Plastic Waste

OPTIONS FOR SMALL-SCALE RESOURCE RECOVERY

Urban
Solid Waste
Series 2

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(Editors)

WASTE Consultants

TOOL Technology Transfer for Development

Plastic Waste

Options for small-scale resource recovery

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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 not-for-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 an income could be created from the uncollected waste lying around the city and industrial areas. Lacking the necessary knowledge and experience, USK asked WASTE Consultants to assist in setting up a waste recovery system. This was the starting point for the so-called 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 five other cities around the world 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 exploited by micro-entrepreneurs who recover urban solid waste materials in Cairo, Bamako, Accra, Manila and Calcutta. In Nairobi, similar research was carried out to inventorize the current state of recycling and to identify new implementation opportunities.

Ten major materials were identified: rubber, plastics, 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, the skills required, municipal waste management policies, and import regulations affecting recycling. These factors make up 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, which also raised new questions. Additional data and literature gathered during the research were included. On the basis of this material, the present book on plastic waste was written.

We hope this book will not be the final product, however. New experience is continually being gained, new technologies are being developed and innovative solutions to problems are being 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 100 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 visiting dumpsites in order to get an idea of what is 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.

This publication made use of the extensive research on plastics recycling in Istanbul, Turkey, carried out by Peter Konings at the request of WASTE Consultants in 1989. During his field visits he took many of the photographs of the processing techniques and products manufactured that are reproduced in this publication.

Research data as such do not make a book. Assistance with the analysis and interpretation of data was provided by Joris Oldewelt (economist), while Hanns-André Pitot (environmental consultant) carried out the missions in the beginning of the project to discuss the set-up of the research in the selected cities. Many people offered their valuable knowledge and took the time to read the manuscript: Rehan Ahmed (sanitary engineer, APE, Karachi, Pakistan), Mounir Bushra Mina (solid waste expert, EQI, Cairo, Egypt) and last but surely not least Han Molijn (plastic waste recycling expert) who made many useful comments and guided us through the complex terminology and processes of plastics recovery. Jaap Voeten (development economist) commented specifically on Chapters 3 (on small reprocessing enterprises) and 7 (on the economics of plastics recovery). Anne-Lies Risseeuw (WASTE Consultants) took care of the language corrections of the draft manuscript, while Valerie Jones did the final editing of the whole manuscript.

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

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Gouda, January 1995

Introduction

Since the publication of Jon Vogler's famous book *Work from Waste* in 1981 there has been silence in the field of small-scale resource recovery, which often takes place within the so-called informal sector. 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. We believe that it is worthwhile documenting the experiences of such enterprises in order to disseminate the information to other interested parties in other countries.

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 to dealing with waste 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 on existing informal systems of recovery. In particular, potentially valuable components of the waste are destroyed, resulting in the loss of means of survival for the large numbers of people who work in the informal waste sector. 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 disposal 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 cities that do not depend only on high-tech equipment. Waste technology that is feasible in high-income countries is usually inappropriate for the socio-economic conditions in less industrialized countries. 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. 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 waste 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 this might be to provide the micro-entrepreneurs with scientific knowledge at no or low cost.

Innovation in this sector 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. However, the products often contain air bubbles that cause the glass to break if it comes into contact with a hot liquid. In Manila, micro-entrepreneurs have found a solution by changing the design of the furnace and by including an additive to prevent the formation of bubbles, making the glass heat-resistant.

- Waste plastics are often covered with sticky liquids and mixed with organic matter, making the sorting of plastics a dirty job for the thousands of scavengers at road and waste dumps. 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 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 adaptations of processes and technology found in the Philippines or India may be useful for micro-entrepreneurs elsewhere to improve the quality of their products and working conditions. Although these changes may result in higher costs, they will also increase the monetary value of the waste products, and thus improve incomes and employment opportunities. This book documents several recycling activities set up by entrepreneurs, 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 sector, but little has been described in terms of micro-businesses. Individual experiences are passed on from parents to children, and neighbouring entrepreneurs may perhaps also 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 of course many differences between, for example, Asian and African countries in terms of their economic and industrial development circumstances, so it may not always be possible for some experiences to be replicated. Asia, for example, has had a longer (formal) industrial tradition than Africa, which has its spin-off to the informal micro-enterprises in terms of the availability of knowledge and of second-hand machinery and (locally made) spare parts. These larger and formal industries also provide a market for semi-manufactured end products. These differences in economic development, plus other differences such as population size, influence market demand and the waste materials produced.

This book is the second in a series on Urban Solid Waste Recovery, and represents an attempt to document the experiences of small-scale recycling entrepreneurs in cities around the world. There are considerable differences between these cities and the level of recovery of the materials investigated. For example, some waste materials such as plastics, rubber, glass and tin cans are reprocessed by many micro-enterprises, especially in Cairo and in Asian cities, and are turned into either final products or semi-manufactured materials ready for use by formal industries. On the other hand, micro-enterprises are rarely engaged in the recovery of organic waste except where it is used for animal raising.

The first book in this series was published in 1993 and dealt specifically with organic waste. Topics that will be covered in future books are: rubber waste and hazardous waste (including motor oil, photo chemicals and household batteries). *Rubber Waste* (just as *Plastic Waste*) will describe the products made, the markets covered and the technologies used for waste recycling, while *Hazardous Waste* will pay specific attention to the environmental and health problems caused by the recycling of hazardous waste materials.

The recovery of solid urban waste certainly has the potential to contribute to solutions of problems such as unemployment and inadequate waste disposal. There is scope for implementation on a much broader scale than has been the case so far. If the urban poor 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 to these efforts.

The scope of this book

The book is intended primarily for intermediate organizations dealing with communities in urban low-income areas and who seek opportunities either to create or to increase employment opportunities among their members. It is also intended for institutions concerned about the potential threat of solid waste to human health as one of the many environmental problems in rapidly 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 ignoring the work of thousands of people and organizations in their attempts to create employment opportunities and at the same time contributing to keep cities clean.

This book is not intended to provide a complete overview of all technical and economic options for the recovery of waste plastics. It is based primarily on the reports of the consultants involved in the WAREN project whose research focused on the actual state of plastic waste recycling by small enterprises, which often operate within the informal sector. The many examples of first-hand observations enrich the publication, while at the same time they are limited because it is difficult to make direct comparisons and generalizations. However, it is hoped that this publication will provide guidelines to the basic principles of some small-scale and low-tech options available for the recovery of mixed plastic waste. The book indicates ways to encourage people to work and earn their incomes from plastic waste recovery activities, while at the same time recognizing existing problems and trying to improve working conditions through the introduction of cleaner and therefore safer production processes.

Attention is also paid to issues such as the problems involved in finding markets for the reprocessed products, the feasibility of activities in this field of recycling, the environmental benefits and the occupational health hazards. These issues need to be considered in order to determine whether, and under what conditions, small enterprises can contribute to a sustainable solid waste reprocessing system in urban areas. The boxes in the text illustrate particular aspects, such as the technology used and the feasibility of an activity.

Chapter 1 provides a general introduction to plastic waste recovery. In order to understand the plastics recycling process, basic information on the various types of plastics and on identification procedures is provided in Chapter 2, followed by an overview of the various stages of plastics recycling. Chapter 3 describes the informal environment in which small enterprises can thrive and the incomes they can generate. The technical possibilities of plastic waste recovery are described in the Chapters 4-6. The reprocessing of plastics involves different stages, all of which are necessary in the manufacture of end products, although the sequence of activities may vary to a certain extent. Chapter 4 deals with initial upgrading techniques such as washing, drying and sorting. Size reduction techniques such as cutting and shredding are described in Chapter 5. Chapter 6 explains product manufacturing processes such as extrusion and injection moulding, and describes the machinery used, the markets covered and the end products. Chapter 7 deals with some financial aspects of small-scale plastics reprocessing. Chapter 8 addresses environmental and health aspects of recovery and provides guidelines on how to improve working conditions. Finally, Chapter 9 presents some general conclusions and some of the pros and cons of plastic waste recycling.

Appendix 1 lists the exchange rates on which the cost calculations in this book have been based, although it should be noted that the calculations have been taken from real life situations and adapted. The prices quoted throughout the text are intended only to give general impressions, and should therefore be used with caution.

Appendices 2 and 3 give some additional information to Chapter 2; Appendix 2 lists the characteristics of some of the most commonly recycled plastics, and Appendix 3 gives an overview of various tests that can be used to distinguish them.

Appendix 4 lists the addresses of the consultants involved in the WAREN project, and other organizations and institutions 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 listed in Appendix 5.

1 Plastic Waste Recovery

In recent years the economically less developed countries have increasingly adopted Western consumption habits, including the use of plastic goods. The amounts of waste plastics have also increased accordingly, and in some countries, for example in India en Egypt, reprocessing is now widely practised.

The context and the organization of the resource recovery sectors in economically less developed countries are often quite different from those in the industrialized countries of Western Europe and North America, largely because of the very different economic circumstances. In the industrialized countries, the shortage of suitable land for waste disposal sites, strict environmental legislation and controls, and the 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 encouragement of both the prevention of waste generation and the minimization of the amounts of waste that need to be disposed of, including the need for recovery.

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

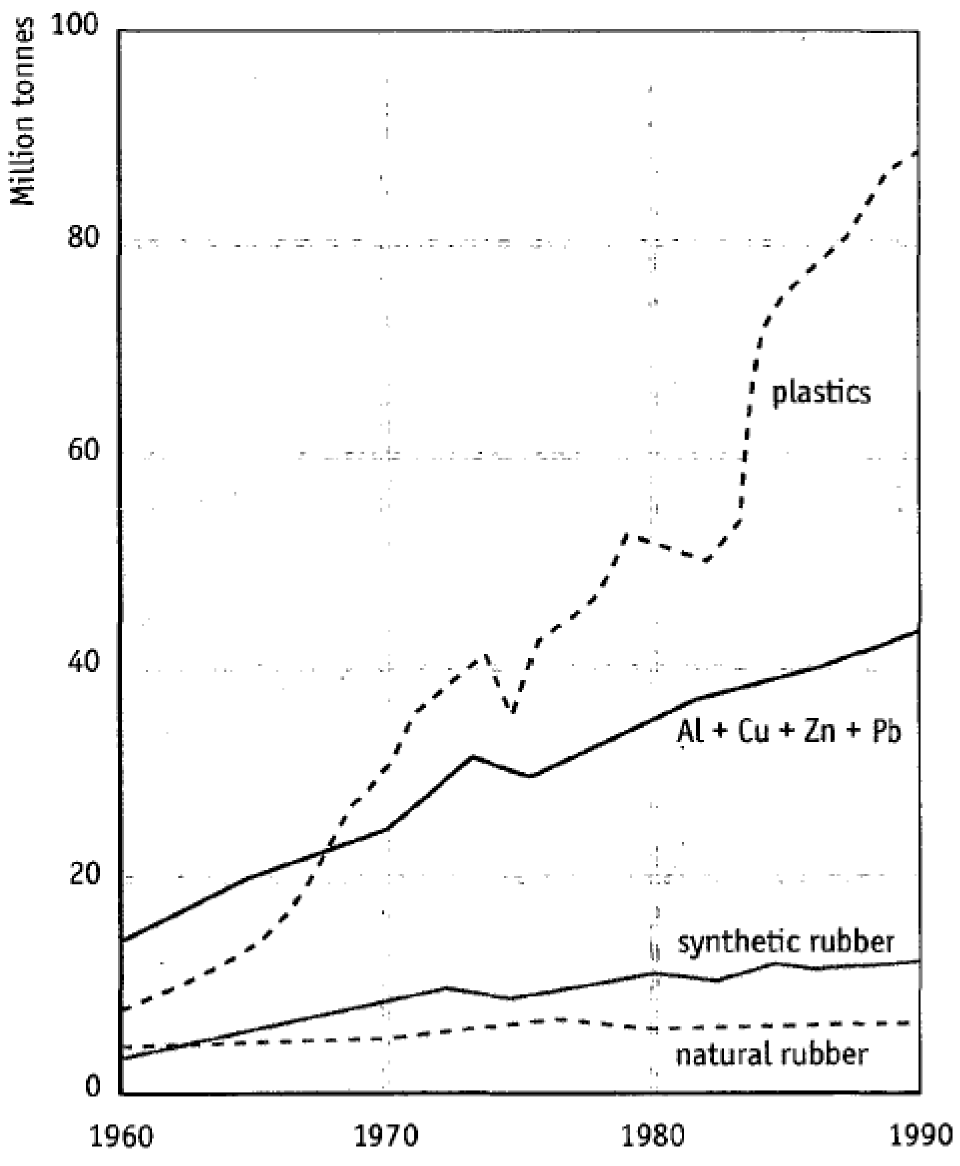
This chapter provides a broad introduction to the subject of plastics. Sections 1.1 and 1.2 address some historical aspects of the production of plastics, with data on plastic waste generation. Sections 1.3 and 1.4 outline the main features of plastics reprocessing in the industrialized and economically less developed countries, respectively, and Section 1.5 stresses the importance of efforts to increase resource recovery for all countries.

1.1 The history of plastics production

From a historical viewpoint, the development of plastics can be regarded as one of the most important technical achievements of the twentieth century. In just 50 years plastics have permeated virtually every aspect of daily life, paving the way for new inventions, and replacing materials in existing products. Plastics are light, durable and versatile, and are now used in countless applications. The success of these materials has been based on their properties of resilience, resistance to moisture, chemicals and photo- and biodegradation, their stability, and the fact that they can be moulded into any desired form.

The plastics industry is relatively young. The first plastics were produced at the turn of the century, and were based mainly on natural raw materials. Only in 1930 were (thermo)plastics, made from the basic materials styrene, vinyl chloride and ethylene, introduced onto the market. But the main growth of the plastics industry did not take place before the 1960s, reaching a peak in 1973, when production reached over 40 million tonnes per year.[37] Following a temporary drop in production during the oil crisis and the economic recession in the beginning of the 1980s, the world production of plastics continued to increase, to approximately 77 million tonnes in 1986,[37] and 86 million tonnes in 1990.[38] Figure 1-1 shows the rapid development of plastics production worldwide, which now far exceeds the combined production of non-ferrous metals such as aluminium, zinc, lead and copper.

Figure 1-1: Development of plastics production worldwide.



Source: Schouten,[38] 1991.

The major producers and consumers of plastic materials are North America, Western Europe and Japan. Currently, about three-quarters of the world's plastics are produced in these regions.[24] Table 1-1 gives an indication of the shares of plastics production in the main world regions in the late 1980s. It can be seen that the share of "other" countries, which include the whole of Africa, is small, even compared with countries in Central and South America and in Asia. However, considerable changes are taking place.[37] Western Europe's share of production is in decline, and capacity plans indicate that the shares of Asia (excluding Japan), Central and South America and the Middle East will increase rapidly at the expense of the traditional producers.[24]

Table 1-1: Location of world plastics production in the late 1980s (%).

North America	32.0
Western Europe	31.2
Eastern Europe and the former Soviet Union	12.3
Japan	11.7
Other Asian countries (excluding Japan)	6.9
Central and South America	4.3
Other	1.6

Source: Johnson,[24] 1990.

In contrast with most African countries, which import plastics, Egypt has rapidly increased its output of plastics, largely as a result of the government's policy to encourage domestic production. The total value of the plastics produced in Egypt increased from $18.5 million in 1979 to more than $200 million in 1991. A part of this output is exported, and total export earnings rose from about $0.5 million in the early 1980s, to more than $60 million in 1990.[17]

The growth of plastics production has also brought about an increase in waste production. The very properties that made plastics so attractive are now also regarded as disadvantages, especially in the industrialized countries. There are very few environmentally sound methods of disposing of plastics; most resist decay so well that it will take centuries for them to break down naturally. Because of their light weight, transportation costs of plastics are relatively high. Also, the huge amount of different plastic types has made sorting a difficult process. For these reasons, the recycling of used plastics into new products has been slower to become established than of some other waste materials such as paper or glass.[47]

1.2 Plastic waste

The quantity and composition of the solid waste generated by a society provide a mirror that reflects among others the cultural habits of the population. The amount of solid waste generated is also closely related to the overall economic level of the population from which it originates. High-income countries generate more plastic waste than low-income countries. According to Cointreau,[12] the amounts of plastic waste, as percentages of total amounts of municipal refuse (wet weight), for low, middle and high-income countries are 1-5%, 2-6%, and 2-10%, respectively.

An average European family of four throws away around 40 kg of plastics each year, which amounts to approximately 7% of the total weight of household waste. Although plastics occupy an estimated 20–30% of the total volume of a dustbin, the volume occupied by plastics in a landfill site is only about 10%, due to compaction among other reasons. These percentages have remained more or less constant for a number of years.[47] In Germany, for example, plastics account for 5% of the 30 million tonnes of domestic waste collected each year, but make up 20% of the volume. About 75% of this waste consists of packaging materials.[21]

These examples demonstrate that in quantifying plastic waste it is important to distinguish between weight and volume. Plastics are voluminous, but are relatively light, so that in terms of weight the proportion of plastics in municipal solid waste is relatively modest.

In the urban areas of Southeast Asia and the Indian subcontinent, the amounts of plastic waste have increased rapidly and have now reached levels similar to those in Western Europe and the United States. In 1982, in Metro Manila, in the Philippines, plastics accounted for 7.5% of the weight of solid waste generated (film plastics 5.9%, hard plastics 1.6%). By 1990, this proportion had increased to 12.4% (film plastics 11.5%, hard plastics 0.9%). These figures do not include the waste generated by the plastics industry itself, since this is sold directly to recyclers.[11]

In Calcutta, the use of plastics has increased by at least 40% in the last 20 years. It is estimated that a total of 30 tonnes of waste plastics (including the 6–7 tonnes of industrial plastic waste) is available for recovery in the Calcutta area alone.[35] Due to the growing demand for reprocessed plastics, however, most of the plastic waste does not end up at the refuse dumps. About 80% of household waste is sold directly to street hawkers or small traders, and the remaining 20% finds its way to the municipal dumps, where part of it is then reclaimed by pickers.[35]

In most sub-Saharan African countries, the amounts of waste plastics are still lower than those produced in Asian countries. According to a study conducted in Accra, Ghana, by GOPA Consultants in 1983, plastics account for 1–5% (of wet weight) of the total amount of waste generated.[1]

The amounts of waste generated also vary within countries, according to the income group from which it originates. The high- and middle-income groups in many countries have adopted Westernized consumption patterns. The richer the citizens, the more waste is generated, as the case of Accra:[1]

- high-income groups: 0.6 kg/capita/day
- middle-income groups: 0.4 kg/capita/day
- low-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 plastics, paper and metals.

As in Calcutta, plastic waste in Cairo is recovered and recycled on a large scale. This is demonstrated by the large number of small workshops involved in reprocessing (see also Section 3.3), and also by the amounts of waste plastics recovered. It is estimated that approximately 1500-2000 tonnes of plastics are recycled each month,[17] half of which comes from the municipal solid waste stream. The rest consists of industrial scrap and discarded household items that are sold directly to street peddlers.

1.3 Reprocessing in industrialized countries

In the industrialized countries, a distinction between the reprocessing of primary and secondary waste is relevant. Primary waste plastics are generated within the plastics producing and goods manufacturing industries themselves. A characteristic of primary waste is that the quality of plastics recovered for reprocessing is almost as high as that of virgin plastics. The waste is pure and suitable for reprocessing with standard equipment into the same kind of products manufactured from the virgin material. The reprocessing techniques include shredding, extruding and pelletizing, resulting in reprocessed pellets (see also Chapters 5 and 6). In manufacturing industries these pellets are used on their own or, more often, are mixed with virgin pellets. The processing of primary waste into products with characteristics similar to those of the original products is called primary recycling.[15]

Plastic goods can not be produced without generating waste, so that primary recovery has been practised since the establishment of the industry. As a result, it has been subject to extensive scientific research, for example on the melting behaviour and thermal stability of plastics during the remelting process. Due to the scientific and "high-tech" nature of this process, publications on this subject are generally of no direct interest to the "low-tech", low-cost environments of less developed countries. Nowadays, almost all major plastics manufacturers are engaged in some form of plastics reprocessing.

The term "secondary waste" refers to waste plastics from sources other than the industrial ones. These waste plastics are impure, i.e. they may be contaminated and often consist of mixtures of various types of plastics. The direct reprocessing of such mixed supplies (so-called secondary recycling) results in "alloys" with poor mechanical properties, because of the different characteristics of the plastics they contain. The potential for marketing these materials is relatively low.

In the industrialized countries both primary and secondary recycling are based on capital-intensive, labour-extensive processing equipment and mass production in order to ensure the maximum return on investments. The processes employed in the plastics reprocessing industries are basically the same as those used in manufacturing products from virgin plastics.

In the early 1980s there was a noticeable increase in interest and activities in plastics reprocessing. For mixed and contaminated waste plastics, both manufacturing processes and markets have been developed to produce bulky final products. Product applications include fence posts and garden furniture, where the plastics are used to replace wood, for which relatively high levels of impurities can be tolerated. At first it was rather difficult to market such products, but recently the variety of end-uses of reprocessed mixed plastics have expanded considerably.[2] However, most plants involved in the production of such secondary products still use relatively pure and well-defined waste plastics from industrial or commercial sources, since such supplies are available and guarantee a better quality of the end products.

In general, reprocessing is not a problem if the supply of waste plastics is pure (i.e. homogeneous and uncontaminated), and is obtained from industrial or commercial sources such as workshops or supermarkets (see also Section 2.3), agriculture, etc. Problems arise when the waste to be reprocessed is highly mixed and contaminated, such as household waste. The identification of the constituent types of plastics is an essential but difficult step in the plastics recovery process (see also Section 2.4). Although technologies have been developed to separate and clean mixed and contaminated supplies, they do not as yet operate successfully on a commercial basis. The opportunities for recovery are greater if the waste materials are separated before they are collected for recycling. Clear labelling of the various types of plastics during manufacturing would facilitate separation at a later stage, and would increase the efficiency of the recycling process.[47]

Both the technical and economic feasibility of the technology for the recovery of mixed plastics remain to be proven. For these and other reasons, in the industrialized countries the recycling of plastic waste has taken much longer to become established than that of other waste materials such as paper and glass. Despite the progress made so far, plastics recovery still has a long way to go. The gap between the amount of plastics generated and that recovered is still enormous.[20] According to the Association of Plastics Manufacturers in Europe (APME), data for 1989 indicate that within the European Community, just 846,000 tonnes of plastics were reprocessed, whereas 1.7 million tonnes were thermally reclaimed (also called tertiary recycling, i.e. using the energy produced during incineration) and 9 million tonnes were disposed of in landfills or incinerated without energy recovery.[47]

1.4 Reprocessing in less industrialized countries

In the less industrialized countries the distinction between primary and secondary waste materials is not as pronounced as in the industrialized countries. Although the plastics manufacturing industries themselves recover most of their primary waste, the general picture is one in which all kinds of waste plastics are recovered (secondary waste plastics). In contrast with the situation in industrialized countries, no markets have been developed for new product applications based on waste plastics. Instead, the same types of regularly available products are manufactured from waste plastics, although they are sold at lower prices and are poorer in quality. The reprocessing sector in economically less developed countries can be characterized as follows:

- Raw materials such as crude oil (for producing pellets) or virgin plastic pellets (for manufacturing plastic goods) have to be imported. These are relatively expensive, and so are the final products. The use of cheaper reprocessed pellets means that raw material costs are reduced.

