastes under controlled conditions, the most important being that they are aerobic (i.e. they occur in the presence of oxygen) and at an elevated temperature. In its simplest form, composting is done by piling up organic materials, covering and turning the pile regularly and then leaving it to decompose until it is suitable for distribution over fields or gardens.

Figure 7-1: Accumulation of waste, mainly organic material, in Calcutta

Photo: Ptr Services, 1992.

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Almost any plant or animal waste will decompose if preservative measures are not taken. Consequently, several kinds of organic wastes are suitable for composting: vegetable and fruit waste, farm waste such as coconut trash and sugar cane waste, crop residues such as banana skins, corn stalks and husks, garden trash such as leaves, grass and trimmings, sawdust, bark, kitchen waste, spoiled food, human and animal excreta, etc. Animal waste such as meat and fish scraps can be used, but may attract dogs, flies and other insects to the composting pile.

Not all materials of biological origin decompose fully. Less readily decomposing materials include wood, bone and industrially 'altered' organic materials such as paper and leather. Also, woody materials such as green coconut shells decompose slowly; the hardness and high moisture content of the shells make them unsuitable for compost. In Calcutta, for example, green coconut shells comprise 5% of the weight of the city's waste 7, so that other solutions, such as its use as a fuel, could be considered.

Items that should not be composted and therefore should be kept separate include plastic, tin cans, stones, glass bottles, broken glass, wax-coated cardboard, newspaper with coloured inks, waste from domestic cats and dogs, batteries, medicines, etc. Organic household waste often has a weak structure and a relatively high moisture content, so that it is advisable to add bulking material such as wood chips or already composted material.

7.2 Pretreatment

Before composting household waste, it should first be pretreated in some way to remove contaminants that may cause process failures, and to ensure the quality of the compost. Inert materials can be removed by several mechanical processes; for example, electromagnets can be used to separate out iron components, and ballistic or aerated separation may be used to remove larger components. Sieving is the simplest method of sorting certain materials.

The process of composting organic waste can be accelerated if the sizes of the components are reduced. Smaller particles have a greater surface area to mass ratio, so that the rate of biological decomposition is increased. In practice, the degree of size reduction is limited by the structural strength of the raw material, or by practical or financial constraints. Also, sufficient interstices for the circulation of air should be conserved. The sizes of the components of waste are generally smaller in economically less developed countries than in industrialized countries, so that mechanical size reduction may not always be necessary. Typical particle sizes of material used for composting should be between 10 mm for forced aeration and 50 mm for static piles or windrows.42

In solid waste treatment plants, the organic fraction for composting can also be prepared by biologicalmechanical processes. The solid waste is placed in biological reactors for short periods (1 - 3 days), during which time it undergoes initial biological transformation together with size reduction. At this stage, the biodegradable organic fraction is already drastically disintegrated and is therefore more easily separated by mechanical means from non-organic materials.

7.3 The composting process

Composting utilizes the ability of micro-organisms to break down organic material by oxidation. Knowledge of the various micro-organisms and their roles in the process of bio-oxidation is therefore essential. Composting comprises two phases, during which the activities of different groups of micro-organisms predominate. The transformation of waste through composting results in the mineralization and humification (see section 6.2) of the organic substances present.

In the first phase, the more easily biodegradable materials are broken down. Simple carbon compounds (such as soluble sugars and organic acids) are metabolized and mineralized by various micro-organisms, forming CO2 and water. High rates of metabolic activity may increase the temperature within the composting mass up to more than 70 °C.35 This first phase can last between 5 days and 3 months. It is important that there is a plentiful supply of oxygen during this phase; the transition to the second phase is gradual.

During the second phase, which lasts several weeks, the more resistant components such as wood and other lignin-containing materials are degraded. These natural large molecules are attacked by a different group of micro-organisms (fungi and acid-producing bacteria). This phase of the process is slower than the first, and the temperature gradually drops to about 30 - 40 °C. The metabolic activity of the acid-producing bacteria is fundamental to the humification of the organic matter.

7.4 Influencing factors

There are several methods of composting, although the principle is the same in each case. The success of each method depends on a number of influencing factors, although the optimal conditions might differ. The main factors that contribute to an optimum environment for the microbial composting processes, and which can be controlled to a certain extent, are the characteristics of the organic waste material, such as moisture content and C/N ratio, the aeration of the compost pile, and the temperature and degree of acidity (pH) within the pile. These factors are strongly interdependent.

7.4.1 Carbon/nitrogen ratio

The carbon/nitrogen (C/N) ratio is very important in the nutrient balance of all organisms. Carbon is a source of energy for the micro-organisms and nitrogen is necessary for the synthesis of protoplasm. More carbon than nitrogen is required, but when there is a too great excess of either, biological activity diminishes and the completion of the process is delayed. Two-thirds of the carbon consumed by micro-organisms is given off as CO2, and the rest is combined with nitrogen in the cell. When there is insufficient carbon to convert the nitrogen into protoplasm, micro-organisms make full use of the small amount of carbon available and eliminate the excess nitrogen as ammonia. Large amounts of ammonia can be formed, and if the compost is applied during this phase of active composting, it may prove toxic to plants.

A material that contains 30 times more carbon than nitrogen has a C/N ratio of 30. Extensive experiments have determined that the optimum C/N ratio for most types of organic material is between 25 and 30. According to Bertoldi, the C/N ratio of the organic fraction of urban solid waste varies between 26 and 45. Low C/N ratios will slow down the rate of decomposition and increase the loss of nitrogen in the form of ammonia. Table 7-1 gives approximate nitrogen contents and C/N ratios of various compostable organic wastes.

Table 7-1: Approximate nitrogen contents and C/N ratios of compostable materials. *Source:* Obeng and Wright42.

Material	*Nitrogen % dry weight*	*C/N ratio*
Urine	15- 18	0.8
Mixed slaughter wastes	7-10	2
Night soil	5.5-6.5	6- 10
Digested sewage sludge	1.9	16

Activated sludge	5.0-6.0	6
Young grass clippings	4.0	12
Cabbage	3.6	12
Weeds	2.0	19
Grass clippings (average mixed)	2.4	19
Farmyard manure (average)	2.15	14
Seaweed	1.9	19
Potato haulms	1.5	25
Oat straw	1.05	48
Wheat straw	0.3	128
Fresh sawdust	0.11	511
Newspaper	nil	-
Food wastes	2.0-3.0	15
Fruit wastes	1.5	35
Refuse	0.5 - 1.4	30-80
Wood	0.07	700
Paper	0.2	170

As composting proceeds, the C/N ratio gradually falls, and in mature compost the C/N ratio is around 12. When an individual organic waste has a C/N ratio that is not optimal, a second complementary waste can be mixed with it to adjust the ratio. Night soil is a good example of an organic waste that is low in carbon and when composted on its own, will produce significant amounts of ammonia. Rice straw, on the other hand, has a high C/N ratio and its composting rate will be retarded. Mixing various organic wastes in co-composting systems is a common practice (see Chapter 8 on co-composting).

7.4.2 Temperature

The metabolic and growth rates of the micro-organisms involved in the chemical and biochemical reactions tend to increase with temperature, up to certain maxima. Each species has different optimal metabolism and growth rates within a well defined temperature range. Micro-organisms can be classified as psychrophilic, mesophilic and thermophilic, according to their optimal temperature ranges, as shown in Table 7-2.

Table 7-2: Optimal temperature ranges for various micro-organisms (in °C). *Source:* van Lierop et al. .

	range	*Optimum*
Psychrophilic	0-30	15
Mesophilic	20-40	32
Thermophilic	40 - 70	55

High temperatures are the consequence of biological activity. Within the pile, the heat liberated through the respiration of micro-organisms that decompose the organic matter builds up, since there is little dispersal of heat because of the natural insulation provided by the waste. Depending on the microbial activity and (therefore) on the temperature, different microbial groups prevail.

Temperatures of 50 to 60 °C provide an optimal environment for the activities of certain micro-organisms, and are also necessary to kill unwanted pathogens that thrive at human body temperature. However, excessively high temperatures (above 65 °C) will inhibit the growth of the majority of micro-organisms present, and will slow down the decomposition of the organic matter. For rapid composting, high temperatures over long periods must be avoided.

Within a compost pile there can be temperature variations. For example, a lack of oxygen can raise the temperature, and a high moisture content can lower it; both of these situations should be avoided. Aeration can solve the problem of temperature control; by turning the organic waste, cool air is introduced into the pile. Observations of temperature changes during the decomposition of organic matter can be used to indicate whether the process is functioning properly. .

7.4.3 Oxygen

The most important factor during the composting process is the availability of oxygen; without oxygen, composting is not possible. A constant level of oxygen should be maintained by aerating the composting material to ensure a stable end product. Aeration takes place naturally by air diffusion in the piles or windrows, but if the supply of oxygen is limited it will slow down the process of biological degradation. To guarantee sufficient aeration, the compost pile or windrow should be turned regularly, either manually or mechanically by wheel loaders. A third option is forced aeration by means of pipes laid under or through the windrows in such a way that air is constantly and uniformly circulated throughout the composting mass. Here, optimal conditions of oxygen supply, temperature and moisture can be maintained by mechanically blowing or drawing air through the windrow. Forced aeration is the best method of providing a controlled supply of oxygen.

The rate at which the material is aerated also affects the process of composting. If the aeration rate is too high, the excess flow of air will cause the compost mixture to cool down. If the aeration rate is too low, aerobic activity will decline and the process may become anaerobic.

7.4.4 Moisture

Moisture content and aeration are closely interrelated. If the air in the intervening spaces in the pile is displaced by water, this will promote clumping, which will make the structure of the material inferior. The optimal moisture content in the composting process varies, depending essentially on the physical characteristics and sizes of the waste particles, but is usually in the range of 50 - 60%. Below 40% moisture content, the pile will begin to dehydrate, causing the biological process of degradation to slow down considerably. This will give a physically stable but biologically unstable compost. Above 60% moisture content, the high moisture levels will interfere with aeration by clogging the pores, and anaerobic conditions are created; these should be avoided at all costs.

The moisture content of a composting mass will tend to decrease as decomposition proceeds, mainly because of evaporation losses during the first thermophilic phase. In some cases water may have to be added in order to maintain optimal conditions. During the rainy season, composting in open systems is less practised.

7.4.5 pH level

In general, organic matter with a wide range of pH values (from 3 to 11) can be composted, although the optimum range is between 5.5 and 8. Whereas bacteria prefer a nearly neutral pH, fungi develop better in fairly acid environments. In practice, it is not easy to change the pH level in a pile. Generally, the pH begins to drop at the beginning of the composting process due to the activity of acid-producing bacteria that break down complex organic material to organic acid intermediates. In some cases, the pH may indicate that the process is malfunctioning. For example, if the conditions within the composting mass begins to turn anaerobic, the pH may fall to about 4.5 due to the accumulation of organic acids. Conversely, as the process approaches stability, the pH shifts towards neutrality (pH = 7).42

7.5 Composting systems

Composting systems can be categorized as open or non-reactor, and closed or reactor systems. In closed systems (container, tunnel or enclosed hall systems) at least the initial composting occurs in a mechanical reactor with forced aeration. A closed system may be easier to control than the open-air alternative, but because of the complexity of the hardware and the need for highly skilled operators, the costs of construction, operation and maintenance are high, whereas open systems are less complex and require less technically skilled staff.

Closed systems are popular in industrialized countries, where the need to compost solid municipal waste is increasing. In addition, complex equipment is required to sort the large amounts of non-compostable waste material in areas where space is limited and labour costs are high. In less industrialized countries, there is less need to opt for the reactor system on the grounds of limitations of space, and sorting can be less sophisticated, offering ample employment opportunities. Often more than 60% of organic waste is compostable material, since scavengers have removed most of the non-compostable material. For these reasons, closed systems are rarely used in economically less developed countries and so are not described here.

In open composting systems the organic waste material can be arranged in piles or in windrows. Each system consists of the following steps: the piles are aerated to ensure adequate levels of oxygen, and the material is sieved either before or after decomposition to remove non-organic materials. As described in section 7.4, various composting techniques can be distinguished according to the method of aeration. Forced aeration is the most technically complex and expensive method. In Box 7.1 three different composting systems are described and compared.

Box 7.1 Comparison of composting systems in Karachi

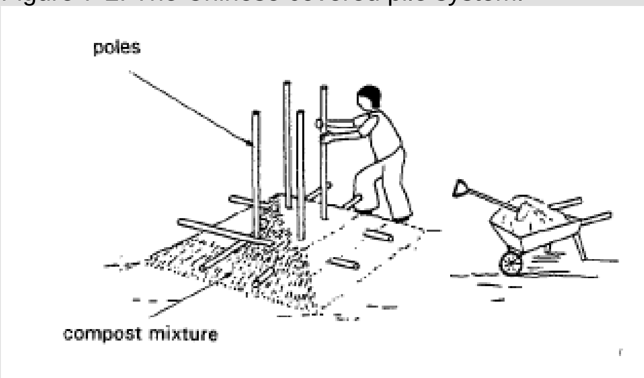
In Pakistan, the effectiveness of three composting systems has been investigated on the basis of their appropriateness to the physical and social context of Orangi, a neighbourhood of Karachi. More than two-thirds (by weight) of the waste generated in Orangi is compostable. The three composting techniques, with differing degrees of mechanization were: the Chinese covered pile system, the windrow system, and the forced aeration pile system. Thermocouples inside the covered piles were used to monitor temperature, since this is a good indicator of process performance.

