

RUBBER WASTE
Options for Small-scale Resource Recovery
Urban Solid Waste Series 3

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WASTE

WASTE is a company for small-scale development projects in countries in the South. WASTE Consultants 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.

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

Ten major materials were identified: rubber, 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, skills, municipal waste management policies, and import regulations affecting recycling. These issues form the context within which resource recovery may form the basis of viable enterprises, and determine the extent to which recycling activities can be introduced in other cities.

A wealth of information was obtained from these six cities, 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 rubber 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 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 hundred individuals and organizations who provided us with addresses, ideas and supporting literature at the start of the project. This book could not have been written without the field research performed by 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 several months doing the painstaking work of visiting and interviewing micro-entrepreneurs, trying to obtain government documents and strolling over dumpsites in order to get a glimpse of what technically and commercially is being done by thousands of people in this informal field of work. We would also like to acknowledge the people in the recycling sector for describing their activities and sharing their experiences.

This publication made use of the research on rubber waste recovery in Naples, Italy and in the Netherlands carried out by Knud Sauer as partial fulfilment of his degree in Engineering from the Technical University of Delft, at the request of WASTE in 1990. During his field visits in Italy as well as in the Netherlands many photos were made of the processing techniques and products manufactured, which are also used 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 time to read the draft manuscript: Mounir Bushra Mina (solid waste expert, EQI, Cairo, Egypt) and last but surely not least Ben van Baarle (rubber waste expert TNO/KRI, Delft, the Netherlands) who made many useful comments and guided us through the complex terminology and processes of rubber recovery. Lex Hemelaar (environmental economist) introduced major revisions in the chapter dealing with the economics of rubber recovery. Anne-Lies Risseeuw (WASTE) took care of the first language corrections of the draft manuscript, K.J. Havelaar (chemical engineer) made the first technical corrections, while Anne Scheinberg made substantive additions and shaped and edited the text, to make it into a real book.

Finally, we would like to thank the Ministry of International Cooperation (DGIS) in the Netherlands for financing the research and this series of publications.

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INTRODUCTION

Since the publication of the famous book *Work from Waste* (Jon Vogler, 1981), there has been silence in the field of small-scale resource recovery, 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 certain economically less developed countries has increased at an impressive rate. These experiences deserve to be documented and disseminated to other interested parties.

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 work as a nuisance to modern urban life. Also small and micro-entrepreneurs who run small workshops producing such items as plastic pellets or rubber trolley wheels do often not get a license or are not legally connected to the electric grid. Nevertheless, municipal authorities and urban elites everywhere are facing mounting problems in dealing with the growing volumes of solid waste. Conventional approaches have included the purchase of high-tech equipment such as compaction vehicles, incinerators and computerized routing programmes, usually with little regard for its potential impacts. In particular, potentially valuable components of the waste are destroyed, resulting in the loss of means of survival for the vast numbers of people who work in the informal waste 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 technology, as well as its high maintenance costs and the need for skilled operators.

The atmosphere however, is changing, and attention is now focusing on finding ways of dealing with the problem of waste in low-income cities that do not depend only on high-tech equipment. 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 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 by providing the micro-entrepreneurs with scientific knowledge at no or low cost.

Innovation could also be stimulated through the exchange of information (knowledge and experience) between micro-entrepreneurs in various parts of the world: the so-called South-

South technology transfer. In the research on which this series of publications is based, many different options were identified that could be helpful to entrepreneurs elsewhere. For example:

- Glass blowers in Cairo produce bowls from used glass. Their products, however, often contain air bubbles causing breakages, in contact with a hot liquid. In Manila, micro-entrepreneurs found a solution by changing the design of the furnace and putting an additive into the glass: the bubbles disappeared and the glass became heat-resistant.
- Waste plastics are often smeared with sticky liquids and are mixed with organic matter. It makes the sorting of plastics a dirty job for the thousands of scavengers at road and dump sites in various cities. In India, this problem has been tackled by washing the waste plastics in a large concrete basin with water pumped by a small electric engine before sorting. The washed plastics are then dried in a rotating mesh drum and are spread out on the ground to dry in the sun. This approach has helped to improve working conditions considerably: the waste plastics to be sorted are almost clean.

Such 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 or the working conditions. Though these changes sometimes will result in higher costs, they will also result in increasing the monetary value of the waste products, and thus increase incomes and employment opportunities. This book therefore presents 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 documented in terms of micro-businesses. The experiences of individuals are passed on from parents to children and perhaps neighbouring entrepreneurs may benefit from innovations. But only rarely does information from Asia, for example, reach entrepreneurs in Sub-Saharan Africa. Documentation of this locally adapted recycling knowledge and experience could assist many entrepreneurs in other less industrialized countries either to set up or to improve their businesses. It could also demonstrate to decision makers that feasible opportunities exist for removing and recovering solid waste. Commercial formal enterprises do see the role such small recycling enterprises play: they buy their 'raw' materials or semi-manufactured products from them.

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

This book is the third in a series on Urban Solid Waste Recovery, and represents an attempt to document the experiences of small-scale recycling activities in cities around the world. The first book in this series was published in 1993 and dealt specifically with organic waste.

The topics to be covered in the on coming publications are: '*Hazardous Waste, Resource Recovery of Household Batteries, Photographic Materials and used motor oil: Existing Practices*' and "*Latrine Pit Emptying: Small-scale Options*. While the first three publications (Organic, Plastic and Rubber Waste) described the products made, the markets covered and the technologies used for recycling, '*Hazardous Practices*' will pay specific attention to the recovery and safe storage of hazardous waste materials. Handling such materials can affect the health of employees, and improper disposal may affect the surrounding environment. '*Latrine emptying*' will on the other hand pay attention to experience in low-income areas of several cities with the latrine emptying service offered by small entrepreneurs and their embedding in the municipal sanitation service. Since this latter publication is dealing with liquid waste, the name of the series will from then onwards change in '*Urban Waste Series*'.

The recovery of solid urban waste certainly has the potential to contribute to solutions of problems such as unemployment and insufficient waste removal. 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.

THE SCOPE OF THIS BOOK

The book is intended primarily for intermediate organizations who deal with communities in urban low-income areas and who seek opportunities either to create or to increase employment among their members. It is also intended for institutions that are concerned about the potential threat of solid waste to human health as one of the many environmental problems in fast-growing cities, and who try to promote solutions. Policy and decision-makers in government institutions or municipal departments may also benefit from the alternatives and experiences described here. Hopefully, it may convince them of the many benefits of supporting rather than ignoring the work of thousands of people and their organizations in their attempts to create employment opportunities and at the same time contribute to keep cities clean.

This book is not intended to provide a complete overview of all technical and economic options for rubber waste recovery; it is primarily based on the reports of the consultants involved in the WAREN project (see Preface). The research focused on the actual state of rubber waste recycling in small enterprises, which often operate within the informal sector. This enriches the publication because many examples are given, and at the same time it is limited because comparisons and generalizations are difficult to make. However, it is hoped that this publication will serve as a guideline to the basic principles of some small-scale and low-tech options available for the recovery of rubber waste.

The book shows ways how people earn their incomes from rubber waste recovery activities, which may encourage others to engage in similar small enterprises. At the same time, it acknowledges existing problems in environmental impacts and unhealthy working conditions, which need improvement through improved control strategies or the introduction of safer and cleaner production processes.

Chapter 1 gives a brief history of rubber, its applications in daily life and the importance of rubber recovery. Chapter 2 describes what rubber is. In order to understand the rubber waste recovery processes, basic information on the different types of rubber, including their characteristics and means of identification is provided. Also, an overview is given of the various rubber recovery. The various technical options for rubber waste recovery are described in the Chapters 3, 4 and 5. Chapter 3 deals specifically with re-use and hand processing, Chapter 4 with the physical recovery of rubber materials and Chapter 5 with the chemical and thermal recovery of rubber material.

Chapter 6 describes the informal context in which small enterprises can thrive, and presents some of the social actors who are actually involved in small waste recovery businesses. Chapter 7 describes the financial aspects of three small enterprises recovering rubber waste using different processes in three different cities. Chapter 8 presents a discussion of the major environmental effects of rubber recovery, and environmental and health aspects, and gives some guidelines as to how to improve working conditions. Some general conclusions and directions for future activity are offered in Chapter 9.

Appendix 1 lists the exchange rates, on which the cost calculations are based. Note, however, that the calculations in this book have been taken from real life situations and adapted. The

prices that are mentioned, are meant to give an indication only. They should be used with caution and seen as practical illustrations.

Appendix 2 offers a list of resource organizations; journals relating to rubber and rubber recovery are listed in Appendix 3. Appendix 4 lists the addresses of the consultants involved in the WAREN project. Other organizations and institutions which can provide additional information on process details, feasibility and equipment are listed in Appendix 5.. They may also be able to refer the reader to local project experience and experiments.

At the end of the book the reader will find a list of references and a glossary of the technical terms used. References are not generally cited in the text, in part because the information comes from many sources, and in part not to disturb the flow of the text.

CHAPTER 1 RUBBER AND RUBBER WASTE RECOVERY

1.1 Brief History of Rubber

India rubber, or caoutchouc, has been known in Europe since the discovery of South America. The first European who mentioned the elastic gum was Pietro Martire d'Anghiera (1457-1526), who, in his *De Orbe Novo* (published in Latin in 1513), describes an Aztec game played with balls 'made of the sap of a certain herb which being bounced upon the ground softly, rebounded incredibly into the air'. Other early references are contained in the work of Antonio de Herrera, historian to Philip II of Spain (1556-98), who told how Columbus, on his second voyage to the new world in 1493-96, saw balls 'made of the gum of a tree' being used by the Indians of Haiti.

The first mention of rubber being used for purposes other than sport told how the Indians, having gathered the milk from incisions made in special trees, brushed it onto their cloaks; also that they obtained crude footwear and bottles by coating earthen moulds and allowing them to dry. By the end of the 18th century the properties of rubber as obtained from the tree were known throughout Europe. The name was derived from the use of the material as an eraser to rub out lead pencil marks - hence the name 'India rubber'.

The greatest progress in the easy manipulation of rubber came at the beginning of the 19th century. Charles Macintosh (1766-1843) discovered that coal-tar naphtha was a cheap and effective solvent for rubber. This enabled the manufacture of double-textured waterproofed cloaks, which have henceforth been known in English as mackintoshes.

In 1839 Charles Goodyear discovered that by combining masticated rubber chemically with sulphur an irreversible process, that he called vulcanization. The discovery of vulcanization in 1850 meant that a whole range of rubber products became available.

Virtually all of the stages of manufacturing, including masticating, compounding, milling, vulcanizing and finishing, are the same today as they were in 1900, although the machinery has been continuously refined and improved. The greatest change in the rubber industry occurred in the early 20th century with the development of the first synthetic rubber called Buna and later synthetic butadiene rubber (SBR).

However, the economics of rubber production have undergone considerable change. This industry has always been at the mercy of rapid and drastic changes, both in the cost of raw rubber and the prices of finished goods. Since 1920, demand for rubber manufacturing has been largely dependent on the automobile industry, the biggest consumer of rubber products. At present, natural rubber is commercially produced in Indonesia, Thailand, Malaysia, Brazil, and in some African countries like Nigeria and Ivory Coast.

1.2 Rubber in Everyday Life

In industrialized countries, rubber products are everywhere to be found, though few people recognize rubber in all of its applications. Rubber is used in radio and T.V sets and in telephones. Electric wires are made safe by rubber insulation. Rubber forms a part of many mechanical devices in the kitchen. It helps to exclude draughts and to insulate against noise. Sofas and chairs may be upholstered with foam rubber cushions, and beds may have natural rubber pillows and mattresses. Clothing and footwear may contain rubber: e.g. elasticised threads in undergarments or shoe soles. Most sports equipment, virtually all balls, and many mechanical toys contain rubber in some or all of their parts. Still other applications have been developed due to special properties of certain types of synthetic rubber, and there are now more than 100,000 types of articles in which rubber is used as a raw material.

The applications of rubber fall into a number of broad categories, described briefly below.

1. Automotive industry

It is the automobile industry which accounts for the largest consumption of rubber, 65% being used for tyres alone. Quantitatively, tyres are the most important use of rubber. The variety and importance of automobile accessories made of rubber continue to increase. In a modern car it is possible to find a whole variety of rubber parts, such as vibration dampers, rubber V-belts, hoses, hydraulic packing rings, and O-rings.

2. Building

The second important application is in building and civil engineering. Civil engineering applications include use in bridge bearings and as flexible parts in flyovers, as well as the inflatable parts of dams. In roads, rubber acts as a modifier of bitumen in asphalt pavements. In railways, rubber bearing parts are used for insertion in between sleepers and in metro's as sound vibration dampers, damping vibrations from air-conditioning equipment, and, through use in furnishings such as floor mats. It may add to safety as in the use of rubber in foundations against earthquakes. Rubber offers interesting and varied possibilities in building, including the manufacture of flooring, flooring tiles, roofing materials, sealing strip for prefabricated units and window sealing strips as well as the better known uses in electrical equipment, pipes, tiles, and the manufacture of mats.

3. Industry

Industrial application in the form of conveyor and vibration dampers follow in order of importance. A myriad of factory wheels turn efficiently because rubber both grips and gives. Conveyor belts, an essential ingredient of almost any manufacturing process imaginable, carry heavy burdens, shifting tens of thousands of tons of minerals without tearing, or carefully guarding soft and fragile items pouring from the machines. Special types of rubbers are used in chemical processes, since rubber remains unaffected by liquids or heat. It seems unnecessary to stress the increasing part played by rubber in the toy and sports equipment industries. Similarly, there have been considerable developments in the use of rubber in industrial equipment: conveyor belting, transmission belting, hoses, joints, flexible couplings, vibration dampers for machines, corrosion resistant coatings etc. The rubber insulation of cables and wires, however, is being increasingly supplanted by plastic (PVC).

4. Agriculture

In agriculture, the principal outlet for rubber is in the form of tyres for the various types of vehicles. Apart from this application, rubber can also be used for various other purposes, including the equipment of livestock sheds; the manufacture of harness, collars, horse-shoes, and rubber saddles; milking machine hoses; and protective covers for potato lifting machines, to list only a few.

5. Clothing

In the field of clothing, the most important applications for rubber are in the footwear industry and in rubberised textiles, rubber thread in underwear, and artificial leather.

6. Latex goods

Various latex rubber articles are also used in medicine and surgery, such as draw sheets, gloves, finger stalls, teats, and hot water bottles.

1.2.1 Rubber Applications in Less-Industrialized Countries

Even in countries where the economy has not reached the level of industrial development in the Northern countries, there are still an abundance of rubber articles used in everyday life. A number of these consist of the types of articles made and applied in the developed countries which have been described above. In the less industrialized countries, however, additional options and applications have been developed in the informal, small-scale and micro-enterprises: the waste recycling industry. There, rubber from used tyres and tubes is used to make shoes, bushings, washers, gaskets, wheels, straps and harness, containers, and a wide range of products for domestic, commercial and industrial use.

1.3 Rubber Waste Recovery

The use of rubber in so many applications results in a growing volume of rubber waste. With the increase in demand of automobiles, the manufacturing and use of tyres has increased tremendously both in the developed and less developed countries. Since at least 65% of worldwide rubber production, and likely an even higher percentage of rubber disposal consists of automobile and lorry tyres, this publication has chosen to focus on rubber waste from tyres and tubes, with occasional references to the recovery and re-use of conveyor belts.