- The markets for low-cost consumer items are extensive. Because of the large numbers of low-income consumers, the level of market acceptance of cheaper, poorer-quality products is high. Within low-income groups, the demand for such products is generally greater than that for products made of more expensive virgin plastics.

- High unemployment and low labour costs mean that the labour-intensive manual processes involved in the reprocessing of waste plastics, such as collecting, washing and sorting waste, is economically feasible.

- There are few or no regulations or quality standards for recycled products. The plastic materials recovered from waste are always inferior to the originals. In the industrialized countries, such inferior quality products may not pass standard quality tests, but in less industrialized countries they are tolerated.

In economically less developed countries, large plastics factories usually do not reprocess municipal plastic waste because of the sensitivity of their machinery to the impurities that are normally present in recycled materials, the irregular shapes of plastic pellets, and the generally low quality of the final products made from waste materials.[17] However, large factories sometimes recycle their own plastic waste, thus ensuring a hygienic production process. Recovered materials are usually mixed with varying proportions of virgin raw materials.

In contrast with the industrialized countries, most plastics are reprocessed in (informal) small-scale enterprises that depend almost exclusively on recovered materials. Small, low-technology workshops generally produce goods for the low-cost, low-quality market, and thus attempt to minimize costs by saving on raw materials. The technologies they use are in principle the same as those used in the (formal) large industries, although most machinery is outdated or has been upgraded with locally available spare parts. Given their small size and the large proportion of scrap they use, these enterprises are highly dependent on a network of dealers and reprocessors for supplies of raw materials that meet their specifications.[17]

1.5 The importance of resource recovery

Resource recovery in economically less developed countries is managed predominantly by informal sector entrepreneurs and is a major source of employment in this sector (see also Chapter 3). For many people, working in the informal waste sector is the last resort in their daily struggle for survival. Incomes are usually minimal, and working conditions are often appalling. Nevertheless, a large number of traders and reprocessors have managed to set up feasible businesses that generate reasonable or high profits, especially in plastics recovery.

All of the workers in this sector 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 and poses risks to human health. Improved recovery processes could therefore reduce the amounts of waste that need to be collected, and thus the costs of municipal waste disposal, finally leading to a reduction in the risk to human health.

Resource recovery reduces the quantity of raw materials needed in production processes. The reuse of plastics may therefore help to reduce the dependence on imported raw materials and to save foreign currency. Moreover, recycling conserves natural resources, particularly raw materials such as oil, and energy. Another positive effect of recycling on the environment is that it may reduce emissions of substances, such as carbon dioxide (CO_2), into the atmosphere. The University of Nottingham in the UK has recently conducted "life-cycle" analyses of materials consumption, energy use and emissions for both virgin and recycled low-density polyethylene (LDPE), a type of plastic.[46] Life-cycle analysis (also called "cradle-to-grave" analysis) techniques can be used to assess and measure the environmental impacts of a product over its complete life cycle. From this study it can be concluded that the use of reprocessed pellets in the production of plastic bags saves around 70% in energy use and 90% in water use, compared to the use of pellets made of virgin material. Likewise, a reduction in emissions of CO_2, SO_2, NO_x (NO and NO_2) can be achieved varying from around 60% to 80%.[46]

2 A Basic Guide to Plastics

This chapter provides a basic introduction to plastics and the recycling process. Sections 2.2 and 2.3 describe the four most commonly used plastics, their characteristics, and the major sources of plastics for recovery. Section 2.4 outlines some simple tests that can be used to identify these materials. Section 2.5 then presents an overview of the various stages in the recovery process, and explanations of the various terms that have become part of the language of recycling. Table 2-1 lists the terminology used throughout this book.

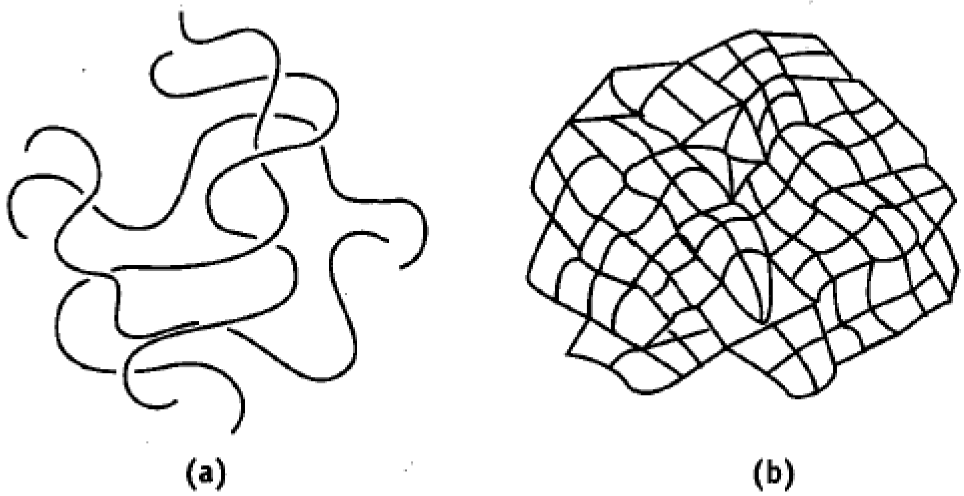
2.1 What are plastics?

Plastics are man-made organic materials that are produced from oil and natural gas as raw materials. Plastics consist of large molecules (macromolecules), the building blocks of all materials. The molecular weights of plastics may vary from about 20,000 to 100,000,000 (for comparison, the molecular weights of water, common salt and sugar are 18, 58.5 and 342, respectively). Plastics can be regarded as long chains of beads in which the so-called monomers such as ethylene, propylene, styrene and vinyl chloride (the beads) are linked together to form a chain, called a polymer. Polymers such as polyethylene, polypropylene, polystyrene and polyvinyl chloride are the end products of the process of polymerization, in which the monomers are joined together. In many cases only one type of monomer is used to make the material, sometimes two or more. A wide range of products can be made by melting the basic plastic material in the form of pellets or powder.[47]

The noun "plastic" refers to any one of a number of synthetic materials produced by polymerization. The adjective "plastic" describes the property of plastics that they "can be moulded into any form", or possess the quality of plasticity. Not all plastics demonstrate plasticity, however; some materials may be plastic only when hot, but at room temperature they are solids.
Plastics can be either thermoplastics or thermosets. Materials that repeatedly soften on heating and harden on cooling are known as thermoplastics. They can be melted down and made into new plastic end products. Thermoplastics are similar to paraffin wax; they are dense and hard at room temperature, become soft and mouldable when heated, and dense and hard again and retain new shapes when cooled (see Figure 2-1a for a schematic overview of the structure of thermoplastics). This process can be repeated numerous times, and the chemical characteristics of the material do not change. In Europe, over 80% of the plastics produced are thermoplastics.[47]

Thermosets, on the other hand, are not suitable for repeated heat treatments because of their complex molecular structures (see Figure 2-1b). The structure of thermosetting materials resembles a kind of thinly meshed network that is formed during the initial production phase. Such materials cannot be reprocessed into new products unlike thermoplastics. Thermosets are widely used in electronics and automotive products. Typical thermosets are phenol formaldehyde, one of the earliest plastics, and urea formaldehyde; both of these are widely used for electrical fittings.

Figure 2-1: The structure of (a) thermoplastics and (b) thermosets.



Source: Nijenhuis te,[33] 1988.

The properties of plastics can be modified by a number of substances known as additives. It is not essential to know exactly what these additives are, but reprocessors should be aware of their possible presence. Some additives include:

- *Antioxidants*, which reduce the effects of oxygen on the plastics during the ageing process and at elevated temperatures. Antioxidants are often added to polyethylene and polypropylene, for example.
- *Stabilizers*, which may take many forms, but of particular importance are those added to reduce the rate of degradation of polyvinyl chloride (PVC).
- *Plasticizers or softeners*, which are used to make polymers such as PVC more flexible.
- *Blowing agents*, which are used to make cellular plastics such as foam.
- *Flame retardants*, which are added to reduce the flammability of plastics.
- *Pigments*, which are used to add colour to plastic materials.

The significance of the effects of additives on the properties of plastics is well demonstrated by the variety of products that can be made from PVC, ranging from drainpipes, domestic flex, gramophone records, baby pants to footballs.

2.2 Types of plastics

In industrialized countries, literally hundreds of types of plastic materials are available commercially. In economically less developed countries, fewer types of plastics tend to be used than in industrialized countries. In Calcutta, for example, about 17 major types of plastics are used for general applications, and including minor types (called grades), more than 50.[35]

In both economically less developed and industrialized countries, the four types of plastics that are most commonly reprocessed are polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). Each of these can be subdivided according to their density, the type of process involved in their manufacture, and the additives they contain. In the following, these four types are briefly described; for a more extensive list of common recyclable plastics and their characteristics, see Appendix 2.

Polyethylene (PE)

The two main types of polyethylene are low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is soft, flexible and easy to cut, with the feel of candle wax. When very thin it is transparent; when thick it is milky white, unless a pigment is added. LDPE is used in the manufacture of film bags, sacks and sheeting, blow-moulded bottles, food boxes, flexible piping and hosepipes, household articles such as buckets and bowls, toys, telephone cable sheaths, etc. HDPE is tougher and stiffer than LDPE, and is always milky white in colour, even when very thin. It is used for bags and industrial wrappings, soft drinks bottles, detergents and cosmetics containers, toys, crates, jerry cans, dustbins and other household articles.

Polypropylene (PP)

Polypropylene is more rigid than PE, and can be bent sharply without breaking. It is used for stools and chairs, high-quality home ware, strong mouldings such as car battery housings and other parts, domestic appliances, suitcases, wine barrels, crates, pipes, fittings, rope, woven sacking, carpet backing, netting, surgical instruments, nursing bottles, food containers, etc.

Polystyrene (PS)

In its unprocessed form, polystyrene is brittle and usually transparent. It is often blended (copolymerized) with other materials to obtain the desired properties. High-impact polystyrene (HIPS) is made by adding rubber. Polystyrene foam is often produced by incorporating a blowing agent during the polymerization process. PS is used for cheap, transparent kitchen ware, light fittings, bottles, toys, food containers, etc.

Polyvinyl chloride (PVC)

Polyvinyl chloride is a hard, rigid material, unless plasticizers are added. Common applications for PVC include bottles, thin sheeting, transparent packaging materials, water and irrigation pipes, gutters, window frames, building panels, etc. If plasticizers are added, the product is known as plasticized polyvinyl chloride (PPVC), which is soft, flexible and rather weak, and is used to make inflatable articles such as footballs, as well as hosepipes and cable coverings, shoes, flooring, raincoats, shower curtains, furniture coverings, automobile linings, bottles, etc.

Other types of plastics include polycarbonate (PC), polyethylene terephthalate (PET), polyurethane (PU) and nylon or polyamide (PA).

2.3 Sources of waste plastics

As becomes clear from the aforementioned list of products, plastics can be used for many purposes, and thus, waste plastics are generated from a wide variety of sources.
The main sources for reprocessing can be classified as follows: industrial, commercial, agricultural and municipal waste.

Industrial waste

Industrial waste and rejected material (so-called primary waste, see also Section 1.3) can be obtained from large plastics processing, manufacturing and packaging industries. Most of this waste material has relatively good physical characteristics, i.e. it is sufficiently clean, since it is not mixed with other materials. It has been exposed to high temperatures during the manufacturing process which may have decreased its characteristics, but it has not been used in any product applications.

Many industries discard polyethylene film wrapping that has been used to protect goods delivered to the factory. This is an excellent material for reprocessing, because it is usually relatively thick, free from impurities and in ample supply. Many industries may provide useful supplies of primary waste plastics:

- The automotive industries: spare-parts for cars, such as fan blades, seat coverings, battery containers and front grills.
- Construction and demolition companies: e.g. PVC pipes and fittings, tiles and sheets.
- Electrical and electronics industries: e.g. switch boxes, cable sheaths, cassette boxes, TV screens, etc.

The reuse of these types of plastics is comparatively new. So far, the quantities of waste have been small, but they are growing. There are various types of such waste plastics with a wide range of characteristics. Plastics processing industries sometimes recycle the plastics waste they generate, as shown in the case of Accra, Ghana (see Box 6.2). Still, considerable amounts of waste plastics generated by many industries remain uncollected or end up at the municipal dump. Industries are often willing to cooperate with private collecting or reprocessing units.

Commercial waste

Workshops, craftsmen, shops, supermarkets and wholesalers may be able to provide reasonable quantities of waste plastics for recovery. A great deal of such waste is likely to be in the form of packaging material made of PE, either clean or contaminated. Hotels and restaurants are often sources of contaminated PE material.

Agricultural waste

Farms and nursery gardens located outside urban areas may provide large quantities of waste in the form of either packaging (e.g. sheets, jerry cans) or construction material (e.g. irrigation pipes and hosepipes).

Municipal waste

Waste plastics can be collected from residential areas (domestic or household waste), streets, parks, collection depots and waste dumps. In Asian countries in particular, the collection of this type of waste is widespread. However, unless they are bought directly from households, before they have been mixed with other waste materials, such waste plastics are likely to be dirty and contaminated. Sometimes the plastics can be separated and cleaned quite easily, but contamination with hazardous waste is not always visible and may be more difficult to remove. Litter that has been waiting for collection for some time may have been degraded by sunlight. This is mainly a superficial effect, however, and does not always mean that the plastics cannot be reprocessed.

2.4 Identifying types of plastics

When recycling plastics it is essential that the materials are correctly identified. If not, this can create severe problems during reprocessing, leading to products with a poor appearance and impaired mechanical properties.

It is usually difficult to tell exactly which type of plastic is present solely from the type of product. Many different types of plastics may look identical, or one type of plastic may appear to have several physical and chemical characteristics depending on the type of additive that has been used (see Section 2.2). Detailed chemical tests, such as infrared analysis, may be needed to make a definite identification of a polymer.

However, experience in this field can be gained with practice, and in case of doubt, testing is the only option. Some simple tests using basic equipment can provide adequate information for identification. In Istanbul, for example, some reprocessors claim to be able to distinguish plastics by touch,[27] but when in doubt, they apply the "burning test" or the "flotation test". Appendix 3 lists a number of tests that have been developed to distinguish the various polymers.[45] Not all of them are easy to carry out, but most of them work reasonably well. A rule of thumb is "If in doubt, test. If still in doubt, throw it out".[45] However, further explanations of some of these tests described in the appendix are needed and follow here.

1. To make a general distinction between thermoplastics and thermosets, take a piece of wire just below red heat and press it into the material. If it penetrates the material, it is a thermoplastic; if it does not, it is a thermoset.

2. The type of plastic can be identified by scratching it with a fingernail or from the flexibility of the material, as can be seen in Appendix 3. However, these tests are not always reliable. For example, PE that has been exposed to all kinds of weather conditions may have become rigid and brittle, and cannot be scratched. Also, very thin material made of any polymer may seem flexible; very thick may seem rigid.[45]

3. Flotation test. This test can be used to disentangle larger quantities of mixed or shredded polymers, as well as to separate them from non-plastics. The test is also useful for making the complicated distinction between PP and HDPE, and between HDPE and LDPE. When placed in a tub of water and alcohol in certain proportions (this can be tested using a "hydrometer", with a range of 0.9–1.0) the materials will separate according to their density; one material will sink and the other will float. For example, in a mixture with an exact density of 0.925, the PP will float and HDPE will sink; in one with a density of 0.93, LDPE will float and HDPE will sink. Note, however, that the flotation test is not exact enough to distinguish between PP and LDPE, since their densities can overlap (see Appendix 2). In this case the fingernail test and the visual appearance of the material may be more conclusive indicators.

   Another flotation test using pure water and salt can be used to distinguish between PS and PVC, both of which sink in pure water. When a specific amount of salt is added to the water, the PS will float to the surface, while the PVC and dirt will remain on the bottom of the container. The amount of salt need not be measured, but may be determined by experience.

4. Burning test. This test is carried out as follows.[45] Cut a 5 cm long sliver of the plastic material, 1 cm wide at one end, and tapering to a point at the other. Hold the sample over a sink or stone, and light the tapered end. The colour and smell of the flame can be used to tell the type of polymer (see Appendix 3). PVC can be confirmed by touching the sample with a red hot copper wire and returning the wire to the flame; it should burn with a green flame. Burn of all residue before repeating the test with the same wire.
   Caution: When conducting this test, be sure to hold the sample at a safe distance from the body and clothing, since the melted material may drip and burn if it falls directly from the flame. Do not breathe in the smoke, since it may contain dangerous substances.

Figure 2-2: A demonstration of the burning test.

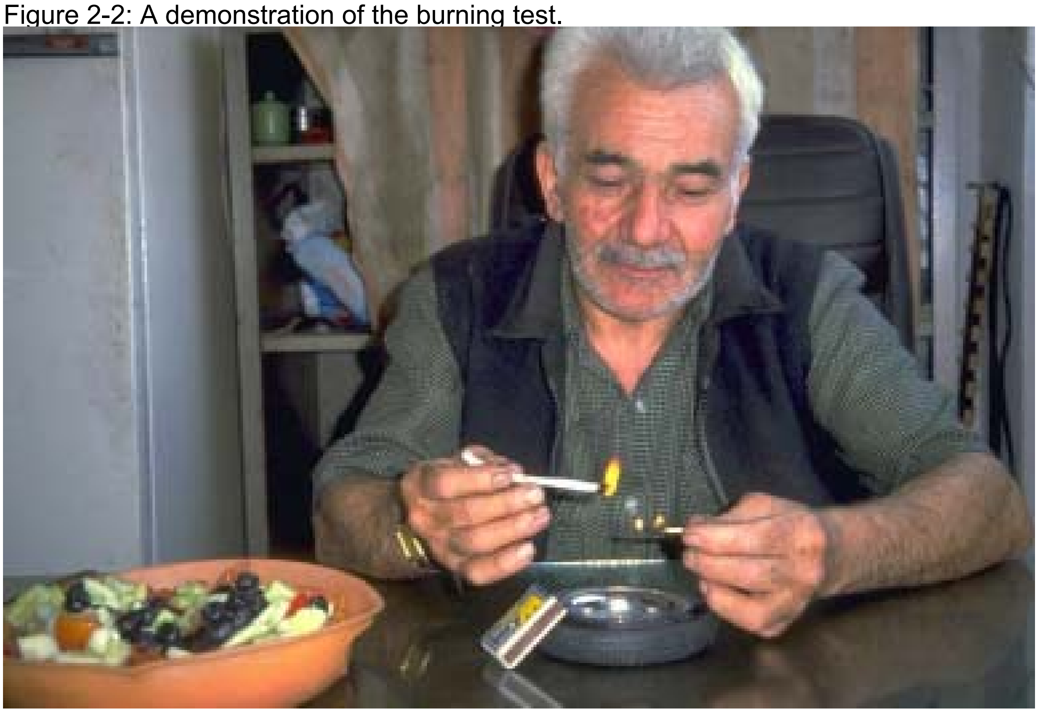


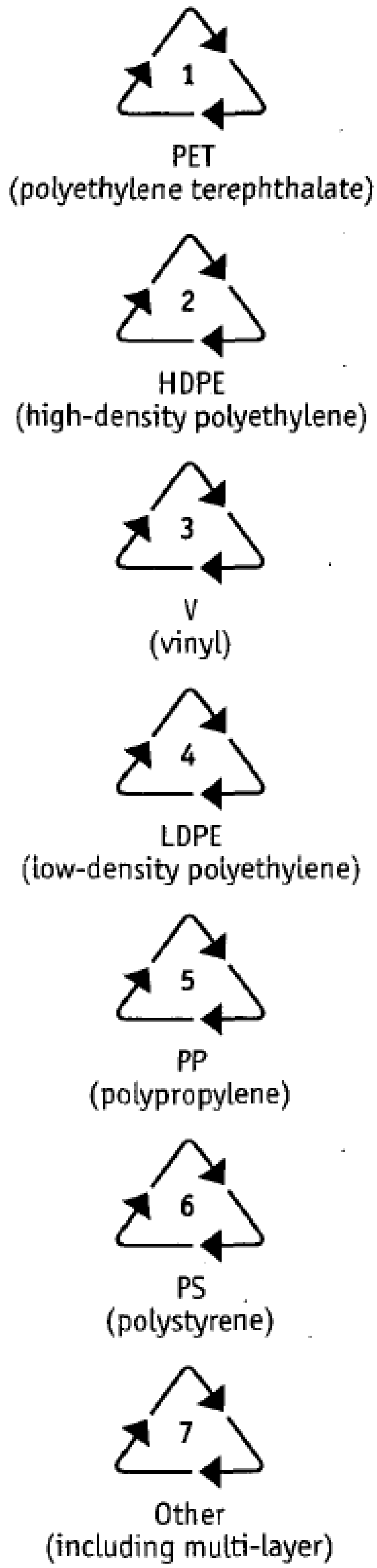
Photo: WASTE Consultants.

In economically less developed countries, particularly in the informal sector, polymers are usually identified by manual/visual inspection, whereas in industrialized countries, mechanical separation techniques are used. Technology is also becoming available to sort plastics using instrumental analytical methods, such as infrared spectroscopy and thermal analysis.

However, as stated in Section 1.3, in Europe and North America, the recovery of household plastics is burdened with several problems, including the high costs of separation and the general low level of purity of the waste materials. The packaging industry, for example, uses more than 60 different kinds of plastics. These are often mixtures or combinations of plastics and other materials, which preclude the melting option, as uncontrolled mixing of different kinds of plastics leads to inferior properties of the resulting material. The plastics may also be contaminated with residues of the packaged product, particularly food, or other packaging material (paper, aluminium). Even elaborate sorting and cleaning procedures cannot resolve these problems satisfactorily. A number of measures have been proposed to reduce the number of different kinds of plastics, combined with the introduction of an effective system for coding such plastics during their manufacture. These measures, which would certainly make identification easier, are now gaining general acceptance and changes in the packaging of some products, for example using less material or only one type of material, are slowly becoming apparent.[21]

To facilitate identification, in the United States, the Society of Plastics Industry (SPI) has developed a model coding system (using numbers combined with the abbreviations PE, PP, etc.), which is now also being introduced in Europe (see Figure 2-3). This coding system is especially suitable for moulded products where the coding can be engraved onto the moulds. In this way, households will be able to identify and separate the various types of plastics before disposal.