1. In the *Chinese covered pile system, a* grid of bamboo poles is laid on a bed of dry grass 15 cm high, with the poles about 1 m apart, and vertical poles are attached at the crossover points, as shown in Figure 7-2. The refuse is piled on top to a height of about 90 cm, and covered with a layer of clay mixed with straw to prevent heat and moisture losses. The straw is added to the clay to help reduce shrinkage cracks during drying. After a day, when the clay dries, the poles are removed, leaving air

ducts.

2. In the *windrow composting system,* mixed refuse is placed in elongated open piles, and turned at regular intervals for aeration. In this trial, the windrows were turned on the 5th, 10th and 1 5th days following the mixing of the refuse.
3. The *forced aeration pile system* is similar to the windrow system, except that instead of turning the refuse, the pile is aerated by a grid of pipes laid on a 1 5 cm thick bed of dry grass below the refuse. The pipes contain a series of holes 2 - 6 mm wide through which air is blown by means of a horse-powered air blower. In this trial the blower was automatically activated by a timer unit for 1 5 minutes every 45 minutes.

Figure 7-2: The Chinese covered pile system.



Source: IRC29

The advantage of the windrow system is that it is the simplest form of composting, but the very high temperatures attained in this process appear to result in the loss of some nitrogen. The temperature can be reduced by turning the pile more frequently, but this means that greater labour inputs are required. The Chinese covered pile system is perhaps the best form of non-mechanized process control available, but it has the disadvantage that it requires a clay cover, which increases the steps in building the composting system. The forced aeration system is suitable for handling very large daily inputs of refuse with minimum effort, but it has the disadvantage that the blower requires a (moderate) power supply. All three systems produced good quality compost within 3 to 4 weeks, but because the windrow system was the simplest to implement and operate, it was considered the most appropriate for Orangi.

Source: Sinnatamby58, 1984.

Several sieving techniques can be used to sort material. The simplest sieves are those used in Bamako, Mali, after anaerobic decomposition of the organic material (see Figure 9-1). In Ghana, an experiment is being carried out with rotating screening drums used to remove non-organic material (see section 7.7). The first system is manually operated and so does not depend on electricity or other power supplies, and can be manufactured and maintained locally. More technologically advanced sieving systems are available, in which conveyor belts are used to transport the composted material to screening drums. Examples are given in section 7.8 and Box 8.1.

Composting can be done on various scales. There are numerous examples of attempts to compost waste material in large-scale facilities, often managed by municipalities. On the other hand, individuals have also been encouraged to compost the organic fraction of their household waste in their own backyards. A number of composting methods have recently been developed for use at intermediate levels as well, for example at the neighbourhood level. In the following sections examples are given of composting systems at the backyard, neighbourhood and centralized levels.

7.6 Backyard composting

Composting at the household level is a simple technique, requiring only organic waste, limited space and some time and effort to make the necessary construction. The waste can be placed in a composting pit of 2 x 2 m and 1 - 1.5 m deep, and left to decompose for 2 - 3 months (if desired, turned once in a while). The resulting compost can be used to enrich the soil of agricultural fields or gardens. If one household does not produce sufficient organic garbage to fill a compost pit within the required time, then one pit could be shared by several households. A simple shelter constructed over the pit can provide shade and keep out animals. Food leftovers can be used, but they should be covered with soil so that they do not attract rats and mice.

If groundwater levels are high, either permanently or periodically, such as during the rainy season, composting piles can be built up above ground level. A simple system involves piling refuse within four poles placed in the ground, making a square of, say, 1.2 x 1.2 m. Leafy branches placed behind the poles will help to keep the composting material together. During the rains, nutrients will leach from the compost into the soil, increasing its fertility. Each new heap could therefore be made at a new place in the garden.

In Manila, backyard composting is actively encouraged. In Box 7.2 the technical details of the process as well as the importance of an educational campaign are described.

Box 7.2 Backyard composting in Manila: some improvements

An improved compost-making process has been developed by the Institute of Biological Sciences of the University of the Philippines in Los Banos. Formerly, the maturation period for compost making was three months, but with a new process, compost can be produced in less than six weeks, on either small or large scales. In a study in 1991 of the contents of a waste dump it was found that 64% of the solid waste was organic; the new system could therefore make a significant contribution to improving the solid waste treatment system. With this shorter maturation period, compost making has become an attractive proposition for the urban residents of Metro Manila.

To produce compost from household refuse, the following equipment is needed: a knife and chopping board, a plastic container with a cover, water, a bamboo basket (to hold about 0.75 m3), old newspapers, used plastic bags, and a shovel. The steps in compost making, and important points to remember, are as follows:

1. Collect biodegradable kitchen waste every day. Chop the waste into small pieces on the chopping board, place it in the plastic container and cover with a lid.
2. Add small amounts of water with each new addition. The amounts depend on the moisture content of the kitchen waste. Chopping the waste and adding water will hasten the decomposition process.
3. At the end of each day, transfer the chopped kitchen waste to the bamboo basket lined with old newspapers. Cover the basket with a used plastic bag. The organic material should be placed loosely within the basket; compacting the waste will prevent the circulation of air.
4. Continue to add the chopped waste until the basket is full. Cover the basket every time new waste is added.
5. After 10 days (counted from the day the basket is full), mix the compost with a shovel and add enough water to keep it damp. It is important that the compost is thoroughly mixed so that decomposition occurs evenly throughout the heap. Never touch the material with bare hands because it contains micro-organisms that may cause disease.
6. 14 days after mixing, the compost should be ready for use. Be sure that the compost is stable (see also Chapter 6, section 6.4) before it is applied to the land, however; unstable compost contains

active micro-organisms that will compete with the plants for nutrients.

The weight of the resulting compost will be around 40% of the original weight of the waste. The recommended application ratio is 50% compost and 50% chemical fertilizer (by weight). This will result in an accumulation of reserve nutrients and organic matter in the soil. The percentage of chemical fertilizer can be gradually diminished over the years and replaced by compost.

An educational campaign has recently been launched to disseminate this appropriate technology to interested parties. For example, a local educational TV program has featured compost making, and an environmental group, the World Ecology Foundation (WEF), has launched a compost-making programme for the *barangays,* the smallest political units in the Philippines. The residents supply kitchen refuse and the necessary labour, while the WEF supplies plastic bags and covers the transport costs and buys the compost at a pre-arranged price of $ 0.04/kg. The compost is then used as fertilizer in the WEF'S tree-planting project.

Source: CAPS8, 1992.

Not all households may be able to set up their own backyard composting systems, however. They may not have enough space for a compost heap, they may not own gardens where they can apply the compost, and extra labour is needed to maintain the piles.

7.7 Neighbourhood composting

At the neighbourhood level several composting systems can be used, varying from capital-intensive to labour-intensive systems.

In Olinda, Brazil, for example, the neighbourhoods of Peixinhos and Bonsuccesso have set up small composting units on plots of about 250 m2 (equivalent to about two residential plots in a high-density settlement).26 Refuse is dumped into a shallow, lined pit and lifted onto a sloping sorting table about 1 x 3 metres in size, and rejects and recyclable materials are removed. The remainder is discharged from the end of the table, and is weighed and formed into windrows for composting. The composting process is controlled by taking daily temperature measurements with a thermometer mounted on a simple probe. The piles are turned manually a few times a week. The main criterion used to judge when a pile should be turned is temperature; either when the temperature drops or when it rises above 65 °C. Although this may sound a rather vague method, the composting process seems to follow a satisfactory course. However, a simple, robust moisture meter would help to improve process control. As the pile is turned, scraps of plastic and other reject material that were missed during the initial sorting phase, are removed. The stabilized compost is sieved before it is transferred to stockpiles ready for use.

Figure 7-3: Screening drum in Accra.

Photo: WASTE Consultants, 1993

The manpower required for this process is about 1.5 person per tonne/day capacity. A team of six men can sort one trailer load of refuse (600 kg) in about 45 minutes, with one person feeding the table, one removing the compostable material, and four sorting26. Regular supervision is necessary to ensure adequate control of the composting process.

In an experimental, decentralized small-scale composting project in Accra, Ghana, screening drums have been introduced to sort waste materials45. At each composting site a drum 'driver' supervises the deliveries of household waste, making sure that the heaps are properly stacked, and he retrieves reusable items from the waste (plastic, bottles, tin cans, plantain shells, etc.) that he can sell. The heaps are prepared in weekly batches so that the composting process can be monitored easily. When the temperature of a heap passes its maximum, it is turned to aerate the decomposing material, and non-compostable materials are removed with a coarse screen or manually to ensure that the composting process can proceed as quickly as possible.

However, turning the compost heap also causes it to dry out, which is a disadvantage for the second phase of the decomposition process. The lost water is replaced by adding waste water from a nearby ditch or from a sanitary sewage disposal truck. Rainfall in the area is scarce, and benefits the composting process only a few days each year. The heaps are generally turned over a second time, and more non-organic matter is removed. The third step involves screening with a fine-meshed sieve or screening drum. The simple mesh sieves, with wooden frames and wire mesh of various sizes, are made locally. If all non-organic matter has already been removed a smaller mesh is used, but under no circumstances is a mesh larger than 5 cm permitted. The first screening drums were obtained from Buhler-MIAG, Braunschweig (Germany), although now they are being replicated by local craftsmen. The use of the screening drum has resulted in higher compost yields, and has also improved the quality of the compost.

Formerly, a small two-stroke engine did the work, because the operation of the screening drum with pedal power proved to be too heavy a task. Eight people were needed per day to turn the drum. At present, only one labourer operates the drum, and is able to produce 300 bags per day. Each bag contains 18 kg compost and is sold at $ 1.10. If the bag is returned empty it is refilled for $ 0.75. Between January and July, 1993 1500 bags were sold. In August alone, 552 bags were sold. Clients are provided with a leaflet 'how to improve the soil in your garden', and they receive advice on quantities of compost to be applied when growing certain types of vegetables.

In Box 7.3 two small-scale composting systems are compared in terms of cost-effectiveness. Both the capital-intensive and the labour-intensive option proved to be non-viable in economic terms. Only when cost savings achieved by less dumping in sanitary landfills and less environmental pollution are included in cost-benefit calculations, the labour-intensive alternative turns out to be the most cost-effective on a small scale.

Box 7.3 Capital- and labour-intensive composting in Kathmandu

In Kathmandu, Nepal, a small composting plant has been set up, run by the municipality of Bhaktapur town, and assisted by the Solid Waste Management and Resource Mobilization Centre. The plant processes organic solid waste from Bhaktapur using a manually operated windrow system and a manual screening system. The compost is sold to local vegetable growers at a price of $ 7 per tonne (excluding deliver), which is only a fraction of the price of chemical fertilizers ($ 70 - 140/tonne) or animal manure ($ 70 - 80/tonne). However, the high transport costs limit the marketing area to the vicinity of the plant.

The production costs of the compost exceed the sales revenue by 100%, although this operating loss is almost entirely offset by the opportunity savings (see section 3.2) of the reduced transport and landfill costs. The production capacity of the plant is limited to 1.5 tonnes of compost per day, but could be extended to 3 - 4 tonnes per day with more personnel (the labour-intensive solution) or with better equipment and organization (the capital-intensive solution). The additional equipment for the second alternative consists of one locally produced rotating drum and an electric crane on wheels for turning the windrows (total investment costs are approximately $ 9000).

At a daily production level of 3 tonnes (instead of the current 1.5 tonnes), the unit costs of production would be reduced from $ 16 to $ 10 per tonne. If the sale price could be increased to $ 9 per tonne, the operating loss would be just $ 1. By including the opportunity savings ($ 8/tonne), the operation would become profitable.

Thus the labour-intensive alternative worked out to be the most cost-effective at a production level of 3 tonnes/day. The main influence on the costs for the capital-intensive alternative is the crane which is responsible for almost 50% of the total production costs. At higher levels of production, however, economies of scale would further reduce the unit costs of the capital-intensive alternative. A third alternative would be the implementation of another compost plant at the other end of town. This would help reducing the transport costs when carrying fresh waste from the downtown area to the plant.

Improved production schedule

Production level	*Alternative 1 (labour-intensive)*	*Alternative 2 (capital-intensive)*
3 tonnes/day (1990)	Increased manpower to 15 (3 supervisors and 12 sweepers)	Additional equipment (screening, piling) same manpower as in 1989
4 tonnes/day(1995)	Extension of platform Increase of manpower to 19 (16 sweepers)	Same equipment and manpower as for 3 tonnes/day

The manpower of the production schedule (1989) is 3 supervisors and 8 sweepers.

It is assumed that one person can manually produce and market 200 kg of compost a day (alternative 1)

Economic comparison of the alternatives

Capacity	*Cost per tonne of compost*			
	Alternative I		*Alternative 2*	
3 tonnes/day	manpower	8	manpower	6
	equipment	1	equipment	6

	repair and maintenance	1	repair and maintenance	1
	Total	$ 10	Total	$ 13
4 tonnes/day	manpower	8	manpower	5
	equipment	1	equipment	5
	repair and maintenance	1.5	repair and maintenance	1
	Total	$ 10.5	Total	$ 11

Year	*Capacity (tonne per day)*	*Production costs per tonne ($)*	*Revenue price per tonne*	*Operating loss per tonne*	*Opportunity savings*	*Net profit per tonne ($)*
1989	1.5	16	7	9	8	-1
1990	3	10 (13)	9**	1 (4)	8	+7 (+4)
1995	4	10.5 (11)	9	1.5 (2)	8	+6.5 (+6)

1 Figures between brackets refer to alternative 2
2 Assumed that sales price will rise to $ 9 per tonne from 1990 onwards
The calculations are based on an exchange rate of 1 $ =28 NRs. The minimum wage is $ 22 per month
Source: Solid Waste Management and Resource Mobilization Centre59, 1988.