After finishing their working life, tyres wear out and have to be discarded and replaced. It is estimated that throughout the developed world an average of one used tyre per person per year is discarded. Used tyres are a challenging problem, since tyres have a virtually unlimited life span. These waste tyres are source of environmental concern in developed countries, where landfilling is still a common waste disposal strategy. Tyres decompose very slowly, at taking over a century to disintegrate at ambient temperatures. They are also bulky and when disposed of they trap air, which may make landfills unstable. Even worse, tyres do not stay buried, but float to the top of a landfill. Piled tyres trap water, and thus can become breeding grounds for mosquitoes and other water-incubating insects and bacteria.

Box 1.1. Waste Tyres in the United States

About 242 million tyres are discarded every year in the United States alone. Less than 7 percent are recycled. 11 percent are incinerated for their fuel value and another 5 percent are exported. The remaining 78 percent are either landfilled, or are illegally dumped. According to a recent report of the US Environmental Protection Agency (U.S EPA), this has resulted in a national stockpile of over 2 billion waste tyres.

Source: Biocycle April 1992

Almost all industrialized countries face similar problems with the growing number of discarded tyres. Furthermore, the recovery of rubber from waste tyres is declining in many developed countries, due to both economic and technological factors. For example, the decreasing natural rubber content in passenger car tyres, combined with increasing reliance on synthetic rubber and the construction of radial tyres, restricts the economic viability of rubber recovery from automobile tyres. Lorry (truck) tyres, which are larger and contain a much higher percentage of natural rubber, can be viably recovered, either through retreading or through the production of rubber granulate for other applications, but demand for the resulting products is weak due to the availability of synthetic materials at attractive prices.

1.3.1 Rubber Waste as a Resource

Rubber waste is present in low percentages by weight in urban waste streams in both industrialized and in less-industrialized countries. For example in Karachi, Pakistan, as well as in the Netherlands, the percentage is below 1%, and usually consists of small waste products from households. The major part of the rubber waste is usually collected separately, directly from generators such as petrol stations, garages and junkyards, and consists of a limited number of items and materials. In the Netherlands tyres, conveyor belts and tubes generally make up more than 70% of this waste.

There is only limited data on the specific composition of rubber waste. The following production data for rubber products gives an idea which products dominate. This in turn can serve as a proxy for waste composition. It can be inferred that tyres, in particular, have at least as prominent position in the waste stream as they do in production.

Table 1.1 shows that tyres, tubes, and conveyor belts, taken together, make up about 72% of all production. Assuming approximately the same representation in the waste stream, these materials then should represent important sources for the reuse of rubber waste. Furthermore, generation of these materials is regular and predictable, making the set-up of collection systems to feed recycling activities a relatively simple project.

As a resource, rubber tyres are somewhat problematic. One of the problems is the great variety of rubber compounds in use. Different products call for different properties, and rubber as a raw material is blended or compounded with other materials, including synthetic polymers, to meet the needs of different users. One rubber factory may produce as many as 500 different products of different composition. Furthermore in tyre production, compounded rubber is layered with other materials. Tyres normally are confectioned with metal and textile layers for reinforcement. Thus even when the rubber compounds are uniform, they are not readily recoverable, due to the presence of these other materials.

Table 1.1. Distribution of Rubber Production by Product Group

glue	3.2
hoses & pipes	3.5
conveyor belts	4.3
tyres	66.6
tubes	1.0
mouldings	3.6
shoe soles	0.7
profiles	2.6
washers, gaskets	1.2
various products	13.3

Source: CBS 1993

1.3.2 Rubber Waste Recycling in Industrialized Countries

Because tyres represent both a problematic and highly visible component of the total waste stream in developed countries, much attention in recent years has been directed to developing tyre recycling strategies.

In the Province of Ontario, Canada, a task force set up by the Ministry of Environment analyzed current practices and processing technologies in various industrialized countries. In the resulting report, the following hierarchy of the most environmentally acceptable management options for used tyres was established:

- 1 Reduction. The used tyre generation rate can be reduced by technological developments that improve the service life of tyres and by programmes that encourage a decrease in car use.
- 2 Reuse as tyres. Suitable used tyres can be processed as casings for retreading. (This is sometimes facilitated by early retiring of tyres, which contrasts with point (a).)
- 3 Reuse of whole tyres. Examples of this application are: artificial reefs, erosion control, stabilizing mine tailing ponds and deep wells.
- 4 Recyclable into other products: This can take two forms: cutting scrap tyres into suitable shapes and assembling them into new products (such as blasting and floor mats, muffler hangers etc.) or by grinding the tyres into crumb and using it in asphalt mix or rubber/plastic compounds for a wide variety of moulded or die cut products.
- 5 Tyre chips in civil engineering projects. This includes road beds, the core of earthen embankments, septic tank drainage field and as composting bulking agent.
- 6 Recovery of the raw materials in tyres. The materials that are used to manufacture tyres, consist primarily of natural rubber; synthetic rubber (which is processed from petroleum); carbon black; fabric and textiles; and steel wire. These materials can be recovered can be used to make new products.

- 7 Process into tyre-derived fuel. Incineration of tyres limits them to a single life (once burned, the material is no longer available for second-level recovery), but it has the advantage of recovering their fuel value, which is high.
- 8 Shred and landfill in monofills. This is a disposal strategy which is designed to eliminate many of the problems involved in landfilling tyres mixed with municipal solid wastes. If at some future time the tyre chips become a valuable resource, the monofill can be mined.

Also in 1990 the European Union Council of Environment Ministers backed the European Commission's waste management strategy, agreeing to focus on products as well as on production processes. The main aim is to create a sustainable 'cradle to grave' life cycle management strategy for each of the products, beginning with design, and covering raw material extraction, production, usage, and ending with disposal or reuse.

1.3.3 Rubber Waste Production in Less-Industrialized Countries

In economically less developed countries, the majority of rubber waste consists of car, lorry and tractor tyres. Depending on their location and ecology, less-industrialized countries production of natural and/or synthetic rubber varies greatly. India, for example, is an important producer of natural rubber, while most African countries have only production from secondary rubber.

In contrast to developed countries, few developing countries have characterized tyre disposal as either a nuisance or an environmental problem. Tyre recovery or recycling in these countries is seldom even listed among policy goals, and is virtually never a policy priority. This is partly because of the relatively small quantities of rubber in the waste stream, and partly because the rubber there is normally diverted from disposal earlier, through scavenging or purchasing.

Table 1.2 presents estimates of the quantity of rubber waste produced in various cities:

Table 1.2 Percent by Weight of Rubber Waste in Urban Domestic Solid Waste in Developing Countries

Accra	rubber & leather	1-5%	3) 5)
Bamako	rubber	0%	3)
Cairo	rubber tyres	estimated 1%	3)
Calcutta city	rubber	0.24% = 5.4 tonne per day	3)
Dar es Salaam	plastic & rubber	1.8% wet weight = 10 tonne	2)
Jakarta	leather & rubber	0.56%	4)
Karachi	leather & rubber	2.1%	6)
Kanpur	plastic & rubber	0.5%	2) 1% 4)
Lagos	plastic & rubber	4%	1)
Metro Manila	leather & rubber	1.8%	4)

Sources (see References for full citation):

- 1) Cointreau 1982
- 2) Haskoning 1985, 1988
- 3) PTR Consultants, GERAD, EQI (WAREN research)
- 4) UNCHS workshop Manila 1993
- 5) GOPA consultants 1983/1990
- 6) Shakaib (KMC) 1991

This does not mean, however, that rubber recovery does not exist. Post-industrial rubber waste from rubber production is recovered and directly added as a granulate to rubber compounds, and is not even counted as having been generated. In garages, used tyres with good casings are retreaded to be reused or retreaded, while completely used tyres may be recycled for secondary use. Used tyres are usually collected by waste buyers long before they reach the municipal collection service and are seldom to be found in domestic waste.

Tyre repair, recycling, and recovery operations in developing countries tend to be considered commercial enterprises, and have little connection with the sanitation or public works aspects of municipal government activities. These enterprises may vary from tiny tyre repair or small production micro-enterprises of five people or less, to larger retreaders with regular employees and a formal place of business.

Rubber recovery is somewhat less likely to occur in the context of family- or community-oriented individual activities than other types of waste scavenging, processing, and recovery. Tyres are generally considered to be too valuable a resource to end up in the waste stream, and their recovery is considered a specialized (men's) business, rather than a casual activity or a public service. Tyre scavenging from garages, residential areas and roadsides does take place in some developing countries. In general, then, it is the informal enterprise section of the informal sector that is most likely to be involved in tyre recovery in developing countries.

Box 1.1: Tyre Recovery In Developing Countries

In Karachi, Pakistan, old tyres are cut into parts by skilled workers to obtain workable secondary materials. First the beads are removed. To recover the steel wires the remaining rubber is burnt. Then the tread and side walls are separated. The treads are cut into strips and used to cover wheels of donkey carts. Sidewalls are cut into products such as shoe soles, slippers or washers. Tyres with steel reinforcements are more difficult to cut and are therefore less usable. Several types of knives are used which need to be sharpened regularly because of the toughness of rubber.

In Cairo, most recovered rubber comes from automobile tubes, which are valued for their pliable and elastic properties. About 1% of waste tyres in Cairo are retreaded, remoulded, or directly used in secondary manufacture of new products. Nylon cord beaded tyres are recycled by removing the nylon cords, which are then used for baling various materials, including waste paper. The recovered rubber can be shaped into semi-final and final products such as gaskets, small swivel wheels for office chairs and tables, and briefcase handles. There are certain cases, however, where tyres or tyre covers are directly used to line the wheels of the animal-drawn carts used by waste collectors. Tyres can also be split into layers, in a longitudinal or radial manner, for direct use in the manual production of certain rubber products including sandals, gaskets, pieces of conveyer belts, stool seats, carrier straps, bed springs, and door mats. Tyres are also burned for a number of reasons, both as a means to obtain the steel wires, which are then used for binding paper bales, and for the calorific value of the rubber for asphalt melting vehicles.

Source: WAREN Report, Karachi, Pakistan and Cairo, Egypt.

1.4 The Importance of Recovery of Rubber Waste

Resource recovery in economically less developed countries is managed predominantly by informal sector entrepreneurs and is a major source of employment in this sector. For many people, working in the informal 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 viable businesses that generate reasonable or even high profits.

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 service 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 needs 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 material input needed in production processes. The retreading of tyres or the use of the material of rubber tyres for shoe soles may reduce the need for import or the production of new products or raw materials, and thus may reduce the need for foreign exchange. 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 aliphatic hydrocarbons, into the atmosphere.

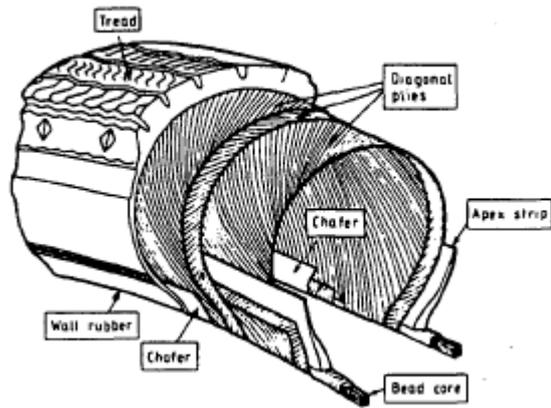


Figure 1. Diagonal ply tyre (four-ply construction), tubed

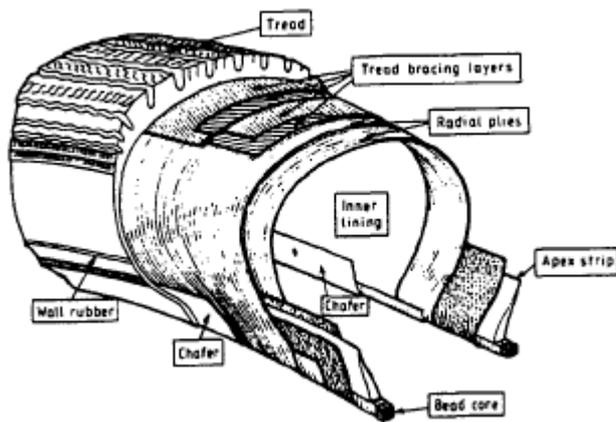


Figure 2: Radial ply tyre (two-ply construction), tubeless

CHAPTER 2 A BASIC UNDERSTANDING OF RUBBER

2.1 What is Rubber?

Natural rubber (NR) is made from the substance known as caoutchouc or latex, a milk-like fluid that is obtained from the sap of the rubber tree, officially called *Hevea Brasiliensis*. The bark of this tree is incised, allowing the latex to drip into a small cup fixed to the tree trunk. At plantation, the preferred method of recovering the caoutchouc is by acid coagulation. The coagulation is washed, milled and dried. Natural rubber is built up by naturally occurring monomers (long chains of molecules) and its chemical name is polyisoprene.

Synthetic rubbers are made from (mineral) oil. The term 'synthetic rubber' is used to describe an increasing number of elastic materials, ranging from some closely resembling natural rubber to others with completely different physical properties.

Various types of synthetic rubber can be produced by means of polymerization processes from mineral oil, such as styrene-butadiene-rubber (SBR), ethylene-propylene (EP), nitrile (NBR) and butyl rubbers (IIR). The properties of these types of rubbers may differ considerably from natural rubber and among themselves.

Table 2.1. Identifying Characteristics of Various Types of Rubber

Characteristics	Natural Rubber	SBR	Butyl	Nitril
Drips when exposed to flame			XXX	
Crackles when exposed to flame				XXX
Strong tendency to extinguish flame				
Sticky combustion surface	XXX		XXX	
Dry combustion surface		XXX		XXX
Hot flame	XXX	XXX		XXX
Quiet flame			XXX	
Weak soot (production)			XXX	
Strong soot (production)	XXX	XXX		XXX

Source: Baarle, van.

2.2 Properties of Rubber

The principle properties of rubber lie in their chemical structure. Its physical properties depend on compounding. In its clean natural state, it is greatly affected by temperature, becoming harder when cooled (at 0-10 °C). It is opaque and softer when heated (above 50 °C), and at higher temperatures becomes tackier and less elastic, liquifying at 190-200 °C.

Natural rubber has very good mechanical properties, i.e. tensile strength and elongation, elasticity and resilience (and hence low hysteresis and heat built up), and good resistance to tearing, flexing and abrasion. For these reasons, natural rubber is an excellent material with versatile mechanical properties. Rubber can stretch to several hundred percent of its length, and when the stress is removed, the elongation turns to zero within a few seconds. The term rubber is used to cover raw material, unvulcanized compounds and vulcanized products.

In terms of its limitations, rubber is seriously affected by the swelling action of such liquids as petrol, aliphatic and aromatic solvents and (lubricating) oils; it is not very resistant to oxidation and ozone cracking, and does not perform well at high temperatures. Natural rubber exhibits a tensile strength of 250-350 kg/cm² (= 25-35 MPa = Mega Pascal) and a modulus of elasticity of 10-30 kg/cm² (1-3 MPa) at 300% elongation (when compounded with 25% carbon black, the modulus can increase to 50-100 kg/cm² (5-10 MPa)). Rubber is impermeable to water and to a large degree to gases. An important consequence of the unique stress/strain resisting properties of rubber is its ability to store enormous amounts of energy and to release most of this energy on retraction.