Figure 2-3: The American SPI coding system.

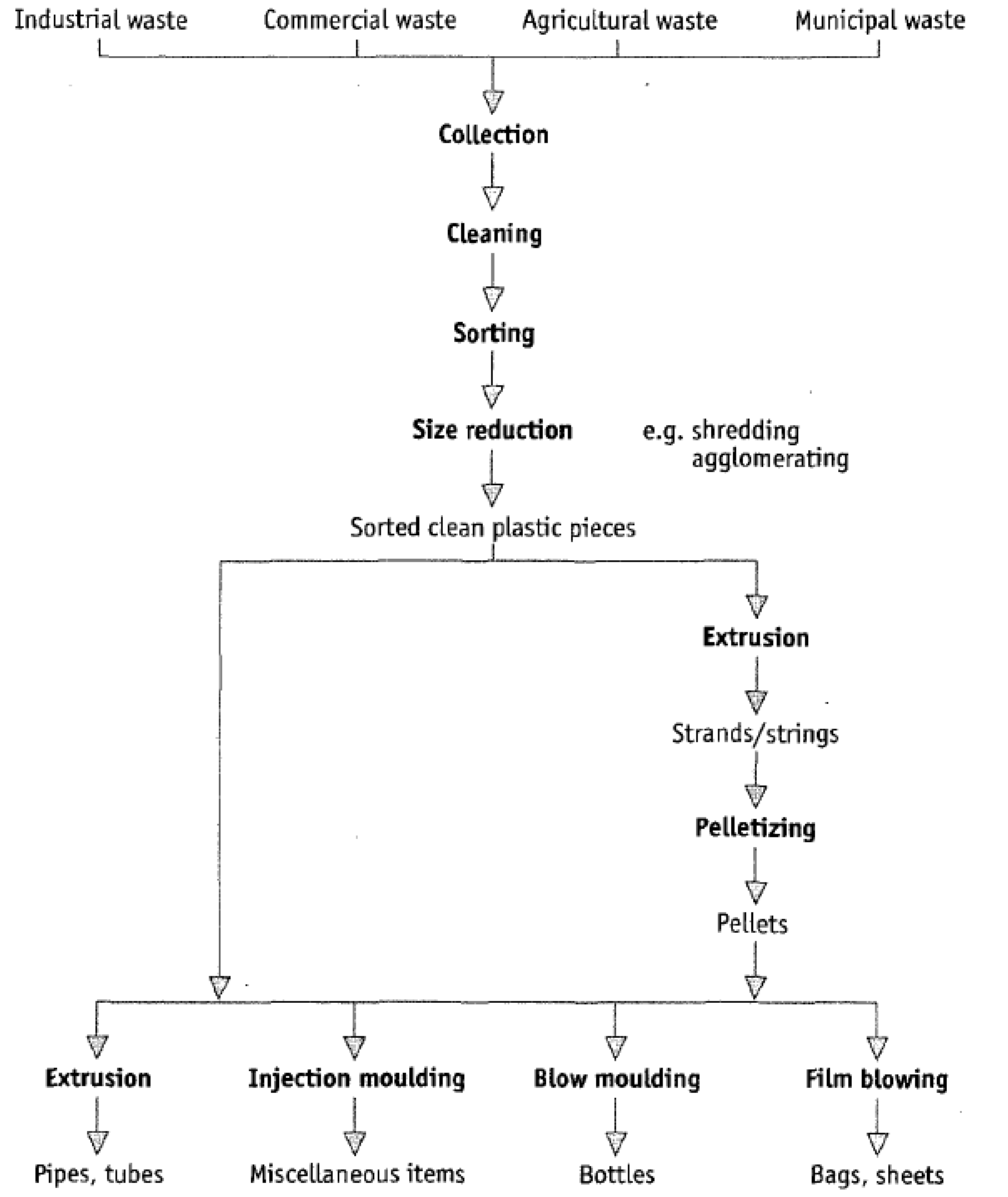


Source: APME & PWMI[3].

2.5 Plastics recycling terminology

Plastics recycling (or reprocessing) is usually referred to as the process by which plastic materials that would otherwise become solid waste are collected, separated, or processed and returned to use. Figure 2-4 shows an outline of the waste plastics reprocessing stream in economically less developed countries. Note the distinction between the initial stages, in which the materials are collected, cleaned, sorted and reduced in size, and the further reprocessing and material transformation stages.

Figure 2-4: Flow chart of a typical waste plastics reprocessing stream in a low-income country.



In contrast with the final stages of reprocessing, the initial stages are labour-intensive, requiring little capital investment and relatively few specific technical skills (see Chapter 4). The pieces of material can be reduced in size by cutting them up with scissors or using more complicated techniques such as shredding and agglomerating (see Chapter 5). Size reduction reduces the bulk of (densifies) the material, thus reducing transport costs, and facilitating feeding the plastics into machines for further processing.

These further reprocessing stages consist of mixing, extrusion, pelletizing and product manufacturing. An extruder produces spaghetti-like strings that are cut into pellets (small, regularly shaped grains of uniform size) suitable for continuous feeding into manufacturing machines. Product manufacturing processes such as extrusion, injection moulding, blow moulding and film blowing are described in Chapter 6. These processes are based on extrusion techniques, in which either the form of the dies or the blowing techniques determine the shape of the end product.

In general, the initial stages of collecting and sorting the waste materials are performed by scavengers (who usually operate on an individual basis), traders and scrap-dealers. In the later stages of size reduction, mechanical washing and drying, pelletizing and product manufacturing, small industries become involved. However, no clear distinction can be made between the various entrepreneurs involved in either the initial or the further processing stages. For example, small manufacturing workshops may also be involved in the initial stages, such as the selection of materials according to the type of polymer, or colour, in addition to the preselection by hand pickers, collectors and traders.

Table 2-1: Terminology used in the waste plastics recycling sector.

Terms used in this book	*Definition*	*Raw material*	*End product*	*Also referred to as*
Shredding	initial size reduction; chopping into pieces	often clean, sorted plastics, sometimes mixed plastics	irregular shaped pieces	granulating grinding
Agglomeration	compacting	films and sheets	crumbs	crumbing
Pelletizing	chopping extruded strings	shredded or agglomerated plastics	regulary shaped pellets ready for feeding in product manufacturing equipment	granulating

In the literature on the various plastics recycling techniques, the terminology is often inconsistent, and may cause some confusion. For example, the term "granulating" is used to refer to both the shredding and the pelletizing processes. To avoid any misunderstanding, therefore, this term is not used in this book. Table 2-1 gives brief explanations of some of the terms used in this book to describe the technologies used in the waste plastics recycling sector.

3 Small Reprocessing Enterprises

In economically less developed countries many small reprocessing enterprises often thrive within the so-called informal sector, although no strict boundaries can be drawn between this and the formal sector. This chapter gives a general description of the informal sector and the circumstances under which such small enterprises operate. It also indicates the level of income that can be generated within the plastics reprocessing sector, and the skills and know-how needed to set up such an enterprise.

3.1 The informal sector

The characteristics of urbanization in economically less developed countries are often quite different from those in the industrialized countries. In particular, an important characteristic of urban areas is the prevalence of so-called informal activities that are carried out alongside those of the formal sector. One of the main reasons for the existence of the informal sector is the lack of formal employment opportunities open to a large proportion of the urban and suburban populations, who therefore need to generate (extra) income. For many of the urban poor in these countries, waste recovery often represents a basic strategy for survival.

There is a wide variety of definitions of the concept of the "informal sector", but there is still no generally accepted definition of this term. Following the International Labour Office (ILO), in this book, the term "informal sector" is used to refer to small-scale units with some of the following characteristics:[23]

- they produce and distribute a wide range of goods and services;
- they consist largely of independent, self-employed producers, sometimes employing family labour and/or a few hired workers or apprentices;
- they operate with very little capital, or none at all;
- they utilize low levels of skills and technology, and therefore operate at low levels of productivity;
- they generally earn very low and irregular incomes;
- they are usually unregistered and unrecorded in official statistics;
- they have little or no access to organized markets, credit institutions, formal education and/or training institutions;
- they are not recognized, supported or regulated by governments;
- they are almost invariably beyond the pale of social protection, labour legislation and protective measures in the workplace; and
- they are generally unorganized and in most cases operate beyond the scope of action of trade unions and employers' organizations.

These are of course generalizations; it should be recognized that the informal sector manifests itself in many different ways. Production or manufacturing facilities are determined largely by their context, i.e. the country in which they actually operate. However, the characteristics of the informal sector listed above are to a certain extent relevant for plastics recycling activities. To illustrate some features, a brief outline of plastics recycling in the informal sector in Istanbul is given in Box 3.1.

Box 3.1 Small-scale plastics recycling in Istanbul, Turkey

Most small- and medium-scale plastics reprocessing units are located in two areas of Istanbul. Access to these areas is good, but the infrastructure within them is poor. The dirt roads are in poor condition, especially during bad weather, and trucks often get stuck. The one- to four-storey buildings in these areas are owned either by the municipality or by the private sector. Most of the buildings are poorly maintained, with broken windows or leaking roofs, but the benefits in terms of lower rents compensate for these deficiencies to some extent.

Most of the workshop owners' relatives are highly dependent on the income generated by the reprocessing activities (pelletizing as well as product manufacturing). They form part of the regular workforce or help out on a part-time basis when extra hands are needed, such as during a sudden peak in demand or when a machine breaks down. Their assistance increases the flexibility of the production process of the reprocessing unit.

The entrepreneurs interviewed by Konings during a field study had acquired their technical know-how from previous experience with scrap dealing or other plastics businesses; through informal contacts, advice and sometimes help from individuals employed in larger companies; from practical tips from friends involved in the plastics business, or through an independent process of learning. All of them had run businesses before, and so had management experience and technical interest. The level of formal education of these entrepreneurs ranged from none at all, to (in one case only) several degrees in mechanical and chemical engineering.

The field study found no evidence of real product innovation or development based on market research and technology development. Even if reprocessors possess or could find the required capabilities, they would not be able to afford product innovation. Sometimes they make small changes to their products, although in response to customer demand rather than on their own initiative. For example, a manufacturer of reprocessed shoe soles has to adapt his product when the shoe manufacturer decides to change models. If there is no demand for change, most manufacturers continue to use the aging moulds, which they have often bought second-hand.

A key problem for the entrepreneurs appears to be the lack of initial capital and the lack of access to the credit necessary to set up a business, to buy equipment, stock, and storage facilities. Some entrepreneurs may have saved some capital from previous businesses, but most new entrepreneurs have to resort to family and bank loans. Once the activity gets off the ground, expansion is very difficult. New machines require relatively large investments; financing is therefore mostly done on the basis of short-term, high-interest credit from the informal sector, which again increases the burden of debt. A second problem is gaining access to technical information on processes and equipment.

Source: Konings,[27] 1989.

Just as there is a lack of universal agreement on the definition of the informal sector, neither is there consensus on the definition and role of "small enterprises".[9] There are no universal standards to classify small enterprises on the basis of their size. Sometimes a distinction is made between micro and small enterprises. Teszler,[39] for example, gives the following broad classification:

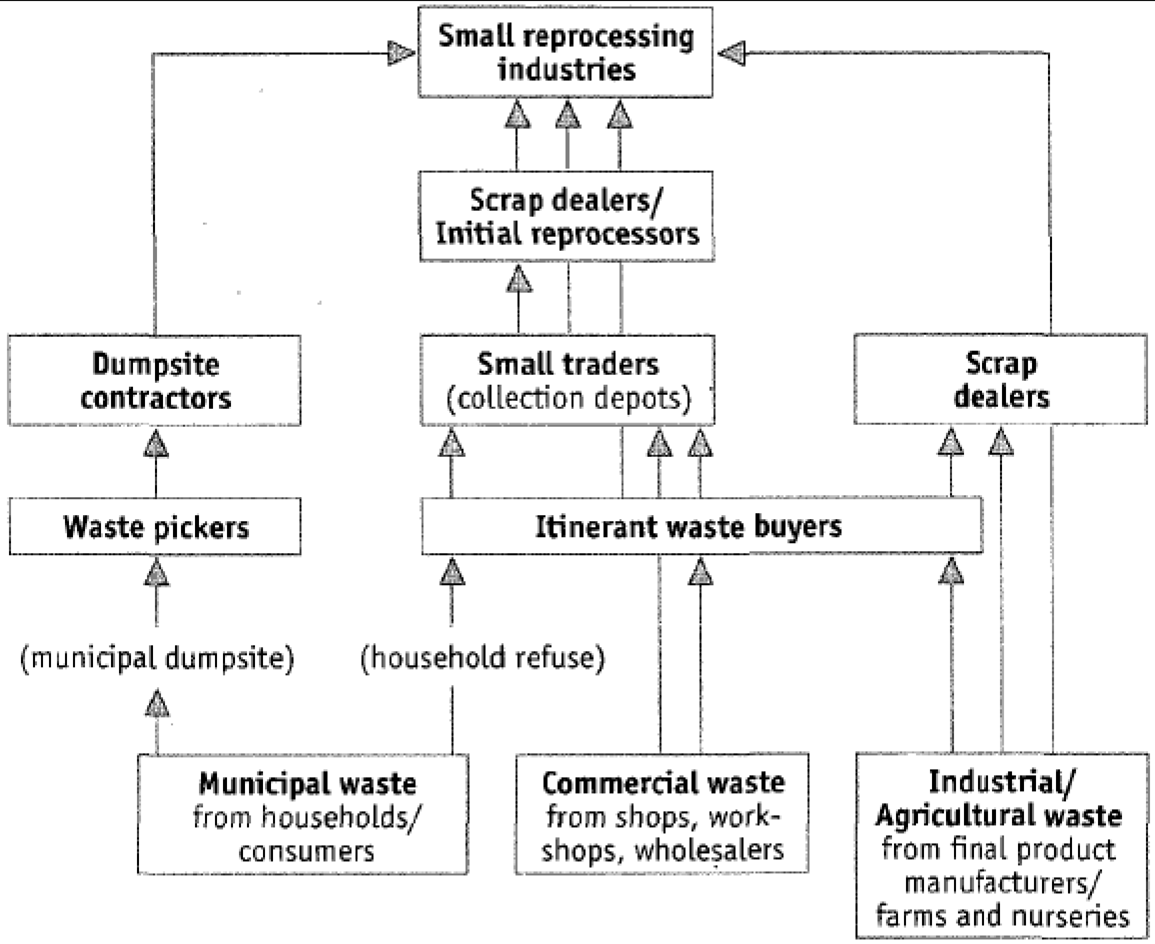
- micro enterprises employ no more than five (or ten) people;
- small enterprises employ between five (or ten) and 25 (or 50) people.

Throughout this book the term "small enterprises" is used to refer broadly to enterprises that employ less than 50 people.

3.2 Organizational networks

As shown in the summary of the plastics recycling process in Section 2.5, the different stages in plastics recovery are closely interlinked, and extensive networks exist between the various entrepreneurs involved. Figure 3-1 shows an example of the informal organizational network as it exists in Istanbul; naturally, networks in other cities may differ.

Figure 3-1: Informal plastics recycling network in Istanbul.



Source: Adapted from Konings,[27] 1989.

On the supply side, we find the sources (as explained in Section 2.3) that generate the waste plastics:

- municipal waste from households/consumers;
- commercial waste from shops, workshops and wholesalers;
- industrial waste from final product manufacturers; and
- agricultural waste from farms and nurseries.

Figure 3-1 distinguishes between the waste pickers who work at the municipal dumps, and the itinerant waste buyers who get or buy their plastic waste from households and commercial operations (see also Section 4.1). The workers in both groups tend to operate on an individual basis.

Traders operate on a supply and demand basis. Groups of traders can be described as scrap dealers or small traders, as follows:[27]

- *Scrap dealers* operate throughout the entire market, buying from factories, small traders, shops, farms, waste pickers and itinerant waste buyers. Some perform initial upgrading work on the waste plastics to increase their value: sorting, cleaning and sometimes shredding. Some scrap dealers specialize in plastics only, while others may be scrap dealers who buy and sell a wide variety of materials.

- *Small traders* run collection depots in the commercial areas, buying waste plastics from individual collectors and commercial sources. Although the waste has, to some extent, already been sorted at source, these traders usually do some further sorting, but no other work to increase the value of the material. Small traders are also active in rural areas, where they may operate collection depots for agricultural waste plastics.[27]

The cleaned and sorted plastic waste is then sold to the reprocessing units where the plastic material is shredded and pelletized. The plastic pellets produced by these reprocessors are supplied directly to the (informal) manufacturers of plastic end products, who belong to the same industrial sector as the reprocessors. Reprocessing and manufacturing are therefore often combined on one site. The final products are sold exclusively through a network of wholesalers who may specialize in one or two products. Semi-processed products may also be sold to the formal plastics processing industries.

The most important task of an entrepreneur running a reprocessing unit is to establish and maintain a network of business relations, consisting of the suppliers of raw materials and technical know-how on the one hand, and customers on the other. Within such a network, business contacts are referred to as friends, and all arrangements (prices, quantities, qualities, delivery terms) are gentlemen's agreements.

It is also important for entrepreneurs to maintain a wide network of suppliers because the supplies of waste plastics are often irregular, and the quality and composition may vary. Some scrap dealers may be able to provide irregular but useful supplies, such as when they come across large quantities of industrial or agricultural waste plastics which they divide and sell to reprocessors. Supplies of industrial and agricultural wastes are usually more reliable and are usually more consistent in composition than commercial and municipal wastes. Thus, before setting up a reprocessing operation and beginning production, adequate relations should be established with a substantial number of potential customers in order to gain a first foothold in the market.

3.3 Income generation

The initial stages of collecting and sorting waste generate most employment. In Metro Manila, for example, it has been estimated that as many as 7000 individuals are economically fully dependent on plastics recovery activities such as sorting, cleaning and drying.[11]

Although with some products large production units are required, plastics can be efficiently processed in small workshops; this is well demonstrated by the huge number of such enterprises in various cities. In Manila, the plastics industry comprises more than 450 companies, the majority of which are small- to medium-scale manufacturers who use reprocessed plastics in their production processes.[11]

As another example, the plastics reprocessing industry in Cairo is very broad based, consisting of about 450–500 workshops and small factories that use a variety of polymer recycling processes.[17]

Data from the Ankara-based Economic and Social Documentation Centre (ESDA) indicate that some 200–300 units in Istanbul use waste plastics to produce pellets. Some of these units are relatively large producers with a capacity of 40 tonnes/day, but most operations have a maximum capacity of 1 tonne/day. Due to frequent machine breakdowns, the real output averages around 60% of the maximum. The local output of reprocessed pellets fluctuates around 100,000 tonnes/year. The total amount of reused waste plastics would be even higher if the number of reprocessors were taken into account who do not buy or sell pellets, but manufacture their products directly from shredded waste plastics.[27]

Compared with the Turkish minimum wage of about $70 per month, the wages earned by waste recyclers in Istanbul are reasonable, varying between $80 and $250 per month.[27] In comparison, a municipal bus driver earns approximately $100 and a university professor $300–400. It is not uncommon that the wives and/or sons of the owners are part of the workforce, and as such they receive regular pay. Most women are employed for the sorting process, since they are generally thought to be more patient, more accurate and careful than men. Men and women earn the same; only age is a discriminating factor: children under 16 are paid less. Children, particularly those of the owner or workmen, often hang around and "assist" in the manufacturing process without pay. People work between 8 and 10 hours per day, six days a week. Some plants operate continuously (24 hours) in three shifts.[27]

Table 3-1 lists the wages paid to employees of nine reprocessing units (excluding sorting and cleaning) surveyed in Istanbul.[27] It also indicates the number of employees, the number of family members and women involved in the production process. From the table it can be seen that far fewer women than men are employed in the sector. However, when they are employed in these units, women perform the same jobs as their male colleagues.[27]

Table 3-1: Wages of employees in reprocessing units.

Unit no.	Number of employees	Family members	Number of women	Wages ($/month)
1	6	1	2	150–200
2	2	2	1	160–170
3	4	-	-	250
4	2	-	-	250
5	5	-	2	80 (incl. food)
6	8	2	-	150–200
7	9	-	1	150
8	20	-	1	125
9	5	-	2	150

Source: Konings,[27] 1989.

Waste pickers in Calcutta belong to the poorest section of society,[35] and are the primary collectors of refuse materials. They are exposed to very hazardous conditions, and earn only 25¢ per day, which is below the local subsistence level. The itinerant waste buyers work in cleaner environments, collecting specific items from housewives and commercial premises. They earn around 50¢ per day, which is marginally above the subsistence level. Contract labourers, who also belong to the poorest section of society, usually earn between 50 and 70¢ for a 10—12 hour day, depending on whether they are male or female, adult or child. The earnings of primary dealers vary between $50 and $70 per month, whereas secondary dealers earn about $100 per month. According to locally acceptable income and living standards, the dealers are reasonably better placed and have acquired a certain social status. The supervisor of a reprocessing workshop, for example, can earn about $40 per month. Waste reprocessing enterprises also provide work for a number of craftsmen, electricians and fitters, who carry out critical tasks in maintaining the production process.

3.4 Know-how and skills

A number of different skills are required at each stage in the reprocessing of plastics (see also Section 2.5):

- Most workers involved in the initial stages of collecting, cleaning and sorting have little or no formal education, and low levels of literacy. Itinerant waste buyers, however, may have basic skills of calculation required for buying and selling household items.
- Sorters need to be able to identify the various kinds of plastics, either from experience or by using tests such as those described in Section 2.4.
- In order to grasp opportunities and to maintain their competitiveness, traders need to keep informed about what is happening on the market (prices, quality, surpluses, shortages, bargains, competitors' activities, etc.).
- Workers who operate machines require basic mechanical skills that are usually gained from practical on-the-job experience. Normally a worker can operate a machine after observing for one week and on-the-job training.
- In general, reprocessors need to have a good knowledge of the types and grades of plastics and the additives used in various products. Many have gained most of their experience from handling plastics, and have developed their own techniques for mixing different grades of polymers to produce blends with the desired properties (such as with the required softness). Such skills tend to be built up from on experience, since there are no standards for waste plastics or mixing ratios. Initial assistance from an expert may be necessary, possibly the purchaser of the product, who will also specify the characteristics required of the reprocessed pellets. For the successful operation of a reprocessing workshop the entrepreneur

requires, above all, management and networking skills.

Establishing a business in this area of work is not an easy task for individuals with no experience. Box 3.2 describes the experience gained by the Zabbaleen community in Cairo, and demonstrates the importance of obtaining long-term support.

Box 3.2 Development of small reprocessing industries in Cairo, Egypt

Between 1983 and 1985 a small industries programme was established at the Manshiet Nasser Zabbaleen Settlement in Cairo, as part of a broader community development scheme.