As with any community-based project, small-scale composting faces all the problems of obtaining sufficient resources initially, of sustaining the motivation of the 20 community, and achieving stable markets . However, there have been several attempts to link composting with urban food production, or with plant nurseries and park improvements, as part of a waste management strategy. Such opportunities may be worthwhile and deserve serious investigation.

7.8 Centralized composting

The large-scale composting plant has become a striking example of a technology that is wholly inappropriate for use in economically less developed countries. Over the last 20 years several city councils have opted to build complex, centralized plants without first studying the potential markets for the output, or the likely overall costs20. Such plants are usually beset by mechanical problems; some have been closed down, others have been scaled down, and many operate well below their planned capacities. The construction and operating costs of these large plants are often higher than the revenue received from the sale of compost. The frequent lack of technical knowledge of operating over-sophisticated equipment and processes often results in mechanical failures, and ultimately in low-quality compost.

In Izmir, Turkey, two composting plants, each with a capacity of 75 tonnes per day were built following the DANO system. In the DANO bio-stabilization unit the waste is treated on its own or in combination with wastewater sludge. The waste is mixed and aerated at the same time in a horizontal drum. However, both plants were shut down, because the system was too complicated and expensive to operate. A forced aeration system is now in operation, supported and subsidized by the municipality, which is working quite well. In Box 7.4 an example is given of a composting plant in Accra, which was scaled down.

Box 7.4 Windrow composting in Accra

In Accra, Ghana, organic waste is aerobically treated at a composting plant near Teshie-Nungua in order to extend the life of the present landfill. The costs of composting are somewhat higher than disposal at the landfill, but because of the environmental benefits of composting, these extra costs have been accepted. The facility, based on Swiss technology, originally had a design capacity of 200 tonnes per day. Operations were suspended due to mechanical failure, although recently the facility was reopened but at a greatly reduced capacity of 35 tonnes per day using a modified process.

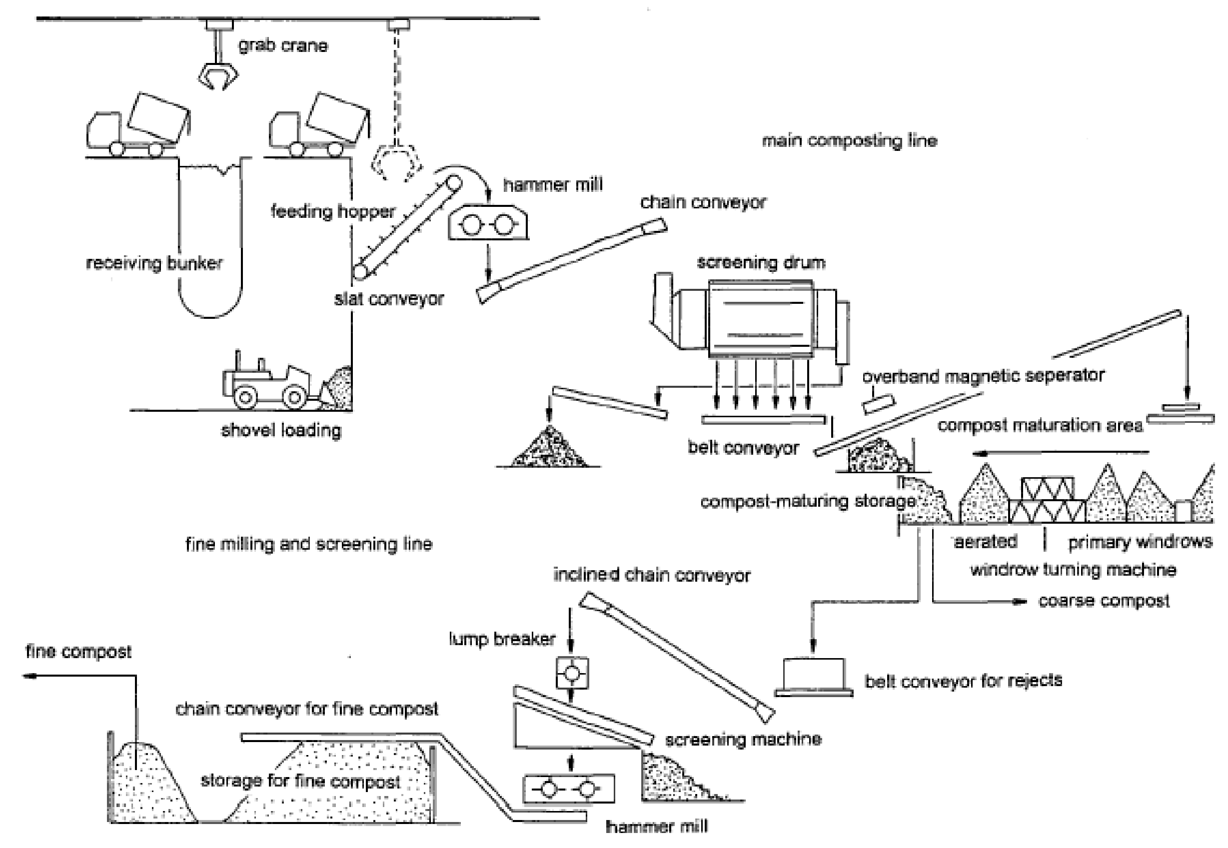
The process of windrow composting used in Accra is outlined in the flow diagram in Figure 7-5, although at present this is not in full use because the hammer mill is not functioning and the fine milling and screening lines are not in operation. The plant employs five labourers, one driver, two technicians, a supervisor and a clerk.

Figure 7-4: Windrow composting in Accra.

Photo: WASTE Consultants, 1992.

The refuse is placed in windrows. Each new windrow is formed, labelled, dated and its weight recorded. The temperature of each windrow is recorded daily in five or six places. After 2 to 3 weeks, temperatures within the windrow rise from an average of 40 °C to 70 °C. Occasionally, a maximum of 75 °C is recorded. While turning with a wheel loader, the temperature falls due to evaporation and aeration, but soon begins to rise again. Each windrow is left for 2 to 3 weeks so that decomposition can occur between turnings. When any windrow attains a constant temperature (usually after 9-12 months), the refuse is said to be mature and the compost is screened ready for use. Before screening, the weight of the mature compost is normally 70 - 80% of that of the raw refuse; after screening the weight is normally 45 - 55% of that of the raw refuse. The rejects, including non-ferrous materials, pieces of wood and plastic, are collected and sent to the landfill. The compost is used as soil conditioner and forms a substitute for imported chemical fertilizer. The major markets for the compost are the vegetable gardens and farms around the city. The market price is about $ 10.24 per m3.

Figure 7-5: Flow diagram of composting plant in Accra, Ghana



Source: AB&P2, 1992.

8 Co-composting

The term co-composting refers to the composting of two or more raw materials together, in most cases a combination of human or animal waste with household garbage or other organic materials. Like composting, co-composting has been practised for centuries, particularly in the rural areas of Asia. In Java, for example, virtually all the available animal dung is collected, composted together with straw, bedding material, vegetable wastes, household garbage, and ash from cooking fires, and is returned to the fields. Composting pits are common features in rural Chinese villages. Dung from animal pens is added, together with excess straw and bedding material, vegetable wastes, ashes and household garbage. This is left to decompose for a few weeks up to six months, before being spread on the fields or vegetable plots. In parts of Egypt, fresh soil is deliberately spread on the floors of animal sheds to soak up urine and some of the dung. The soil builds up, and is periodically transferred to the compost heap, and from there it is eventually recycled back to the fields.

The borderline between composting and co-composting is not very strict. In this chapter the process of co-composting will be explained as in relation to the various examples given.

8.1 The principle of co-composting

The combined use of organic garbage and animal waste has several advantages because these materials complement each other very well. Human and animal wastes are high in nitrogen content and moisture, whereas garbage has a high organic (carbon) content and is a good bulking material. Co-composting can also provide an answer to the problem of treating human and animal excreta in a safe way. Night soil and wastewater sludge do not compost well on their own: they are too moist and their C/N ratios are too low. Co-composting agents such as refuse, straw, water hyacinth, and rice husks are able to absorb the excess moisture and to correct the C/N ratio (see also section 7.4).

Other reasons for adding organic material to night soil is to increase air spaces enabling proper aeration, to provide structural support, to reduce the bulk weight of the composting mixture, and to increase the quantity of degradable materials. In Port- Au-Prince, Haiti, research was carried out in the early 1980s to compare the nutrient quality of compost from municipal refuse with co-composted refuse and sewage. As can be seen in Table 8-1, the addition of sewage clearly raises the nutrient level of the compost.

Table 8-1: Nutrient contents of two Haitian composts. *Source:* WASH™.

Nutrient	*Municipal refuse %*	*Municipal refuse and sewage %*
N	0.20	1.7
P	0.17	1.4
K	0.45	1.0

In principle, the process of co-composting is the same as that of composting. Sewage sludge and night soil can be co-composted with various organic waste materials. A list of possible combinations and their advantages is given below, but the best way to find the optimal combinations and quantities under actual field conditions is to try each of them out.

Bark. When bark is used as a bulking agent, it has the added advantage that it absorbs foul odours. The bark can be mixed with dewatered, digested sludge in the ratio of three parts bark to one part sludge. Problems can occur if the wood has been treated with pesticides, however, since they may persist in the compost. The use of bark naturally depends on its availability, for example, on the proximity of a wood-processing plant.

Wood chips or sawdust. Both wood chips and sawdust can be used as bulking materials and to absorb excess liquids. For example, digested sewage sludge can be mixed with wood chips in the volume ratio of 1:3. The wood chips can be screened out later for reuse.

Straw. In co-composting systems used by many farming communities, straw is added to night soil to absorb the excess liquid and to improve aeration. Appropriate ratios of straw to sludge vary between 1:1 to 1:28, depending on the desired quality of the end product, and on the characteristics of the available starting material (such as the amount of solids and their composition).

Shredded paper. Paper improves the C/N ratio of the substrate, prevents the leaching of excess liquids into the ground by absorbing moisture, and it reduces odour problems. A possible organic waste/paper ratio is 5:1.

Compost. Compost is sometimes added during the process of co-composting to reduce the need for additional bulking agents. For example, dewatered raw sewage (25% solids) can be mixed with sawdust and compost, for example in the ratio 5:1:4. Many other types of organic waste, such as mushroom wastes, rice husks and grass cuttings can also be used for co-composting.

8.2 Influencing factors

Since the principle of the biological process of co-composting is basically the same as that of composting, the influencing factors are also more or less identical. These factors are described here only insofar as they differ from those described in section 7.4. The C/N ratios of various types of manure are listed in Table 7-1.

8.2.1 Temperature

Since the sludge added to the organic fraction of solid waste is likely to contain high concentrations of pathogens, special care should be taken to ensure that the end product is pathogen-free and therefore safe for use. A high temperature is the main prerequisite for killing pathogens. During composting a temperature of at least 50 °C should be sufficient, if maintained for a sufficient length of time (say, more than two days).[42] Some heat-resistant pathogens, however, can survive even this temperature (see also section 4.3).

8.2.2 Moisture

Untreated sewage sludge and night soil contain a great deal of moisture (typically about 92%). Even when dewatered, they may still be too wet to be composted on their own, and amendments or bulking materials are then required to reduce the moisture content as well as to increase the carbon content. Typical amendments include sawdust, straw, garbage, grass and wood chips, but also shredded tyres and peanut shells can be used as bulking materials.

8.3 Methods of co-composting

Organic household waste can be co-composted with human or animal waste in either open or closed systems, although for the reasons discussed in Chapter 7, closed systems are rarely used in economically less developed countries. The techniques for the various composting systems mentioned in Chapter 7 also apply to co-composting. Because of the higher concentrations of pathogens in excreta, however, special attention is needed to ensure sufficient pathogen die-off. In the following, examples of co-composting systems at the household and community levels are given.

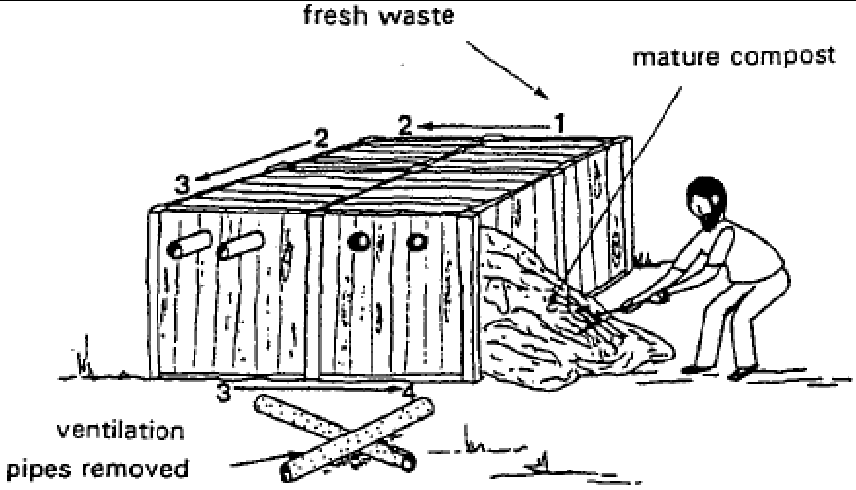
8.3.1 Backyard co-composting

The simplest co-composting system is to dig a pit in which the various types of organic waste can be deposited and decompose. The best results will be achieved when the pit is filled in layers, as follows30:

- a first 15 cm thick layer of grass, leaves, straw and household waste,
- a second layer of animal dung and/or poultry manure;
- a third 3 cm thick layer of ash and/or soil.