Generally, rubber is a very poor conductor of heat, and is thus an excellent heat insulator. The coefficient of thermal expansion of rubber is much higher than for metals. It is about 20 times that of steel. This difference becomes serious for low-temperature applications. Rubber is normally an excellent electrical insulator, hence its extensive use in insulating cables, and other electrical materials. On the other hand, the incorporation of certain types of finely divided carbon black often makes it sufficiently conductive to dissipate static electric charges, or even to behave as a conductor.

Most types of rubber have the property of absorbing varying quantities of such liquids as petrol, benzene, chloroform, carbon tetrachloride, ether, mineral lubricating oils, and other hydrocarbon liquids. This so-called 'swelling' and the accompanying loss of mechanical strength make it difficult or impracticable to use these types of rubber where contact with such liquids is involved.

Rubber has a very high coefficient of friction, and hence unique gripping properties. These properties are highly valued in many engineering applications. Another important characteristic of rubber is that its friction is greatly reduced when wetted with water; thus, water acts as a lubricant for rubber.

Rubber, like many other organic materials, undergoes an ageing process with the passage of time. With rubber, the results of the ageing process include the loss of strength, extensibility and other mechanical properties. Even the minute amount of ozone in ordinary outdoor air (about one part in 100 million) can produce minor cracking if the rubber is not specially developed to resist this effect.

2.3 Production of Rubber Products

Virgin rubber, both natural and synthetic, must be extensively processed before it is fit for use. The rubber (polymer) must undergo several processes, including mixing, shaping and (usually) vulcanizing, to achieve the desired properties. The usual components and additives are selected according to technical as well as economic considerations. While the technical considerations for products which have to meet severe mechanical specifications such as car tyres, conveyor belts, highly elastic mounts etc. are of highest importance. During mixing and compounding, various components are mixed to obtain a homogeneous compound. Some of these components are:

- polymers;
- activators;
- fillers (carbon black);
- anti-degradants;
- plasticizers;
- accelerators;
- vulcanization agents;
- other materials including processing aids, fire retardants, colorants and blowing agents to improve particular properties of the rubber product.

The addition of all of these components means that the compounding and vulcanization process adds much of the value of finished rubber, making the finished product much more valuable than the virgin rubber. The basic steps in rubber production are briefly described below.

2.3.1 *Mixing*

The quality of the final product is largely depending on the mixing or compounding process. In the first step, all components except the vulcanization agents are mixed. In the second step, the vulcanisation materials, among them sulphur, are mixed in the compound on a two roll mill, later on the compound is shaped and vulcanized under pressure at about 150 °C.

The preparation of the compound, which formerly was done on two roll mills, is today accomplished in internal mixers. With modern equipment the emissions can be controlled through the use of closed systems.

2.3.2 *Moulding*

After the specified compound has been mixed, the moulding can begin. This process includes:

- Calendering, to obtain a sheet of rubber of uniform thickness
- Extrusion, to shape compounds into products, such as tubes, profiles and hoses, in a continuous process
- Pressure moulding, whereby rubber sheets are placed in a mould and are moulded and vulcanized at the same time under high pressure and temperature
- Injection moulding, a combination of extrusion and pressure moulding

2.3.3 Vulcanization

During vulcanization - the third step in rubber processing - the rubber is heated under pressure for some time. Vulcanization is the conversion of rubber molecules into a network by the formation of cross links. Vulcanizing agents are necessary for this cross linking. During the irreversible process of vulcanization, the rubber compound changes from the thermoplastic to the elastic state. Two types of vulcanization methods exist:

- Pressure vulcanisation: a batch (non-continuous) method in which the product is moulded under simultaneous pressing and heating. The heat is transferred through the metal of the mould. This is the most frequently used non-continuous (batch) method.
- Free vulcanization: this continuous method is usually used for large and/or endless products shaped by the extrusion process (for example, conveyor belts and water hoses), when 'pressure vulcanisation' is not possible. Hot air, steam, 'salt baths' or occasionally microwave systems are used for this method.

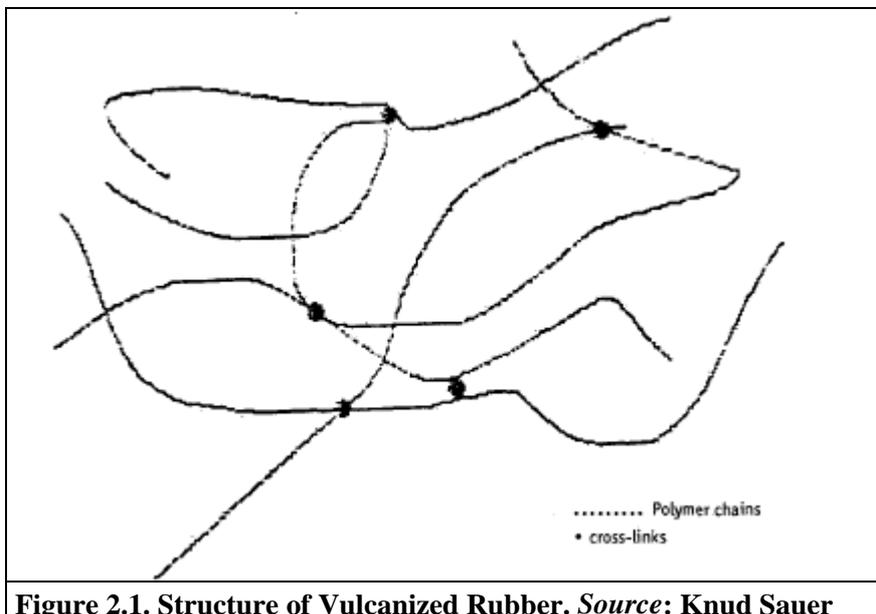


Figure 2.1. Structure of Vulcanized Rubber. Source: Knud Sauer

2.4 Use of Natural and Synthetic Rubber in Tyres

Synthetic rubber (SR) used in the tyre manufacturing industry are: styrene butadien rubber (SBR) and butadine rubber (BR). Natural rubber (NR) is predominantly used for commercial vehicles such as lorries (trucks), busses, and trailers. SBR is mainly used for small lorries, private cars, bicycles and motor bikes. Butyl (IIR) is used for tubes, since it is gas-impermeable.

The composition of tyres differs depending on their use. Also the various tyre parts differ in composition. Typical composition of tyre treads is given in table 2.1.

Table 2.2 Comparison of Commercial Vehicle and Passenger Vehicle Tyre Tread Composition

truck tyre tread (in %)		passenger vehicle tyre tread (in %)
mineral oil	13	20-24
carbon black	30	33-37
rubber	52	40-45
natural rubber	65	25
BR & SBR	35	75

Source: Information Document on Used Tyres, Final Draft, December 1991.

Since tyre treads differ in their composition, old tyres (which have no tread left) differ in composition from new tyres. Table 2.2 compares the composition of old and new tyres.

Depending on their size and application, tyres vary in design and construction and total weight. Approximately 80% of the weight of car tyres and 75% of truck tyres is rubber compound. Table 2.2 shows that the proportion of reinforcing materials used does not vary much for each of the various types. Some approximate tyre weights are given in Table 2.3.

Table 2.3: Average Composition in Percent of New & Used Passenger Car and Truck Tyres

Tyre	Car		Truck	
	New	Used	New	Used
Materials				
Rubber Hydrocarbon	48	47	45	43
Carbon black	22	21.5	22	21
Steel	15	16.5	25	27
Textile	5	5.5	-	-
Zinc oxide	1.2	1	2 - 2.2	2
Sulphur	1	1	1	1
Other chemicals/oil	8	7.5	6	6

Source: BLIC

Table 2.4. Approximate New Tyre Weight

Type	Size	Weight (kg)
Car	165 - 13	7
Car / Van	175 - 15 / 700 - 14	8 - 10
Light truck	205 R 16	16 - 20
Truck	1100 / 20	55 - 70
Truck	1200 / 20	70 - 80

Source: BLIC

In general, truck tyres are mainly made of natural rubber (NR), whereas car tyres are mainly made of styrene butadiene rubber (SBR). However in practice all tyres are based on a combination of NR, SBR and BR; the combination depends on the specific application e.g. dynamic behaviour (heat build-up), rolling resistance and wear resistance. The composition of used tyres may therefore vary.

Box 2.1 Types of Tyres

There are two types of tyres, diagonal or bias ply tyres, and radial tyres. **Diagonal or bias ply tyres** Figure 2.1.1 are manufactured using an abrasion-resistant tread compound, a sidewall compound capable of withstanding dynamic loads, and a casing, made of textile cord and bead wire. The casing ensures a proper fit at the heel of the tyre, seals to the rim and serves as a lower fastening for the casing.

The casing for passenger cars consists of two to four layers; truck and commercial vehicles, depending on size, may have six to ten layers. The layers alternate the direction of fibre bias: hence the name diagonal, or bias ply.

The radial tyre, introduced by Michelin in 1984, is shown in Figure 2.1.2. Radial tyres are constructed of at least four layers of two textile belts and two steel belts under the tread. Truck and commercial vehicle tyres may have three to five layers. These belts are located at the shoulder of the tyre, and serve to stabilize the tread. As the tyre is correspondingly stiffer than a bias ply tyre, the sidewalls must be made softer, and are made of a sidewall compound which is compounded to protect against flexing and aging. Under the sidewall are one to three layers of casing wrapped around the bead wire, with the cord fibres laid at 90 degrees angle to the beads. The tread is applied to the belt. Radial tyres require hard, abrasion-resistant rubber compounds or suitable textiles.

Source: Information Document on Used Tyres, Final Draft, December 1991, pp 7-9.

CHAPTER 3 RE-USE AND HAND PROCESSING OF RUBBER PRODUCTS

This chapter covers a variety of approaches to rubber recovery through reuse. These approaches are organized according to the idea of a “recovery hierarchy.” The relationship of this hierarchy to the concept of value added is discussed in section 3.1.

The first approach to reuse of rubber products is the repair and reuse of rubber products, specifically tyres, tubes, and conveyor belts, in their original forms. Secondary reuse is “partial” or “hybrid” reuse, where a product or its constituent materials are partially broken down or disassembled and form secondary materials for the manufacture of other products, which may or may not have any recognisable relation to the original product.

Table 3.1. Principal Rubber Recycling Processes and Products.

kind of recovery		recovery process
product re-use	-repair	-retreading: + unvulcanized, direct and smooth tread extrusion, pattern cutting, prevulcanized tread replacement -regrooving: + pattern cutting -vulcanization
	-physical reuse	-use as weight -use of form -use of properties -use of volume
material re-use	-physical	-tearing apart -cutting: + by hand, splitting, die cutting -processing to crumb: + mechanical, swelling & mechanical, cryogenic
	-chemical	-reclamation: + reclamator, digester, pan, mechanical, high temperature
	-thermal	-pyrolysis -hydrogenation -combustion
energy reuse		-incineration: + cyclone & fluidized bed combustion, direct kiln burning, starved air incineration, water tube boilers

Source, Baarle, van

The rubber product classes covered in this chapter are rubber tyres and tubes, and conveyor belts. Reuse of tyres includes regrooving and retreading. Other secondary uses of tyres and tubes are also discussed. Reuse of conveyor belts involves repair and remanufacture; this is normally carried out by specialized companies in industrialized areas. Conveyor belts nearly always serve secondary functions before being discarded. At the end of their service life all products become waste.

3.1 Rubber Recovery and Value Added

This paragraph provides some economic context for the discussion of the various options for rubber recovery in developing countries. Rubber recovery, in all of its forms, falls under the general heading of materials recovery. Here, as in other aspects of resource reclamation, there is a hierarchy of recovery activities. One key to understanding this hierarchy is the concept of value added.

In the raw materials process, latex is extracted from rubber trees. Although latex has a value, this value is low per volume of latex: The true value is created by putting the raw material through a number of processing steps. These steps usually begin with refining the material, then making it into an industrial feedstock, then using it as input to an industrial process, followed by finishing and packing. Finally, through marketing, the market value of the material is realized when it is bought in its final form. The difference between this market value (selling price) and the original value (cost price) of the sap of the rubber tree, on a weight or volume basis, is called value added.

A finished product such as a tyre, therefore, has accumulated a great deal of value added through its manufacturing steps. The value added consists of materials, energy and water applied or added during the process, combined with the accumulated value of the technology, or technical information, used to produce the final product.

Since the value added is a large part of the value of the tyre, it contributes to the price that can be charged for products and materials made from whole or processed waste tyres. In general, the more value added that is retained, and other aspects of the market such as demand for the product being equal, the closer the price of the recycled product can be to the price of the original.

When the tyre is reused or repaired to be used again as a tyre, virtually all of the value added that went into its manufacture is retained. When a tyre is regrooved or retreaded, all of the value added that went into design and manufacture of the casing is retained, while the value added that went into the tread must be reapplied through the process.

When rubber tyres are cut up and used for secondary applications, such as harness or shoe soles, the retained value added is much less. In fact, the value added in manufacturing the tyre is lost, but the value added in manufacturing the rubber is retained. When rubber is reduced to crumb or reclaim, it is only the value added of the physical composition or compound that is retained.

Value added also has a meaning in terms of sustainability and sustainable development. Value added generally is a reasonable proxy for the amount of energy and materials that have gone into a product, and therefore the amount of environmental impact that has been created in its production. When value added is retained, additional environmental impact is avoided, representing real gains for the environment, as long as the steps involved in recovery do not result in yet more use of energy or materials.

Finally, while the initial manufacturing steps often produce value at a high energy and materials intensity (and thus a high cost to the environment as well), reclamation activities usually derive most of their value added from labour. In developing countries the abundance of inexpensive labour, together with the high cost and relative scarcity of energy and materials, makes reclamation activities a good match with the local circumstances.

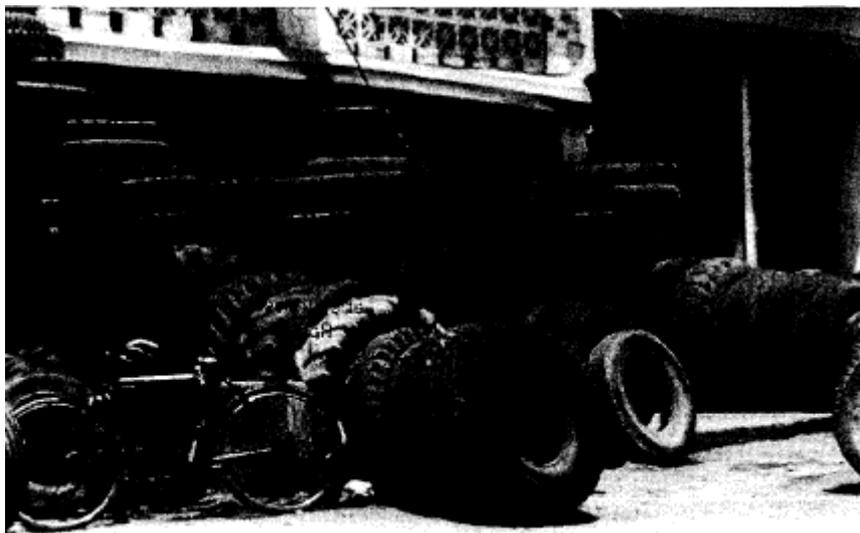


Figure 3.1. Tyre Wholesaler in Pakistan Selling used Tyres for RS5-30.
Photo: PCSIR



Figure 3.2. The Value of the Resulting Products will be Rs15-50.
Source: PCSIR.