Before the programme, the Zabbaleen community was dominated by powerful interest groups who profited from their ignorance, and its members suffered from a wide range of disadvantages, such as:

- almost total illiteracy among those in the age group able to operate small businesses;
- an almost total lack of financial and administrative experience in managing waste collection activities;
- very limited access to capital for investment; and
- total absence of technical knowledge and skills.

The programme involved the provision of small loans for the establishment of small waste processing modules, and of skills training. A technician provided training in basic mechanical skills for repairs, maintenance, safety precautions and minor adaptations to increase productivity. An expert in communicating with illiterate people, and an specialist in management and administration were also involved.

By the end of the programme, the following successes had been achieved:

- the incomes of the families who were granted the loans and their employees had increased substantially;
- the quality, and therefore the prices, of the reprocessed products had improved substantially, not only at Manshiet Nasser, but also at other Zabbaleen settlements;
- a community-based organization, the "gamaya", had been trained to manage a small loans programme;
- huge volumes of waste materials that had previously been discarded as unusable were no longer damaging the environment; and
- an "industrial mentality" had been established where none had existed before.

At the start of the programme, the urban reprocessing industry in Cairo was technically not very advanced. The market for reprocessed materials faced a relatively low level of competition, and to a large extent the products were tuned to market demands. The loans issued were not large, but the institutional component, training and the psychological support provided turned out to be critical, requiring a high level of investment during the early phases.

This programme clearly demonstrated that such communities do not and cannot spontaneously set up industrial establishments without some form of external stimulus, regardless of the potential that may exist. The skills required for operating and managing small-scale industries are complex, and require considerable expertise from the individuals involved. The major problem in the Zabbaleen settlement appears to have been the lack of expertise rather than the lack of investment capital. Skills training is almost invariably an informal process involving social networks of co-residence, kinship or close friendship. It became clear that the creation of an "industrial mentality" requires at least 2.5 years (the duration of the project).

Concerning the institutionalization of industrialization at the community level, three main conclusions were drawn:

- It is advisable to focus on initiating the process of industrialization via pilot programmes that are highly visible.
- The programme should be as inexpensive as possible.
- The programme should be closely tuned to the potential in the market.

Source: EQI,[16] 1986.

4 Initial Upgrading Techniques

The quality of the final products derived from waste plastics will be improved considerably if all contaminants (non-plastics, dirt, etc.) are removed prior to reprocessing, and if the degree of moisture is reduced to a minimum. It is also important that the different types of plastics are separated as carefully as possible. Thus the waste plastics should be sorted, washed and dried, preferably before size reduction (see Chapter 5). The order in which these procedures are carried out is flexible.

From an environmental health point of view, working conditions will be improved considerably if the waste plastics are washed and dried before they are sorted. Although collection is not an upgrading process, this is discussed in Section 4.1, since it is the first step in the recycling process (see Section 2.5) before the materials are cleaned and sorted ready for sale. These two procedures are examined in Sections 4.2 and 4.3, and Section 4.4 considers potential markets for such materials

4.1 Collection

Waste plastics from municipal sources (i.e. refuse containers and waste dumps), are collected by hand and are roughly pre-selected by waste pickers or primary traders. This stage is labour-intensive and requires little or no capital investment.

There are several points within a municipal solid waste system where waste can be retrieved for recovery: at source, i.e. directly from private homes; from waste bins; from refuse collection vehicles; and at municipal waste dumps.[12] In general, the nearer to the source, the less mixed and dirty will be the materials. The four collection points can be described in more detail, as follows:

1. Housewives and/or servants sell (or give) waste materials to itinerant waste buyers. In Calcutta, for example, housewives sell plastic items such as containers and buckets directly to waste pickers at a price of 15–20¢ per kg. Torn plastic bags are thrown away with other domestic waste at roadside dumps, and are collected by waste pickers. Other plastic bags, such as milk pouches, are usually given away free of charge to servants, who sell them to primary collectors in their area at prices of approximately 10¢ per kg.[35]

2. Early in the morning or late at night, waste pickers examine refuse bins and select the items that interest them. They tend to specialize in one type of material: some may collect paper, others plastics, etc. Preferably, they sell to traders who run collection depots for that particular type of material. Porters or caretakers who are responsible for collecting and transferring refuse bins from apartments to waste collection trucks, do the same: sorted materials are sold to depots or to itinerant waste buyers.

3. During working hours, waste materials are also picked directly from collection vehicles. In Metro Manila, for example, an average of 158 kg of recyclable material per truck are collected by these waste pickers each day, of which 13.55 kg are hard plastics.[4] Recovered items are sold directly to traders along the collection route, since their prices tend to be much higher than those paid at the dumps.

4. Waste picking at the dumps takes place on a large scale, despite the fact that the waste materials are often contaminated. In many Asian countries, plastics (particularly the "hard" plastics) are the most popular items among the waste pickers.[4]

Figure 4-1: Organized collection with a handcart in Jakarta, Indonesia.

Photo: WASTE Consultants.

At municipal waste dumps the process of waste recovery is usually quite well organized. There is often intense competition among waste pickers, so that outsiders cannot enter a dump and start picking waste. Istanbul provides a good illustration of this situation. Each year, the municipality puts the contract for recovering solid waste from the four disposal sites up for tender, and interested contractors then bid for it. In 1985, for example, the municipality sold this contract for $35,000.[13] The contractors employ waste pickers, usually members of migrant families living at or near the dump, who sort and collect the recyclable solid wastes as soon as the collection vehicles empty their loads. They are paid by the contractors according to the amount of material they collect. The municipality has ruled that the waste can be spread out for sorting for a maximum of six hours. The waste pickers can therefore collect only the large items, and large amounts of other valuable materials are lost. In 1986, the percentage (by weight) of plastics out of the total amount of waste was 4.59%; after collection this was reduced to 2.5%.[13] The contractors supervise the work at the dump, and help to sort the waste. If water is available, the material is washed, and this increases its value. The contractors sell the materials directly to reprocessors in the city, thus avoiding intermediary trader channels.

People who collect waste plastics tend to do so on an individual basis, either as independent traders, or working for others. They base the quality of their services on a correct, timely and regular operation. Sometimes they operate in groups and some collecting units have even developed their own corporate identities, clearly displaying company names and logos (see Figure 4-1). Some collectors use their own makeshift carts, and others obtain them on loan from traders or middlemen. The level of investment per vehicle may range from $100 for a simple handcart, to several thousand dollars for a small truck.

The quantities of reclaimed materials sold depend strongly on whether the characteristics of the supply of material match those demanded by the local reprocessing industries. The quality of much of the waste could be increased considerably if consumers were to be informed and instructed on how best to separate and dispose of their waste.

4.2 Cleaning

The cleaning stage consists of washing and drying the plastic items. A number of these techniques are described in the following, together with some illustrative examples of the cleaning processes that are used in a number of cities.

4.2.1 Washing

It is important that the waste plastics are washed, because clean waste materials fetch better prices and they improve the quality of the end product. The plastics can be washed at various stages of reprocessing: before, after, or even during sorting. Films and rigid materials are usually cleaned before the size reduction stage. Foreign materials such as glued paper labels are also removed. Rigid plastics are often washed a second time after they are shredded.

The material can be washed manually or mechanically. Manual washing may be done in oil drums that have been cut in half, in bath tubs or in specially built basins, and the water may be stirred with a paddle. If the waste is greasy, hot water with soap, detergent (e.g. from scrap detergent bottles) or caustic soda should be used (*Note:* when using caustic soda, always wear protective gloves).

The water may also be stirred mechanically. In one mechanical washing installation in Istanbul, a water-filled basin is equipped with a motor that drives a set of paddles at low speed. The plastic materials are left to soak for several hours, while they are stirred continuously by the paddles. Dirt (mainly sand) settles out during the process, and the clean plastic material is removed with a drainer.

In Istanbul, for example, telephone cable sheaths are shredded and reused.[27] The sheaths are made of black PE and aluminium reinforcement, from which the copper wires have been removed. The shredded sheaths are placed in a bathtub filled with water and left to soak for several hours, while being stirred occasionally to ensure separation and to dissolve any remaining dirt from the PE. During washing, the aluminium separates from the PE, which floats to the water surface, and the aluminium sinks. The PE is then drained, and stored in bags to await drying and further processing. The aluminium is then packed into bags and sold to scrap dealers.

All waste plastics need to be washed, except for some rejected materials from industrial and commercial sources. The washed and unwashed fractions should be kept separate from non-plastics and dirt.

4.2.2 Drying

As with washing, plastics can be dried either manually or mechanically. With the manual method the plastics are spread out in the sun to dry, and turned regularly. Plastic films can be hung on lines, and thus require only half the area normally used when plastics are spread out to dry.

Figure 4-2: Drying plastic films in Bangkok.

Photo: WASTE Consultants.

After they have been shredded, plastics may be either centrifuged or spread out in layers several centimetres thick to dry. To spread out 300 kg of shredded plastics (bulk density 210 kg/m^3) requires 15–20 m^2. The shredded plastics are stirred occasionally while they dry. Rigid objects are never centrifuged, but spread out to drain.

Figure 4-3 shows a drying installation in Istanbul, which consists of a tray equipped with a grid on which the shredded plastics (PE) rest, a fan and a gas burner. The fan blows heated air underneath the shredded plastic, thus reducing its moisture content. Occasionally, the shredded material is stirred with a stick.

Figure 4-3: Drying installation with fan in Istanbul.

Photo: WASTE Consultants.

Plastics require 2-3 hours to dry, at temperatures between 70 and 90^{o}C.[45] The time needed for solar drying will depend on the wind and the prevailing temperature.

4.2.3 Examples

Washing and drying waste plastics are not separate activities but tend to be carried out within the same unit. In this section a number of examples of enterprises in Manila, Calcutta, Cairo and Istanbul that wash and dry waste plastics are described.

In Manila, soft plastics are sometimes cleaned by submerging them in the river, and stomping on them to remove any dirt and impurities. Cleaned 200-litre oil drums, cut in half, also serve as basins for washing hard and soft plastics. Usually only water and soap are used, but caustic soda may be used to remove contaminants such as oil or paint from plastic scraps. The soft plastic scraps are dried by simply hanging them on wire in the sun. Hard shredded plastics are also dried in the sun on bamboo baskets.[11]

In Calcutta, broken plastic containers are washed in pond water while being stirred with sticks. The scraps are then dried in the sun for 3–4 hours, and finally packed in jute bags weighing 25–50 kg. Milk pouches fetch a high price, so these are cleaned and dried with great care. The pouches are carried to the nearest pit or pond where they are scrubbed to remove the milk sediment. No chemicals are used. After cleaning, the pouches are left to dry in the sun for 3–4 hours, stacked and bundled, and returned to dealers. Workers are paid about 50¢ per kg to wash, dry, sort, and deliver them (depending on where they are washed and dried). Four to five employees, working 12 hours per day, wash, dry and sort 350 kg of materials per day.[35]

In Cairo, rigid plastics are washed after cutting, using a hot and a cold water tank, along with a burner. For every tonne of plastics, 25 kg of caustic potash ($1/kg) and 2 kg of a substance called stripping powder are added to 2000 l of hot water.[17] The plastics are then rinsed in cold water. Two labourers take five days to wash one tonne of plastics, which is sold for approximately $75/tonne.[17]

In an enterprise in Istanbul, nine female workers manually wash and sort an average of 750 kg of rigid plastic objects per day, which gives a capacity of about 80 kg per person per day.[27] From a survey in Jakarta, it was found that the capacity is about 70 kg per person per day.[5] If the productivity of manual labour is a limitation, it can be improved by introducing mechanical devices.

4.3 Sorting

The degree of sorting of plastics waste varies considerably, depending on the demand and the special wishes of the manufacturers to whom it will be sold. The material may be sorted at any stage in the recycling process, according to colour, type of plastic, etc.

In most economically less developed countries, waste is sorted by hand by women and children, mainly because of the low wages and the large labour supply. Figure 4-4 shows women sorting waste plastics in Bangkok. Their working conditions are fairly hygienic because the materials are washed before sorting.

Figure 4-4: Sorting waste plastics at a Bangkok refuse dump.

Photo: WASTE Consultants.

Some basic guidelines for the sorting process are as follows (for information on the tests that can be used to identify the different types of plastics, see Section 2.4):

- All attached materials (such as paper labels) should be removed from the plastic items.
- Films (soft plastics) and rigid objects (hard plastics) should be separated.
- Various polymer types (PE, PP, PS, PVC) should also be separated, particularly PVC.
- PE films should at least be separated into transparent and mixed-colour fractions.
- Rigid PE objects should at least be separated into light-coloured (transparent and white) and mixed-colour fractions.

The general sorting procedure followed in Cairo, for example, is that after collection, the scrap plastics are first sorted and classified into thermosets and thermoplastics.[17] The thermoplastics are then classified into bottles, transparent plastics, rigid plastics and flexible plastics; within these fractions, a distinction is also made according to type and colour. It takes six unskilled labourers to sort one tonne of plastics per day. An unskilled labourer earns approximately $4 per day.

In Calcutta, primary traders or dealers do some sorting; they roughly separate low-and high-density plastics and PVC, since different prices are paid for different qualities. Primary dealers act as intermediaries between itinerant waste buyers and secondary dealers. They sell various grades of materials to secondary dealers (who are often primary reprocessors), with whom they may have permanent arrangements. The secondary dealers first sort the plastics according to type, colour and quality, and then wash, clean (usually in water tanks) and dry the materials in the sun. They hire mostly women and children to sort the many collected items such as shopping bags and broken household articles (for example buckets, baskets, drums, etc.). Especially shopping bags may be in a bad state (torn and dirty).[35]

Waste plastics obtained from industrial, commercial and agricultural sources are often already sorted, but even then the reprocessors may do some additional sorting.

4.4 Potential markets

After the initial upgrading stages, the plastic materials are clean and well sorted, and are ready for sale or for further processing. Bottles and jars can be sold directly to households or shops for refilling. The opportunities for selling these items to reprocessing enterprises will depend on whether such a sector exists, or could be developed. In some African countries, for example, plastic materials are not reprocessed further, such as by shredding, since there is no plastics reprocessing industry to which they can be sold.

In setting up a small enterprise, it is important to take into account the level and type of competition that may already exist. In Nairobi, for example, there is no small-scale plastics reprocessing sector comparable to those in Cairo and Istanbul and the large-scale (formal) industries (mostly run by Asians) dominate the market. In such a situation competition with the Asians should be avoided and other markets be explored. There may be a potential market for low-cost and low-quality plastic consumer goods, for example. Also, Asian manufacturers may be interested in buying clean and sorted waste plastics.

A collection, washing and sorting enterprise can be set up as the basis for future expansion to size reduction and product manufacturing activities. Box 4.1 describes an example of a workshop in Kingston, Jamaica.

Box 4.1: Washing and sorting workshop in Kingston, Jamaica

Kingston has a population of almost 1 million. Unemployment is high and poverty is widespread, but this has not prevented the middle and working classes from adopting Western consumer habits. The use of plastic packaging materials and moulded plastic containers has resulted in significant increased quantities of waste plastics in urban refuse and street litter.

To utilize this waste, a workshop project was set up in Kingston by the Wesleyan Methodist Church to organize a number of activities: collection (from streets, homes, stores, hotels), purchasing (from waste pickers at the city waste dump), washing, selection according to the type of polymer, and size reduction. The deaconess acts as the supervisor and received three weeks' training along with six female workers. To ensure good quality control, only women were employed. It took only two weeks for two of the women to become expert, and the rest competent, in distinguishing the main polymers, using a series of simple tests such as burning, floatation, scratching, etc.

The first stage of the project was to establish a link with organized industry. The most important element was the vision and enthusiasm of the senior technical manager of one of the best managed and technically advanced factories in Kingston. He committed his company to buying certain grades of scrap, and also played a major role in setting up the project and training the workers. In the second stage of the project a system of shredding the sorted scrap material is being set up, using a robust, low-cost machine imported from India.

This project shows the positive effect of a cooperative relation with an established, well-organized and technically advanced plastic goods manufacturing industry. In particular, the clean, sorted products are bought directly by just one purchaser, who also provided assistance in the form of skills training, and in organizing and managing the workshop.

Source: Vogler,[44] 1982.

5 Size Reduction Techniques

Size reduction techniques such as cutting, shredding and agglomeration of the waste plastic articles serve to increase the density of the material. This "densification" helps to reduce transport costs, and the smaller pieces can be more easily fed into further reprocessing machines. There are many variations of the techniques and procedures that can be applied; this chapter gives some general descriptions as well as some practical examples.

5.1 Cutting

The first step in the process of material transformation involves cutting up the waste plastic materials into smaller pieces. This is needed for items such as jerry cans and buckets, which are too large to fit into the hopper of the shredder. These items can be cut first with a circular saw or with a bandsaw, as shown in Figure 5-1. The cut pieces either fall to the floor to be collected later, or are thrown directly into a washbasin before being fed into the shredder.

Figure 5-1: Cutting with a bandsaw.

Photo: WASTE Consultants.

Uncut soft plastics tend to stick in the spiral screw of an extruder and are therefore usually not fed directly into this machine. In Manila, soft plastics such as films and sheets are cut into 5 cm strips with ordinary scissors to prevent damage to the pelletizing machine.[11]

In Cairo, the sorted and washed plastics are cut into small pieces with special scissors fixed on a wooden base. It is estimated that three labourers, each using a pair of scissors, can cut up one tonne of sorted plastics per day.[17]

5.2 Shredding

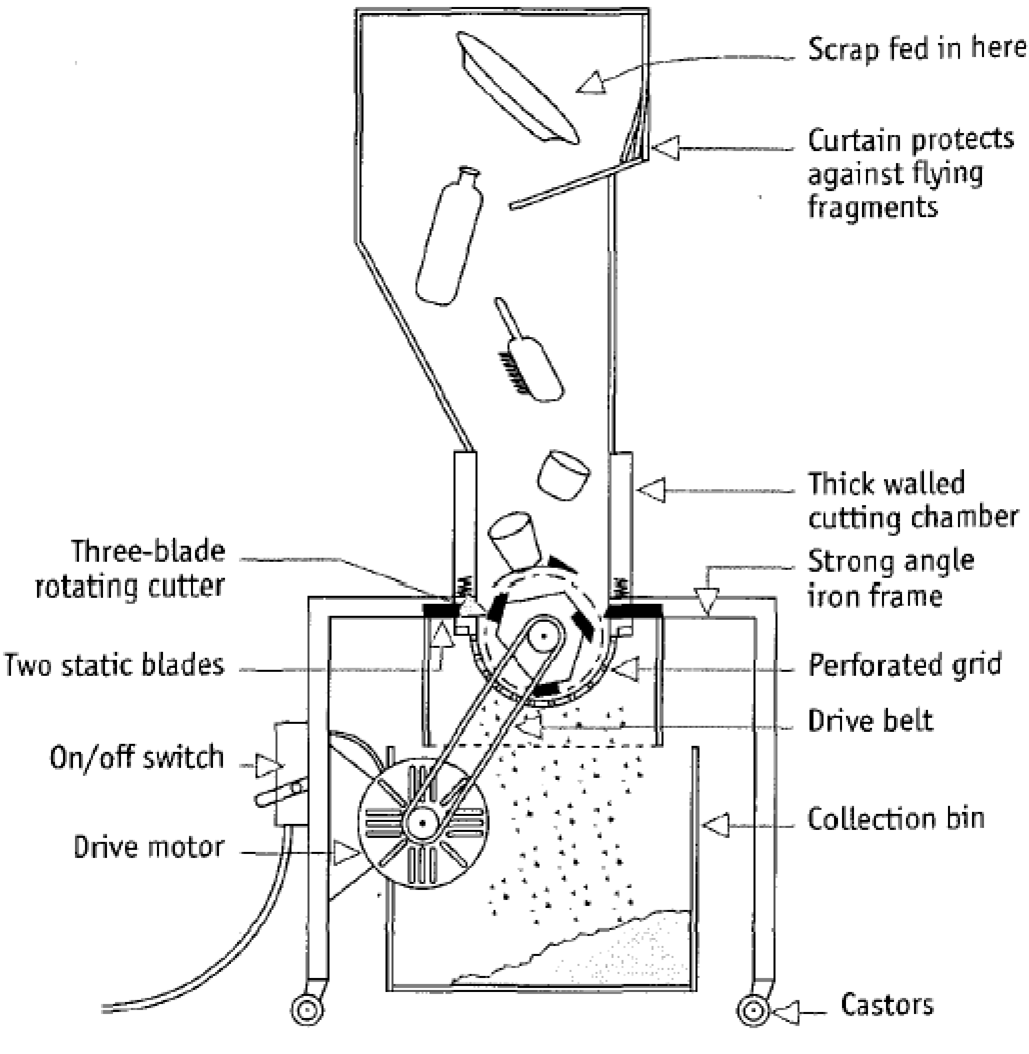
The raw materials to be fed into a shredder, if necessary cut into pieces beforehand, should consist of clean objects, selected according to product form, polymer type and colour. These materials are fed into the hopper on top of the shredder, as shown in the example in Figure 5-2. The rotating cutting blades then shred the materials. When the pieces are small enough, they fall through a grid into the tray placed to the right of the machine.

Figure 5-2: Shredder with a horizontal axis in Istanbul (capacity: 60 kg/h; motor power: 10-15 kW; cost: $3000-4000 second-hand).

Photo: WASTE Consultants.

In the shredder shown in Figure 5-2, the rotating blades are driven by an electric motor located behind the machine; the belt transmission is visible on the left. A bag or piece of cloth covers the hopper to prevent pieces of plastic being thrown back by the rotating blades. The shredded material is scooped into bags from the tray to be stored, or is fed directly into an extruder. Figure 5-3 shows a schematic overview of the interior of a shredder, which can have either a horizontal or a vertical axis.

Figure 5-3: Shredder with a horizontal axis.



Source: Vogler,[45] 1984.

Figure 5-4 shows the inside of a shredder equipped with two rotating cutting blades, one of which is visible on top of the rotor. On the right, attached by three bolts, the adjustable blade can be seen. At the bottom of the drum is a grid with holes that determine the size of the final pieces. The cutting continues until the pieces are small enough to fall through the grid.

Figure 5-4: The rotor and cutting blades of a shredder.

Photo: WASTE Consultants.

The end products of shredding are irregularly shaped pieces of plastics that can then be sold to reprocessing industries and workshops. Figure 5-5 shows shredded PE produced from detergent bottles, jerry cans, and other waste plastic containers. The materials have been sorted according to colour, in this case white. If the waste plastics have not already been washed, the shredded pieces may be placed in a hand-held sieve and rinsed with water to remove any dirt or dust.

Figure 5-5: Shredded PE.

Photo: WASTE Consultants.

Depending on the quality and type of raw material, and the desired quality of the end product, different types of plastic waste may be mixed to a certain extent. Figure 5-6 shows an example in Istanbul, where two types of waste material, HDPE film and pieces of LDPE string, are being mixed and shredded. The string is extrusion waste from previous production processes in the same factory. The two kinds of PE are mixed to obtain particular physical properties in the resulting product. However, no ratios can be established or maintained, since accurate definitions of the properties of neither type of PE are available. After extrusion and pelletizing, the softness and other properties of the material may be determined by simply chewing the pellets.