This three-layer system should be repeated until the pit is full, after which the contents of the pit should be stirred occasionally. During dry weather a little water should be sprinkled to stimulate the composting process. After 2-3 months the decomposed material should be stable and can be used as a fertilizer. fresh waste mature compost ventilation pipes removed

Figure 8-1: The rotating bin co-composting system.



Source: iRC29

The Chinese covered pile system described in Box 7.1 can also be used for co-composting using four types of raw material: human excreta, animal manure, soil and street sweepings, and household waste, mixed in equal proportions.

A rotating bin system can also be used for co-composting human or animal excreta in combination with organic kitchen waste (see Figure 8-1). For this system, four wooden bins are needed (each 1.5 x 1.5 x 1.5 m), with removable walls so that the contents can be easily taken out and turned over. The bottoms of the bins should be lined with heavy plastic sheeting to prevent liquids leaching into the ground, and the tops should be screened or have lids. The four bins should be arranged in a square, and the organic waste placed into the first bin. When this bin is full, the contents should be taken out, turned, and transferred to the second bin. The first bin should be filled again. The contents of the second bin should then be transferred to the third bin, and those of the first bin to the second, and so on, until all four bins are full. By this time the contents of the fourth bin will be mature compost that can be removed and used as a garden fertilizer. The complete cycle will take one or two years, and the compost will have been turned at least four times. More frequent turning, and the use of perforated pipes to aid ventilation, will speed up the process of decomposition. Remember that a mask should always be worn when turning and transferring the material from bin to bin, in order to prevent the inhalation of active pathogens.

8.3.2 Neighbourhood co-composting

When composting urban waste, the quality of the compost is often improved by the addition of human or animal excreta or sewage sludge. In the comparison of the three composting systems in Orangi, Karachi, described in Box 7.1, the organic waste was mixed with 10-15 % poultry manure to adjust the C/N ratio.

In China, co-composting is a common practice, which takes place at various scales. The principle is similar to the covered pile system described in Box 7.1. In one neighbourhood-level system, urban organic waste that is free of non-organic materials such as glass or metal, and night soil are mixed in the proportion of about 75%:25% by weight.

The thoroughly mixed material is then piled in a heap about 4 m wide at the base, 2 m wide at the top and up to 5 m high. When the heap is about 30 cm high, a grid of bamboo poles is laid horizontally across it with the poles 1.5 - 2 m apart, and at each intersection a vertical pole is attached. The rest of the heap is built up, and is then sealed with a 2 - 3 cm thick cover of 40% soil:60% cinders mixed with water. This cover is important because it prevents rainwater soaking into the pile, reduces evaporation, reduces nitrogen loss, prevents flies and odours, and increases the surface temperature.

The day after the heap is completed, the bamboo poles are withdrawn, leaving airways for ventilation. These holes also enable the temperature of the heap to be finely controlled: they can be blocked in cool weather to stop the pile cooling down, and in hot weather to help prevent the loss of water and nitrogen.

Within a day or two the temperature of the heap rises to over 50 - 55 °C, which is maintained for more than 10 days, effectively destroying pathogenic micro-organisms and parasite eggs. The compost is ready for use in 3 - 4 months.17

The Accra Metropolitan Authority also composts the sludge from communal *f* \ pit latrines and from a wastewater treatment facility at a number of locations. The sludge is mixed with sawdust and composted in windrows. Front-end loaders are used to mix and to turn the material. The compost produced from this sludge is mixed with solid waste compost to increase its nutrient value.

In Jakarta, Indonesia, a simple co-composting system was developed in 1988 that combines animal waste from the Ragunan Zoo with domestic waste from nearby neighbourhoods. After pickers have retrieved the recyclable items from the garbage, over a period of 11 days the mixed waste is mounted, watered and turned, and is then packed into wooden frames and 'blocked'. After a few days, the compost is ready for packaging for sale in supermarkets, and part of it is also used in the zoo's vegetable gardens where 20 corn and beans are grown as animal feed.

Figure 8-2: Composting blocks in the Rangunan Zoo, Jakarta.

Photo: WASTE Consultants, 1989.

To ensure the destruction of all faecal pathogens, it is recommended that a forced aeration system is used. In small-scale systems excreta may be composted without forced aeration, but pathogen die-off is not as good or as reliable as with forced aeration. **oo** Based on extensive research, Stentiford and Pereira Neto (as described in Mara), have devised the following procedure for forced aeration co-composting:

1. The materials to be co-composted (20 - 55 mm in size) are mixed together to give a C/N ratio of 25 - 35 with a moisture content of 50 - 55 %.
2. The pile (1.5 - 2 m high, 2 - 4 m wide and 10 - 50 m long) is constructed over a length of perforated plastic pipe. This pile is covered with a 10 cm thick layer of compost that acts as an insulator and filter.
3. A 250 - 370 Watt fan is used to blow air through the pipe to maintain aerobic conditions within the pile. The fan is operated for 3 - 5 minutes every 15 - 20 minutes.
4. As the temperature rises, the fan aerates the pile and maintains a reasonably uniform temperature distribution. The fan pushes heat from the hot inner core to the cooler outer edges, preventing heat build-up above 60 °C in the core, which would be detrimental to the thermophilic organisms responsible for the composting activity.
5. The temperatures of the core and edges of the pile are monitored during this thermophilic phase; when they both fall to 35 °C, the pile can be dismantled.
6. In a final maturation phase the material from the pile is stored to allow it to mature for a further 2 - 4 months, depending on the ambient temperature. During this phase the process of humification of high-carbon compounds such as lignin and cellulose is completed. When it is mature, the compost can be screened and particles larger than 5-10 mm removed. The compost is then ready for use on fields or gardens.

The case of the Zabbaleen (derived from *zabell,* which means garbage) in Cairo, is a good example of an integrated co-composting system. The Zabbaleen, a marginalized group of Coptic Christians in the predominantly Islamic society, survive by raising pigs fed on the organic household waste they collect. They also earn money by collecting relatively high-value waste from middle- and high income areas of the city. Excreta from pigs and the leftovers are brought to a composting plant in the area. Other valuable materials such as plastics and paper are sorted and reprocessed by a large number of micro-entreprises. Box 8.1 describes the co-composting process.

Box 8.1 Composting garbage and pig manure in Muquattam

Muquattam is one of the seven Zabbaleen areas in Cairo, with a population of around 15,000. A compost plant is situated in a former quarry in one of the hills of Muquattam. The area is unique in that for several decades the Zabbaleen have managed to derive (marginal) incomes from garbage collecting. They raise pigs on the organic material in so-called *zeribas,* or enclosed courtyards. Once or twice a year the *zeribas* are cleaned and the mixture of leftovers and pig manure is carried on donkey carts to the compost plant. Since the organic material has already undergone partial decomposition, the composting process is quite short, varying from 6 to 15 days. The organic material is composted in windrows that reach temperatures of 60 - 65 "C, and are turned once every two days.

Figure 8-3: Composting area with mechanical sieve in Muquattam, Cairo. ***Photo:*** **WASTE Consultants, 1992.**

The garbage from which the recyclable items have been removed is dumped by a mechanical front-end loader through a grid onto a conveyor belt, which transfers the garbage to a hopper and finally to a rotating, cylindrical drum, where the compost is sieved (see Figure 8-3). At the end of the sieve, children anxiously wait for some useful remnants. The maturity of the compost is determined by measuring the temperature.

Normally, the plant processes 30 tonnes (60 m3) of compost per shift per day. During the season when land is prepared for cultivation (November to February) output is doubled by working two shifts per day. The plant provides jobs for 11 employees (1 consultant, 1 plant manager, 1 technician, 1 electrician, 1 operation and maintenance manager, 3 security guards, 2 drivers, and 1 messenger). Mechanical parts for the plant can be bought in Egypt, although some electrical parts have to be imported. Although the quality of the compost appears to be good, it has been found to contain small pieces of glass and plastics, and large quantities of heavy metals.

The compost is sold at $ 4.50/m3 (based on the 1993 exchange rate of $ 1 = 3.5 Egyptian pounds), mostly to farmers within a radius of 100-150 km around Cairo. The farmers also pay the transport costs, which amount to approximately $ 3/m3. The compost is a highly valued product, and is applied to reclaimed land in sandy desert areas, and to upgrade existing agricultural (clay) soils that lack humus, especially those that have received too much chemical fertilizer. Sales of compost are highest just before and in the beginning of the cultivation season, which is between October and December. In 1991 this was about 2600 m3 per month, compared with 700 m3 per month over the rest of the year. The operating costs and also part of some welfare projects are paid for from the sale of the compost.

Source: Information from EQI and APE (Association for Protection of the Environment), 1993.

9 Anaerobic Digestion

Anaerobic digestion can take place in uncontrolled systems (for example at waste dumps) and in controlled systems (for example in reactors). In reactors especially human and animal waste are used as raw materials. New ways of using municipal organic waste are still being intensively tested especially in industrialized countries. At the moment tests are hardly being carried out in low- and middle-income countries. For this reason the process of anaerobic digestion will be explained less detailed than the composting process.

In this chapter, examples of the various treatment systems will be given. The potential of recovering methane from sanitary landfills is receiving increased attention, but will not be elaborated upon here.

9.1 History

One of the earliest writers to mention the appearance of mysterious flickering lights and flames emerging from below the earth's surface was the Roman writer Pliny. Only in the seventeenth century was it found out that this 'marsh gas' is created by the decay of dead plants in waterlogged conditions. This could present a nuisance if not a great danger, since when mixed in certain proportions with air it can be explosive. On the other hand, it was found that if substantial amounts of the gas were produced under controlled conditions, it could be collected and used as a fuel.

At the beginning of this century in Western Europe and the United States, as well as in India and China, scientists began experiments to develop this property of marsh gas under controlled conditions. In Germany the fuel shortages experienced during World War II were the driving force behind the research, while in India the impetus was the overwhelming need to exploit all possible sources of energy in order to raise standards of living. Today, anaerobic digestion systems of various designs and modifications are being tested to improve the efficiency of the reaction and to adapt it to a wide variety of organic materials.

9.2 The process

Anaerobic decomposition or digestion in a waste heap occurs when the oxygen supply is restricted or absent. This process is also called 'fermentation' and, like composting, it is a biological process in which organic materials are broken down. In this case, however, the biomass that can serve as compost is only one of the end products. In addition to this solid material, a combustible gas, often called 'biogas', is produced. Biogas consists of 50 - 80% methane (CH-O, 20 - 50% CO2 (by volume), and other gases (although in much smaller amounts) including hydrogen and nitrogen. Due to the formation of biogas, less compost is formed with digestion than with composting. The biogas plant or digester is a device that harnesses and controls the process of anaerobic fermentation to produce gas and soil conditioner.

The degradation of organic matter to produce methane relies on the complex interaction of three groups of micro-organisms. Due to the absence of oxygen, some of the micro-organisms involved differ from those in the composting process. Three phases can be distinguished:

1. *hydrolysis,* in which a mixture of fermenting bacteria break down complex organic compounds to simpler compounds (such as short-chain fatty acids and alcohol);
2. *acetogenesis,* in which acid-producing bacteria produce acetate and hydrogen; and
3. *methanogenesis,* in which the intermediate products are converted into methane and carbon dioxide.

The operation of the digester needs to be stable to ensure that these bacterial groups remain in a dynamic, yet harmonious equilibrium. Changes in environmental conditions such as temperature or the sudden addition of new substrate can affect this equilibrium and can result in the build-up of intermediate products, which will inhibit the overall process. If such upsets are not corrected (for instance by changing the temperature or the pH value), the performance of the digester will decrease and failure may ultimately occur.

9.3 Raw materials

During the process of anaerobic degradation the various waste fractions degrade at different rates, as is the case with its aerobic equivalent. In general, most natural organic wastes can also be degraded anaerobically.

In Asian countries in particular, the primary substrate for digesters is cattle dung. This is a good substrate, since it is moderately degradable and its nutrient contents are well balanced (its C/N ratio is 25). Pig and poultry manure produce more biogas per unit weight and at higher rates than cattle manure. Human excreta, while high in nitrogen 9S (its C/N ratio is 6), can also be easily digested. In urban areas anaerobic digesters are sometimes used for wastewater treatment.

Agricultural residues can be digested in combination with human or animal manure, but problems may arise because these materials can float on the surface in the reactor and form hard layers of scum. These residues should therefore be pretreated by composting them with night soil and lime before digestion.

Organic wastes generated in urban areas (domestic as well as industrial) are in principle also amenable to anaerobic conversion. Food wastes decompose more rapidly than paper products. Lignin cannot be degraded under anaerobic circumstances, so that wood, which contains a lot of lignin, should not be used. To a lesser degree, this is also true for paper and cardboard, which are slowly digested.