Seen in this context, informal rubber recycling activities have both economic and environmental benefits. Because of the small scale of their work and the need to “make something from nothing”, informal sector recyclers, both individuals and entrepreneurs, usually retain the maximum value added possible.

Box 3.1. Rubber Recycling in Cairo: Levels of Value Added.

Virtually all levels of recovery, from repair through to secondary manufacturing, occur in Cairo, which also consumes 25% of all tyres used in Egypt. Primary collection is done by garbage collectors, pedlars, and scavengers, who sort the rubber into tyres and tubes, and sell it to specialised dealers.

Rubber tyres that cannot be repaired are retreaded by one of two companies (one of these is a public company which only retreads for its own use). Rubber tyres may also be exported or recycled for their steel bands or nylon cords. Certain small entrepreneurs also cut tyres into parts for use as a rubber raw material for new products, or produce crumb rubber for use in recompounding as a polymeric filler in compounds. The recycled rubber is moulded to form new products, such as wheelchair wheels, rulers, gaskets, shoe soles, bicycle pedals, and automotive parts.

About 50 small enterprises in Cairo use tubes as the basis for secondary manufacturing, and 90% of the tubes generated are recycled, either through cutting or remoulding. Processing by cutting produces strips for textile weaving or elastic for clothing manufacture. In remoulding, the two millimetre thick tube walls are directly remoulded into new products using a hydraulic press and flat dies, called “platters.” The resulting products are priced at 30% to 50% of the price of corresponding products made from virgin materials.

Source: EQI, 1991

3.2 Tyre and Tube Repair

Repair of tyres and/or tubes for continued use in their original form and function retains the most value added. Technically, tyres are products that can be repaired and remanufactured with relative ease. Remanufacturing in the form of retreading was a widespread activity in developed countries until the availability of inexpensive new synthetic rubber tyres made it less economically feasible¹. Tubes are repaired, but other methods of reuse are difficult to find in the nations of the North.

The functional life of automobile tyres depends on primarily on four factors: the quality of the tyre itself; the quality of the roads it is used on; the conditions it is used in, including tyre pressure, the weather, speed, and the like; and the loads it must carry. Excessive wear and tear can occur through overloading of vehicles and during movement on (unpaved or) poorly maintained rural roads and tracks.

Certain aspects of tyre wear, such as punctures, can be repaired relatively successfully. Patching, for example, means that the tyre itself can serve its function for a longer time. The other two types of tyre reuse, regrooving and retreading, are forms of remanufacture, rather than being “true” repair.

3.2.1 Tyre Repair Methods

Two methods are used for repairing tyres: the cold method and the hot method.

i Cold Method

The edge of the hole is smoothed and a special cement is added. Prefabricated rubber is put in the hole and glued to the tyre. This method can only be used for small punctures or rents. The only equipment needed for the cold method is a rasp or other smoothing tool and mixer and applicator for the cement.

ii Hot Method

For the hot method, the edge of the hole is made smoother and uncured rubber is placed over it. The uncured rubber is then cured on the tyre using a small electrically heated press. In some countries coal heated presses are also used. The equipment needed for the hot method includes rasping equipment to smooth the damaged area, and a small electric or coal-heated vulcanisation press.

In the Netherlands, the hot method is used almost exclusively for the repair of truck tyres. As a comparison the hot method costs US \$33, compared to the lower cost (US\$10) of the cold method. In Italy, the hot method is also used for small tyres, perhaps because the lower cost of labour makes it less costly as an option.

Box 3.2. Integrated Recovery in Naples, Italy

Economic feasibility of retreading in developed countries varies widely. In the US, retreading, except for truck tires, is marginal, while in the Netherlands 28% of waste tires are retreaded (VROM/VACO 1993).

The area in and around Naples, Italy, gives a good idea of the interrelation between various levels of recovery. Small micro-enterprises called the *gomnisti* work in small workshops, and provide a range of tyres for a range of prices:

- used tyres with profile or repaired tyres: IL 8,000-15,000
- regrooved tyres: IL 15,000-20,000
- retreaded tyres: IL 30,000-40,000
- new tyres: IL 60,000

Source: Sauer, 1990

3.2.2 Tube Repair

Tyres provided with tubes tend to have a longer life-span than tubeless tyres. Due to poor road conditions and the presence of pins, thorns, nails, glass and metal, tyres are easily damaged, and the inner tubes receive frequent punctures. The punctures in these tubes are repaired according to the hot method described above. Similar, manual procedures using simple, locally fabricated and/or imported machines are used in almost all developing countries.

Box 3.3: Puncture Shops in Karachi, Pakistan

In Karachi, Pakistan, tyre puncture shops are located at almost every gasoline filling station, in commercial areas and on major highways. In addition to tyres, these shops also sell second-hand and reused tyres and new tubes.

The repair process for tubes is as follows. The punctured tube is extracted from the tyre, inflated and immersed in a water bath. The holes (punctures), identified by escaping air bubbles, are marked with a piece of chalk. The tube is then buffed and rasped at the damaged location. Rubber joining solution and special uncured rubber are then placed on the tube, which is inserted into the electrically heated curing machine or iron. The repaired tube is used until it becomes weak from too many punctures. The damaged tube is then no longer usable and must be replaced by a new one.

Previously, the only machinery available for hot method tyre repairs was imported into Pakistan. Currently, various types of puncture repairing machines are imported. One such is the Italian brand Croghi, which works with 0.75 Kw, 50-60 Hz. This machine costs approximately US\$ 3,000.

In addition to the imported machines, locally manufactured machines have recently come onto the market. These resemble the foreign designs and meet their performance standards, but cost considerably less. On an average, one puncture repair costs US\$0.75. On an average approximately 50 punctures are mended in one shop per day. Two persons are generally employed in each puncture shop, one for tyre fitting and another for puncture repair.

Source: PCS&IR, 1987

3.3 Regrooving of Tyres

Regrooving automobile tyres is a common phenomenon and is practised in nearly all of the less industrialized countries. It consists of cutting or scoring a new pattern into the base tread of a tyre after the original tread pattern has been worn away by use. Regrooving a worn tyre increases the grip and the driving performance on wet roads. Regrooving requires no machinery, and can be done with relatively inexpensive hand tools of the type often in use by local craftsmen in developing countries. The main problem in regrooving car tyres is the scant availability of good quality casings with enough rubber left to allow regrooving.

The quality of regrooved tyres differs. Bus, truck and heavy duty tyres are often designed to be regrooved and achieve quality comparable with that of new tyres. Companies like Michelin design special truck tyres to be regrooved prior to any retreading. The regrooved tyre is both safe and reliable.



Figure 3.3. Following the Grooves is a Labour Intensive Process.
Source: Knud Sauer.

Passenger car tyres are not designed to be regrooved, in part because they have less tread rubber. When they are nevertheless regrooved, a new pattern is cut into the tread rubber. Regrooving can result in a serious enough decrease in quality and safety that it is forbidden in many countries. In spite of this, regrooving does occur where there is a demand for regrooved tyres, as the case of Naples, Italy, shows. Certain retreaders have called for legal limitations on regrooving, both because it competes with more expensive retreading, and because retreadable casings can be damaged beyond recall by improper regrooving.

The regrooved tyre is an inexpensive alternative for worn tyre recovery. Regrooved tyres generally cost only 1/4 of the price of new tyres and half the price of retreaded tyres. The relatively low price is attractive to low-income car owners and even more so for old model cars. In low-income countries, such as Pakistan, good-quality regrooved tyres are in great

demand for pickup vehicles. Generally poor road conditions result in excessive tyre wear, creating a demand for early replacement of used tyres.

3.3.1 *The Regrooving Process*

In order to achieve reasonable levels of production, the regrooving entrepreneur needs sufficient indoor or outdoor space in which to store the tyres to be regrooved, the already regrooved stock, and the rejected tyres which are not fit for regrooving and which must be disposed of or directed to secondary uses. Tyres take a lot of space. Since workshop space is expensive, the micro-entrepreneurs carry out most of their business in the open air and in the street.

The first step in regrooving is to check the quality of the worn tyre: the quality of the carcass, the adhesion between the layers (to ensure that there is no ply separation); and the quality of the tread rubber surface.

There are generally two methods of regrooving: manual or cold regrooving, using a manually operated gouge or cutter, and hot regrooving, which uses an electrically heated gouge.

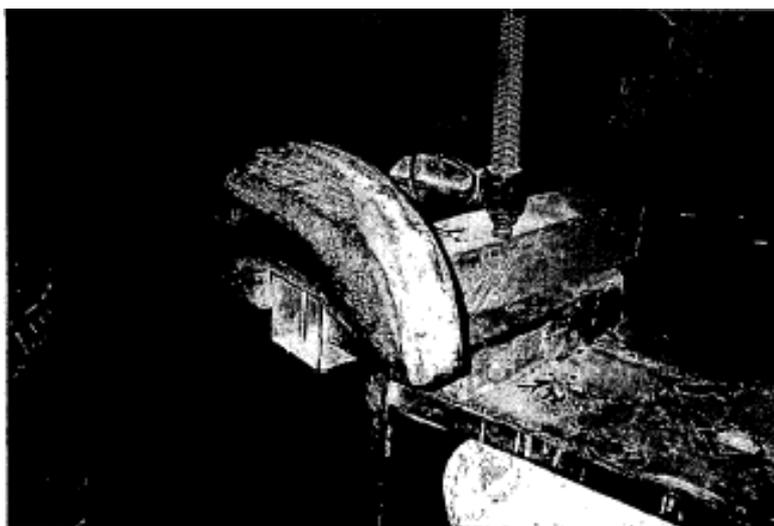


Figure 3.4. Wooden Frame for Rotating the Tyre During Hot Regrooving.
Source: Knud Sauer.

The cold regrooving method was observed in a manually operated regrooving enterprise in Karachi, Pakistan. The craftsman operates the hand cutter which is dipped into soapy water to ease the cutting of the tough rubber tyre surface. He operates in the open air near various car repair shops and second-hand spare part shops. His costs are low, but his income is limited due to the low production rate associated with manual regrooving procedure.

In hot regrooving, the tyre is placed over a wooden frame which supports the tyre during the regrooving process. Using a small electric transformer, the cutting blade of the gouge is heated. This heated gouge is used to deepen the grooves of the original tread pattern. The new groove pattern has a depth of 5-10 mm. It takes about 15 minutes to regroove one tyre in this way. Different sizes of cutting blades can easily be designed according to the width of the grooves.

After regrooving, black polish is applied to the regrooved tyres to obtain the appearance of retreaded tyres. Sometimes the regrooved tyres are sold inflated to hide the fact that the rubber is really very thin. Depending on the depth of the new pattern, regrooved tyres will serve about half the life-span of a new tyre, at only about one quarter of its cost. However, the safety of regrooved tyres, especially passenger car tyres, is inferior to retreads, and so this option should be considered for commercial vehicle tyres designed for regrooving.

3.4 Retreading

Retreading of tyres may be considered to be the most complete approach to tyre reuse. The tyre is refurbished by replacing the worn tread with a new treaded rubber layer. Retreading actually reconditions the tyre and gives it a second or third (or more) life. Unlike regrooved tyres, retreads are comparable in safety and quality to new tyres.

Tyre retreading is practised in both developed and developing countries, but in some developed countries it is declining due to the high cost of labour and restrictions imposed by environmental legislation. Because of the relative low labour costs in developing countries, retreads may be price-competitive in these countries. Even within Europe there is a difference between North and South; Italy, with relatively low labour costs, is a major retreader.

Truck and tractor tyres are more likely than passenger car tyres to be candidates for retreading, in part because of their higher value. Tyre retreading, particularly of these large tyres, may be inexpensive in comparison to production of new tyres. The retreaded tyres are comparable in quality to new tyres and work quite satisfactorily for a reasonable period of time, generally over 60% of the mileage of the same tyre when new.

3.4.1 *The Retreading Process*

The retreading processes can roughly be divided into two main processes:

- hot cap method, using unvulcanized new rubber
- cold cap method using prevulcanized treads

The retreading process can be divided into six stages:

- Acquisition of worn tyres and rubber materials.
- Examination and selection of tyres.
- Preparation of casings and compounds.
- Application of new materials (confectioning).
- Vulcanization.
- Inspection and quality control.

All retreading processes begin with a thorough inspection of the worn tyres to ensure that there is no ply separation nor damage to the casing and beads. In some countries more than half of the tyres presented are rejected at this stage, and must be recycled in other ways or disposed of.

After a tyre casing is accepted, the old tread is peeled or rasped off. The tyre is mounted on a spindled span, while a rotating, rough-toothed cutter or rasp removes rubber to leave an even, flat or slightly rounded surface with a rough texture, to which the new tread can be securely bonded. In this way, the beads are ground to the required dimensions.

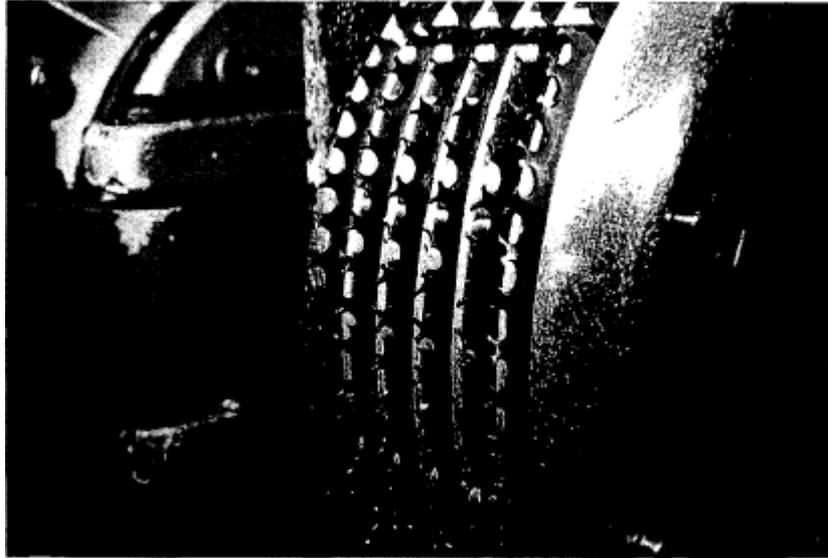


Figure 3.5. Close Up of the Buffering Rasp.

Source: Knud Sauer.

The de-treaded tyre (the carcass) is then brushed to remove any adhering dust or crumb produced during this operation. The tyre is covered with new rubber as soon as possible to prevent contamination and surface oxidation and to assure good adhesion. New, uncured tread rubber known as 'camel back' is spirally wound onto the carcass and the tread markings are cut. Alternatively, it is possible to lay a new, cut tread layer onto the carcass using a special bond at the joint. Finally the complete tyre is vulcanized. In the case of large tyres only the tread section is renewed (top capping and recapping). 'Bead-to-bead' moulding is often used in passenger car tyre retreading to give the sidewalls a more attractive appearance.