Figure 5-6: Mixing HDPE and LDPE in a shredder (Istanbul).

Photo: WASTE Consultants.

In Cairo, rigid scrap plastics are pulverized using shredders with capacities ranging from 250 kg to 2 tonnes of shredded plastics per day. The motors of such machines vary accordingly, from 15 to 30 HP. Locally manufactured shredders, which cost between $1250 and $2500 each, regardless of their capacity, are operated by two labourers at a daily wage of $4 per person. The cost of shredding one tonne of rigid plastics is approximately $30.[17] In Calcutta, a shredder with a capacity of 300 kg per day costs between $800 and $900.[35]

A low-cost option is a self-made version of a shredder. The simplest design may be a vertical axis machine.[45] Making such a machine requires only basic mechanical skills, but it has the disadvantage that it will be less robust and efficient, and is unlikely to be as safe to operate as a purchased machine. The best policy would be to start by building a small shredder with a 5 kW motor, and to use future profits to purchase a larger, more powerful, factory-made machine.

Where electricity is expensive or not available, the electric motor of a conventional shredder can be replaced by a heavy flywheel and a combination of gears with a cranking handle. A 4:1 differential gearbox from a motor car, combined with a pair of 2:1 ratio spur gears gives an overall ratio of 8:1 (in other words, the cutting blades and the flywheel rotate eight times for each turn of the handle).[45] An adult man can do this for several hours, although it is hard work. In an experiment conducted by Vogler[45] it was found that this machine could successfully shred PS waste only. Other types of plastics cannot be processed with this method.

Manufacturers who do not own their own machinery may shred their materials using hired machines. In Calcutta, for instance, machines can be hired on an hourly basis, at 7¢ per kg.[35]

5.3 Agglomeration

It is not advisable to feed soft plastic waste, such as bags and sheet plastics, directly into a shredder or extruder. Preferably, an agglomerator should be used to cut, pre-heat (or pre-plasticize) and dry these plastics. Agglomeration improves the quality of the final product. Also, it will increase the density of the material, which results in a more continuous flow of material in the extruder and thus, in an increase of efficiency. The materials fed into the agglomerator should be clean, since all foreign objects will be processed together with the plastics, and will be evident in the partially plasticized materials. They can only be removed during the extrusion process.

Figure 5-7 shows an agglomerator in use in Istanbul. In such a machine, mechanical energy produced by the rotation of the cutting blade at high speed is transformed into heat through friction. The bulk density of the raw materials in the agglomerator increases through shrinkage and partial plasticization. When the material is cooled rapidly at this stage, it solidifies as it is being cut, resulting in coarse, irregularly shaped grains, often called crumbs.

Figure 5-7: An agglomerator in Istanbul.

Photo: WASTE Consultants.

Additional heating is provided by a heating element fitted around the agglomerator or by the introduction of steam into the agglomerator. The rapid cooling can be achieved by adding a cup of water, or by creating an outward current of air. Sometimes the resulting crumbs are then sieved to remove any fine particles. An electric motor (on the right of the platform) drives the cutting blade by means of a belt transmission (underneath the platform), similar to that in the shredder shown in Figure 5-2. Spare belts can be seen hanging on the wall on the right. The agglomerator is filled through the lid at the top, and the contents are emptied into bags via the valve below, on the left side. Figure 5-8 shows the inside of the agglomerator: a cutting blade with the remains of fine-cut film, and Figure 5-9 shows the resulting product, in this case agglomerated PE film.

Figure 5-8: Inside of an agglomerator, showing the cutting blade and the remains of fine-cut film.

Photo: WASTE Consultants.

Figure 5-9: Agglomerated PE film.

Photo: WASTE Consultants.

In Cairo, a vertical axis agglomerator costs approximately $500-750. The only maintenance required is to sharpen the cutting blades occasionally.[17] The prices of some new Turkish-made machines are as follows:[27] circular saw, $3000; shredder, $5000; and an agglomerator, $7000. A workshop operating a sawing machine, a shredder and an agglomerator with a production capacity of 300-500 kg/day will require at least two workers in addition to the owner.[26]

6 Further Reprocessing Techniques

Pelletizing and product manufacturing are the final steps in the plastics recycling process. These processes require that the waste plastics have first been sorted according to polymer type, and that they have been cut into small, relatively uniformly sized pieces. Shredded and agglomerated materials can be used directly for product manufacturing processes (except the pelletizing stage), although this is not usually done. Normally, the shredded and agglomerated waste plastics are pelletized first. This way, the quality of the moulded end products can be improved. The use of pellets also increases the efficiency of the product manufacturing process, due to the lower bulk density of shredded and agglomerated waste plastics compared to pellets. The most common moulding processes in low-income environments are extrusion, injection moulding and blow moulding. Film blowing, the last technique described, is used in the manufacture of plastic bags.

This chapter first explains the pelletizing process and describes principles of the various product manufacturing processes. The machinery and equipment used in these processes, the products made and their markets are also described.

6.1 Pelletizing

6.1.1 The pelletizing process

Shredded rigid plastic objects or agglomerated films are subjected to the process of extrusion and pelletizing to produce plastic pellets. These can then be used as the input materials for various moulding processes. Besides plastics, the process is also used to produce such diverse materials as pasta (spaghetti) and some metals. Figure 6-1 shows an example of an extruder in India.

Figure 6-1: Extruder used in Bombay, India.

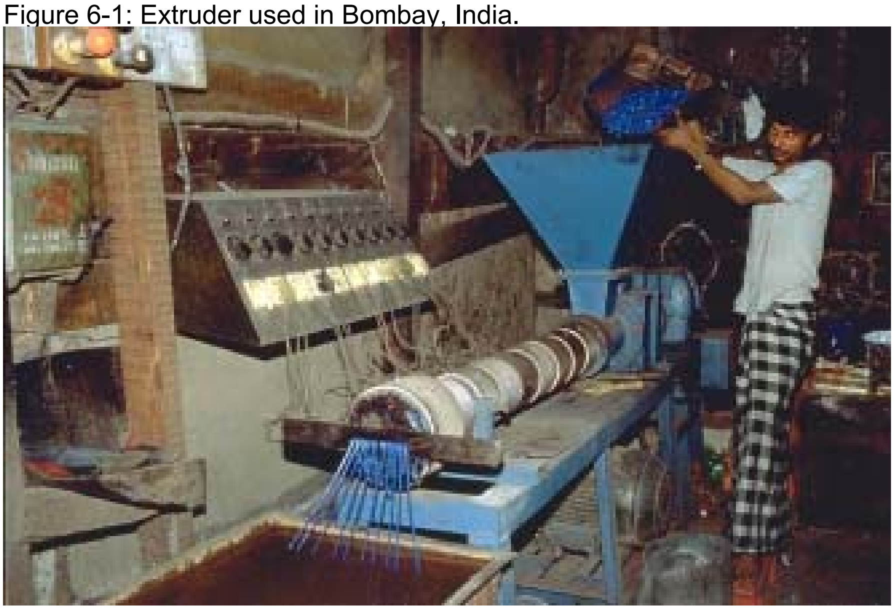
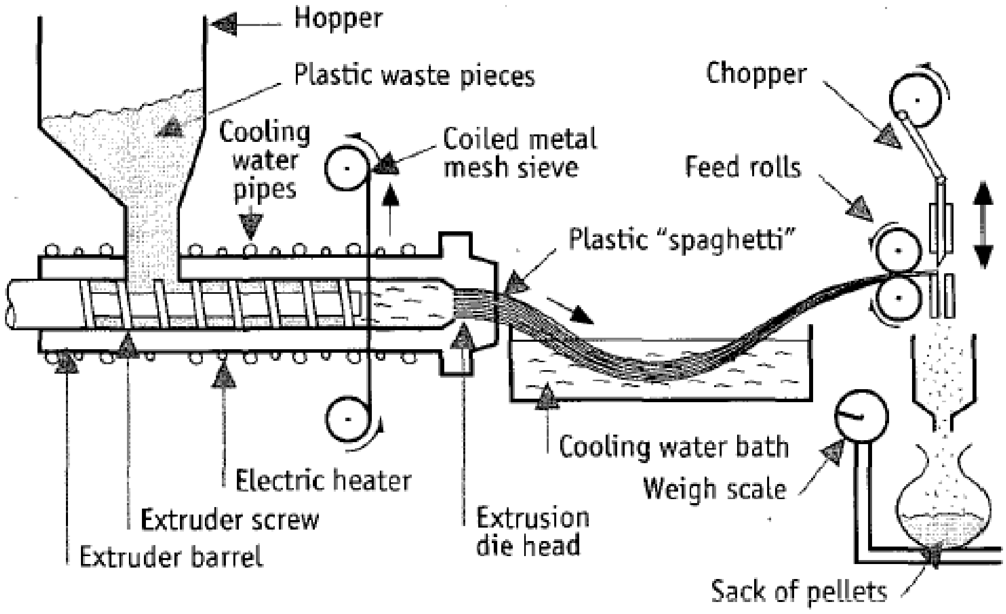


Photo: Johannes Odé.

The main functions of the extrusion phase are: compounding (mixing) the various substances, homogenization, compression, degassing, plasticization and melt filtration. The pieces of plastic raw materials (compounded with any desired additives, such as pigments) are fed into the hopper of the extruder. Figure 6-2 gives a schematic overview of the pelletizing process.

Figure 6-2: Extruder with a pelletizer.



Source: Vogler,[45] 1984.

The materials are picked up from the hopper by a rotating screw, and are forced down the barrel to the extrusion die head. Heat from friction and the heating elements fitted around the barrel cause plasticization and the special geometry of the screw compresses the material. Electric heaters, water or air coolers are fitted around the barrel to control the temperature. Just before the materials reach the extrusion die head, they are forced through a filter screen to remove any solid particles. Figure 6-3 shows a filter being replaced. The filters can be reused after the plastic remains have been removed, sometimes by burning them.

Figure 6-3: Changing the filter of an extruder.

Photo: WASTE Consultants.

The spaghetti-like plastic strings that emerge from the extrusion die head are then cooled by passing them through a basin of water or a ventilator. The strings, supported by rollers placed at the end of the water basin, are then drawn by a mechanical system into the pelletizer. Figure 6-4 shows the strings being extruded from a machine in Turkey. The die head shown here produces 24 strings to be cut into pellets. It is tilted in such a way that a large part of each string is under water. On the right, behind the die head, the filter can be seen.

Figure 6-4: Extruder used in Turkey (capacity 500-800 kg/day; cost $5000 (second-hand) to $10,000 (new), including a pelletizer).

Photo: WASTE Consultants.

The pelletizer (an example is shown in Figure 6-5) chops the strings into short, uniform, cylindrical pellets that are ready for use in manufacturing processes. The plastic waste generated by this process can be extruded again.

Figure 6-5: A pelletizer.

Photo: WASTE Consultants.

The production capacity of the pelletizing process depends on the size of the extruder that is used. A micro-pelletizing workshop needs two to three workers besides the owner. Sheltered accommodation is required, the size of which will depend on the size of the extruder, the water basin, the pelletizer, and the amounts of plastic material to be stored. Both water and electricity supplies are needed.

Box 6.1 describes a typical plastics reprocessing unit in Calcutta, and provides some technical and financial data.

Box 6.1: Small-scale pelletizing unit in Calcutta, India

This existing unit in Calcutta reprocesses waste plastics into pellets. The installed capacity is 300–400 kg per day, although the actual capacity is only 60%, which amounts to 250 kg per day, or 6500 kg per month. The assumed raw material losses are 15%, which means that for an output of 6500 kg per month, an input of 7500 kg is required. The stages in the pelletizing process are as follows:

Stage 2: The raw material is melted by electrical heaters at 80–130°C, depending on the requirements for the different stages. The melted material is passed through a filter screen to remove dust and grit, and then through an exit nozzle to the ground where it is allowed to cool into a solid mass.

Stage 3: The mass is manually chopped into small pieces.

Stage 4: The pieces are shredded into pieces of less than 1.5 cm. At this stage, some of the material is bagged and sold to plastics reprocessors.

Stage 5: The material resulting from stage 4 is melted through an extruder a second time. The melt passes through a finer filter screen and is extruded through a die perforated with holes of about 3 mm. The strings are passed through a cooling tank and are then chopped into pellets of less than 3 mm.

Stage 6: The pellets are usually packed in 25 kg bags and sold to plastic goods manufacturers.

The following equipment is used (cost in $):

(a)	Locally made screw-type extruder with a 20 HP motor; Capacity 40 kg/hour	1833
(b)	Locally made shredder with a 15 HP motor; batch capacity 300 kg	867
(c)	Second extruder with perforated die similar to (a), with a cooling tank and a water circulating system	2333
(d)	Pelletizing and bagging equipment	500
(e)	Miscellaneous tools such as dies, weighing scale, etc.	333

The total cost of the equipment (excluding the second extruder, which belongs to an ancillary processing unit) amounts to $3533. Table 6-1 shows the necessary personnel, wages, and total personnel costs per month (assuming two shifts of 10 hours each per day, and 26 working days per month). The minimum wage in India is 50¢ per day.

Processing stage	Manpower (per day)	Wages ($/day)	Total costs ($/month)
Stage 1	10	0.50	130
Stage 2	2	1.16	60
	6	0.67	105
Stage 3	2	0.50	26
Stage 4	4	0.67	70
Stage 5[a]			
Stage 6	4	0.50	52
Supervisor	1	-	40
Total	29	-	483

[a] Stage 5, the second extrusion phase, is done outside this unit by a subcontractor who charges 12¢ per kg for this service.

As can be seen from Table 6-1, the total labour costs are $483 per month. Unskilled workers (usually women and children) are engaged in light duties such as cleaning, sweeping, sorting, cutting, etc. The workers paid 67¢ per day are usually strong manual workers who carry out heavier duties related to the manufacturing process, such as weighing, packing and loading. The workers paid $1.16 per day are the extruding machine operators, who also supervise the production process and are responsible for their shift to the owners. None of the workers in these categories has any formal education or technical training.

Assuming that the average life-span of the machinery is five years, the depreciation will be $707 per year. The net profit is $2712 per year. The period needed to recover the initial investment through the profits earned is 16 months.

Source: Ptr Services,[35] 1992.

6.1.2 Quality improvements

The quality of the pellets and thus of the final manufactured products can be improved by adding the following steps:

- Virgin plastic pellets may be added at a ratio depending on the desired quality of the end product. The higher the percentage of virgin material, the higher will be the quality.
- If shredded rigid plastics are pre-heated in a drying installation the resulting pellets will be higher in quality (see Figure 4-3 for an example).

- As in the example of the unit in Calcutta, described in Box 6.1, if the quality of the pellets is not high enough for the manufacture of consumer articles, the pellets may be extruded a second time through a finer filter screen. This also reduces the moisture content of reprocessed pellets that have been cooled in a basin of water.
- To increase the production capacity of the extruder, a rotating spiral gear wheel may be positioned vertically in the hopper, as shown in Figure 6-6. The rotating wheel presses the material down into the feeding hole of the extruder screw. The wheel is driven by the same electric motor as the extruder screw, and has been built and added to the extruder in a local machine workshop.
- An extruder equipped with a ventilator to release humid hot air, reduces the porosity of the pellets and thus improves their quality.

Figure 6-6: Filling the hopper of an extruder for low bulk-density materials.

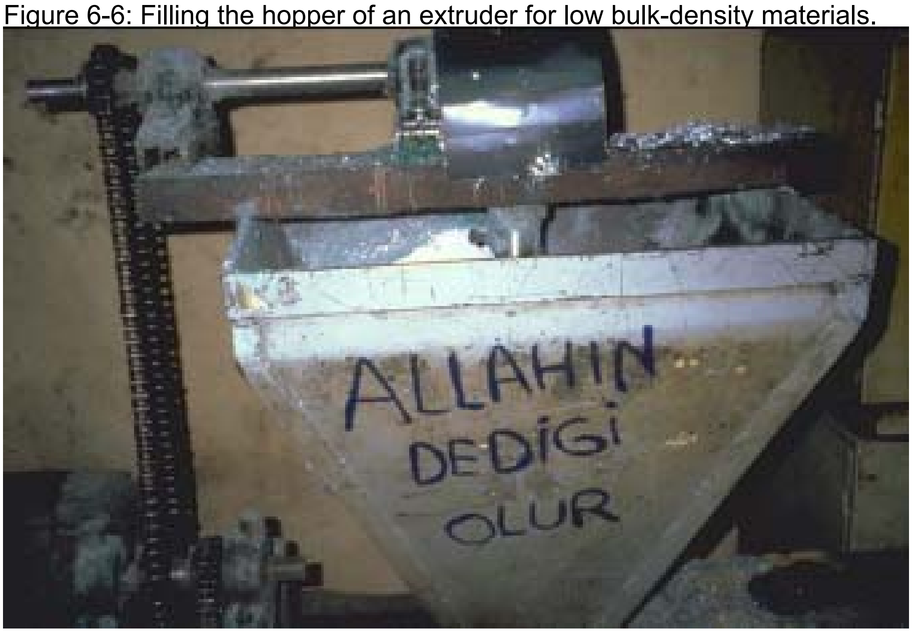


Photo: WASTE Consultants.

In Manila, a classification system is used to denote the purity of plastic pellets: Triple A (the highest quality), double A, single A, B and C. The prices of the pellets differ accordingly.[11]

6.2 Product manufacturing

A number of mechanical manufacturing processes are used by small enterprises to produce particular final products, including:

- extrusion (piping and tubing);
- injection moulding (miscellaneous products);
- blow moulding (bottles); and
- film blowing (plastic bags).

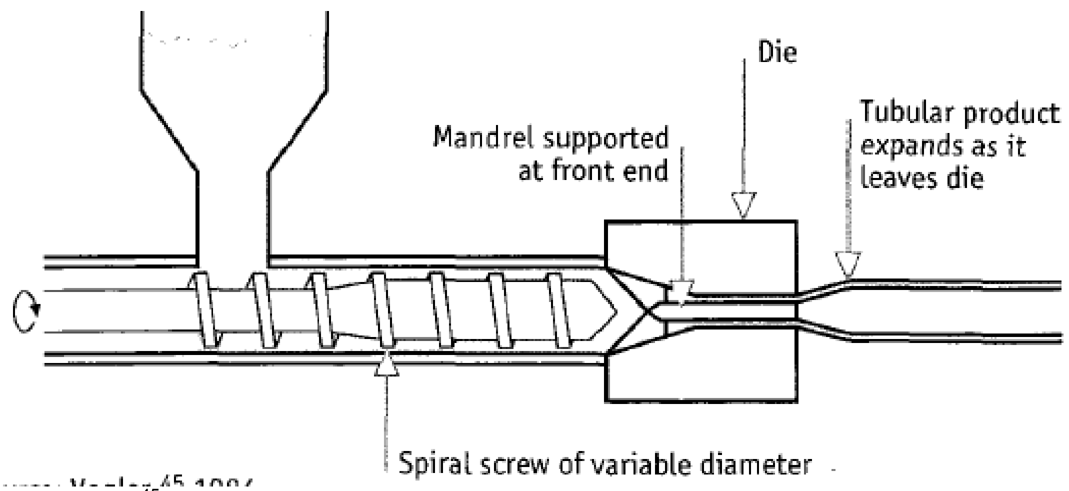
All of these processes require an electricity supply. Only for injection moulding does a low-cost, relatively simple, hand-powered alternative exist.

Usually the type of product and the demands on physical properties will determine the ratio of reprocessed to virgin plastics that can be used. For massive final products, such as furniture and (fence) posts, 100% waste plastics can be utilized. With other finer items, such as fishing nets, only a minimal amount of waste plastics can be used,[11] in the form of shredded or agglomerated waste plastics as well as pellets.

6.2.1 Extrusion

Extrusion moulding is similar to the extrusion process preceding the pelletizing process described in Section 6.1, except that the end product is a continuous, parallel stream of plastic such as tubing. This is made by a special die: a steel plate pierced with a hole that determines the shape of the product. The extruded material is cooled and solidified in air, in a water bath, or on a chilled drum, before being wound onto a reel or cut into straight lengths. The principle of the technique is shown in Figure 6-7.

Figure 6-7: The principle of extrusion moulding.



Source: Vogler,[45] 1984.

Figures 6-8 and 6-9 show the process of manufacturing soft PVC tubing, which has two extrusion cycles:

(1) In the first cycle, shredded PVC scrap is used to produce a string of undefined shape. During this cycle the moisture content of the material is reduced, the material is filtered and compounded with additives or pigments.

(2) The second cycle uses the shredded string resulting from the first cycle to produce tubing. Again, the moisture content is reduced, the material is

filtered, and in this case a die is put on the extruder to form the end product.

Figure 6-8: Feeding extruded soft PVC string (product from the first cycle) into a shredding machine.

Photo: WASTE Consultants.

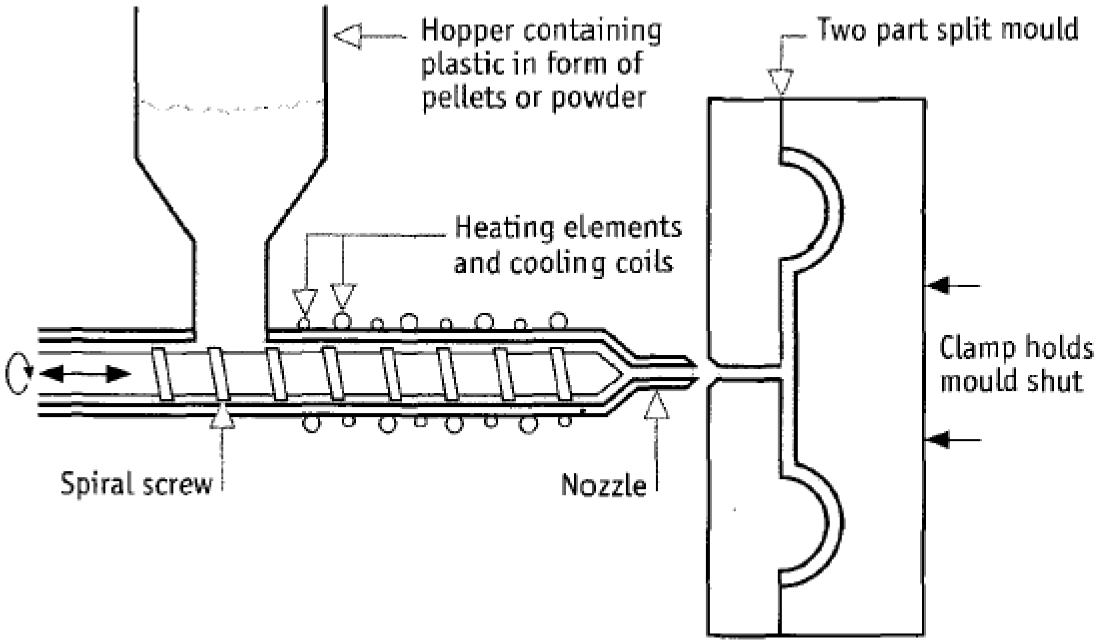
Figure 6-9: Soft PVC tubing being extruded (second cycle).