9.4 Influencing factors

When the process of anaerobic digestion occurs in a closed system, environmental factors that influence biological reactions, such as pH, temperature, composition of raw material and concentrations of toxins, are more amenable to external control than they are in open composting systems. Consequently, anaerobic digestion in a closed reactor system is more complicated. The influencing factors will only be briefly mentioned here, however, since closed reactor systems for municipal organic waste digestion are rarely used in economically less developed countries. The appropriate C/N ratios are the same as those described in section 7.4.

Environmental factors influence the various groups of bacteria in different ways. The methane-forming bacteria appear to be particularly sensitive to changes in temperature and pH than other micro-organisms present in reactors, and are most affected by the presence of toxic compounds such as ammonia, volatile acids and heavy metals.25 An absolute precondition for anaerobic digestion is the absence of oxygen. For anaerobic micro- organisms, oxygen is a toxic substance, in the presence of which the fermentation process will stop.

9.5 Natural degradation at waste dumps

The process of natural anaerobic degradation is utilized by many farmers and people living near waste dumps to derive compost. Most of the garbage that has accumulated over the years in these dumps and sanitary landfills contains reasonably high proportions of organic material, which is easily degradable by means of natural biochemical processes without the need for additional constituents. Some of this natural compost is used in the cultivation of vegetables in areas adjoining the dumps, thus avoiding transportation costs. Because the process is not controlled, aerobic as well as anaerobic degradation can take place, although after some time anaerobic processes will come to dominate. The use of compost derived naturally from waste dumps is common in Calcutta, as described in Box 1.1. In Bamako, Mali, people try to make a living by selling compost at the dumping grounds, as illustrated in Box 9.1.

Box 9.1 Economic benefits of two compost selling micro-units in Bamako, Mali

Mali has a long tradition of composting household wastes. This is certainly due to the poor soils and arid climate, which mean that fertilizers are required to improve the soil in order to grow anything during the short wet season. Chemical fertilizers have to be imported; they are therefore relatively expensive and are often in short supply. In Bamako, municipal solid waste contains a high proportion of organic material, which is allowed to decompose via natural anaerobic processes, and the resultant compost is highly valued as a soil conditioner.

Many individual farmers and traders exploit this free source of raw compost for their own benefit. When the garbage is delivered to the dump it is stacked into piles, which are left until they decompose. The process is not controlled, and the piles remain undisturbed for an indefinite period. Using relatively simple tools (sieves, spades, brooms, pushcarts) the traders manage to produce fine compost by sieving out the impurities and non-organic materials (see Figure 9-1). The resulting compost has a good appearance and is almost free of visible foreign matter. The regular supply, the low price and the proven quality of this soil conditioner have created a high demand, particularly from vegetable farmers in the peri-urban areas just before the planting season (April - June). However, because the compost is bulky, the cost of 94 transporting it tends to be high, therefore reducing its potential for use in the more remote areas.

Figure 9-1: Sieve used in compost making at the waste dump in Bamako, Mali.

Photo: WASTE Consultants, 1992.

Example of two micro-units

Here two small-scale enterprises are described. An elaborated cost-benefit analysis is given below. One unit consists of a farmer and his son working for themselves on a parttime basis. On average, they work 8 days a month to produce 20 m3 of compost per month using simple hand tools valued at $ 145. The son is paid pocket money only, of $ 17 per month. From this operation the farmer realizes a net profit of $ 64 per month, or S 8 per working day, which is more than three times the minimum wage. The initial investment in equipment ($ 145) was recovered from profits within three months. The second unit consists of three labourers employed by a trader at a minimum wage of $ 2.50/day. They produce 3.5 m of compost per day and work on average 20 days per month, giving a monthly production of 70 m3. If all compost is sold, the trader realizes a net profit of $ 168.50 per month. The profit per working day is $ 8.40, about the same level as the first unit, although the higher labour costs mean that the profit of $ 2.40 per m3 of compost is lower than in the first production unit ($ 3.20/m3).

	A	*B*
Personnel	Farmer and his son Son receives pocket money of $ 17 per month	Three labourers receiving S 2.50 each per day (minimum wage) employed by trader
Equipment	Locally manufactured screen, spade, pickaxe, containers, pushcart all valued at $ 145 Depreciation 33% a year	same as A
Taxes	Municipal tax of $ 10 per month	
Production capacity	2.5 m3 per day Average of 8 days per month: 20 m3 per month, given the seasonal variations in demand 240 m3 per year	Municipal tax of $ 10 per month 3.5 m3 per day Average of 20 working days per month: 70 m3 per month 840 m3 per year
Market price of compost	$ 4.75/m3 (excluding transport)	$ 4.75/m3 (excluding transport)
Cost/Benefit of operation per year Sales revenues Production costs	240 x$ 4.75 = 1140	840 x $ 4.75 = 3990
Raw material	0	0
Municipal tax	120	120

Depreciation equipment	48	48
Labour	204	1800
Total costs	372	1968
Net profit per year	768	2022
Net profit per month	64	168.50
Net profit per workday	8	8.40
Net profit per m3 of compost	3.20	2.40

Source: GERAD23, 1992.

This case study clearly demonstrates that compost making can be an economically feasible business. With relatively simple tools and a simple process compost is produced.

In Benin, the natural process of degradation is utilized by spreading several layers of refuse directly onto agricultural or vegetable fields and ploughing it in after the non-compostable substances have been removed. In addition to the hygienic disadvantages and its unaesthetic appearance, the system of ploughing in waste has several other disadvantages. Coarse, sharp-edged components of the refuse inhibit cultivation of the soil using animals or any mechanical method, since they can cause injuries to feet or can damage machinery. This simple method of producing fertilized soil has therefore been adapted into a windrow composting system. After spreading the waste onto the fields, sufficient time should be allowed for the decomposition of the organic substances before crops are grown. This is necessary because at the beginning of the process of decomposition the micro-organisms bind nitrogen and withhold it from the plants. The waste is often highly saline, so that if too much waste is spread out, there is also the danger that the soil and even the groundwater will be contaminated with salt.

9.6 Closed systems

Because of the required absence of oxygen, anaerobic degradation usually takes place within closed systems. The simplest technique is to dig a hole in the ground, throw in the waste and cover it with soil. This can be done in any backyard, although the availability of space might be a limitation. In order to control the process of anaerobic digestion, many different reactor systems have been designed.

9.6.1 Trenches

In several cities in India trenches are used as means of treating organic waste together with night soil. The garbage is dumped in a trench 0.9 - 1.2 m deep, with an area of 8 - 20 m . A layer of night soil is placed between two layers of waste, each 15 cm deep, and the layers are repeated until the trench is full and finally covered with soil. The trench is dug up after six months, and the anaerobically degraded material is sold as a soil conditioner.

A similar method of waste treatment can be observed in Tunisia, where refuse is placed in trenches 1 - 1.5 m deep, 60 m long and about 2 m wide, and finally covered with topsoil or sand. The anaerobically degraded material is dug up after one or two years and is also used as a soil conditioner.

9.6.2 Reactor systems

For anaerobic digestion to take place in a closed reactor with sufficient volume for the biological reactions to occur asks for some basic technical know-how. Based on external limitations such as capital costs, treatment efficiency, net energy yields and operational skills, the technology available can range from the rudimentary to quite sophisticated.

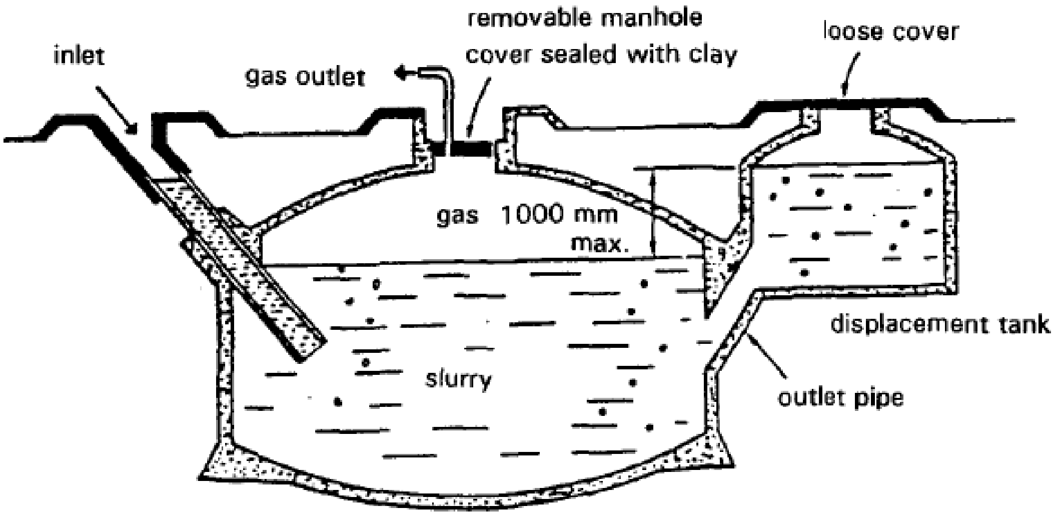
Figure 9-2: Animal waste digester in Cairo.

Photo: WASTE Consultants, 1993.

Batch and 'dry' fermentation is the simplest of all processes. The operation merely involves charging an airtight reactor with substrate containing certain bacteria, and in some cases a chemical to maintain a satisfactory pH. The reactor is then sealed, and fermentation is allowed to proceed for up to six months. During this period the daily gas production builds up to a maximum and then declines, after which the system can be fed again with substrate. The reactor has a removable cover with a gas outlet. Depending on the solid content, the process is known as 'dry' fermentation.

In Jiangsu, China, fixed-dome biogas digesters were being used as early as 1936. The reactor consists of a gas-tight chamber constructed of bricks, stone or poured concrete (see Figure 9-3). Both the top and bottom are hemispherical, joined by straight sides. The inside surface is sealed by many thin layers of mortar to make it gas-tight, although gas leakages through the dome remain a major problem in this design. The digester is fed semi-continuously (i.e. once a day). A removable manhole at the top of the digester provides access for cleaning, and through which the gas outlet pipe exits. The gas produced during digestion is stored under the dome and displaces some of the contents of the digester into the effluent chamber.

Figure 9-3: Chinese fixed-dome digester.



Source: Gunnerson et al.25.

In terms of absolute numbers, the fixed-dome digester is by far the most common type of digester used in Asian countries. Approximately six to seven million of these digesters are in use in China, and many in India and other countries. These digesters are typically fed with a mixture of pig or cattle dung, water hyacinth, night soil, and agricultural residues, depending on availability, and C/N ratios. Many experiments are currently under way to study the digestion of municipal waste in reactor systems. In Calcutta, for example, a pilot plant has been set up adjacent to the municipal dump to produce biogas from market wastes. The plant comprises a digester, a gas holder, a trommel (a revolving cylindrical sieve) for washing to remove dust and ash, a shredder for cutting the organic waste into small pieces, a water supply for the trommel and the digester, pits for the residue that emerges from the digester, etc. Each day 500 kg of market waste are placed in the digester, and the system produces 12 to 98 15 m of biogas containing 65 - 70% methane. Via a gas engine, approximately 15 kWh of energy per day are produced.67 In industrialized countries such as the Netherlands, anaerobic digester systems are developing very rapidly. The system of separate collection of the organic fraction of household waste has led to a rapidly growing demand for treatment facilities. The Dutch government is encouraging anaerobic treatment, because biogas can partly replace fossil fuel and thus reduce CO2-emissions.

10 Briquetting

In many parts of the world, wood is the primary source of energy for essential activities such as cooking. However, as shortages of fuelwood become increasingly severe, alternative sources of fuel such as agricultural products or sawdust are gaining acceptance. The use of solid wastes as sources of energy is attractive because it addresses both problems of waste disposal and fuelwood shortages.

The briquetting of biomass can be an effective, low-cost method of increasing fuel supplies. The technology of briquetting is easy to understand and simple to operate. With the continuing depletion of tree resources, woodfuel supplies are bound to worsen in the coming decades. Switching to conventional fuels such as bottled gas or kerosene may be a solution for those who can afford them, but given the desperate energy situations in many cities in economically less developed countries, organic waste may be the only feasible alternative fuel. Depending on economic circumstances, and lacking other natural resources, many people already rely on fuel derived from organic waste: for example, woody residues such as coconut shells are used as fuel for cooking.

This chapter explores the possibilities of using organic waste as fuel and deals with some technological and socio-economic aspects.

10.1 History

The use of organic waste as fuel is not new. In times of scarcity, people all over the world always have turned to agricultural residues and animal dung as sources of energy. However, the use of dung as a fuel varies very much according to cultural beliefs and practices.

Peat is formed by the anaerobic decomposition of plants in waterlogged areas, and is cut, dried and burned as a fuel by households and by industry. In the northeast of the Netherlands, for example, peat moss was widely used as a fuel for centuries, until it was displaced by newer energy sources such as coal, oil and gas.

In seventeenth-century England, the rural poor often burned dried cow dung because of the acute shortages of wood due to widespread deforestation. In some Asian countries cattle and buffalo dung are still used as relatively good cooking fuels; when dried, dung loses its smell, is easy to store, and burns with a steady flame. Its main problem is that it tends to produce a lot of smoke, which can irritate the eyes and lungs, and if inhaled in large quantities can cause health problems. Another disadvantage is that when such animal dung is burned, valuable nutrients are lost, which should ideally have been returned to the soil.

In Egypt, when the Wahi migrated to Cairo about 100 years ago, they assumed responsibility for collection, transport and disposal of household wastes. Initially they dried waste materials in the open air. They sold the end product as a fuel for cooking *fuul medamis,* a popular Egyptian bean dish, and for heating the water for Turkish baths. This practice died out when other energy sources became cheap and abundant .