A problem in retreading is that large numbers of casings must be rejected, due to holes in the fabric-reinforced substructure or weaknesses in the sidewalls. Such faulty tyres are often used by unscrupulous small retreaders; the retreaded tyres appear in perfect condition but are virtual death-traps in use. The major retreading companies can preserve their reputation for quality by being stringent about rejecting unfit casings.

i Unvulcanized Rubber (hot cap method)

Unvulcanized rubber is mostly used in the form of 'camel back,' an extruded strip of the required cross section needed to cover the area to be retreaded. The casing is coated with an adhesive, the camel back is uniformly applied, the two ends are linked and the tread is carefully pressed onto the casing to remove entrapped air. Instead of using camel back it is also possible to apply the new rubber directly from the extruder onto the casing. As the extruder presses the hot rubber onto the casing, a better adhesion is claimed and no adhesive is needed. The temperature of the mould has to be high enough to ensure good vulcanization of the tread in a reasonable time.

ii Prevulcanized Treads (cold cap method)

The use of prevulcanized treads is of growing importance, especially for large truck tyres and radial tyres. Because the prevulcanized tread is partly cured and only a thin layer of adhesive has to be activated for bonding, the actual retreading operation can be performed at lower temperatures, (100 C), and in shorter times, compared with the hot cap process using unvulcanized rubber. It is claimed that this method can prevent excessive curing of the carcasses.

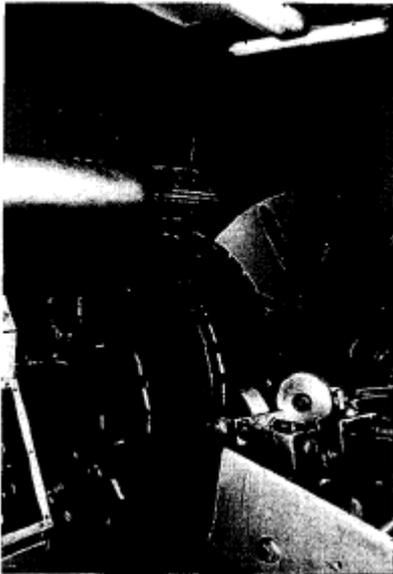


Figure 3.6. The New Tread is Pressed Mechanically onto the Tyre

Source: Knud Sauer



Figure 3.7. After Vulcanization, the Retread is Ready.

Source: Knud Sauer

India is known to have a large retreading industry and is actually importing large numbers of casings for retreading. In India, retreading plants supplement the eight to ten new tyre factories in meeting the growing demand for vehicle tyres. Retreading is an intermediate-level technical process for which an investment of RS 187,000 (approximately US\$ 6,300) is required for cold retreading using prevulcanized treads. In contrast, investment in a hot method retreading plant in the an OECD country like the Netherlands costs US\$ 1 million, and produces retreads at a cost of about US\$ 160 per truck tyre.

3.4.2 Waste

There are two types of waste in the tyre retreading process: the rejected casings, and rubber produced in the retreading process itself, which consists of tyre buffings and crumb. The rejected casings must either be directed to other forms of secondary recovery or discarded. The crumb rubber and buffings may be used, if a local market is willing to take them. Otherwise they are disposed of. Although this material is of a high quality, it requires special production facilities and a local market demand to allow it to be used.



Figure 3.8. Rejected Tyres and Buffings from Retreading.
Source, Knud Sauer.

Box 3.4. Tire Recovery in Nairobi

In Nairobi, Kenya, about 10,000 tyres per week are received for retreading, while the retreading capacity can only accommodate about a quarter of this volume. Rejected tyres are used for secondary recovery or disposed of (generally by burning).

The retreading process produces about 12 tonnes of crumb rubber per week. Until recently, this has been disposed of at the City landfill, but this is expected to change when a planned regeneration facility comes on steam. In addition, post-industrial waste rubber produced at the rate of about one tonne per week is sold to the Jockey Club for lining race courses at a cost of US \$ 5.70 per tonne. Secondary recovery from rejected casings includes wire separation and production of sandals, strapping, shoe soles, floor tiles, rubber matting, washers, seals, force cups, rubber batons, tubing, solid rubber wheels (for carts and wheelchairs), straps, automotive parts, and the like.

Source: USK/Nairobi, 1991

3.4.3 Opportunities

Although it is actually a relatively small-scale operation, the technology of retreading requires an industrial environment, including reliable electric power, machinery and a body of skilled workers. A supply of used and usable casings must be available in the region. Machine parts, high quality tread compound and prevulcanized treads have to be available locally or through import.

The capital/labour ratio in retreading is quite high, as most work is done mechanically. The process requires electrical energy for buffing and vulcanisation. Using Indian equipment, the cost of a new plant with a capacity of about 15 tyres per day is about US\$ 4,000.-. Using prevulcanized treads can enable production of high quality retreads at a smaller scale, with lower capital cost and with less energy expenditure compared to methods using unvulcanized rubber; however, this is likely to raise the variable costs since the pre-cured tread is a more highly processed, and therefore costlier, product than camel back.

For most independent informal-sector entrepreneurs in urban centres in developing countries, the level of investment in a whole plant is too high to be viable. Even an option to retread only passenger car tyres using second-hand locally produced or imported equipment would

probably require too large an investment. Operations exclusively involving buffing and low temperature vulcanisation (cold cap method) may be more feasible, since these have a lower capital requirement. In certain circumstances a community-based organization (CBO) or a cooperative of small enterprises might be able to raise the capital needed.

In certain circumstances, the rubber supplier or purchaser is willing to provide machinery, technical assistance and publicity support to the new entrepreneur. The support may also be extended to buy camel back compounds.

3.5 Secondary Uses for Waste Tyres

Secondary reuse of tyres can be characterized as lower in the reuse hierarchy than primary tyre recovery, since only limited use is made of the properties of the tyres, and therefore only a fraction of the value-added of the tyre is retained. Tyres are attractive for secondary uses because of their weight, shape, volume and elasticity. In the industrialized countries, secondary use is more often motivated by the need to find destinations for the growing number of discarded tyres that out of a perceived need for the resources. In developing countries, entrepreneurs engage in processing for secondary use as an income-producing activity, since the resulting products have value and can be sold into the low-income consumer products marketplace. Secondary uses of waste tyres include the following:

i. Artificial Reefs

In Japan, Australia, New Zealand and the U.S.A. millions of scrap tyres are used to create artificial reefs in coastal waters. Tyres are tied together or poured into concrete and sunk to the bottom of the sea. There they serve as shelter for fish and contribute to the improvement of the water circulation; artificial reefs are said to increase marine life. The approach is expensive and the benefits are difficult to assess.

ii. Coastal Erosion Control

In the U.S.A. waste tyres have been used as building materials for breakwaters to protect the coast from erosion. Barriers have been put in place and found to be an effective and inexpensive source of protection, absorbing 80% of the power of the waves of 1-1.3 metres high. The costs amount to 0.1% of that of conventional systems.

iii. Dock Fenders

Waste tyres are used as shock absorbers in harbours, to protect ships and waterside docking facilities from damage incurred during mooring.

iv. Crash Barriers

Piles of tyres are used to lining racetracks to protect racing cars from crashing. Roads known to be dangerous could be lined for a similar purpose.

v. Coverings

Used tyres are used to weight down plastic sheeting covering manure, hay or on ensiled agricultural goods. Tubes are used to cover the water surface of water reservoirs to reduce the water evaporation.

vi. Well Reinforcement

Truck tyres tied on top of each other are used for reinforcing wells and preventing them from collapsing.

vii. Containers

Tyres are used as various sorts of containers, including plant pots and dustbins. Tubes are cut, tied at one end, filled with water or food for storage, and tied at the other end for closure.

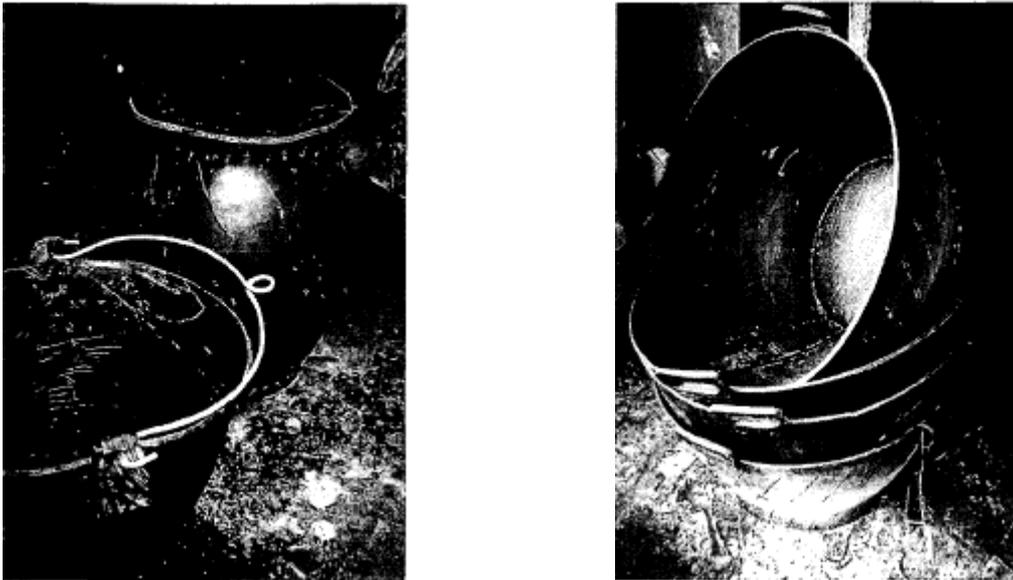


Figure 3.9. Buckets, Tubes and Stools are Made of Tyre Sidewalls, Indonesia.

Source: WASTE .

viii. Wheels

Used tyres are used for hand and animal drawn carts fastened onto wooden, steel or even concrete rims.

ix. Playground Equipment

Used tyres are often used in children's playgrounds, where they form the basis for climbing structures, swings, and other pieces of equipment.

3.6 Secondary Uses for Tubes

The inner tubes of automobile tyres are often reused, or reworked to secondary uses, and are in extensive use in all developing countries. Among the applications for tubes are:

i. Ice Crushing

In South East Asian countries part (usually one fourth) of the rubber tube is used for crushing ice. Big ice pieces are put in the tube and a wooden plank is used to crush the ice to be used in syrups, cold drinks and water.

ii. Swimming Aid

Inflated tubes are used by people, especially children, as a swimming aid in pools and at public spaces. In the US, inflated tubes are used as recreational raft-boats for travelling downstream over rapids in swiftly-flowing rivers.

iii. Tubes as Storage

Tubes of automobiles are cut into halves, with one end of each half tied with a cord. The tubes are then cleaned, dried, tied and used for storage of food items like maize, rice, and wheat. Two containers can be made from one tube. This storage is free from pests, moisture and insects.

iv. Tube Buckets for Water Storage

Tube buckets can be used for storing water. As in the case of the containers, the tubes are cut and tied.

3.7 Secondary Uses for Conveyor Belts

Conveyor belts are primarily used in industrial applications. They are an expensive part of industrial equipment, and are therefore repaired for as long as possible to allow continued use in the designated application. Holes are filled with unvulcanized rubber and are then vulcanised by means of electric presses. Cold vulcanising compounds for repairing holes and rips exist as well. Conveyor belts which get worn out at the sides are cut to a smaller size and continue their primary function, but on smaller machines. When a conveyor belt is worn beyond use, secondary use is accomplished by cutting the belt into strips, which are woven into mats or used in other applications.



Figure 3.10. Manual Separation of the Tread from the Sidewalls, Karachi, Pakistan.

Source: PCSIR

3.8 Material for Use in Other Secondary Products

The secondary uses described above mostly involve the use of whole tyres or tubes. The secondary uses described in this section involve hand production using the tyre or tube as a resource whose shape and properties are altered through manual labour. In a great number of countries in the South, there are many small and medium-sized enterprises where rubber processing is largely done by hand. In the North, manual recycling of rubber is seldom practised any longer, although it was common practice as recently as 40 years ago.

Rubber can be processed by hand by means of a number of rough processing techniques: grinding, cutting, scoring, turning and punching. Unlike regrooving or retreading, manual recycling techniques differ widely, both in relation to product and process. It is not possible to describe the “typical” small-scale recovery operation in detail. However, as the examples illustrate, most small-scale producers first acquire the tyres, then prepare them through some combination of inspection, pre-cutting, and the like. This creates the intermediate resource which serves as secondary materials for their products, and generally consists of rubber chunks, sheets, chips, or strips.

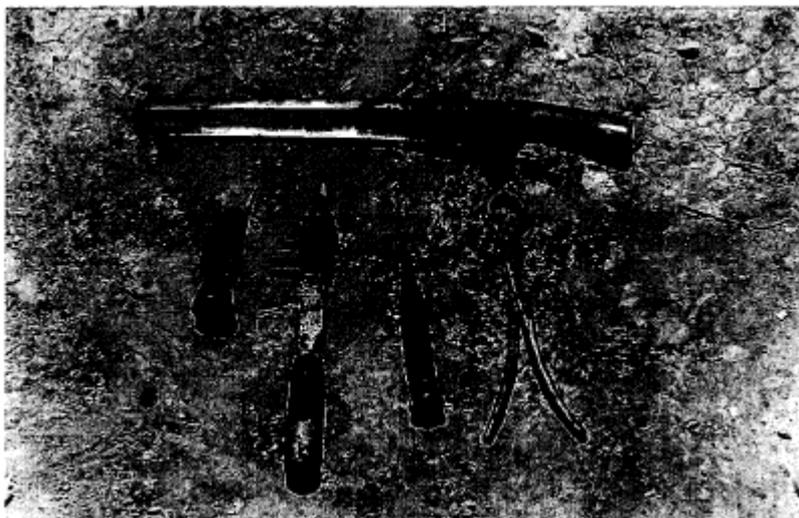


Figure 3.11. A Set of Specialized Knives for Cutting Rubber Tyres, Pakistan.
Source: PCSIR.

The next general step in the production process is to manufacture the secondary (sometimes intermediate) product. This is usually done using a hand-held knife or specialized cutting tool. Frequently the knife or knives are affixed to a bench or mounted on a wheel to provide a measure of the uniformity associated with mechanization. More elaborate products then pass a number of assembly and finishing steps, such as bolting, gluing or pinning various parts together, adding metal or textile parts, or greasing or painting the finished product to improve its appearance.

3.9 Examples of Secondary Production

In Africa, production of secondary products takes place in small open workshops along the road. Tyres are processed into sandals, chair and bed webbing, harness, shoe soles, hinges, and simple valves and seals for water pipes. Small car parts, including flexible rings for the gear mechanism and small bushings for the stabilizer bars and suspension system, may also be produced. The prices of these parts are considerably lower than those of the original products. On a limited scale parts such as pump pistons are also produced. In Ghana, one manufacturer also makes bumpers and cabin stops for trucks and drive roller.



Figure 3.12. Clutch Rubbers and Bushings, with Knives Used in Production. Dar es Salaam, Tanzania.
Source: WASTE .