Photo: WASTE Consultants.

6.2.2 Injection moulding

The injection moulding process is similar to that of extrusion, except that the materials (the melt) are forced from the barrel through a nozzle into a strong, split steel mould, as shown in Figure 6-10.

Figure 6-10: The principle of injection moulding.



Source: Vogler,[45] 1984.

The rotating screw conveys the plastic forward and the heating elements plasticize it. The screw then stops moving, allowing the melt to accumulate in the front part of the barrel. When an adequate amount has accumulated, the screw moves forward again, pushing the melt into a closed steel mould. The mould is kept cool so that the material quickly solidifies. The mould is then opened, the product is removed, and the mould is then made ready for the next amount of melt. Some (old-fashioned) machines may use pistons or plungers rather than screws. The moulding process is similar to the pressure die casting of non-ferrous metals, from which it was developed. The shape of the mould determines the type of product produced. Figure 6-11 shows a mould used for the production of flexible PVC shoe soles.

Figure 6-11: Shoe soles being removed from the mould.

Photo: WASTE Consultants.

Hand-powered moulding is possible, but this usually results in products of poorer quality (e.g. caused by unequally applied pressure) destined for low-income consumer markets, even if virgin raw materials are used. Mechanical injection moulding usually results in products of a better quality. Figure 6-12 shows a hand-powered moulding machine in use in India. This machine, which costs about $150, is relatively simple to operate, maintain and repair, with a daily production capacity of about 200 pieces of 50 g each. It offers employment to the entrepreneur, assisted by one worker or apprentice, but profits are low due to the relatively low value of the final products.

Figure 6-12: A hand-powered moulding machine in India.

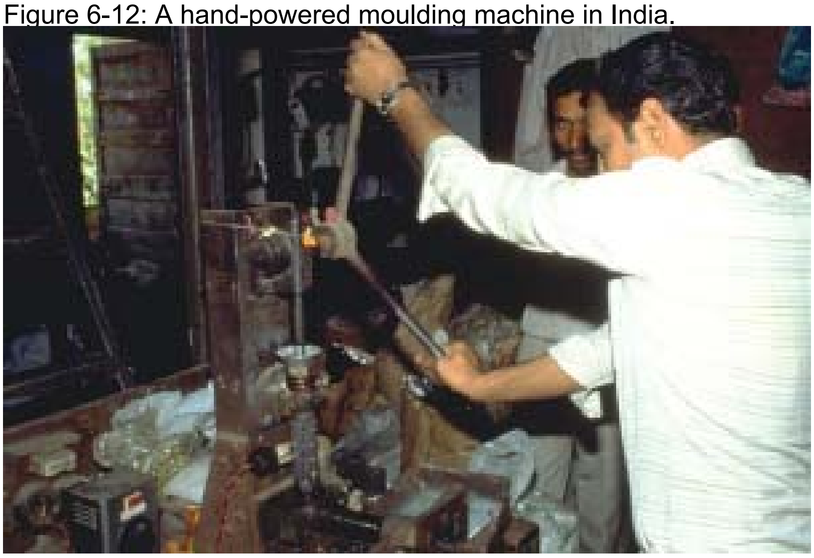
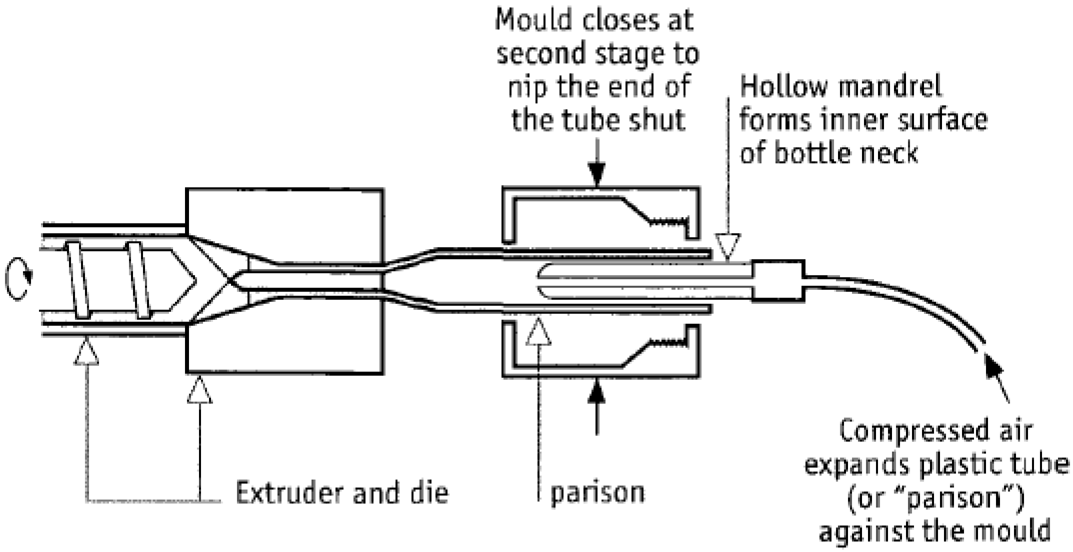


Photo: Johannes Odé.

6.2.3 Blow moulding

The term "blow moulding" is used to describe the process of producing hollow articles such as bottles, where the tops or bottoms are narrower than the body itself. The process is similar to the one used in blowing glass objects. The principle of the process, which takes place in two stages, is shown in Figure 6-13.

Figure 6-13: The principle of blow moulding.



Source: Vogler,[45] 1984.

First, a piece of plastic tube, or "parison" is extruded, and is then transferred to a split mould with the shape of the final product. The mould is then closed around the parison. Compressed air is blown into the open end to expand the parison to the shape of the mould. The formed shape is allowed to cool until the finished object solidifies, which is then ejected from the mould and the cycle is repeated.

The production capacities of the blow moulding machines used in Cairo, for example, vary between 100 and 200 kg of final products per day, depending on the power of the motor, which can range from 10 to 15 HP.[17] Each machine requires one motor for the operating process and another for the cooling process, each of which costs between $1700 and $2000. The operating costs of the machines are between $75 and $100 per tonne of production. For the production of 150 kg of final products per day, the total cost is $89/tonne (comprising labour $56/tonne; electricity $28/tonne; and contingencies $5/tonne).

6.2.4 Film blowing

Film blowing is technically the most complicated of the processes described in this chapter. Various methods are used: the process of making garbage bags shown in Figure 6-14 is as follows. After extrusion from a tubular die, the product, in this case a thin tube, moves upward to a film tower that contains a collapsing frame, guide rolls and motor-driven pull rolls. Compressed air is passed through the centre of the die and inflates the tube. The outside surface is cooled by air from an air ring mounted above the die. When the tube has passed through the pull rolls, it is sealed and cut to form the bag. For this process only high-quality pellets can be used as the raw material.

Figure 6-14: The production of garbage bags.

Photo: WASTE Consultants.

Box 6.2 illustrates the reprocessing of municipal waste and relatively clean industrial waste into flat sheets and carrier bags, as it is done in Accra with new imported machinery.

Figure 6-15: Plastics reprocessing equipment used in Accra.

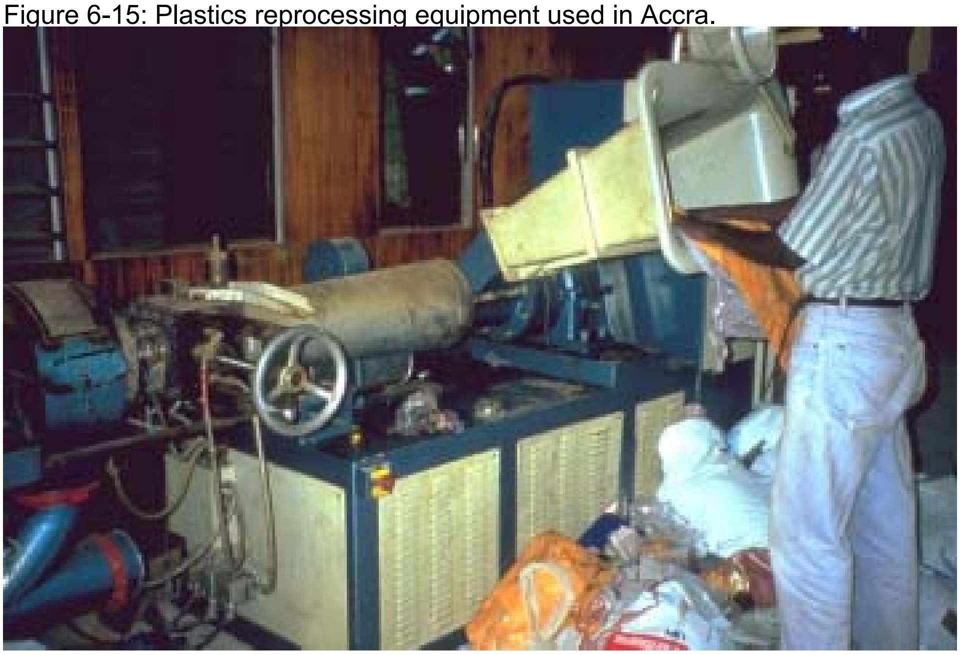


Photo: WASTE Consultants

Box 6.2 Plastics recovery with modern machinery in Accra, Ghana

Although there are various plastics manufacturing industries in Accra, Ghana, waste recovery is not common in this line of business. In fact, the only Ghanaian company engaged in reprocessing plastics is Polymers Ltd. The company's primary products are plastic films and flat sheets; plastics recovery only accounts for 10% of its business.

Besides the recovery of the company's own plastic waste materials, shopping bags (i.e disposable packaging materials) are collected from special garbage bins. The collectors are trained to recognize the desired types of plastic waste. In the factory, women sort and wash the materials in metal drums to remove dust and other contaminants, such as oil or food. The washed plastics are dried on wooden platforms, and then fed into an extruder and pelletizer. The plastic pellets are dried and packed into bags, using the equipment shown in Figure 6-15. The processing equipment has been imported from Europe. The pellets are further reprocessed by remelting and blow moulding them. The pellets are sometimes coloured by adding pigment pellets into the hopper of the extruder.

The two kinds of end products are flat plastic sheets for table covers, rain and dust protection etc., and carrier bags for non-food container applications. The personnel and skills needed in the recycling process are shown in Table 6-2.

Table 6-2: Processes and personnel requirements.

Process	Workers required
Collection	3 unskilled contractors
Sorting	2 unskilled female workers
Washing/drying	2 unskilled female workers
Shredding	1 technician/operator
Extruding	2 operators
Pelletizing	1 operator

Other technical and administrative personnel include a sales and distribution manager, a technical manager, a general manager, an administrator and a secretary/bookkeeper. The total cost of the equipment for the factory was about $3 million.

The reprocessed products can compete with other local and imported goods, used for the same applications. The bags, made from industrial plastic waste, are of good quality and therefore fetch good prices. In some locations, the bags are hardly distinguishable from imported ones, and are even sold for the same price.

Source: AB & P,[1] 1992.

6.3 Machinery and equipment

The small-scale plastics reprocessing sector in Calcutta is illustrative of the situation in most Asian countries. The sophisticated plastics processing machines used by industries in the formal sector usually require large capital investments. The machines used for the recovery of plastic waste are cheaper versions of the standard equipment and are made with cheaper materials, and improvised local technology and expertise to meet specific requirements. A study carried out by Ptr Services[35] has shown that the machinery used is very cheap. Table 6-3 gives the prices of elementary screw extruders (including drive units) in Calcutta.

Table 6-3: Prices of extruders in Calcutta.

Capacity (kg/hr)	Unit costs ($)
12	750
30	1400
40	1850

Source: Ptr Services,[35] 1992.

Similar standard machines of sophisticated design cost about $20,000 for a capacity of 12 kg/hr and $40,000 for 40 kg/hr capacity. The reasons for the low prices of the machines in Calcutta are as follows:

1. Only scrap and reject materials are used in the manufacture of these machines. Even the barrel and the screw are made from reject tubes and shafts obtained from scrap dealers. The standardized variable-speed drive is replaced by a single-speed drive with a standard commercial reduction gear (ratio 20:1). In situations where a change in speed is needed, this is achieved by changing the pulleys. In some versions of even cheaper machines, old gear boxes taken from trucks and buses are used, rather than commercial reduction gears.

2. Motors, starters, pulleys are purchased from second-hand dealers at very low prices and are repaired. Much second-hand machinery is available in Calcutta due to the various modernization programmes introduced in the last 20 years.

3. There is practically no quality control of the materials used in these machines.

4. Due to the low initial capital investments, the high rate of wear and tear or breakages is easily absorbed in the day-to-day economics of the production process. Expert fitters, electricians and other repairmen are available locally to attend to these machines.

With such a background, the working life of the various machines with light and heavy repairs is no more than 5–7 years, assuming that they will often be required to operate throughout two eight-hour shifts per day. However, the total production and the profit margin easily make up for the extra costs resulting from the short working life of the machines.

6.4 Products and markets

The demand for reprocessed waste plastics is generally much higher in Asia than in Africa, due to the higher level of industrialization (resulting in a demand from the plastics industries) and the larger (low-income) markets.

Different markets demand goods of different quality. First, there is the demand for regular or good quality products from high-income consumers and more specialized markets: such products incorporate only small proportions of recycled waste plastics (5–20%). Second, there is a high level of demand for lower-quality products made of recovered materials, which are sold at lower prices. In low- and middle-income countries the demand for cheaper products is high due to the large numbers of low-income consumers.

This difference in demand is clearly demonstrated in Turkey, where, for example, both regular water pipes and a low-quality version are manufactured. The regular, high-quality version is manufactured from virgin polyethylene and is pale blue in colour; this is destined for use in the formal market in the construction of new apartments, shops and office buildings. The low-quality version made of reprocessed polyethylene is black, due to the mixture of differently coloured waste plastics used; such pipes often vary in thickness, with thin patches that may be porous. These pipes are sold for example in rural villages in Anatolia, in the east of the country, for use in housing and as irrigation pipes.[27] The customers accept the poor-quality product for which they pay a lower price. Also in Istanbul the demand for the reprocessed pipes is higher than that for the regular quality pipes.

Various other products are also available in Turkey in two different qualities:[27]

- black versus semi-transparent, fashionably coloured shopping bags;
- reprocessed hosepipes made from scrap soft PVC versus semi-transparent, brightly coloured ones made from virgin PVC; and
- sewage pipes and drainpipes made from scrap PE versus drainpipes made of rigid virgin PVC.

Based on these observations of potential markets in Turkey, a number of articles that could be made from recycled waste plastics can be identified:[27]

- low-cost popular consumer items (such as kitchen ware);
- sanitation equipment (such as sewage pipes);
- electrical equipment (such as PVC-insulated electrical wiring, PS light switches and bulb sockets, wall plugs and sockets);
- accessory equipment for the textile industry (for example, Turkey's extensive and relatively well developed textile industry represents a large market for various types of plastic cotton reels);
- various kinds of toys and components.

Except for sanitation equipment, the major markets are located in the metropolitan area of Istanbul and its surroundings. A number of the various final products manufactured from waste plastics in Turkey are illustrated in Figure 6-16.

Figure 6-16: Examples of Turkish reprocessed end products.
Top row (left to right): soft PVC shoe soles (black); soft PVC slippers (brown); soft PVC fly swatter (yellow); and two types of PE shopping bag (semi-transparent purple and black).
Bottom row (left to right): a PP cotton reel (red); four types of soft PVC hosepipe (grey and brown); a PE water pipe for housing/irrigation (black); and a PP screwdriver grip (black). Electrical equipment: PE tube and PP connector for electrical wires, and a PP dowel (black); two sizes of PE dowel for screw-plug connections (green); two PE combs made of clean production waste (black and yellow); and a PE sewer pipe (light grey).

Photo: WASTE Consultants.

7 The Economics of Plastics Recovery

This chapter discusses some of the economic factors that are relevant for plastics reprocessing activities. Sections 7.1 and 7.2 deal with financial considerations (costs and benefits) at the micro-level. External macro-level factors that influence the feasibility of small enterprises, such as government policies and world market prices, are discussed in Section 7.3.

7.1 Costs

The costs associated with plastics recovery can be divided into three main categories: raw material costs, production costs and transportation costs.

7.1.1 Raw material costs

The costs of raw materials for reprocessing differ according to the source, the quality and the type of waste plastics that will be used. Although the market situations in each country and city are likely to vary considerably, some general observations can be made. Industrial, commercial and agricultural waste plastics retrieved directly from the source can sometimes be obtained for free. When the plastic waste is picked straight from the streets, dustbins or collection trucks it may also be free, although the crews may sometimes demand a small fee. Waste plastic items obtained from households by door-to-door collection often have to be paid for.

The costs of raw materials for reprocessing enterprises depend among others on the type of upgrading carried out, for example sorting and cleaning and on the number of intermediate dealers involved. More information on the prices of the various plastics used as raw materials can be found in Section 7.2. The end product of one reprocessing stage, such as shredded material, can be used as the input material of the next stage, such as pelletizing. Thus, for each stage or activity in the recycling process, a separate cost/benefit analysis should be made.

Improving the quality of the end product, such as by adding virgin plastics to the waste material, or by including additives such as pigments, will also add to the material costs.

7.1.2 Production costs

The most important production costs are labour, transportation (see also Section 7.1.3), electricity and water, equipment and rent. Generally it is difficult to obtain reliable data on production costs, since (informal) reprocessors usually do not keep records. As an example Table 7-1 lists the main production costs of a pelletizing workshop in Istanbul. This workshop is also partially involved in manual sorting, shredding and mechanical washing.[26] In this case, sorting forms the most labour-intensive activity.

Table 7-1: Main production costs (as percentages of total costs) of a pelletizing workshop in Istanbul, 1988.

labour (five workers)	31%
transport (long distance and bulky low-density material)	22%
electricity, water, etc.	18%
rent (two floors)	7%
loan repayments and interest	9%
other costs	13%

Source: Konings,[26] 1989.

The further extension of plastics reprocessing activities to include product manufacturing, basically means that higher investments will be needed in machinery, and that these will incur greater expenditures on spare parts and maintenance. Also, a product manufacturing machine will consume considerably more electricity (by the larger motor) and more water (for continuous cooling) than a shredding machine. The necessary moulds for product manufacturing also add to the production costs. However, labour costs will diminish in relation to the other costs.

7.1.3 Transportation costs

As can be seen in Table 7-1, transportation costs may constitute a considerable proportion of overall production costs, especially in the case of bulky low-density plastics. PE film from agricultural waste plastics, for example, is quite voluminous and is likely to be expensive to transport from the farm to a reprocessing plant in the city.

One way to reduce the costs of transporting such waste plastics is size reduction, by cutting or shredding (see Chapter 5). In Cairo, for example, transportation costs vary from $5 to $7.50 per tonne for non-shredded polymers, but after shredding, these costs fall to $2.50-3.50 per tonne.[17] In Istanbul, waste plastics imported from Europe are transported in compressed bales. For unknown reasons, this method of compressing plastics in order to reduce transportation costs is not used by local reprocessors and dealers.[27]

The site of the reprocessing plant should therefore be carefully chosen in order to minimize transportation costs. Factors that need to be taken into account include the distances to the sources of plastic waste (such as to waste dumps or factories) and customers, as well as the frequency of collection. As a rule, suppliers of waste plastics in Istanbul do not provide delivery services, and reprocessors have to collect their raw materials themselves.[27]

7.2 Benefits

For the reprocessor (involved in size reduction, pelletizing or product manufacturing), the clearest benefit is the income generated by selling the end product. These reprocessors mostly deal only with plastics, and derive no income from selling the by-products. Waste pickers and traders may deal in more than one waste item.

The prices of recycled plastics depend, among other things, on their physical characteristics. For example, recycled pellets with poor properties may sell for only half of the price of pellets made from virgin material, while the prices for high-quality materials may approach those made of the virgin material.[27] Prices also vary according to the cleanliness of the material. Dirt, foreign objects and moisture may represent as much as 20% of the original weight of the waste plastics, which will be lost during the sorting, washing and drying processes.[11]

Table 7-2 shows the market prices of various waste plastics, the original polymers and high-quality imported waste plastics in Istanbul. It can be seen that the market prices of the various materials vary considerably, and increase with each upgrading stage. It can also be seen that transparent and white scrap plastics yield pellets of higher value, since pigments can be added to give them any colour.

Table 7-2: Market prices (in $/kg) of waste plastics after the different reprocessing stages, Istanbul, 1988.

Polymer type	*Category*	*Sorted*	*Clean and dry*	*Shredded*	*Pelletized*	*Manufactured product*
PE/PP	Original *a	2.1-2.2				
Mixed	Contaminated unsorted waste	0.2-0.3				
PE (Alketon)	Transparent	-	1-1.5	-	2	-
	White	-	0.9-1.2	1.2-1.7	1.4-1.8	-
	Mixed colours	0.4-0.5	0.5-0.6	-	1.2-1.5	2.8 (30mm diameter pipe)
PP (Mobylen)	General	-	0.5-1.2	-	1.5	-
PS (Anti-shock)	Industrial	-	1-1.5	-	*2*	-
PVC (Soft)		0.3-0.5	-	1	-	3.6 (shoe soles)
PE/PP	Imported waste from Europe	-	1	-	-	

a Obtained from PETKIM, the state-owned petrochemical industry.
Source: Konings,271989.

The market value of waste plastics and their products is determined by a number of other factors, including the availability and the price of virgin materials (which are determined by the price of oil); the accessibility of other scrap material (including the amounts of waste plastics imported from industrialized countries); the seasonal demand for the final product; the relative strength of the domestic economy; and government policies on trade, including import restrictions. The market for recovered plastics is characterized by a competitive structure but also by a high degree of volatility; the demand for and prices of waste plastics and reprocessed pellets can fluctuate enormously.[17]

Table 7-3 lists the average market prices of reprocessed plastics in Istanbul, the increase in value after each reprocessing stage, and the value as a percentage of that of the comparable virgin material. It is clear that washing and manufacturing provide the largest increases in market value of the plastic material. The profit margins of small-scale industries that sort, wash, shred and pelletize waste plastics are about 20% of total sales. Manufacturing can yield profit margins of up to 50%.[26]

Table 7-3: Increases in the average market prices of waste plastics after the various reprocessing stages, and their value as a percentage of that of the virgin material in Istanbul, 1988 ($/kg).