As early as the beginning of the nineteenth century, attempts were made to make sawdust briquettes using binding materials such as tar, resins and clay to hold the small particles together. None of these processes attained any importance, however, because of the high costs involved. In those days, briquettes pressed without a binder were usually not successful, because temperature and pressure were too low. In the 1950s several economic methods were developed to make briquettes without a binder. During the two World Wars, households in many European countries made their own briquettes out of soaked waste paper and other combustible domestic waste using simple lever-operated presses. Today's industrial briquetting machines, although much larger and more complex, operate on the same principle.

10.2 Organic waste as fuel

The usefulness of a material as a fuel depends on its composition and calorific value (measured in units of megajoules per kilogram, MJ/kg). The average calorific values of several waste materials are given in Table 10-1. Although the calorific value of most organic household waste is not very high, it may still be used as fuel when dried if other energy sources are not available. Sometimes the burning characteristics of this waste material can be improved by mixing it with paper.

Agricultural residues are more interesting fuels. The calorific values of some agricultural residues together with the ash content are given in Table 10-2. The residues with the highest calorific values tend to be those with the lowest ash content, as is shown in the case of among others coconut shells. For example, rice straw and husks, which contain a large amount of non-combustable silica, produce more ash and less heat when burnt.4 Also the moisture content of the fuel determines the energy available.

The gross calorific value of wood charcoal is 32 MJ/kg, making it a valuable source of energy. Charcoal dust is also valuable; losses of charcoal dust during handling have been estimated to be as high as 5%, which could be retrieved and briquetted. Other possible sources of energy include the residues from the wood processing industry, such as sawdust, or twigs from gardens or parks. Non-woody crop residues make poorer fuel products. From the point of view of the cook, however, calorific value figures are of little relevance. The most important factors that determine which materials make the best fuels are their convenience of collection and storage, how easily they dry out, and how well they burn in the kitchen, and all of these factors are carefully considered in relation to the price paid.

Table 10-1: Average calorific values of waste materials. *Source:* WARMER[69].

Item	*(CV) as received* MJ/kg*
Dust and cinders	9.6
Paper	14.6
Vegetable	6.7
Metals .	nil
Glass	nil
Rag	16.0
Plastic	37.0
Unclassified (wood, shoes etc.)	7.6

* Moisture content typically 20 - 30% by weight

Table 10-2: Average calorific values and ash contents of selected raw agricultural residues. *Source:* Barnard and Kristoferson[4].

Material	*Ash content(%)*	*Gross calorific value tovendry) (MJ/kg)*
Rice straw	19.2	15.1
Rice husks	15.7	15.9
Maize stalks	4.9	17.5
Maize cobs	1.7	18.2
Coconut shells	0.8	20.1
Groundnut shells	4.4	20.1
Walnut shells	1.1	21.1
Olive pits	3.2	21.4

10.3 The process of briquetting

One way of making more efficient use of existing waste resources is densification, such as briquetting. Briquetting involves the collection of combustible materials that are not usable as such because of their low density, and compressing them into a solid fuel product of any convenient shape that can be burned like wood or charcoal. The material is compressed to form a product of higher bulk density, lower moisture content, and uniform size, shape, and material properties. Briquettes are easier to store, cheaper to transport, and more convenient to use, and their burning characteristics are better than those of the original organic waste material.

The raw material of a briquette has to stick together during compression; otherwise, when the briquette is removed from the mould, it will crumble apart. Improved cohesion can be obtained with a binder but also without, since under high temperature and pressure, some materials can act as their own binders. Wood, for example, becomes more plastic under high pressure, and can be briquetted using its natural resins as a binder. However, the presses required are expensive.

A binder must not cause smoke or gummy deposits, while the creation of dust should be avoided. Two types of binder can be used: combustible, including natural or synthetic resins, animal manure or dewatered sewage sludge; and non-combustible, such as clay and cement. Although combustible binders are preferable, non-combustible binders may be suitable if used in low concentrations; if the organic waste is severely contaminated with clay, the briquettes will not burn. Suitable binders include starch (5 to 10%) or molasses (15 to 25%). Experiments should be carried out to find suitable local ingredients and appropriate ratios. Sometimes other products such as conifer sawdust can be added to make the combustion more fragrant.

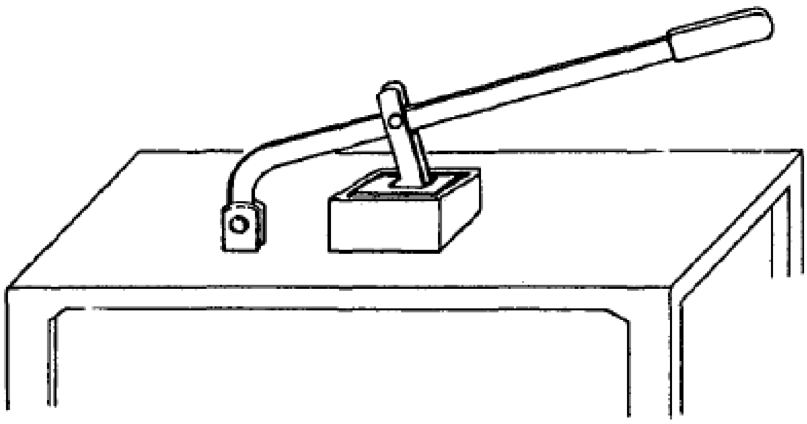
The method of preparation depends partially on the material being briquetted, but the procedure generally includes some or all of the following steps:

1. *Size reduction.* If necessary, the raw material is first reduced in size by chopping, crushing, breaking, rolling, hammering, milling, grinding, cutting etc., until the particles are suitably small and uniform size.
2. *Drying.* The feedstock for the briquetting press is often wet, so that it may be necessary to dry it either before or after size reduction. It can be dried in the sun, with a heater, or

using heated air and a rotating drum.

3. *Preparation of feedstock.* If no binder is used, the dried material can be fed directly to the briquetting press. If a binder is necessary, it should first be mixed with the raw material. The techniques that can be used vary from a simple trough and hoe to a modified commercial cement mixer. The correct proportions of raw material and binder can best be determined by simple trial and error. Different mixtures should be tested to determine the optimal mechanical strength and burning properties. The binder may be expensive, so the smallest necessary amount should be used.
4. *Carbonization.* If a biomass material such as wood is heated to very high temperatures without enough oxygen for the material to burn, charcoal is produced, which is a smokeless and clean-burning fuel. This process is called carbonization.
5. *Compaction.* The briquettes may be formed and compacted by hand or by means of simple presses that exert a pressure ranging from 50 to about 500 kg, depending on the length of the lever and the force exerted. A simple type of ball press produces round briquettes. More pressure can be exerted with the type of press shown in Figure 10-1, which produces rectangular briquettes up to about 5 x 5 x 10 cm in size. Briquettes formed in this simple way are usually dried in the sun before being sold

Figure 10-1: Design of a manually-operated briquetting machine



Source: ILO.28

In Nairobi, experiments have been carried out by the Undugu Society of Kenya (USK) with a press for making mud blocks for low-income housing projects. Various organic materials have been tried in several combinations. The materials included sawdust obtained from a nearby sawmill, charcoal dust collected from charcoal transfer and selling points, and waste paper. The waste paper was wetted to bind the various materials, however, this did not work out very well. USK is now searching for a suitable binder.

Figure 10-2: Briquetting machine used in Nairobi

Photo: WASTE Consultants, 1990

The design and scale of the various briquetting processes can vary considerably. The design depends on such factors as the feedstock used and its basic characteristics, the availability of local transport, and access to markets for the end products.

10.4 Some examples

When organic waste is used as a fuel, it is usually in its original form. In Calcutta, India, for example, waste pickers remove green coconut shells, coal cinders and pieces of wood from transfer stations and dump sites for use as domestic fuel.

In Kampala, Uganda, 15% of a sample of residents of a neighbourhood stated that they use the waste they generate, mostly as fuel: scrap waste paper and dried organic matter are used for cooking or for starting charcoal fires. Also in Kampala, charcoal balls are successfully used as fuel. Charcoal dust is obtained free from the local market. The charcoal is then mixed with water and mud, shaped into balls by hand, and left to dry in the sun for about half a day.

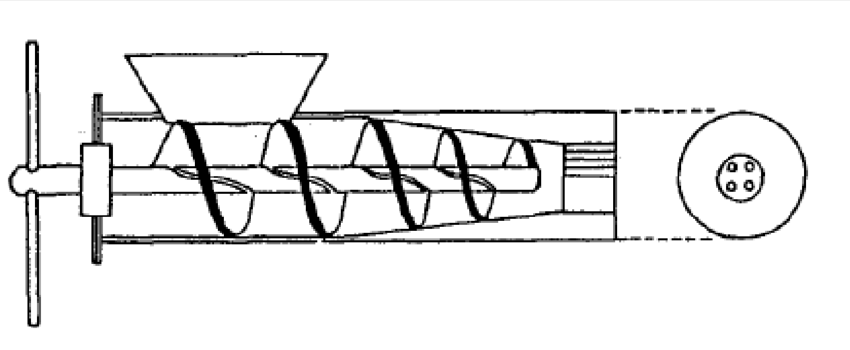
In Ghana, experiments are being carried out with the production of fuel briquettes from sawdust.

The mechanical briquetting technique is described in Box 10.1.

Box 10.1 Fuel briquettes from sawdust in Ghana

In Ghana, sawdust from hardwood mills is used in the production of briquettes. Sawdust is an unavoidable waste material in all types of primary and secondary wood processing. Between 10 and 13% of a log is reduced to sawdust in milling operations. Sawdust is bulky, and is therefore expensive to store and transport. Also, the calorific value of sawdust is quite low, so that briquetting is an ideal way to reduce the bulk, to increase the density, and thus to increase the calorific value. The equipment consists of a sawdust drying chamber, a pressing machine, and an extruder consisting of a tapered screw and a large revolving disk with dies. The principle of the machine is similar to the one shown in Figure 10-3, although this is a design of a manually operated tapered screw (developed by Hodam Associates, the Philippines). The machine consists of a feed chute, a handle, a screw and an extrusion die.28

The briquettes are formed under a sufficiently high pressure to produce cohesion between wood particles as the lignin softens because of the heat induced within the extruder. The briquettes are 11.5 cm in diameter and about 30.5 cm long. Chemicals or mechanical binders are not needed.



106 Figure 10-3: A manually operated extruder. *Source:* ILO28

The briquetting plant is integrated into the larger sawmilling operation. The briquettes are used as fuel to generate steam in the sawmill and, on a limited scale, also as charcoal substitutes for cooking. In this way, both wood and energy are saved. However, due to present limitations of the equipment, the briquettes do not burn completely and tend to produce smoke when they burn. Attempts are being made to further develop the technology, particularly the screw length to diameter ratio, the screw rotation speed, die pressure, and residence time in the extension chamber. *Source:* AB&p2, 1992.

This case shows the need for technical adaptation of the machinery. A market for the briquettes is guaranteed by their use inside the sawmilling plant.

The problems associated with briquetting arise not only at the technical level, but also at the social and economic level, which might be somewhat more difficult to overcome. The key requirement for the success of a briquetting enterprise is to develop a market for the product, and to overcome customer resistance to change. Price is also an important factor; briquettes should be sold at least as cheaply as other fuels such as wood or charcoal. Thus, the economic viability of such enterprises will depend on local conditions and the prices of other fuels.

Although the calorific value of a final briquetted product is comparable with that of wood, it may burn differently from traditional fuels and the stove (or the briquette) may have to be modified to make them compatible. Briquette manufacturers should therefore take into account the designs of locally used stoves before deciding on the characteristics of a briquette.

In Kenya, a coffee growers' organization called the Kenya Planters' Cooperative Union developed a method of making charcoal briquettes from coffee husks. The briquetting and charcoal-making equipment consisted of a horizontal drum oven to carbonize the coffee husks after drying. Then, the charcoal granules were briquetted using local maize starch as a binder in the ratio of 4% starch and 30% water. This charcoal product had a good quality because it burned for six hours, whereas the ordinary charcoal burns for only one hour, and it was sold in shops at four times the price of ordinary charcoal. However, the product was not very popular because the smoke of the coffee-charcoal spoiled the taste of the food. The technology has been further developed to improve the characteristics of the smoke.

At present there are few examples of small-scale successful ventures in this field, since most projects are still in an experimental phase. An example of a succesfull plant, operating at a larger scale, is a coal dust briquetting factory south of Lima. In Villa el Salvador, Peru, briquettes are made of coal dust that accumulates during mining activities. An automatic press produces 50 briquettes per minute. The coal dust (75 - 80% by weight) is mixed with a glutinous substance (20 - 25% by weight) and calcium oxide (1%). In one month three workers can produce 20,000 cylindrical briquettes (7.5 cm long and 15 cm wide), with a value of $ 0.13 each. Sales represent a value of $ 140,400 per year, which covers the costs. In comparison to the calorific value of kerosene, which is 43.2 MJ/kg, a coal dust briquette has a calorific value of 17.6 MJ/kg, enough to heat a 45 litre pot of soup.