The basic equipment for this recycling consists of a knife and a grinding stone to sharpen the knife. Water, and occasionally a water/soap solution, is used as a lubricant during the cutting process. Holes are burned into the rubber using a heated bar or are punched using a sharpened iron tube or pipe.



Figure 3.13. Bushings, Pedal Rubbers, and Bicycle Bearings from Punched Tyres, Malang, Indonesia.

Source: WASTE

In Indonesia, inventive equipment is used to make bushings, which are punched using with a sharpened tube of iron. The bushings are perfectly round and are used as parts for the many rickshaws that are used in Indonesia. Other products from Indonesia are buckets and wash basins made of tyre parts that are turned inside out. The parts are fastened by nails and are made water tight with asphalt or paint. Parts for bicycles and rickshaws, such as pedals, bearings and valves, are also made.

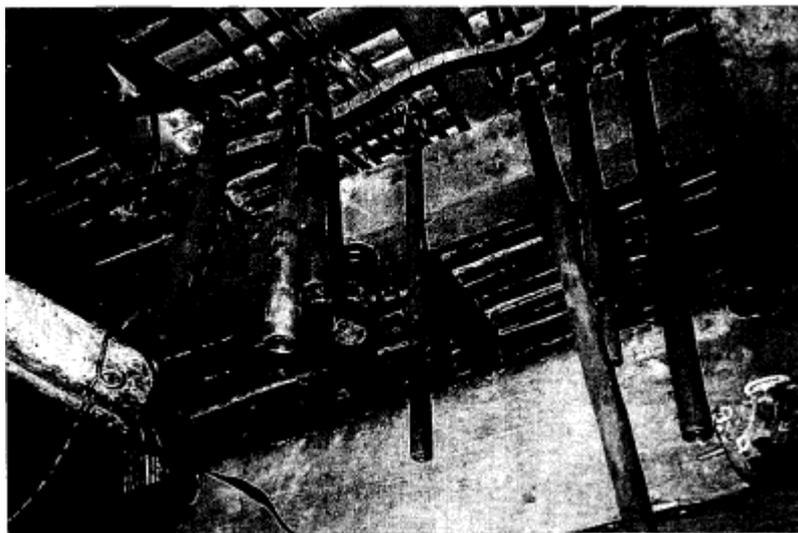


Figure 3.14. Drills of Several Sizes, Made of Sharpened Steel Pipes, Malang, Indonesia.

Source: WASTE .

In Pakistan, a rather large number of products are made from used conveyor belts. Rings, washers and gaskets are made with steel punching tools. These products are of a relatively high quality. Car parts are also produced, and exhausted tyre treads are used again as shallower treads for wooden wheels.

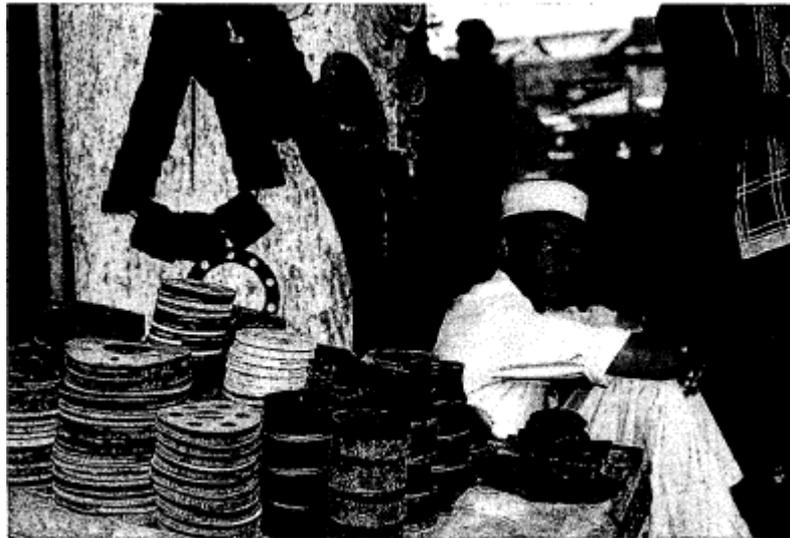


Figure 3.15. Dealer in Products from Used Rubber, Karachi, Pakistan.

Source: PCSIR.

In the People's Republic of China, tyres are parted by hand into the inner ring, main ply, and tread. The different parts are torn apart using a drawing bench (knives affixed to a stationary bench). The remaining profile is removed from the tread by means of a splitting machine with a fixed knife. The sheets of rubber are cut by hand and processed into bumpers to cushion rails using a press and a steel punch. In Shanghai, products are punched from used tyre parts using an excenter press together with a heavy steel punch .

In the North, changing economics has limited the manual production of secondary items from waste tyres and tubes. It is often no longer cost-effective to make products manually from waste rubber. Nevertheless, some enterprises do survive in niche markets: in Massachusetts, USA, one firm specializes in making rubber washers, fenders, mats, and docking and fishing gear for the marine fishing industry. Conveyor belts or low-quality rubber matting made from compounds containing crumb rubber or rubber reclaim are often used as mats in sheds and for the inside of ice-skating rinks, and sometimes as flanges in large pumps. Car tyres are also used as fenders in shipping. Some years ago, mats were still produced in the Netherlands that were used in the building industry to keep debris together, and as sheets to drive on in muddy terrain. These mats were made of car tyre treads reinforced with steel wire.



Figure 3.16. Doormat Made From Used Tyres, Manila, the Philippines.
Source: CAPS.

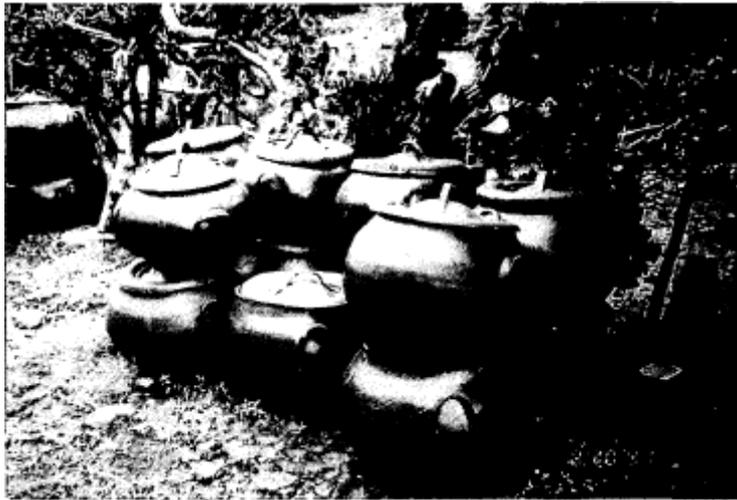


Figure 3.17. Garbage Containers Made From Truck Tyres, Manila, the Philippines.
Source: CAPS

CHAPTER 4 PHYSICAL RECOVERY OF RUBBER MATERIALS

The waste materials for mechanical production include rubber tyres, inner tubes and conveyor belts, all of which have been discarded as being too worn to continue fulfilling their original purposes.

The mechanical processing of used rubber is the most direct and common manner for discarded rubber to serve as an industrial raw material. Waste products are reduced to an intermediate material which can then be directly processed into new products or parts of new products. While the value-added product has lost its integrity in the process, the physical and chemical structure and properties of the rubber remain intact and at least some of its value-added is retained. The resulting products make use of the specific characteristics of rubber, such as its extensibility, resistance to wear and tear, resilience, water tightness, and ability to resist chemicals. The processes for recovery described in this chapter are mechanical in nature, and are distinguished from chemical and thermal processes, which are described in chapter 5.

4.1 Separation of Rubber Material

For rubber to be available for secondary production, two conditions must be met. First, the rubber must be present in the discarded product; secondly, it must be possible to separate the rubber from the primary product and to make it available for secondary production. This is also true for other products, such as steel wiring or textiles.

Tyres consist of varying combinations of natural rubber (NR) and synthetic rubber (SR). The construction of a tyre also includes textile and steel reinforcing materials, which make it difficult to extract the rubber directly from the tyre. Truck and bus tyres, together with tyres that have been used in agriculture and the mining industry, contain a great deal of natural rubber in the tread. In these products, the coarse profile provides blocks of rubber material suitable for the making of products.

Tubes are made from gas-impermeable butyl (IIR) rubber. The 2 mm thick tube is a suitable basis for production of flat products. Conveyor belts are large flat sheets of rubber, often strengthened with layers of textile and sometimes with steel. Conveyor belts are sometimes manufactured of rubbers that are oil- or heat-resistant. These rubbers can be used for specific purposes.

4.1.1 *The Process of Rubber Separation*

Separation of rubber from tyres requires expertise and experience, in combination with appropriate tools and machines. In most small-scale applications in developing countries, the tyre is initially cut with a knife. First the two sidewalls are removed, and the tread is torn from the tyre, after which the remaining rubber is cut into pieces. The resulting blocks, chunks, strips or pieces of rubber then become the basis for either further intermediate

processing or the production of new products. The side walls, which are mostly reinforced with steel wires (the bead cords), are burnt to remove the steel from the rubber.



Figure 4.1. Cutting the Profile from the Tread Using a Stationary Knife, Shanghai, China.

Source: Buekens

Rubber separation is highly labour intensive. Technical improvement in the tyres themselves makes extraction using this method even more difficult: 'improved' tyres have more steel wiring and less rubber than in previous times. As a result, modern truck tyres cannot be cut without specific tools. In China, where many car tyres contain textile reinforcement, tyres can still be torn apart into different layers by means of a drawing bench.



Figure 4.2. The Tyre is Torn into Several Layers, Shanghai, China.

Source: Buekens

4.1.2 Splitting

Rubber separated from tyres is of a high quality. However, when the profile of the rubber varies in thickness, its use is limited. In Shanghai, the People's Republic of China, tyre treads are split on a splitting machine to remove the profile. This splitting machine consists of two

rolls transporting the rubber and pressing it against an adjustable knife. In this way the profile of the tread is cut to a uniform thickness.

In the United States, tyres were split for the regeneration industry up until the 1950s. Splitting was done on tyre splitting machines. These machines were originally used in the leather industry. They consist of a horizontal tyre knife that runs over two wheels. Transporting rolls transport the rubber against a moving knife, which is oriented to cut at a precisely uniform thickness. Indiana Rubber in Roosendaal, the Netherlands, still uses such a machine to split rubber mats. This tool makes it possible to make two mats with a profile on one side through a single pressing. With such a tyre splitting machine, parts of tyres and conveyor belts can be cut into sheets of any thickness, which can then be used to make flat products.

4.1.3 Punching

Punching is a cutting technique that is widely applied in producing bushings, washers, and gaskets. A number of small enterprises in both countries in the North and in the South manufacture gaskets from rubber.

One way of punching gaskets is shown by Delta Rubber in the Netherlands: Single products are cut by hand. The rubber gasket material is scored using a ruler and a pair of compasses and cut using a sharp knife, a pair of cutting compasses or a manual punch. Larger product series are produced using punches driven by hydraulic or eccentric presses. The punches are made from steel for large product series (more than 10,000) or when the gasket material is difficult to cut.

For smaller series (100-10,000 pieces) simpler punches are made, so-called band steel punches. These are manufactured by the company itself from sharp metal strips, which are affixed to a wooden board in the shape of the required gasket. With this technique complex forms of a remarkable precision can be produced. Although producing these steel punches calls for certain level of technical skill, including the ability to work very precisely from a drawing, it is in fact a relatively simple process.

At the Delta Rubber Company, large, heavy hydraulic presses are used to flatten the rubber surface. For faster and smaller jobs excenter presses are used. It is, however, also possible to use manually operated presses.

4.2 Extraction of Rubber Material

Producing granulate is one way of recycling waste rubber. Rubber granulate is a granular or powdered vulcanized rubber. Rubber granulate has a number of industrial applications; as a feedstock for the production of regenerated or reclaimed rubber; as an inexpensive filling material in rubber compounds; as a modifier to asphalt, etc. In the US, a process was developed in the middle 1980s called re-compounding, which involves using crumb rubber in a polymer matrix which allows it to be compounded while retaining its physical properties. Other processes like this are also in use in other countries.

Rubber granulating processes have a relatively large economy of scale, and are generally only feasible when a large supply of tyres are available in a region: transport costs for tyres (which do not pack efficiently) quickly make the operation economically unfeasible. The minimum investment for a full granulation plant is about US\$ 3 million.

4.2.1 Production of Rubber Granulate

The three ways of producing rubber granulate are listed below:

i Grinding at Ambient Temperature

In general, the grinding of rubber tyre waste requires a number of stages. First, the waste materials are cut or shredded into large pieces in a shredder. Then the pieces are ground in a cracker mill or a shear shredder, to about 4 mm. The resulting granulate is screened or sieved at different sizes of 1 mm to 4 mm.

Grinding is an energy-intensive process since rubber is a tough and resilient material: 100-1500 kwh/tonne (Baars 1981) is needed to produce a granulate with a grain size of 1 mm. For this reason most tyre grinders are only cost-effective at a large economy of scale, beginning at about 1 million tyres per year.

The behaviour of the rubber results in high machine wear and tear, requiring frequent replacement of knives in the grinder. In addition, most passenger tyres are reinforced with textile and steel wires. This not only makes high demands on the equipment, but also creates a problem for the quality of the granulate. Therefore, steel wires must be removed after grinding by means of magnetic separators. Separation of textile can be accomplished using cyclones, whereby the textile is blown off the rubber granulate.

ii Grinding at Low Temperatures

Cryogenic grinding uses low temperatures to alter the properties of the rubber, making it less viscous and more brittle. In cryogenic milling, the rubber is cooled down to -40 C with liquid nitrogen, so that it becomes brittle and can be 'broken' into (very) fine rubber grains or powder in a hammer mill. The resulting grains are angular in shape and have smooth sides, as the rubber has been shattered like glass. In contrast, granulates produced at room temperature are irregular in shape and have a relatively large surface, since have been torn apart.

The economic feasibility of cryogenic grinding is currently under discussion. The liquid nitrogen makes up most of the variable costs. Installations that apply cryogenic grinding to grind whole tyres are not economically feasible. The Rumal Company in Weert, the Netherlands, uses cryogenic grinding as a supplementary grinding step to obtain powders of very small sizes.

iii Crumb Rubber from Tyre Retreading

Crumb rubber is generated as a waste material from retreading operations. As the residual tread is scraped from the tyre to get a smooth surface for a new tread, scrapings, or crumb rubber, are generated. These needle-shaped tyre scrapings are a high-quality rubber that is free from steel or textile contamination and can be used directly in rubber compounds or may

be ground and sieved at various grain sizes. To make this feasible, there must be a user of crumb rubber in the region willing to buy the crumb.

In Naples, the crumb generated by retreading can be sold for IL 100-150 per kilogram to rubber manufacturers in the region. In contrast, in Nairobi, the crumb is normally landfilled or burned.

4.2.2 *Moulding with Granulate*

To be useful for rubber moulding, crumb must be rather fine and it should be screened in a sieve of about 0.8 mm mesh. The amount of crumb in a rubber compound that can be used will depend on the quality of the product to be made. These formulations can be adopted to suit locally available materials.



Figure 4.3. Devulcanization in a Large Autoclave, Shanghai, China.
Source: Beukens.

Moulding requires that the ingredients be thoroughly mixed. At the end of the process the compound is discharged as a sheet of uniform thickness according to the specifications of the particular manufacturing process.