Reprocessing stage	*Market price ($/kg)*	*Value increase ($/kg)*	*Value of material relative to that of virgin material*
Collecting	0.25	0.25	11.6
Sorting	0.40	0.15	18.6
Washing	1.00	0.60	46.5
Shredding	1.35	0.35	62.8
Pelletizing	1.60	0.25	74.4
Manufacturing	3.20	1.60	-
Imported virgin granules (PE)	2.15	-	100

Source: Konings,[26] 1989.

As with the prices of the plastic waste material, the prices of end products also vary enormously, depending on the form and purity of the material. The differences in prices also reflect the various reprocessing techniques, transportation and handling costs.

7.3 External influences

The viability of a waste plastics recycling plant will depend upon a number of important technical factors, and socio-economic and political circumstances. Macro-economic factors such as international prices and trading policies, government policies (including import restrictions), and municipal policies related to solid waste management will all determine the level of recycling that will be feasible.

In Cairo, for example, plastics were one of the first non-organic waste products to be reprocessed once their potential value was recognized. The increase in the value of waste plastics was due to a number of interdependent factors: the fluctuating prices of imported plastic polymers, the rising exchange rate against hard currencies, and rising domestic inflation.[17] The Egyptian government has played a crucial role by introducing laws prohibiting imports of most plastics products, with the exception of certain essential items such as spare parts. The government has also encouraged the domestic production of polymers, resulting in a sharp increase in the production of plastics products. Consequently, the plastics reprocessing industry has provided employment for both technicians and unskilled labourers. This has led to a situation in which, of the 25 tonnes of waste plastics generated in Cairo each day, almost 15 tonnes are now collected, sorted and reprocessed.[17]

In Kenya, the government increased the levels of duty on imports several times in the 1980s, in accordance with a policy to reduce national expenditures on imported raw materials, technology and equipment. These moves have created positive conditions for the reprocessing of waste plastics for the future.

On the other hand, higher import duties may adversely affect other industrial sectors, for example local industries that depend on imported raw materials. In the Philippines, a 9% import levy on goods of foreign origin, was reduced to 5%, despite the fact that the imposition of the levy would boost resource recovery activities, especially of plastics (due to high raw material costs).[11] Thus, there are limits to the level of import duties that can be imposed, but it will certainly affect plastics reprocessing.

Municipal policies related to solid waste management also influence the level of recycling to a certain extent. Many municipalities have chosen to introduce capital-intensive waste collection and treatment systems, thereby overlooking the usually strong informal waste collection and recovery sector. The expensive waste compacting trucks that have been introduced by some city councils provide 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 (the waste densities are already high because of the large proportion of organic material), but merely crushes the waste and mixes it thoroughly, making waste picking (including plastics), separation and recycling more difficult.

In several Asian countries the informal plastics recycling sector flourishes alongside the formal industries. Some small-scale entrepreneurs receive their training within the formal sector, and the availability of second-hand machines and locally manufactured equipment means that huge savings on capital investments can be made (see also Section 6.3). The same is true in Turkey, particularly Istanbul, where for the last few decades the small-scale plastics reprocessing industry has benefited from the existing plastic goods manufacturing industry. Also, the prices of reprocessed pellets depend on the prices of the virgin polymers that are produced locally by PETKIM, the state-owned petrochemical industry, and those of German imports.

These examples demonstrate that favourable government policies and the existence of a well-developed indigenous plastics processing industry are crucial for the feasibility of plastics reprocessing enterprises.

8 Environment and Health

Over the last decade, public awareness of environmental issues has grown considerably, especially in the industrialized countries of Western Europe and North America. Technologies have been developed to clean up water, soil and air pollution (so-called end-of-pipe solutions), but these have become so expensive that priority is now being given to the minimization and avoidance of pollution. Rising transportation and disposal costs, as well as the shortage of land for waste dumps, have also clearly demonstrated the need to minimize the amount of waste that is generated, and to develop alternative waste treatment systems. Although the importance of environmental protection strategies has now been recognized, the implementation of possible measures is often rather slow due to economic constraints, the lack of political will, and because the change to cleaner production processes takes time.

In many economically less developed countries, environmental awareness is also increasing, particularly 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 the industrialized countries. Protection of the environment is not always a priority when survival economics dominate, and when foreign currency is so badly needed.

This chapter discusses the environmental and health problems that may be encountered during the various reprocessing stages. The sorting of plastics from municipal solid waste may be unhygienic, since this waste may contain pathogens that cause diseases. The waste may also contain chemical substances such as heavy metals, which may pose problems during reprocessing. Some steps that can be taken to improve the safety of reprocessing activities are also described.

8.1 Waste: a potential health threat

For the individuals handling urban solid waste one of the greatest health threats is posed by the pathogenic micro-organisms that may be present in faecal material in raw municipal waste. The micro-organisms that are the causative agents of such diseases as diarrhoea and dysentery spread from the excreta of infected individuals, via faecal-oral transmission routes, and eventually reach other people either orally (in drinking water contaminated with faeces) or through the skin. Waste can also attract rats, and thus 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. These dangers are also present in collecting and sorting plastic waste from mixed municipal waste.

Waste recovery may create income generating opportunities that can conflict with environmental and health considerations. Although, on the one hand, the reuse of plastic waste helps to prevent environmental degradation and pollution, the recovery methods themselves are often not environmentally sound and may pose serious health hazards to the workers. It is often difficult to determine the exact causes of human health problems, since they are likely to be influenced by a number of factors, and disease transmission routes may be long and complex. But, since it is known that waste collection and recovery activities pose environmental and health risks, ways should be sought to minimize these dangers as far as possible. Full assessments of the effects on both the environment and on human health should therefore be made in any choice of technology.

8.2 Hazardous effects of plastics

8.2.1 Polluting substances

In terms of environmental and health effects it is important to differentiate between the various types of plastics. Most polymers (macromolecules) are considered non-toxic (PVC is an important exception). Polyethylene (PE) and polypropylene (PP), for example, are inert materials,[29] but it should be realized that polymers are not completely stable. Under the influence of light, heat or mechanical pressure they can decompose and release hazardous substances. For example, the monomers from which polymers are made may be released and may affect human health. Both styrene (which is used to make polystyrene, PS) and vinyl chloride (used to make PVC) are known to be toxic, and ethylene and propylene may also cause problems.[7]

The environmental effects of plastics also differ according to the type and quantity of additives that have been used:

- Some flame retardants may pollute the environment (e.g. bromine emissions).[32]
- Pigments or colorants may contain heavy metals that are highly toxic to humans, such as chromium (Cr), copper (Cu), cobalt (Co), selenium (Se), lead (Pb) and cadmium (Cd) are often used to produce brightly coloured plastics. Cadmium is used in red, yellow and orange pigments. In most industrialized countries these pigments have been banned by law.
- The additives used as heat stabilizers (i.e. chemical compounds that raise the temperature at which decomposition occurs), frequently contain heavy metals such as barium (Ba), tin (Sn), lead and cadmium, sometimes in combination.[32]

From the heavy metals mentioned, lead and cadmium are the most serious environmental pollutants, and have different effects on human health, depending on their concentrations. When present at or above specific concentrations, they interfere with processes in plant and animal tissues, and in the soil.

Polymers such as PVC may also have serious impacts on the environment because they contain a number of hazardous substances. For example, PVC contains chlorine which can be released during heating as hydrochloric acid (HCl). As is the case with many other hazardous materials, HCl in itself is not an unfamiliar nor a necessarily harmful substance (it is produced by the stomach to digest food), but at high concentrations in the air it affects the human respiratory system. Pure PVC contains

58% chlorine; when plasticizers are added, it contains about 49% chlorine. From a survey of the composition of waste carried out in the Netherlands, it was found that the chlorine present in PVC contributes about 50% of the total chlorine content of municipal waste.[32]

Other potentially hazardous substances in PVC include the relatively large quantities of additives such as plasticizers (up to 60%) and heat stabilizers (sometimes up to 3%).[32] In the opinion of some environmental and consumer organizations in Western Europe, the use of PVC and other plastics containing chlorine (or bromine), especially for packaging, should be halted entirely.

8.2.2 Air pollution

Taking into consideration the process of plastic recycling, the most important environmental problem caused by the (afore mentioned) polluting substances is air pollution, either within the reprocessing units or in the open air. During the extrusion process several substances such as additives, may be released. Since PE and PP do not contain large amounts of additives, potential problems with PE and PP are far less than with PVC. While extruding PVC additives may be released, but also vinyl chloride and HCl.[41]

One way of dealing with waste is to incinerate it. However, unless the combustion is complete, burning plastics within the waste may release considerable quantities of polluting substances. With complete combustion, almost 90% of the plastic material is reduced to carbonic acid (CO_2) and water (H_2O). PVC is an exception to this rule, since the chlorine it contains produces HCl when burned. The incomplete combustion of PE, PP, PS and PVC can cause further problems, as CO and smoke may be produced. As a result of incomplete combustion of PVC also dioxins and other hazardous substances may be formed.

In the Netherlands, the largest proportion of total hydrochloric acid emissions into the atmosphere is produced by the incineration of waste. Chlorinated polymers, particularly PVC, are the principal sources of hydrochloric acid emissions. During waste incineration chlorodioxins may be formed, which are highly toxic.

In the plastic waste reprocessing sectors of economically less developed countries, on the other hand, dioxins are not generally formed because the temperatures reached during the recycling processes are not high enough. However, the combustion of plastic material during the recycling process should be avoided at all costs in order to prevent the release of smoke and other hazardous substances.

In reprocessing machines, PVC may decompose and give off fumes of hydrochloric acid, which will speed up decomposition, may damage process machinery, and discolour and may spoil the finished product. Processing temperatures for PVC range between 150 and 210^{o}C, but decomposition may occur at temperatures as low as 180^{o}C. These serious difficulties can be overcome by keeping the moulding period very short, and by adding a heat stabilizer.

8.3 Safety measures

In low-income countries many informal recycling activities do not comply with labour and health regulations. In Calcutta, for example, a survey showed that practically none of the plastics reprocessing units had obtained a health licence.[35] The lack of safety arrangements and precautions, together with the polluted atmosphere in many working areas, may present serious health hazards, particularly for the workers themselves, but also for residents in the neighbourhood of the units.

Of course, if waste materials could be separated at source this would prevent mixing, resulting in cleaner waste fractions that are both easier to process and present fewer health hazards. The environmental and health risks arising from plastics recycling are different for each stage of reprocessing, but in general, plastics contaminated with unknown substances and mixed plastic waste pose the greatest dangers to human health and the environment.

However, a number of basic precautionary measures can be taken to improve general standards of hygiene and safety, and thus to protect employees, in plastics recovery activities. The following safety measures are strongly recommended.

- Protective clothing and gloves should be worn when sorting dirty waste plastic materials.
- Plastic materials should be washed before they are sorted; this will improve working conditions considerably.
- When using the burning test to identify types of plastics, try to avoid inhaling the fumes.

The sorting of plastics from mixed municipal waste may give rise to unhygienic working conditions, whereas clean material (e.g. from industrial sources) creates few health problems. Urban solid waste may contain large quantities of pathogenic micro-organisms that may cause infections.

The initial stages of reprocessing, such as washing and sorting, are often done in the open.

- Protection from the sun may sometimes be necessary.

Mechanical reprocessing (e.g. shredding, pelletizing) of plastic waste is mostly done in workshops.

- Keep all working areas properly ventilated and kept as clean as possible.
- Ensure that dust and other emissions are prevented from escaping from the reprocessing equipment, and that waste in general is kept to a minimum.
- When handling machines, protective clothing (such as gloves, ear plugs, glasses) should be worn.
- During the shredding operation, face masks should be worn to avoid the inhalation of dust.

During the extruding process, the higher the degree of contamination of the plastics, the worse will be the odour created. This is because it is more difficult to fine-tune an extruder to the optimal melting temperature if the inputs are not homogeneous.

- All waste should be thoroughly cleaned and sorted before it is reprocessed; this will help to minimize odours, and will improve the quality of the end product.
- Do not allow plastics to burn; the gases released may be toxic and pose a health risk to the workers.
- Avoid the use of PVC for recycling.

8.4 Product safety

Plastics reprocessing involves remelting the materials at high temperatures. This alters the chemical structure and results in an inevitable degradation of the material. Even the reprocessing of pure and well-defined plastic waste entails some sacrifice in terms of the quality of the end product. It is important to realize that the process of recovering plastics in fact only delays the time of inevitable final disposal. Considering the benefits of plastics products for society, this delay should be prolonged to a maximum; this can be partly achieved by conserving the properties of the material as far as possible.

Some recycled plastics, depending on the type of waste, should not be used in products that will come into contact with food. In the case of a manufacturer's own waste materials that have not left their point of origin, the re-user is in complete control and can therefore be sure they are not contaminated. Such waste materials may be safely used for products that will come into contact with food. However, it is not advisable to use waste from unknown sources for such purposes, since the reprocessor cannot guarantee that the plastics contain no additives or contaminants, nor can they be removed by washing. In particular, poisonous substances such as pesticides pose a direct health risk. Also, oil or food residues may have been absorbed by the scrap plastics, which may spoil the properties and the appearance of the final product, or may even create an unacceptable smell.

Waste plastics from unknown sources should also not be used for toys, kitchen utensils and drinking water pipes, since it is impossible to know whether they are contaminated or not. In hospitals, plastics are used for many applications including packaging materials, which are sometimes used for recovery. Plastic wastes from these sources must be approached with care as they may contain dangerous or unhygienic materials.

9 Future Prospects

Resource recovery may provide part of the solution to the problem of what to do with the uncollected heaps of waste found in the streets and around collection depots. It may also offer opportunities for income generation and the improvement of environmental and health conditions.

In many economically less developed countries the plastics reprocessing industry offers good prospects, mainly because of increasingly Westernized consumption patterns. The demand for plastic products is growing, and so are the amounts of plastic waste being generated as a result. Plastics recycling has some positive benefits for these countries: it can generate incomes, it requires relatively low levels of investments, it can yield reasonable or high profits, and involves relatively technically uncomplicated production processes.

This chapter gives an overview of some general conclusions that can be drawn from the information and the examples given in this book, and addresses some dilemmas concerning the future of small-scale plastics recycling in a sustainable waste management system.

9.1 Feasibility and product quality

The existence of hundreds of small plastics reprocessing businesses in, for example, Istanbul, Cairo and Calcutta clearly shows the viability of this sector. Part of this success is due to the use of cheap and sometimes freely available waste materials, which increases the profitability of small plastics reprocessing enterprises considerably. In principle, all the stages within the plastics recycling process can be profitable. The study carried out in Istanbul[26] showed that washing and product manufacturing yield the highest profit margins (see Table 7.3), even though the machinery being used was operating at only 60% of its production capacity.

In Asian countries in particular, many people are engaged in plastics recycling activities (see Section 3.3). The initial stages of collecting, cleaning and sorting are labour-intensive and require low capital investments and little or no specific technical skills. In general, women tend to be involved in the initial stages, whereas men tend to be involved in pelletizing and product manufacturing activities.

As noted in Section 6.4, the quality of the end product depends to a large extent on the percentage of waste plastics used. In general, the higher the proportion of waste materials used, the poorer will be the quality of the end product, and the lower will be the price. Thus, the low-income groups will be able to afford plastic products made using a high percentage of reprocessed pellets. In Istanbul, for example, products of poor quality made entirely of waste plastics are sold at half the price of those made of virgin plastics, and therefore the demand is high.

Although the demand for low-quality plastic goods provides viable business opportunities in the short term, several other factors should be taken into account when seeking longer-term solutions to the problem of disposing of waste plastics. First, the life-span of products made from low-quality materials is short, and second, the degradation that inevitably occurs during the reprocessing of plastics reduces opportunities for further reprocessing in the future. Both the socio-economic and the long-term environmental benefits will be enhanced if the quality of the material and of the product can be preserved for as long as possible. At present, however, both the producers and the consumers benefit from cheap but low-quality products. Ultimately, this dilemma can only be resolved by aiming at the improvement of the socio-economic status of the people involved, so that, in turn, they will be able to afford higher-quality durable goods.

9.2 Starting a plastics reprocessing enterprise

The effective operationalization of recycling activities in terms of product manufacturing in a low-cost environment requires, first, the establishment of an "industrial mentality". As illustrated in the case of the Zabbaleen small industries programme (see Box 3.2), this may take several years, and requires high investments in terms of continuous project guidance by experts. On the other hand, the Zabbaleen case also shows that in the long term there is a potential for newly established industrial product manufacturing workshops to become sustainable, which in the end may result in spin-off activities that generate additional employment.

However, if there is no local tradition in small-scale manufacturing of consumer goods, short-term successes may be easier to achieve by initiating activities such as collecting, washing and sorting plastic waste materials (see Box 4.1, which describes the set-up of a washing and sorting workshop in Kingston) rather than product manufacturing.

Depending upon the demand, several types of plastics, such as PE and PP (various grades and colours), can be collected. These can be feasible activities and require only basic skills, such as the ability to identify the types of plastics. Such activities can be organized and implemented at short notice and have a high likelihood of becoming sustainable. The products (clean and sorted plastics) can be sold to existing formal plastics processing industries, which in itself will create useful business relations with these industries. Also for these activities, the achievement of maximum quality should be a major starting goal, not only to improve environmental conditions, but also because clean and sorted plastics fetch higher prices.

It is recommended that contacts with these industries are gradually extended in order to take advantage in terms of sorting skills, incidental know-how, second-hand equipment, spare parts and operating and maintenance skills and facilities. Then, a choice can be made to start the production of either shredded or agglomerated plastics material, based on the availability and the market potential of hard (rigid) or soft (film) plastics. Another important consideration is whether the necessary machinery is available locally. Once these early processing stages have been established on a firm, profitable basis, the development of a pelletizing, and eventually a product manufacturing, workshop can be considered.

9.3 Improving working conditions and the environment

Although the reprocessing of plastics can bring many benefits, including environmental improvement (see Section 1.5), recycling activities in themselves are not always environmentally sound and may pose health risks to the workers. Some examples of ways to improve working conditions have been given throughout this book, such as to collect clean industrial and agricultural waste, and to follow a preferred sequence when handling waste: mixed plastic materials should be washed before they are sorted. Also, a number of precautionary measures should be taken, such as wearing protective clothing and ensuring that the workshop is well ventilated (see Section 8.3).

However, it should also be recognized that the goal of improving working conditions for low-income groups will not be easy to achieve, because of the meagre financial margins, the surplus of cheap labour and the low level of organization among workers. Another difficulty is the lack of knowledge of the precise dangers for human health when dealing with plastic waste within an informal setting. This applies not only in the collecting and sorting stages, when plastics are taken from mixed waste, but also and especially in the reprocessing stages when hazardous substances may be released, particularly during the reprocessing of PVC.

These considerations may pose a dilemma as to whether certain activities should be encouraged or not. Ideally, the same standards and criteria used in Western Europe and North America should be applied in less developed countries. But these health and pollution risks should also be seen in relation to the existing danger of exposure to other sources of contamination, such as domestic drinking water supplies and sanitation facilities. It is even of little use to improve working conditions or to forbid certain activities, when these individuals are often already struggling for survival and lack access to basic services. Also, no other income-generating alternatives may be available. For the long term, an integrated approach should be adopted, with the ultimate aim of improving the living conditions of the low-income groups and creating safe and environmentally sound employment opportunities.

9.4 Technology transfer and development

Methods of recycling plastic waste have developed in very different ways in the various continents. In the industrialized world, only a small proportion of municipal plastic waste is reprocessed, and if it is done, the processes are capital-intensive and based on mass production of goods (such as fence posts). In contrast, in Asian countries, for example, many small enterprises are involved in such activities.

Until now, the transfer of (plastics reprocessing) technology has tended to occur from the industrialized to the economically less developed countries, although often the technology has not been 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 characteristics that must be considered when developing a sustainable solid waste recovery system in low- and middle-income countries. As the examples in the boxes and in the text indicate, technology transfer consists of more than just technical solutions; answers also have to be found to a number of other problems, including the provision of finance (e.g. to cover maintenance costs), the building of institutional capacity (e.g. management) and the avoidance of environmental pollution.

Due to these differences, efforts simply to transfer reprocessing technologies based on high-cost equipment should be discouraged. However, there should be a permanent awareness as to which specific incidental know-how or techniques or parts thereof could be of value to economically less developed countries. An example could be the development of safe and environmentally sound recycling technologies. Some important limitations, however, underlie this notion. In the Netherlands, research and development on processes is to a great extent executed and financed by the plastics industries themselves. Detailed information on processes is therefore not easily accessible, since it is screened off from the outside, competitive environment.

Also, the difference in prices between locally available machinery and imported Western equipment is enormous (Box 6.2, for example, describes plastics recovery with imported machinery in Accra, Ghana). Low-income groups cannot afford such high investments; the question then is who will pay for this safe and environmentally sound technology. This poses a difficult dilemma as to which track for technology development should be followed in low- and middle-income countries.

While advanced technologies continue to be developed in the industrialized countries, very few innovations are being made within the informal sectors of most low-income countries. Thus, the gap between high- and low-income countries in terms of technology seems to be becoming even wider. This trend is alarming; instead of becoming a world where resources and wealth are more equally divided, the poor and rich seem to be drifting even further apart.

South–South exchange and technology development have not yet received the attention they deserve, and yet offer some opportunities. Entrepreneurs, especially in Asian countries, have shown that they are capable of inventing and adapting recycling technology to local circumstances, such as shredders or product manufacturing machines. This technology could be more suitable for transfer to sub-Saharan African countries, for example, and the machinery is also much cheaper than that developed in industrialized countries. The most important problem with this kind of technology is the hazardous situations it may create for both the employees and the direct environment.

In conclusion, opportunities should be created to optimize South–South exchanges of technology (through networking, exchange visits, etc.), and to enable a free flow of information from North to South. Also, possibilities should be created to attract funds for innovation within the informal sector.

9.5 Interdependence of the formal and informal sectors

It appears that there are enormous differences in the scale and the technologies used in plastics reprocessing by continent and by country. As described in Section 7.3, this depends partly on historical influences, such as whether there is an existing tradition of manufacturing, government policies (see also Section 9.6) and the level of industrialization within each country.

In many Asian countries, the informal plastics reprocessing sectors are flourishing alongside the formal sector industries. In terms of technology, to a certain extent, the informal sector is dependent on the formal one. Entrepreneurs often receive their training there and the formal industries often represent markets for reprocessed products, such as pellets, from the informal sector. The use of second-hand machines and the locally manufactured equipment means that huge savings on capital investments are possible.

Direct competition with formal industries should be avoided, however. In Nairobi, for example, the high level of competition from existing industries is a factor that has prevented the manufacture of high-quality reprocessed products.

In setting up and maintaining small enterprises, it is essential to establish business linkages with formal large-scale industries, because they are more powerful. Without their active participation, little collaboration is possible. Practical experience in Kingston, for example (see Box 4.1), and oral information suggest that formal industries (including multinationals) are becoming more interested in contributing to employment generation on the one hand, and recycling on the other. They are becoming aware of their responsibilities and the possibilities to create employment for low-income groups, and are striving to build up a "green" image, to demonstrate that they care for the environment. Small enterprises may be able to benefit from these tendencies and to take advantage of the expertise available within these industries.