10.5 Enzymatic charring

In Laguna, a province south of Manila in the Philippines, a fuel product called green charcoal is produced from agricultural and urban cellulosic waste. The process was invented and patented by an enterprise called Mapecon. In this process any form of agricultural waste, cellulosic garbage and biodegradable matter is shredded or sized, put into piles and (according to the inventor), special enzymes are introduced. To sustain proper enzyme action, the moisture content and internal heat of the pile are closely monitored. After 3-10 days, depending on the desired calorific value of the end product, the Q biomass is mixed, sized and compacted by a helical feeder into cylindrical briquettes. The briquettes are then dried to a moisture content of about 10%. Around 4 - 5 kg of biomass are needed to produce 1 kg of green charcoal. The fuel briquettes are compact, easily transportable, clean and easy to handle, and economical in use. The average calorific value of green charcoal is 16.7 MJ/kg.37

Green charcoal is the most obvious product of enzymatic charring, but products other than fuel can also be obtained from the same process. These additional products include a durable, lightweight building material that is suitable for low-cost housing construction, as well as various novelty and decorative items such as vases, figurines and trays. Most of these products require changes only in the enzymes applied during the process, or in the final moulding or compacting and finishing stages. In making the construction material, enzymes are used to improve the binding characteristics. Thus urban and cellulosic waste is converted into durable mouldable construction materials that look like wood.

Green charcoal board about 7.5 cm thick can be moulded to any desired width and length. By wrapping wrought iron around the green charcoal board and applying a concrete mixture of about 5 cm thick around it, an economical and simple construction block can be made that is light, very durable, is a good insulator, and is protected by the concrete cover from termites and decay.

Another example of construction material made from organic waste also comes from the Philippines. Used styrofoam is applied as a binder for organic materials such as wood shavings, sawdust, leaves, twigs, etc. The product is known as Marwood, a synthetic wood that is resistant to water, fire and termites.7

11 Future Prospects

Waste forms a health hazard when it lies scattered in the streets and at transfer stations without being collected. In low- and middle-income countries, a large proportion of urban waste has an organic component. It may therefore offer ample opportunities for employment generation and improvement of environmental and health conditions. Organic waste can be the basis for many diverse activities, many of which have been described in this book. Although much is known about several systems of organic waste reprocessing with greater or lower success rates, some of these, in particular anaerobic digestion and the reuse of organic waste as fuel, are still in an experimental phase.

This chapter gives an overview of some general conclusions that can be drawn from the information and the examples described in this publication. Also, some suggestions are given as how to integrate organic waste recovery activities in an urban waste management system.

11.1 Towards integrated waste management systems

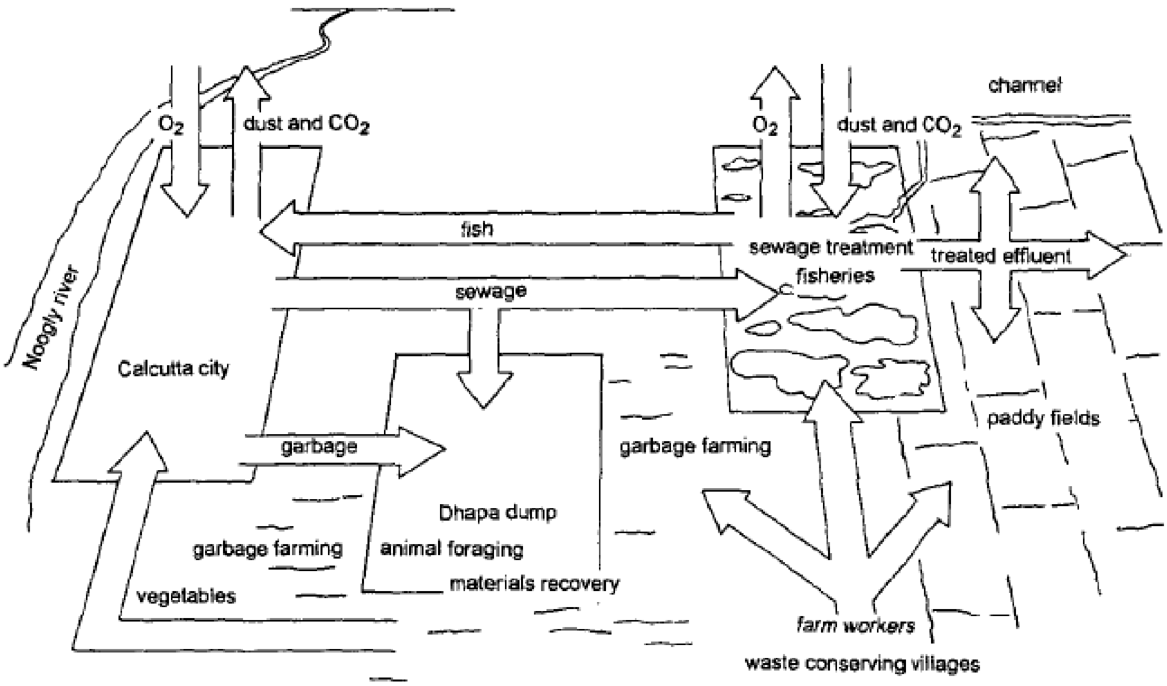
The reuse of organic material as animal or fish feed, compost or fuel can contribute to solving urban problems such as the need for income-generating employment opportunities, food production, the lack of adequate waste disposal sites, energy supplies, and maintaining environmental quality. In managing waste collection and disposal systems, these benefits should be taken into account and the various recycling possibilities should be incorporated on both the implementation and the policy level.

The earth's resources are finite, so that resource recovery and utilization are essential elements in any effort to achieve a sustainable level of waste management. Enhancing the recovery of organic waste can restore various natural cycles, thus preventing the loss of raw materials, energy and nutrients. An example of an integrated system of urban waste recovery is given in Box 1.1, which describes the multiple uses of waste at a dumps ite in Calcutta. Organic waste is used both for feeding animals and for growing vegetables. Sewage water flows into fish ponds and the effluent is used as irrigation water. Figure 11-1 indicates the various cycles of nutrients and the optimal use that is made of the various waste resources.

The waste recovery system as it is operated by the Zabbaleen in Cairo, including pig raising on organic waste, co-composting of pig manure and garbage and reprocessing of other waste materials such as paper and plastics, is another example of the integrated reuse of organic waste. Both systems, however, could be improved in terms of product quality and working and living conditions, by separation at source (section 2.1) and by other quality enhancing activities.

Resource recovery centres at neighbourhood level, which aim at an optimal reuse of all kinds of waste materials, including the organic part (see section 2.3), may also provide an opportunity for contributing to sustainable waste management in cities. Proposals have been made to establish these systems in Bandung and in Kampala, but these have not been fully implemented yet. Such decentralized systems are more flexible in terms of type and quantity of production than centralized ones. They may generate more labour and income and reduce municipal transportation and disposal costs.

Figure 11-1: Ecological system of urban waste recovery in Eastern Wetlands of Calcutta.



Source: Furedy and Ghose[19]

11.2 Technology transfer and development

A tentative conclusion is that in the urban areas of economically less developed countries, large-scale reprocessing of organic waste is undergoing a crisis. All over the world, municipal authorities have started initiatives in this area, the most important being composting. Installations have been purchased that were often too expensive, too complicated, and not tailored to local conditions. An example is the compost installation in Accra (see Box 7.4), which is functioning below its full capacity. A search for new small-scale recovery methods has therefore been started.

Until now, transfer of technology has mainly taken place from the industrialized countries to the economically less developed ones, although most often these technologies were not directly applicable. The type and composition of waste, the lack of capital and specific technical know-how, the need for employment generation, the existence of a large informal waste collection sector and cultural attitudes are just a few examples of aspects that should be considered when developing a sustainable solid waste recovery system in low- and middle-income countries.

Efforts to simply transfer reprocessing techniques based on high-cost equipment should therefore be discouraged. At the same time, one should remain alert to valuable know-how and technologies that could be of use to economically less developed countries. Reprocessing techniques and methodologies, such as forced aeration systems or separation at source that are applied in industrialized countries may provide an option if the aforementioned aspects have been taken into account in the feasibility studies that precede the choice of technology. Adequate on-the-job training should also form an integral part of the technology transfer process.

The so-called South-South exchange (for instance between Asian, African and South-American countries) of technical know-how and practical experiences probably offers more opportunities, but this has as yet not received the attention it deserves. The example of GIE BESEYA in Bamako, involved in waste collection as well as compost production by simple means, certainly deserves more attention and provides excellent possibilities for application elsewhere. The Undugu Society of Kenya, for example, where the original question for the WAREN project (see Preface) came from, could benefit from the experience gained in Bamako and set up similar activities. The same holds good for, for example, a recycling activity in Cairo, where a non-governmental organization gained practical experience with co-composting at neighbourhood level. The Chinese covered pile system described in various sections of this book could also be applied elsewhere, both at household and at neighbourhood level. Transfer of technology consists of more than just technical solutions; answers also have to be found to a number of financial and social problems, as the examples in the boxes indicate.

11.3 Economic feasibility

The recovery of organic waste differs from the reprocessing of other waste materials such as plastics and rubber in that the latter have proven their economic profitability in small-scale enterprises: in Asian cities hundreds of such micro-enterprises exist. There are only a few examples of feasible small-scale enterprises reprocessing organic waste. Compost making as carried out at the dumpsite in Bamako (see Box 9.1) has been shown to be a profitable activity, mainly due to the simple and cheap technologies used and the absence of transportation costs. In Cairo and Manila animal raising has also been shown to be feasible as a part-time activity (see Box 5.1).

For the other reprocessing activities described the cost-effectiveness is less sure. A comparison of a labour-intensive and a capital-intensive composting system, both small-scale and located in Kathmandu, demonstrates that the labour-intensive alternative is economically more feasible. But neither options cover all costs and both need financing from other sources. This could, for instance, be realized by savings on municipal transportation and disposal costs.

The use of organic waste as fuel (either through briquetting or anaerobic digestion in reactor systems) in itself is attractive, but is not taking place on a large scale yet. So far, cost-benefit analyses on small-scale activities are not available.

One of the bottle-necks in organic waste processing is the marketing of end products, in particular the marketing of compost and fuel briquettes. High transportation costs limit the use of compost to the surrounding areas of the city. Urban agriculture could be an example of a possible application of large amounts of organic waste. Links could be sought with the many urban women who grow and market vegetables. Urban 'greening', that is, supplying green areas for the improvement of living conditions, also offers possibilities for the application of compost.

So far, these issues have not yet received the attention they deserve and their potential is hardly utilized, also because of the negative image of urban waste.

Figure 11-2: Tree nursery in a low-income area of Nairobi

Photo: WASTE Consultants, 1990.

The briquetting techniques described in Chapter 10 need some adaptations before they can be feasibly implemented on a small scale. But there are also other aspects that make their introduction difficult. The briquettes are often more expensive than the common sources of energy such as wood and kerosine, and cultural acceptance of the briquettes may be problematic (due to, for instance, the smoking characteristics of briquettes). Only when the usual fuels are scarce or expensive briquetting does become an economically viable alternative. A sound marketing system is a prerequisite for any reprocessing activity.

There is a conflict between the financial constraints and the ecological advantages of resource recovery of organic waste material. Large-scale composting activities, such as in Accra, have shown that environmental benefits are more realistic targets than economic feasibility. The question is whether compost production and organic waste recovery in general should be seen as a way to secure profits or rather as a contribution to social and ecological improvements. Therefore, the objectives of organic waste processing activities need to be clearly defined at the outset.

The needs and priorities of women, as well as those of men and young people, should be taken into account in improvement programmes. However, instead of overburdening women, the combination of several tasks within the household could be taken as a starting point. Resource recovery activities should involve women, not only as actors and labourers, but also as decision makers. The community waste recovery system in Mexico described in Box 2.3 illustrates this point. Because women traditionally deal with household waste disposal, they eventually became the managers of the system. Also COFESFA, which provides a health eduction and waste collection service in Bamako, is run by women (see Box 2.1).

11.4 Improvement of working conditions and environment

Although the recovery of organic waste has many benefits in terms of environment, the reprocessing methods themselves may pose health hazards to the workers. This book aims at indicating ways to encourage people to work and earn their incomes from organic waste recovery activities, while at the same time improving their working conditions through the introduction of safer and cleaner production processes. For example, the book describes separation of waste at source. If waste is separated at or near its source, less sorting and processing will be needed and the raw materials will be less contaminated. Precautionary measures, such as the need for protective clothing and face masks (see Chapter 4), should be taken into consideration as much as possible. However, it should also be realized that improvement of working conditions for low-income groups is not an easily obtainable goal, due to meagre financial margins and a surplus of cheap labour. Another problem seems to be the lack of scientific knowledge about the precise dangers for human beings when dealing with waste.

These considerations pose a dilemma as to whether certain activities should be encouraged or not. Animal raising in urban areas can serve as an example, because it may cause several health problems. One way of dealing with the problem is banning livestock from the urban areas. Another option is to attempt to improve the situation, for example by immediate recycling of animal waste into agricultural production. However, the environmental risks should be seen in relation to their context and local circumstances. It is of little use improving working conditions or forbidding certain activities, when citizens are struggling for their survival and lack access to basic services, such as adequate water and sanitation supplies.

The treatment of waste near the source of generation and separation at source could be an important means of preventing the shift of environmental problems to adjacent urban areas, to urban fringes, to more remote places or to future generations. Backyard composting as encouraged in Manila (see Box 5.1) could be part of such a strategy.

The best way of preventing environmental and health problems caused by waste would be simply avoiding the generation of waste. Prevention should always be an important measure. However, this is difficult to achieve for low- and middle-income countries, whose populations still lack a reasonable standard of living, which implies that waste generation rates will increase and waste composition will change. On the other hand, this does not mean that the less developed countries are relieved from the responsibilityof creating sustainable livelihoods for their populations.