Figure 4.4. The Devulcanized Rubber is Refined on a Calendering Machine, Shanghai, China.
Source: Beukens

There are three different types of moulding processes (Vogler 1981):

i Compression Moulding

Compression moulding process is the simplest form of moulding and can be used to make shoe soles and heels in addition to a variety of saleable products. In this process, a press is used that consists of a number of horizontally platens. Each mould is in two halves, upper and lower, and a sheet of compound or 'blanket' is placed in the lower half. Through the application of heat (often by steam), pressure and the elapsing of sufficient (vulcanization) time, the material vulcanizes and becomes a elastic product.



Figure 4.5. Producing Compounds on a Teo-Roll Mixer, Naples, Italy.
Source: Knud Sauer.



Figure 4.6. Moulds for Shoe Soles, Naples, Italy.
Source: Knud Sauer.

ii Transfer Moulding.

Transfer moulding is a refinement of the compression moulding method and is related to injection moulding: the material is heated in a separate chamber and then forced down channels into the shaped moulds.

iii Injection Moulding.

Injection moulding is a process whereby the heated compound is transported and pressed into a mould consisting of two dies. The two halves are then closed to form the shape of the product to be produced. After vulcanization and cooling, the mould is opened and the product is released.

4.2.3 Applications for Rubber Granulates

Rubber granulate is usually bought by the formal rubber processing industries. Many of these are already using substantial volumes of crumb rubber or granulates, and the ability to increase either the percent of secondary rubber or the throughput of the facility is likely to be constrained by both technical and economic factors. In spite of this, new options for the use of granulates continue to be developed. Some options are described below.

Rubber granulate can also be used in small- and intermediate-scale moulding processes to produce low-grade rubber products, ranging from solid rubber wheels for wheelchairs and carts to auto floor mats.

The cases available from Italy and developing countries include the following applications:

- moulding of low-grade rubber goods such as automobile floor mats: 50% crumb, 25% reclaim and 25% virgin material
- moulding of shoe soles and the like: up to 50% crumb, ground (probably cryogenically) to a powder
- moulding of additional low-grade items in small- and intermediate-scale production facilities: 35-30% granulate/crumb; 25-30% reclaim; 40-50% virgin rubber

i Raw Material for Production of Regenerate

The oldest application for rubber granulate is the regeneration industry. For most regenerating processes, it is necessary to grind the waste rubber first. Truck tyres containing a high percentage of NR and are the basic materials for regeneration.

ii Processing Aid and Extender in Rubber Compounds

A maximum of 30% of granulate is used as a filling agent in compounds to lower the costs. Generally the physical characteristics of a compound diminish when rubber re-granulate is added. A Dutch investigation (TNO/KRI/NL) has shown that the size of the grain influences the characteristics of the compound; the smaller the grain, the higher the physical properties, such as tensile strength. The addition of extra accelerators and vulcanizers has a positive influence on the physical characteristics. By coating the rubber granulate with extra vulcanisers before mixing it in a compound, better physical properties are also obtained (v. Baarle 1988).

Rubber granulate is applied in compounds for products that are not exposed to high performance demands, such as mats, floor coverings, fenders, massive wheels etc.

iii Full Rubber Granulate Compounds

At the University of St. Etienne, France (Dufton, 1987), and at the TNO KRI Institute, Delft, experiments have been done to develop the vulcanising of mixtures of secondary rubber without the addition of virgin (new) rubber, by adding process oil. This results in a rubber with a porous structure and a low drawing strength. When bent, the rubber surface will break. Applications are sheets for sound and heat insulation or vibration dampers.

iv Granulate with Binder Systems

Rubber granulate can be bound with binder systems including liquid polyurethanes, or other reactive liquid polymers. In this way, tiles can be pressed and sports floors can be manufactured.

v Granulate in Plastic Compounds

Applying granulate in synthetic compounds seems a relatively inexpensive way of binding rubber granulate. The technique consists in mixing the synthetic polymer granules with rubber granulate. The rubber mix is heated in an extruder, compressed and transported by means of an extruder screw. At the end of the extruder there is a die. Extruding typically produces long, products such as hoses, sheets, sealing strips and profiles, but trolley wheels can also be made from extruded material. Experiments with compounds of PE and granulate at the TNO KRI Institute have shown that compounds containing 30% PE make a homogeneous and fairly strong material. An irrigation hose-pipe produced from recycled PE and granulate is already in production. The porous hose-pipe can emit water to its surroundings under low water pressure.

vi Applications in Road Construction

Waste rubber can be added to bituminous products to modify products like asphalt. In particular, the addition of rubber granulate or regenerated rubber to asphalt has a positive effect on the characteristics of asphalt, where it has been shown to:

- improve temperature characteristics (low and high temperatures)
- improve resistance against creep at higher temperatures
- improve adhesion between the additives (stones)
- improve resistance against bleeding
- decrease loss of force in road surfaces that are wet for longer periods
- decrease sensitivity for oxidative hardening
- increase sound reduction due to the open structure

Although the material costs and construction costs of rubber asphalt are twice as high as conventional asphalt, it has a longer lifespan and the maintenance costs are lower. Another application is a viscous filling material for filling holes and cracks in the road surface.

vii Controlled Release of Pesticides

Pesticides that have been absorbed in rubber granulate and have been spread over agricultural land are released slowly over a long period. To make the granulate suitable as a pesticide carrier, substances that are present in the rubber such as softening agents and anti-degradants are first extracted. After that, the granulate is treated with the pesticide. In the soil, the pesticide diffuses from the granulate into the environment by the diffusion action of water. It is not clear how long the granulate itself persists and how it affects the environment. This application is still in an experimental stage at the TNO/KRI Institute.

CHAPTER 5 CHEMICAL AND THERMAL RECOVERY OF RUBBER MATERIAL

The reuse of rubber waste materials for their chemical and/or thermal value is lower in the recovery hierarchy than all forms of primary or secondary mechanical or manual processing. When the reuse of the whole product, as in Chapter 3, or parts of it, as in Chapter 4, has been exhausted, chemical recovery of rubber's constituent parts allows for some of its value added to be retained and used in new production. Thermal recovery allows only for recovery of energy value.

This chapter considers various relatively high-technology approaches to low-value rubber recovery: low-grade materials recovery, including fabrication of rubber reclaim; and energy recovery, including pyrolysis and incineration with energy recovery. These technologies are included in this report in brief for the sake of completeness. It should be emphasized from the outset that their relevance to small-scale recovery enterprise in developing countries and/or activities of the informal sector is limited in the extreme.

The three recovery processes described here are:

- rubber reclaim: the rubber waste is heated or frozen, treated with chemicals, and mechanically processed;
- pyrolysis: the rubber waste is heated in the absence of oxygen, causing decomposition into constituent parts and gases;
- energy recovery: the rubber is burned (heated in the presence of oxygen), releasing energy, which is recovered to produce heat, electricity or steam.

5.1 Rubber Reclaim

Reclaim is produced from vulcanized rubber granules by breaking down the vulcanized structure using heat, chemicals and mechanical techniques. Reclaim has the plasticity of a new unvulcanized rubber compound, however, the molecular weight is reduced so reclaim compounds have poorer physical properties than compared to new rubber. The main reasons for their use are price and improved processing of rubber compounds. The main processing advantages claimed can be summarised as:

- shorter mixing times
- lower energy consumption
- lower heat development
- faster processing on extruder and calenders
- lower die swell of the unvulcanized compound
- faster curing of the compounds

In many rubber products 5-10% reclaim can be added to the new rubber content without serious effects to the physical properties. Far higher percentages (20-40%) are used in products like car mats. Traditionally, however, compounds used in the production of tyre carcasses have been the

main outlet for reclaim, due to its processing advantages. In spite of this, the proportion of reclaim in radial tyres is limited to around 2-5%.

5.1.1 Processes

Rubber may be converted into reclaim by means of a number of processes. In all these the scrap rubber must first be shredded and ground into crumb to permit chemicals and swelling agents to react adequately with the vulcanized structure, to promote good heat transfer, and to remove the fibres by mechanical or chemical action. Each of the processes described below is followed by final processing.

i Digester Process

The digester process is a batch process where the crumb rubber and the reclaiming agents are heated in an autoclave with steam 15 bar (=180 °C) for 8-12 hours. The fabric dissolves and the rubber softens. The aqueous phase is separated and the regenerate is dried for final refining. Significant amounts of residual fabric may remain with the reclaim if the digester processes is being used. The reclaiming chemicals used in this process include zinc and calcium chlorides (to dissolve the fibres) together with a very complex mixture of solvents, softening oils, hydrocarbon resins, pine tar and reclaim catalysts.

ii Pan Process

Finely ground scrap rubber that has been freed of fibres by mechanical cyclones is mixed with reclaiming chemicals, then placed in open pans in an autoclave and heated with 'live' steam at 15 bar (=180 °C) for 4-12 hours. Any residual water is removed and the reclaim is ready for final processing. The reclaiming chemicals used in the pan process are similar to those used in the digester process except that no zinc or calcium chloride are used. The pan process is also a batch process.

iii Mechanical Processes

Several processes are used, all of which are continuous processes. Fine (fabric-free) scrap rubber is mixed with reclaiming chemicals and fed continuously into an extruder in which the rubber is devulcanized at 205 °C for about 5 minutes. The heat is partially generated by the electrical heating of the extruder and the friction of the crumb. The devulcanized rubber is extruded from the machine in a dry form ready for refining. The reclaiming chemicals are essentially the same as those used in the pan process.

iv Microwave Devulcanization

Ground rubber size 6-10 mm is fed into a microwave oven where the compound is heated to 260-350 °C (depending on the compound) for about 5 minutes. The compound is devulcanized and can be ground and refined. This is a continuous process, which uses relatively little energy, requires little grinding, and does not require the use of chemicals. The process is of little industrial importance and no procedure for upscaling is known. Experiments were carried out on EPDM polymer.

v Final Processing

The final stages of rubber reclaiming involve taking the material from one of the devulcanization processes and mixing it with oils and fillers. It is then passed through heavy rollers, strained through a wire mesh screen, and rolled again to a final sheet thickness of 0.05-0.13 mm. The

discharged sheets are wrapped around a rotating drum. The wrapped layers are then cut off from the drum to give a slab of reclaim of predetermined size and weight.

5.1.2 *Technical Difficulties with Reclaiming*

Reclaiming involves recovering a complex blend of natural and synthetic rubber vulcanizates. The complexity of the vulcanised materials creates, almost by definition, technical barriers to effective reclamation. This is exacerbated by the fact that reclaiming plants must treat a wide range of scrap tyres originally produced by different manufacturers using different rubber compounds. The main problem with reclaiming mixtures of natural and synthetic vulcanizates is the actual devulcanization time. While natural rubber vulcanizates readily soften with heat alone to give a satisfactory millable reclaim, synthetic vulcanizates (SBR), after an initial softening with heat, quickly harden on further heating.

5.1.3 *Applications for Rubber Reclaim*

The use of rubber reclaim has decreased since World War II, when 32% of all rubber used was rubber reclaim. The decline is due to shortages in natural rubber supply, combined with technical, environmental and economic factors. In the intervening years a number of inexpensive, high-performance synthetic rubbers have been replacing natural rubber. Specific factors in the decline of reclaim include:

- Radial tyres, which comprise over 80% of the market, have a lower tolerance for reclaim.
- Traditional non-tire applications, like shoe soles, floor mats, car mats, battery cases are increasingly being taken over by plastics.
- Reclaim installations have extreme difficulty meeting modern environmental and worker health and safety standards.
- The development of crumb production offers a cheaper extender for rubber compounds than reclaim; the price for crumb varies from US\$300 to US\$550 /ton while reclaim costs from US\$550 to US\$1200.
- The capital investment needed for economically viable installations is quite high.

Although the consumption of reclaim in industrialized countries has declined from 32% to about 2%, the consumption in industrializing countries like Brazil, India and China is still increasing and forms a large share of the rubber consumption. The high consumption of reclaim in these countries is attributable to:

- Cheaper and lower quality rubber products and tyres are marketable in these countries
- Import restrictions and balance of payments concerns make new rubbers more expensive and less available.
- Low labour costs allow simpler, more labour intensive processes to be economically feasible.
- Environmental protection and worker health and safety restrictions are less strict and less likely to constrain an industrial operation, so older, more polluting, and less expensive installations can be operated without sanction.

The case of Vredestein Recycling (the Netherlands) shows that a capital-intensive reclaim plant can be feasible in industrialized countries. When the tyres are obtained for free and the product maintains a high and reliable level of quality, there is a good if limited market for reclaim in the

modern rubber industry as well as for other uses. In less developed countries reclaimed rubber is an important source of affordable rubber materials. The price advantage of reclaim over new material is larger and there is a larger market for low- or moderate quality products. The production of several grades of reclaim for application in specific products is feasible because low labour costs make collection, separation and pre-processing of rubber wastes possible, as the case of Shanghai illustrates.

5.1.4 Option for Small Scale Recycling Activities

Production of rubber reclaim offers no option for small scale application. A “small scale” plant with a throughput capacity of approximately one tonne per day requires a minimum investment of US\$ 4,000, as projected by SIRI. For small and micro-entrepreneurs in developing countries, this level of investment is too high. A smaller plant could not achieve the economies of scale that allow it to produce a reasonable quality product at an affordable cost.

5.2 Pyrolysis

Pyrolysis is one of two thermal approaches to recovering energy and basic materials from waste rubber. Pyrolysis is a controversial, complex, large scale, capital intensive, high-technology approach which is still considered experimental as a method for processing tyres. It is only briefly described here, since its practical application to rubber recovery in developing countries is extremely limited.

The term 'pyrolysis' is correctly used to describe 'the decomposition of a material through, or as a result of, the application of thermal energy.' Technically, the term 'pyrolysis' covers all forms of heat decomposition, including combustion, although in practice it is normally understood to mean thermal decomposition in a non-reactive (anaerobic, or in the absence of oxygen) atmosphere. Pyrolysis is used to describe processes geared towards the recovery of such materials as carbon black, metal, oils, and gasses, as well as those involving the use of waste material for its energy value.

5.2.1 Process

Pyrolysis should be understood as the process of heating the rubber under pressure until it decomposes. Three processes are used, involving different thermal ranges: above 600°C; between 400°C and 600°C and below 300°C. The processes differ from each other in production of carbon black, oil and gasses. At high temperatures less carbon black is produced, and more gasses.

5.2.2 Products

Whereas the compounds resulting from combustion are relatively predictable, products of pyrolysis differ widely depending on the conditions under which the process is performed. The main products are metals, oils, carbon black, plus a wide range of gaseous and liquid hydrocarbon mixtures, together with varying amounts of residual char. Generally 25-50% of the

weight of rubber pyrolysed can be recovered in the form of a distillate of approximately 42 MJ/kg calorific value, which is higher than when burning tyres (37.5 MJ/kg) and even higher than coal (29 MJ/kg). Tests have indicated that this distillate is an excellent low sulphur (less than 0.5%) fuel which can be distilled into a variety of light and heavy fractions, all having similar heating values. The quantity of char produced varies from 40% to 50% of the weight of rubber pyrolysed. The char generally has a calorific value of 33 MJ/kg, which is higher than coal, but it contains most of the sulphur. The char is also being investigated for its use (after processing) as an activated carbon which could be used in the tertiary treatment of industrial waste water. The gas produced from tyre pyrolysis ranges from 5-20% by weight of the scrap rubber treated. The composition of the gas varies widely with the pyrolysis conditions, but in all cases a readily combustible high calorific value fuel is produced.