9.6 Public authorities and private initiatives

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

One major difficulty in municipal solid waste management is that the total costs of safe and environmentally acceptable solid waste disposal are poorly documented and are therefore underestimated. Besides, the potential of resource recovery is not used to its full extent, because its economic, social and environmental benefits are not fully recognized and valued. It is against this background that informal resource recovery needs to be supported in order to improve existing practices and to integrate it within municipal solid waste management systems. The various recycling possibilities should be incorporated at both the implementation and policy levels. In some countries, the contribution of the informal sector to waste collection and recovery is slowly being recognized and valued, and ways are being sought to integrate public and private systems in order to optimize both. Private companies and community-based organizations are increasingly taking over part of the responsibilities of the municipality.

Nevertheless, government authorities play an important role in the promotion and viability of plastics reprocessing activities, not only by their approaches to local waste management approach but also by the economic policies they adopt. For example, import regulations on virgin pellets may determine the feasibility and the level of recycling, as outlined in Section 7.3.

Some issues that governments (as well as intermediary organizations) could address, depending on their resources and responsibilities, include the needs for the following:

- to facilitate plastics recovery activities;
- to recognize and integrate existing informal recycling networks within municipal solid waste management systems;
- to stimulate the development and implementation of appropriate technologies for plastics recovery;
- to formulate policies to protect and encourage the horizontal growth of small-scale resource recovery initiatives;
- to create legal frameworks and control mechanisms that will both improve safety in the workplace, and protect the environment; and
- to disseminate information both to the general population and to enterprises on the benefits of preventing the generation of waste and of recycling.

9.7 Towards sustainable integrated waste management

The best way to prevent environmental and health problems caused by waste would be simply to avoid the generation of waste in the first place. Prevention should always be an important first measure. This is especially true for high-income countries where, for example, the packaging industry uses plastics unnecessarily. Stimulated by government legislation and the influence of environmental action groups, steps are slowly being taken to encourage the use of more efficient packaging. However, because of strong economic interest groups, for example, it is proving difficult to reduce or prevent waste generation, and is probably not a priority at the moment for low- and middle-income countries, whose populations still cannot meet their basic needs and lack access to resources. To improve standards of living implies that without investments (for example, in developing cleaner technologies generating less waste and consuming less energy) the amounts of waste being generated (including plastics) will continue to increase. On the other hand, economically less developed countries are also responsible for creating sustainable livelihoods for their own populations and, despite obvious limitations, they should take preventive measures (such as to avoid unnecessary packaging, as well as to produce fewer types of plastics), as far as possible.

The treatment of waste near its point of generation, and the separation of waste at source could also be an important means of preventing the shifting of environmental problems to adjacent urban areas, to urban fringes, to more remote places, or to future generations. If waste is separated at or near its source, less sorting and processing will be needed later, and the raw materials are less likely to be contaminated.

The problem of integrating small-scale (informal) resource recovery activities within a sustainable urban waste management system is more a matter of perception than one of technology. To be effective, such a system requires interdisciplinary cooperation at different levels among various actors, such as municipal departments and councillors, national governments, non-governmental organizations (varying from welfare to environmentalist groups), research institutions, academics, community representatives, etc.

Many questions remain unanswered, however, such as how small-scale recycling activities can be optimized under local circumstances, and can best fit within a broader waste management perspective. From the practical experiences already gained all over the world, some of which have been described in this book, important lessons can be learned and conclusions can be drawn. Hopefully, these experiences may result in the adoption of more appropriate and sustainable solid waste management systems, including the increased and improved recycling of plastic waste.

Appendix 1 Average exchange rates in selected countries

In 1991–92, the period during which the WAREN research was carried out, the average exchange rates were as follows:

Philippines	\$1 = 30 Pesos (P)
Egypt	\$1 = 2 Egyptian Pounds (£E)
Ghana	\$1 = 450 Cedis (C)
Kenya	\$1 = 25 Kenyan Shillings (Ksh)
India	\$1 = 30 Rupees (Rp)
Mali	\$1 = 300 Francs (CFA)
Turkey (1988)	\$1 = 1000 Turkish Lira (TL)

Appendix 2 Characteristics of Recyclable Plastics

Resin type	Density (g/cm^3)	Softening or melting range (^oC)	Properties/applications
Low-density polyethylene (LDPE)	0.910—0.925	102—112	Largest volume resin for packaging; moisture proof transparent film
High-density polyethylene (HDPE)	0.94—0.96 0.95 (coloured bottles) 0.96 (clear bottles)	125—135	Tough, flexible and translucent material, used primarily in packaging; product examples include milk and detergent bottles, heavy-duty films, wire and cable insulation
Polypropylene (PP)	0.90	160—165	Stiff, heat and chemical resistant, used in furniture and furnishings, packaging; product examples include drinking straws, fishing nets, food containers, vehicle bumpers
Polystyrene (PS)	1.04—1.10	70—115	Brittle, transparent, rigid, easy to process, used in packaging and consumer products; product examples include foam take-away containers, insulation board, cassette and compact disc cases
Polyvinyl chloride (PVC)	1.30—1.35	150—200	Hard, brittle and difficult to process, but processed easily using additives; a wide variety of properties and manufacturing techniques are possible using different copolymers and additives; product examples include sheet bottles, house siding, cable insulation.

Source: B.A. Hegberg *et al.*, *Mixed Plastics Recycling Technology* (Noyes Data Corporation, Park Ridge, NJ, USA, 1992).

Appendix 3 Tests to Distinguish Polymers

(table)

Source: J. Vogler, *Small-scale Recycling of Plastics* (Intermediate Technology Publications, London, 1984).

Appendix 4 Useful Addresses

Consultants involved in the WAREN project

Asafo-Boakye and Partners
P.O. Box 7186, Accra North, Ghana
Contact persons: Mr E.A. Kuma, Mr James Gordon
Tel: +233 (21) 77 30 78 / 77 30 81 / 77 30 93
Fax: +233 (21) 77 30 94

The American University in Cairo
Department of Engineering
113 Sharia Kasr El Aini
P.O. Box 2511, Cairo, Egypt
Contact person: Dr Salah El-Haggar
Tel: +20 (2) 354 29 64, ext. 5309/5455
Fax: +20 (2) 355 75 65

Environmental Quality International (EQI)
7th floor, 3 B Bahgat Ali Street
Zamalek, Cairo, Egypt
Contact person: Mr Mounir Bushra Mina
Tel: +20 (2) 340 86 28 / 340 00 52 / 340 82 84
Fax: +20 (2) 341 33 31

PTR Consulting Engineers
15 Ganesh Chandra Avenue, 2nd floor
Calcutta 700 013, India
Contact person: Mr R. K. Banerjee
Tel: +91 (33) 26 26 90

GERAD/IMRAD
Boîte Postale 1988, Bamako, Mali
Contact person: Mr Bakary Diakité
Tel/fax: +223 22 59 99

CAPS (Center for Advanced Philippine Studies)
Room 8, Maya Building
678 EDSA, Cubao 1102,
Quezon City, Metro Manila, The Philippines
Contact person: Mr Dan Lapid
Tel: +63 (2) 912 36 08

Fax: +63 (2) 912 34 79

Undugu Society of Kenya
Landhies Road
P.O. Box 40417, Nairobi, Kenya
Contact persons: Mr Aloys Opiyo, Mr Kuria Gathuru
Tel. +254 (2) 55 22 11
Fax: +254 (2) 54 58 88

Institutions with information on solid waste management

The following institutions hold databases on subjects such as solid waste management, recycling, production processes, technology, legislation and case studies.

AIT/ENSIC (Environmental Sanitation Information Centre)
GPO Box 2754, Bangkok 10501, Thailand
Tel: +66 (2) 524 5863
Fax: +66 (2) 524 5870

- Database, library and courses on solid waste management in general, but also specifically on plastics recycling.

Waste Management Resource and Information Center (WMC)
(for address, see CAPS in list of consultants involved in the WAREN project) has a programme called Infowaste, focusing on solid waste.

- On-line recycling inquiry system, training and technology sharing, information & education campaigns.

ENDA (Environmental Development Action in the Third World)
Head office: P.O.Box 3370, Dakar, Senegal
Tel: +221 (22) 42 29 / 21 60 27
Fax: +221 (22) 26 95
Telex: 51 456 ENDA TM SG
Regional offices in Colombia, Zimbabwe, Bolivia

- Database, library, publications and advice.

GTZ (German Agency for Technical Cooperation)
Post Box 5180
Dag-Hammarskjöld-Weg 1
D-6236 Eschborn, Germany
Tel: +44 (6196) 790
Fax: +44 (6196) 791115

- Database, library and publications.

IRCWD (International Reference Centre for Waste Disposal)
Überlandstrasse 133
CH-8600 Dübendorf, Switzerland
Tel: +41 (1) 823 50 18/17
Fax: +41 (1) 823 53 89

- Research, library and advice.

ILO (International Labour Organization)/INSTEAD
4 Route des Morillons
CH-1211 Geneva, Switzerland
Tel: +41 (22) 799 83 19
Fax: +41 (22) 798 86 85

- Database service on products and processes and socio-economic aspects of waste recycling; documentation on urban basic services (including SWM) related to employment generation.

UNDP/World Bank
Integrated Resource Recovery Programme
1818 H. Street NW, Washington, DC, USA
Tel +1 (202) 477 1254
Fax +1 (202) 477 1052

- Publications on policies and case studies.

UNCRD (UN Centre for Regional Development)
Environmental Planning Unit
1-47-1 Nagono, Nakamura-ku
Nagoya 450, Japan

- Documentation on SWM in Asian cities.

Waste Management Information Bureau,
Enquiry Service and Waste Information,
AEA Environment & Energy
B 7.12
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Oxon OX11 0RA, UK
Tel: +44 (235) 433442
Fax: +44 (235) 432854

- Database service covering 60,000 abstracts from literature published worldwide; short enquiries free.

Institutions with information on plastic waste recycling

In Europe and North America, many institutions are involved in plastic waste recycling and may provide information. Here only a selected number is presented.

Plastic Waste Management Institute
Fukide-Bldg. 1-13-4 chome, Toranomon,
Minto-ku, Tokyo, Japan
Tel: +81 (3) 3437 2251
Fax: +81 (3) 3437 5270

- Major projects: technological development, surveys, public relations, international communications, aid to the plastics recycling industry.

Plastics Institute of America, Inc. (PIA)
277 Fairfield Road, Suite 100
Fairfield, NJ 07004, USA
Tel: +1 (201) 808 5950

- Primary goal is the advancement of education and research in plastics, offers courses on plastics recycling technology.

Plastics Recycling Foundation (PRF)
1275 K Street NW, Suite 400
Washington, DC 20005, USA
Tel: +1 (202) 371 5337

- PRF's mission is to sponsor research to improve the technology and economics of plastics recycling, to demonstrate pilot programs in recycling technology, and to provide information on recycling technology and product markets. Funding is provided to the member companies, state and federal agencies, and academic institutions.

The Plastics Processing Industry Training Board
Coppice House
Halesfield 7
Telford, Shropshire, UK

- The PPITB provides training courses on such subjects as injection moulding, extrusion and blow moulding and also provides a number of training grants.

European Centre for Plastics in the Environment (PWMI) and Association of Plastics Manufacturers in Europe (APME)
Avenue E. van Nieuwenhuyse 4, BP 3
B-1160 Brussels, Belgium

Tel: +32 (2) 675 32 97
Fax: +32 (2) 675 39 35

- Provides information on plastics waste recycling and plastics waste management in general; also attention for environmental aspects.

TNO Plastics and Rubber Research Institute
P.O. Box 6031
2600 JA Delft, The Netherlands
Tel: +31 (15) 69 66 21
Fax: +31 (15) 56 63 08

- Basic and applied research is carried out on plastics, rubber and composites. Aims at material and product development and processing, in addition to advice, testing, expertise activities and training.

Glossary

Additive: a substance added intentionally to a polymer mixture to alter its physical or chemical properties.

Agglomeration: the coalescing of small particles into a clump.

Antioxidant: an additive that inhibits a plastic from chemically reacting with oxygen.

Blow moulding: the established technique for producing bottles and other containers based on simple hollow shapes.

Capital-intensive: indicates that a relatively large percentage of the total production costs is associated with the initial costs rather than the operating costs; also used to differentiate from technologies which are labour-intensive.

Colorant: a dye or pigment added to the plastic to give it colour.

Compound: mix or combine (for example, plastic material with additives or pigments).

Compression: the reduction in volume causing an increase in pressure.

Degassing: removing unwanted gas.

Extrusion: the process of forming continuous shapes by forcing molten plastic through a shaped die by means of pressure.

Feasibility study: a technical evaluation to determine the economic or social viability of an activity.

Flexibility: the ability of a material to be deformed without fracture.

Garbage: household fraction of municipal refuse, which includes kitchen residues and other organic wastes.

Granulation: the size reduction of plastic materials into small particles using a granulator.

Granulator: a machine with rotating and stationary knives that cut the plastic material into small particles.

Homogenize: make or become of the same kind.

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

Injection moulding: the process of manufacturing with plastic by forcing molten plastic into a mould under pressure.

Labour-intensive: a process or procedure requiring a large workforce.

Macromolecule: an alternate name for a polymer; giant molecule.

Mandrel: a cylindrical rod round which the plastic material is shaped.

Market: processor or end-user.

Marketing: the process by which buyers and sellers are brought together.

Mixed plastic: a mixture of plastics, the components of which may have widely different properties.

Monomer: a molecule that typically contains carbon and is of a low molecular weight (compared with the molecular weight of plastics), which can react to form a polymer by combination with itself or with other similar compounds, or: the small molecule that is reacted to produce a polymer.

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

Parison: a hollow tube or other preformed shape of plastic that is inflated inside a mould in the blow moulding process.

PE: polyethylene.

Pelletizing: the process of melting and extruding small, clean pieces of plastics into small regularly shaped pellets.

Plastic: derived from the Greek word *plastikos*, meaning easily shaped. It is now used as a general term for all synthetic macromolecular materials.

Plasticization: the process of plastic material becoming soft and mouldable.

Plasticizer: an additive used to increase the flexibility or plasticity of a polymer.

Plastics recycling: a process by which plastic materials that would otherwise become solid waste, are collected, separated, processed and returned to use.

Polymer: the word is derived from the Greek words for many, *poly*, and small part, *mer*. A polymer is indeed made up of many small parts (monomers) to form a large molecule.

Polymerization: process whereby polymers are produced from monomers.

Polymers: a group of materials made up of large molecules, which include plastics and rubber.

PP: polypropylene.

Primary recycling: the processing of waste into a product with characteristics similar to those of the original product.

PS: polystyrene.

PVC: polyvinyl chloride.

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

Reduce: convert to a simpler form.

Reuse: the use of a product more than once in its original form.

Refuse: rubbish; garbage; mixed waste materials.

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

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

Secondary recycling: the processing of waste into materials which have characteristics less demanding than those of the original product.

Shredder: machine used to reduce the size of pieces of (hard) plastics into smaller particles.

Thermoplastic: a plastic that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped into products.

Thermoset: plastic that, after having been cured by heat or other means, is substantially infusible and insoluble. Cross-linking between molecular chains of the polymer prevent thermosets from being melted and resolidified.

Virgin plastic: plastic material in the form of pellets, granules, powder, or liquid that is not been subjected to use or processing other than that required for its initial manufacture.

Waste picker: person who collects material from e.g. a waste dump.

Zabbaleen: generic term for several Coptic Christian minority groups who partly take care of the collection and recycling of solid wastes in Egyptian cities.

References

1 AB & P. *Product-market-technology combination of waste materials recycling in Accra, Ghana.* WAREN project, WASTE Consultants, the Netherlands, 1992.

2 APME & PWMI. *New markets for recycled mixed plastics.* Information brochure. Brussels.

3 APME & PWMI. *Plastics in perspective.* Information brochure. Brussels.

4 Baldisimo, J.M. *Recycling potentials of solid wastes at source and disposal sites in Manila, the Philippines.* AIT, Bangkok, 1985,

5 Baldisimo, J.M. *et al.* Scavenging of municipal solid waste in Bangkok, Jakarta and Manila. *Environmental Sanitation Reviews* No. 26, December 1988.

6 Basta, N. *et al.* "Plastics recycling gains momentum: Recycling everything, Part 1", In: *Chemical Engineering* 97 (11), November 1990.

7 Beumer, P.F.M. *et al*., *Arbeidsomstandigheden in de chemische industrie: overzicht van de voornaamste knelpunten wat betreft de blootstelling aan geluid, trillingen, gassen, dampen en stof.* Directoraat-Generaal van de Arbeid van het Ministerie van Sociale Zaken en Werkgelegenheid, Den Haag, 1991.

8 Binder, G. "PVC in der Umweltdiskussion", *Glaswelt*, Hüls Publications, October 1989.

9 Bromley, R. (ed), *Planning for small enterprises in Third World Cities.* Centre for Development Studies, University College of Swansea, UK, and Regional Planning Program, State University of New York at Albany, USA. Pergamon Press, Oxford, 1985.

10 Brydson, J.A. *Handbook for Plastics Processors.* Published in association with the Plastics and Rubber Institute. Heinemann Newnes, Oxford, 1990.

11 CAPS. *Recycling Activities in Metro Manila.* WAREN project WASTE Consultants, the Netherlands, 1992.

12 Cointreau, S. *et al. Recycling from municipal refuse: A state-of-the-art review and annoted bibliography.* Integrated Resource Recovery. Technical Paper No. 30. World Bank, Washington, DC, 1984.

13 Curi, K. "Solid waste recycling in the city of Istanbul and possible application in other developing countries", in: Thomé-Kozmiensky (ed.), *Recycling in Developing Countries,* 1982.

14 Delft van, J. *Hergebruik kunststoffen geen koud kunstje.* Milieudefensie. June 1985.

15 Ehrig, R.J. (ed.) *Plastics Recycling: Products and Processes.* Hanser Publishers, Munich, 1992.

16 EQI. *Zabbaleen Small Industries.* Final report. Presented to Oxfam, 1986.

17 EQI. *The recyling of solid waste in Cairo, Egypt.* WAREN project, WASTE Consultants, the Netherlands, 1991.

18 Friege, H. and Tötsch W., "Experten-Streit um PVC", in: *Kunststoff-Journal* March 1993. Hüls Publications.

19 Glenn, J. "Progress in plastics recycling", in: *Biocycle,* December 1990.

20 Glenn, J. "An industry shapes up for recycled plastics", in: *Biocycle,* January 1991.

21 Halbekath, J. "The hazards of recycling plastics", in *GATE*, No. 3, 1989.

22 Hegberg, B.A. *et al.*, *Mixed Plastics Recycling Technology.* Noyes Data Corporation, Park Ridge, NJ, USA, 1992.

23 ILO. *The Dilemma of the Informal Sector.* Report of the Director-General (Part 1), ILO, Switzerland, 1991.

24 Johnson, D. *The Future of Plastics: Applications and Markets Worldwide.* Financial Times Business Information Ltd, London, 1990.

25 Kirloskar Consultants. *Urbanisation, informal sector and employment. Technology adaptations in plastic processing industry in the informal sector: A case study in India.* World Employment Programme Research Working Paper. ILO, Geneva, 1985.

26 Konings, P. *Plastics reprocessing for Nairobi, Kenya. Including a low-cost workshop design, learning from a field-study in Istanbul, Turkey.* WASTE Consultants/Delft University of Technology, the Netherlands, 1989.

27 Konings, P. *Small-scale industrial reprocessing of plastics: A field-study in Istanbul, Turkey.* WASTE Consultants/Delft University of Technology, the Netherlands, 1989.

28 Mead D.C. *et al.*, *Baseline Surveys of Micro and Small Enterprises: An Overview.* Growth and Equity through Microenterprise Investments and Institutions (GEMINI) project, Bethesda, 1991.

29 Mewis, J. *Gevaarlijke stoffen. Monografieën leefmilieu nu.* De Nederlandse boekhandel, Antwerp/Amsterdam, 1983.

30 Morton-Jones, D.H. *Polymer Processing.* Chapman and Hall, London, 1989.

31 Mustafa, N. (ed) *Plastics Waste Management: Disposal, Recycling, and Reuse.* Marcel Dekker, New York, 1993.

32 Nagelhout, D. *et al.*, *Information document waste plastics.* Report no. 738902005. RIVM, Bilthoven, 1989.

33 Nijenhuis te, K. *Kunststoffen en hun verwerking en toepassing.* Working Paper, Delft University of Technology, The Netherlands, 1988.

34 Plastics Waste Management Institute. *Plastics waste: Disposal and recycling, past, present and future in Japan.* Second revised version, Tokyo, 1992.

35 Ptr Services. *A report on recycling of waste in city of Calcutta.* WAREN project, WASTE Consultants, the Netherlands, 1992.

36 Richert, W. *(Dood)lopende kringlopen. Juridische en technische belemmeringen bij de recycling van verpakkingsmaterialen.* Vereniging Milieudefensie, Amsterdam, 1993.

37 Saechtling, H. *International Plastics Handbook for the Technologist, Engineer and User,* 2nd edn. Hanser Publishers, Munich, 1987.

38 Schouten, A.E. and van der Vegt, A.K. *Plastics,* 9th edn. Delta Press BV, Amerongen, 1991.

39 Teszler, R. What are small enterprises? In: *Small enterprises, new approaches.* Proceedings of the Workshop on "Small Scale Enterprise Development: In Search of New Dutch Approaches", March 1989. Ministry of Foreign Affairs, The Hague, 1989.

40 Thomé-Kozmiensky, K.J. (ed.) *Recycling in Developing Countries*. EF-Verlag für Energie- und Umwelttechnik, Berlin, 1982.

41 TNO. *Emissiefactoren Kunststof- en rubberverwerkende industrie. Publikatiereeks Emissieregistratie Nr. 11.* Ministry of Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, The Hague, The Netherlands, 1993.

42 Undugu Society of Kenya. *Waste Recycling in Nairobi, Kenya.* WAREN project, WASTE Consultants, the Netherlands, 1991.

43 Vogler, J. *Work from Waste: Recycling Wastes to Create Employment.* Intermediate Technology Publications/Oxfam, UK, 1981.

44 Vogler, J. "Reclamation of derelict vehicles, scrap tinplate and used

plastics in developing countries", in: Thomé-Kozmiensky (ed.), *Recycling in Developing Countries*, 1982.

45 Vogler, J. *Small-scale Recycling of Plastics.* Intermediate Technology Publications, UK, 1984.

46 *Warmer Bulletin*, "Plastics recycling vindicated", No. 36, February 1993, p.12.

47 Warmer Fact Sheet, *Plastics recycling,* No. 32, February 1992.