11.5 Public authorities and private initiatives

Governments play an important role in the promotion and viability of resource recovery systems, as stated in section 3.3. Thesubsidies on chemical fertilizers, for instance, have a negative impact on the use of compost and thus on the recycling possibilities of organic waste. On the other hand, in Curitiba, Brazil, political commitment and continuity over two decades have resulted in .some innovative urban environmental programmes.

Private initiators, such as businesses and non-governmental organizations can also make an important contribution. The informal sector should not be overlooked in this respect, as the example of the Zabbaleen in Cairo shows. However, to maintain public health and environmental standards the final responsibility for waste collection, treatment and disposal should rest with the government.

If positive environmental and health effects are considered to be substantial enough, organic waste reprocessing activities should be subsidized, since they are not always economically viable. But who is going to subsidize these activities, when neither public budgets nor private households are able to provide more than the absolute minimum of funds? Under these circumstances, the success of an activity is dependent on, among other things, the establishment of an efficient management system, on motivated and creative personnel, and on the willingness of the population to participate and cooperate. A prerequisite for well-functioning organic waste recycling activities is cooperation between government and private initiator. The wave of democratization processes all over the world facilitates cooperation between governments and private initiators. This is clearly shown by the Bamako case (see Box 2.1), where several private enterprises and non-governmental organizations have started waste collection and treatment services.

Cooperation could also be sought in areas such as compost production and urban agriculture. The issue of resource recovery could also be taken up by existing agricultural extension services or by organizations and institutions working in this field, which has seldom been the case so far.

Some issues that governments and intermediate organizations could address, depending on their resources and responsibilities, include:

- stimulating urban agriculture and the 'greening' of cities;
- encouraging the separation of waste fractions at source;
- facilitating composting of organic waste and other resource recovery processes;
- recognizing and integrating the existing informal recycling networks within municipal solid waste management systems;
- stimulating the development and implementation of appropriate technologies for organic waste treatment;
- formulating policies to protect and encourage the horizontal growth of smallscale resource recovery initiatives;
- creating legal frameworks and controlling mechanisms that will enhance safety in the working place as well as protect the environment;
- developing educational material for public information and awareness.

The problem in introducing small-scale resource recovery modules that can contribute to sustainable waste management systems is more a matter of perception than one of technology. It requires interdisciplinary cooperation at several levels among various actors, such as municipal and national governments, non-governmental initiators (varying from welfare to women and environmental organizations), research institutes, scholars, community representatives and so on.

Many questions are still to be answered, such as how small-scale resource recovery activities can be optimized under local circumstances and best fit in a broader perspective on waste management. From the practical experiences gained all over the world, some of which are shown in this book, important lessons can be learnt and decisive steps in the appropriate direction can be taken.

Appendices

1 Average Exchange Rates in 1991

Philippines:	$1 = 30 Pesos (P)
Egypt:	$1 = 2 Egyptian Pounds (LE)
Ghana:	$1 = 450 Cedis (C)
Kenya:	$1 = 25 Kenyan Shillings (Ksh)
India:	$1 = 30 Rupees (Rp)
Mali:	$1 = 300 Francs (CFA)

2 Classification of Solid Waste

See table. *Source:* B.N. Lohani, G. Todino, R, Jindal and H.V. Ludwig, Recycling of Solid Wastes, *Environmental Sanitation Reviews,* No. 13/14, September 1984.

Refuse (solid wastes)	Garbage	Wastes from the preparation, cooking and serving of food Market refuse, waste from the handling, storage and sale of products and meats		From: households, institutions and commercial concerns such as hotels, stores, restaurants, markets, etc.
	Rubbish	Combustible (primarily organic)	Paper, cardboard, cartons Wood, boxes, excelsior Plastics Rags, cloth, bedding Leather, rubber Grass, leaves, yard trimmings	
		Non-combustible (primarily inorganic)	Metals, tin cans, metal foils Dirt Stones, bricks, ceramics, crockery Glass, bottles Other mineral refuse	
	Ashes	Residue from fires used for cooking and for heating buildings, cinders		
	Bulky wastes	Large auto parts, tires Stoves, refrigerators, other large appliances Furniture, large crates Trees, branches, palm fronds, stumps, flotage		From: streets, sidewalks, alleys, vacant lots, etc.
	Street refuse	Street sweepings, dirt Leaves Catch basin dirt Contents of litter receptacles		
	Dead animals	Small animals: cats, dogs, poultry, etc. Large animals: horses, cows, etc.		
	Abandoned vehicles	Automobiles, trucks		
	Construction and demolition wastes	Lumber, roofing and sheating scraps Rubble, broken concrete plaster, etc. Conduit, pipe, wire, insulation, etc.		From: factories, power plants, etc.
	Industrial refuse	Solid wastes resulting from industry processes and manufacturing operations, such as: food-processing wastes, boiler house cinders, wood, plastic and metal scraps, and shavings, etc.		
	Special wastes	Hazardous wastes: pathological wastes, explosives, radioactive materials Security wastes: confidential documents, negotiable papers, etc.		Households, hospitals, stores, industry, etc.
	Animal and agricultural wastes	Manures, crop residues		Farms, feed lots
	Sewage treatment residues	Coarse screening, grit, septic tank sludge, dewatered sludge		Sewage treatment plants, septic tanks

3 Further Information

Relevant Magazines

students and teachers. Articles deal with approaches to the problem and experiences gained in city projects and are not technology oriented.

Environmental Sanitation Reviews, (for address see List of Institutions: AIT/ENSIC)

- Published twice a year
- $ 130 (includes *Environmental Sanitation Abstracts* and *ENFO Newsletter)*
- ENSIC is an information centre on water supply and sanitation and in the publication
- state-of-the-art reviews on various environmental topics are given.

German Appropriate Technology Exchange (GATE),
(for address see List of Institutions: GTZ)

- Published quarterly
- Free of charge
- Offers a free information service on appropriate technologies for all public and private development institutions in countries dealing with the development, adaptation, application and introduction of technologies. Each number carries a special theme; at regular intervals numbers appear on solid waste management, recycling and composting.

IRCWD-Newsletter, (for address see List of Institutions: IRCWD)

- Published on an irregular basis
- Free of charge
- Small magazine with R&D articles on solid and liquid waste, events in the hygiene sector and recent publications.

Newsletter Biogas, Editor: Dr Amrit B. Karki, PO Box 1309, Kathmandu, Nepal

- Published 34 per year
- $ 22 per year
- Small magazine which publishes practical experiences from biogas projects and applied research in Nepal and elsewhere in the region.

WARMER Bulletin, 83 Mount Ephraim, Turnbridge Wells, Kent TN4 8BS, UK

- Published four times per year
- Acts as a worldwide information service to encourage recycling of materials and energy from post-consumer waste and is circulated to more than 100,000 readers in 100 countries. The topics covered deal with Northern recycling technologies, but also awareness and promotion campaigns and policy measures, their failures and successes. The magazine includes factsheets showing basics on various recycling technologies.

SWM-Info, (for address see List of Institutions: UNCRD/Japan)

- Published five times per year
- Free of charge
- Describes experiences of SWM and recycling from cities in the Far East and
- Pacific and reports on conclusions from seminars and workshops held in the
- region.

African Environment, (For address see List of Institutions: END A)

- Published quarterly in French and English, sometimes in Arabic
- CFA 10,000, FF 200, Third World, Regular; CFA 15,000, FF 300 to institutions
- and other countries
- The bulletin deals with environmental studies and regional planning issues that are relevant to problems of environment and development in Africa. Occasional papers are also published.

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Glossary

Acid-producing bacteria (or actinomycetes): the group of bacteria in a digester that produce volatile acids as one of the by-products of their metabolism
Aeration: exposure to the mechanical or chemical action of the air
Aerobic: in the presence of freely available oxygen
Aerobic bacteria: bacteria that live and reproduce only in an environment containing oxygen
Alkaline: pH 7.0
Anaerobic: in the absence of freely available oxygen
Anaerobic bacteria: bacteria that live and reproduce in an environment containing no free or dissolved oxygen
Batch: single quantity of raw material, not continuous
Binder: material that holds fibres or particles together
Biodegradable: capable of being decomposed by bacteria or other living organisms
Biogas: a mixture of gases, predominantly methane (CH4) and carbon dioxide (COi), produced by anaerobic digestion
Biogas plant: a facility used to process organic matter to produce biogas and sludge
Briquette: compacted block of a loose combustible substance that can be used as a fuel
Calorific value: the amount of heat that can be obtained from a fuel
Capital-intensive: indicates that a relatively large percentage of the total cost of production is associated with the initial cost rather than the operating cost; also used to differentiate from technologies which are labour-intensive
Carbonization: conversion of wood into charcoal by heating to very high temperatures without enough oxygen for the material to burn
Carbon/nitrogen (C/N) **ratio:** the ratio of organic carbon to total nitrogen, used to indicate the nutrient value of organic material
Chemical fertilizer: refers to nitrogen, phosphorus or phosphate fertilizers manufactured from virgin raw. material feedstock
Combustion: a process by which organic material is burned in the presence or near absence of air
Compaction vehicles: collection vehicles equipped with hydraulic systems that compress voluminous waste materials
Compost: end-product of the process of biological degradation
Composting: controlled decomposition of organic matter under aerobic conditions by which material is transformed into compost 130
Degradation: the breakdown of substances by chemical, physical and/or biological action
Dewatered sludge: effluent sludge of a digester, of which the water has been removed by evaporation or by filtration
Digestion: controlled decomposition of organic matter, normally under anaerobic circumstances
Digester: a tank in which the degradation of organic matter by anaerobic bacteria takes place
Enzyme: a complex organic substance (protein) produced by living cells. Accelerates transformation processes
Exothermic: occurring or formed with the evolution of waste
Feasibility study: a technical evaluation to determine the economic or social viability of an activity

Fermentation: the anaerobic biological degradation of organic material

Forced aeration: controlled aeration, either by mechanically blowing air in or drawing air through a compost windrow

Garbage: household fraction of municipal refuse typified by kitchen residues and other organic wastes

Gender: refers to the ideological and material relationship that exists between men and women within a society. Is not a biological fact but socially constructed and can thus be changed

Hazardous waste: residual of industrial process or individual consumption which is potentially dangerous to living beings and/or the environment

Humus: end-product of biological degradation processes, such as composting or digestion

Informal sector: extensive economic activity which is usually small-scale, labour-intensive, unregulated and competitive.

Integrated resource recovery: recovery of materials and energy from waste in different sectors of society which are compatible with each other

Labour-intensive: needing a large workforce

Leach: wash out or through with liquid

Manure: animal excreta, normally faecal matter from livestock

Market: processor or end-user

Marketing: processing by which buyers and sellers are brought together

Metabolism: the biochemical changes in living cells by which energy is provided for vital processes and activities, and new material is synthesized

Methane (Cttj): a colourless, odourless, flammable gas that is the main constituent of biogas

Municipal solid waste: waste generated from household, commercial and industrial sources

Night soil: human excreta, collected from homes without their own means of disposal by buckets or vacuum trucks

Non-organic material: material such as sand, dust and minerals like salt and iron, which are not degraded by micro-organisms

Nutrient: part of a feed or fertilizer that has food value

Opportunity savings: cost savings, such as a reduction in transportation and disposal costs realized by composting or other treatment processes which reduce the volume of the solid waste to be disposed of

Organic material: material derived from animal or vegetable sources, which can generally be degraded by micro-organisms

Pathogen: an agent that causes disease pH: a number that denotes the acidity or alkalinity of a substance (pH 7 acid; pH 7 alkaline)

Picker: person who collects material from a waste dump

Recycling: the use of secondary materials to produce new products, as opposed to reusing or remanufacturing of secondary products

Reduce: convert into a simpler form

Refuse: rubbish, mixed waste materials

Resource recovery: a general term referring to any productive use of what would otherwise be a waste material requiring disposal

Sanitary landfill: site specifically engineered for the disposal of waste on land, which minimizes potential air and leachate pollution _ '

Scavengers: people who live by collecting material from waste dumps

Sewage: human waste material carried away by pipes

Separation at source: separation of waste commodities at the place where the waste is generated, such as within households or industries

Sludge: wet, solid material that settles from sewage or other solution

Toxicity: a condition that will inhibit or destroy the growth or function of an organism

Volatile: a substance that evaporates rapidly
Zabbaleen: generic term for several Coptic Christian minorities in Egyptian cities who are responsible for the collection, recycling and disposal of solid wastes

Organic Waste describes low-cost option. 1 for the use of organic waste to produce suitable end P products. The focus is on the recovery of urb ' organic waste through activities such as animal raising, composting, the production of biogas a * briquettin Attention is paid to technologies that invo manual labour in order to create employment for low-income people. Financial aspects, marketability of end products, environmental problems and government policies are also dealt with. f The book is based on data and seven research reports compiled by local consultants on the recovery of organic waste in Cairo, Nairobi, Accra, Bamako, Calcutta and Manila. The book is the first title in the 'Urban Solid Waste Series'. It is co-published by TOOL and WASTE Consultants. and local NGOS. TOOL Publlcatlons IS actively involved in lmprowng the programmes of local institutions for information generation and dissemination. TOOL provides expertise on writing and editing, the use of modern media, marketing and dlstributlon. ISBN 90-70857-33-2 4