The gasses are usually burned to maintain the pyrolysis process and to enable the purification and separation of other fractions. The calorific value depends very much on the percentage of carbon dioxides (CO₂) and nitrogen (N₂) and may vary between 26,250 and 46,200 kJ/m³. The oil fraction can also be used as fuel. Its caloric value is at the level of heating oil: 40 MJ/kg. This oil is also considered by some to be suitable for use as process oil and as an input material for chemical manufacturing.

Even though the process of thermal decomposition is theoretically simple, the process factors need to be very well controlled and the products require extensive processing to produce marketable commodities. The capital investment costs of pyrolysis plants run to several millions of dollars, and cannot take place on a small scale. Finally, it should be emphasized that there are few successful examples of operating pyrolysis plants in the world. The products appear so attractive that attempts are continually being made to get this technical approach going, but they consistently fail either financially or technically. The plants which are in operation seldom meet either technical or economic projections, and are often idled during or immediately after their shakedown period.

5.3 Energy Recovery Through Combustion

Energy recovery through combustion is the lowest form of recovery, in the sense that entropy is lost and only the energy value of the rubber is recovered. Rubber burns well due to the hydrocarbons in the polymer structure. The elemental constituents of a rubber compound are almost equal to those found in coal. Indeed coal provides about 30 MJ/kg and rubber provides about 32.5 MJ/kg of heat energy, which compares with liquid fuels at about 56 MJ/kg. The calorific value of scrap rubber merits at least theoretical consideration of incineration. Table 5.1, gives the calorific values of a number of common fuels.

Table 5.1 Calorific Values of a Number of Common Fuels

Fuel	Calorific Value (MJ/kg)
gas	84.7
diesel oil	45.5
scrap tyres	32.5
coal	30.2
coke	26.7
wood	12.4

Source: Johnson

Although tyres have been burned almost since they were first produced, open uncontrolled burning is now prohibited in many countries, because it produces large amounts of acrid black smoke and high levels of sulphur dioxide. Consequently, considerable effort has been directed to developing efficient, pollution-free incinerators. The basic problems associated with rubber incineration are:

- The need to have an augmented air supply to ensure complete combustion. A lower percentage oxygen results in smouldering which causes heavy air pollution and inefficient combustion.
- The need for the incinerator to have walls capable of withstanding the high temperatures associated with rubber incineration (about 2000 °C);
- The need for elaborate pollution control equipment on the exhaust stack to minimise particulate and sulphur dioxide emissions;

Evaluating these problems has resulted in the development of a new generation of incinerators costing approximately 10 times more than a furnace using liquid fuel. These incinerators have a large economy of scale and are extremely capital-intensive.

Partially to lower these costs, incinerators are often coupled with heat boilers, which generate steam and electricity. In Europe, steam from incinerators is frequently used in residential district heating or is linked to adjacent industrial installations that use process steam in their manufacturing operations. In North America, the generation of electricity is more common (although the electric generating equipment makes the installation still more expensive), in particular due to the large distance between industrial and residential areas, and because there is greater acceptance of private electric generating installations supplying power to the grid.

5.3.1 Processes

There are several design parameters in incinerator technology of particular relevance to tyres. The main objective is to guarantee complete combustion since this results in the greatest volume reduction, the maximum energy extraction and the least air pollution. Complete combustion depends on an adequate and uninterrupted air supply; some form of agitation to ensure that new tyre or rubber surfaces are continually exposed to heat, flame and air, and the provision of two distinct heat-level zones, a primary burning zone for complete combustion of solids and liquids, and a secondary zone for combustion of gases and airborne particulates. The two zones need not to be separated, but if they are, the second zone acts as an afterburner. There are currently five approaches which have been used to achieve rubber combustion. These are:

- cyclone combustion
- direct kiln burning
- fluidised bed combustion
- starved air incineration
- water tube boilers

i Cyclone Combustion

The first commercial furnaces designed specifically for tyre combustion were based on the cyclonic principle. This involves, as its name implies, the production of a rapidly spinning column of hot gas similar to the natural phenomenon of the meteorological cyclone. The centrifugal action of the spinning gases creates a vortex of very high temperature (anywhere between 800 and 1500 °C), through which the products of combustion are cycloned. This pattern of combustion replaces the need for secondary after-burn stages.

ii Cement Kiln Burning

Cement kiln burning is a direct method of processing tyre waste. The products of combustion are absorbed by the process, due to the extremely high temperature (1500 °C) generated in the kilns. This form of disposal is on the increase in the USA.

iii Fluidised Bed Combustion

Fluidised bed combustion offers a good theoretical technical solution, but only limited trials have been undertaken to test tyre combustibility. One problem is that the steel wires become entangled in the ash handling systems. Since the equipment is very expensive and capital-intensive, it is likely to be viable only on a large scale.

iv Starved Air Incineration

Despite the earlier use of cyclonic furnaces, work in the early 1980's seemed to favour starved air systems for the combustion of tyres. This is somewhat akin to a partial pyrolysis approach, where adjustments to the air flow and fuel feed can produce different quantities of combustion gases and liquid and solid products. The requirement for tyres to be shredded in a pre-processing stage has led to a less favourable view of this method, which is also capital-intensive.

v Water-tube Boilers

Industrial boiler systems have enabled scrap tyres to be utilised further as a fuel. Inclined chain grate stokers have been altered to take tyres as feed. Supplemental air is introduced at the back of the boiler to redistribute the combustion pattern in the hearth and prevent the flames spreading back to the entrance of the furnace.

5.3.2 Economies of Scale

The main problem with incinerators is economy of scale limitations. Furnaces are built to handle at least 80 tyres per hour (500-1000 kg), or a minimum of 600,000 tyres per year (based on continuous operation). Equipment of this size is expensive, and only large installations could provide the equipment and the operating supervision necessary to avoid pollution.

5.3.3 Economic Implications of Steam Production

Most operating tyre incinerating installations were motivated more by a need to dispose of tyres in an environmentally acceptable way than by an interest in developing a new enterprise. Energy recovery in these installations can lower the operating costs, but it is clearly an activity of secondary importance. If energy extraction is to be viable, it must be matched with on-site or immediately adjacent industrial users with a continuous steam demand.

Despite the ready availability of tyres, a study by Goodyear, the USA tyre manufacturer, estimates that, in terms of overall cost per unit of heat output, tyres are 40% more expensive than coal as a fuel. This is due to two main factors:

- The overall efficiency of tyre furnaces is only 30%, compared to about 60% for coal furnaces;
- The operating costs (storage, handling, preparation, pre-processing, and emission control) are more than 50% higher for tyre furnaces.

Goodyear estimates, however, that the overall costs per unit of heat output from tyres is 18% cheaper than from gas and 43% cheaper than from oil.

5.3.4 Environmental Implications

As a means of waste disposal, incineration is very efficient. However, it is important to ensure that secondary wastes (ash, air emissions and waste water) cause a minimum of ecological damage. The air pollution problem is basically the same as that encountered in coal furnaces. With straight incineration, the hot gasses are quenched with water to remove particulates. A combination of scrubbing and chemical treatment removes sulphur dioxides. Waste water is neutralised and treated to remove particulates before discharge. In some steam-generating plants, the hot gases are first passed through a hot electrostatic precipitator before passing heat boiler for heat recovery. In others, the electrostatic precipitator is not required because the gases are scrubbed and treated chemically after exiting from the waste heat boiler. Residual ash is disposed of.²

There is a continual debate in industrialized countries as to whether incinerator ash should be treated as a domestic or hazardous waste material. In most cases this debate is resolved by requiring regular testing of the ash for metals and other contaminants. Ash that meets the standards may be landfilled in an ordinary landfill for municipal solid waste, while ash failing to meet the standards must be taken to a hazardous waste treatment facility at a much higher cost.

5.3.5 Conclusions

Modern (rubber) incinerators with heat recovery are capital-expensive installations, whose environmental safety depends on the quality of their pollution control equipment. Incineration as an economically viable option for recovery of rubber is only possible where there are good supplies of waste tyres, and the demand for electricity is high. In an industry such as tyre production or retreading that has a continuous demand for steam and produces large quantities of waste rubber, an incinerator could be a viable option.

The economic feasibility is also largely dependent on disposal costs of waste rubber. When disposal costs are high, waste rubber producers will be willing to pay the cost of transporting their waste tyres to the incinerator. The minimum scale on which it is possible to recover heat on an economically feasible scale and in an environmentally safe way requires an investment in the order of US \$1,000,000 and a throughput of about at least 80 tyres (500-1000 kg) per hour 24 hours per day. Smaller scale incinerators cannot achieve the high temperatures required for a clean burn, and treatment of exhaust gases and pollution control will be too expensive.

The employment generated by incineration occurs mainly in the collecting and transporting of the tyres. Incineration itself requires only a few operators.

When less attention is given to environmental factors, selling rubber as fuel for small scale heat production is economically feasible. In Karachi Pakistan cuttings from tyres are being sold as fuel at US\$25-40/ton.

5.3.6 Options for Small Scale Recycling Activity

Neither chemical nor thermal recovery of tyres lends itself to small-scale applications. Not only is the technology capital-intensive, but it is only viable at relatively large throughputs. For combustion, economy of scale issues are complicated by the need for an economic return.

Given all of these factors, the smallest scale option would be a steam boiler with waste rubber incineration on the site of a plant, such as a rubber factory or a retreader, with a constant demand for steam. A small incinerator would have to be developed that would be able to withstand the high temperatures, have a controllable oxygen injection system, and prove capable of meeting local and/or international air pollution standards, either with conventional equipment or through the use of filters. Feasibility depends on the availability of a constant supply of rubber wastes at a low, null, or negative (payment of a tipping fee) price, as well as on incineration efficiency compared to other fuels like wood, coal and oil. This option is of limited relevance for micro and small enterprise development in developing countries.

CHAPTER 6 THE CONTEXT FOR SMALL SCALE RUBBER PROCESSING

The September 1994 plague outbreak in Surat, India, showed that an inadequate waste management system can have a grave impact on the health of the population of densely populated cities. The impetus for municipal authorities in economically less developed countries (elc's) to provide and improve services is thus frequently motivated by a well-meant intention to prevent disease and improve living conditions.

Problems arise when these Southern municipal authorities, frequently supported by donors and financing institutions, attempt to recreate the typical waste management systems from the North. There are three important problems with this approach. First, Northern nations are far from having solved their own waste management problems, and most Northern operating systems, even if they give the illusion of being technologically and institutionally sophisticated, are transitional or hybrid attempts to stem the effects of what has basically become an insoluble problem. Furthermore, the most successful waste management systems in the industrialized world are not usually the ones with the most expensive or newest technology, so that attempts to identify and replicate the 'state of the art' are bound, almost by definition, to go looking in the wrong place.

Secondly, even if there were good systems to copy, the waste stream in elc's differs significantly from that in a typically industrialized country, so the technical aspects of waste handling have to be transferred and adapted with care.

Thirdly, and most importantly for this publication, the existing waste handling infrastructure in elc's is significantly different than that in the industrialized world. Major change in waste handling systems has a far greater potential to disrupt this infrastructure, displacing the literally tens of thousands of people who make their living from it.

The purpose of this chapter, therefore, is to establish the institutional and economic context for the development of rubber recycling systems in the elc's. To this end, the roles of actors other than the municipality in the field of solid waste recycling are highlighted, with an emphasis on non-governmental (e.g. women and welfare) organizations and small enterprises.

6.1 Employment in Recovery

Retaining value added in rubber tyres, tubes, and conveyor belts is generally a labour intensive activity, as can be seen from the case studies in Chapter 7. Because of its labour-intensity, recovery of rubber, even in the relatively small quantities in which it is generated, offers significant potential for employment consistent with sustainable development goals.

Recovery, recycling, and reclamation is already a major source of livelihood for thousands of citizens in the South, most of whom operate in the unrecognized grey area known as the informal sector. Asian cities have extensive 'waste economies' structured around itinerant waste buyers,

waste pickers, small waste shops, second-hand markets, dealers, transporters and a range of recycling industries. A study of the recycling practices in Bogota, Colombia, estimated that waste or recycling is the principle income earning activity for between 30,000 and 50,000 people. These people are engaged in the collection, transportation, and processing of urban waste; in terms of value added, they are reclaiming value added from products and materials whose value is no longer recognized by those who have discarded them into the waste stream.

Large numbers of 'working poor' have unrecognized, marginalized livelihoods concerned with producing valuable goods and services associated with the recovery of waste materials and their production into intermediate industrial materials or finished goods. Informal sector activities are generally neither recognized, recorded, protected nor regulated by public authorities. These waste handlers can be roughly divided into three groups:

Formal waste collectors and processors

- Municipal workers paid to engage in waste collection, street cleaning, waste disposal and sanitation activities
- Workers in the formal private sector paid to engage in waste collection, street cleaning, waste disposal and sanitation activities
- Municipal governments levying taxes to households, companies and institutions, and using the income to pay for waste collection, street cleaning, waste disposal and sanitation
- Businesses involved in formal sanitation and/or recovery activities as an income-producing activity under contract to individuals, other businesses, or municipal authorities

Informal waste collectors and processors

- The largely invisible group of scavengers, waste and street pickers, dump pickers, and the like, who recover the waste from the waste stream
- Itinerant waste buyers, processors, and brokers who collect valuable waste materials, increase their value added through separation and small-scale production processes, and resell the items either to brokers or individuals.
- Small-scale entrepreneurs who perform a broad range of services ranging from repairing broken items to using discarded materials as the basis for manufacturing new products.

The grey area in between:

- Municipal workers such as garbage truck personnel and street cleaners who make private deals to sell their collected waste to intermediary traders.
- The small and micro enterprises processing the waste materials in more or less established workshops, sometimes provided with electricity, perhaps at an illegal site but paying rent to a landlord.
- NGOs and CBOs which, on the basis of their humanitarian welfare missions, try to improve the circumstances for waste and dump pickers, and nowadays aim increasingly at stimulating the development of income generation projects for their target groups. From this standpoint they try to secure waste collection agreements with municipal services and private persons.

For rubber recovery, it is primarily the last two groups which are of interest. Rubber materials, specifically tyres, tubes, and conveyor belts, are not normally generated as part of the mixed municipal waste stream. While some tyres are disposed by individuals, these are not usually mixed up with other domestic waste. Tyres and tubes are generated in far greater quantities by

tyre and automotive shops. Conveyor belts are almost exclusively generated by the industrial sector. For this reason, rubber recovery tends to be a relatively specialized activity, dominated by small entrepreneurs, and predominantly male.

6.2 Networks

Networks of organizations and individuals involved with waste and recycling have the potential to strengthen the position of waste workers considerably. The following description of a network in Bangalore, India includes a number of aspects typical of networks in non-industrialized countries.

The collection and recycling of urban solid waste is done by an extensive network of actors, who pick, collect and transport the waste materials, who deal and wholesale separated and selected materials to small recyclers or large industries. The links between these informal and formal-sector actors are illustrated in the figure 6.1 and are described below.

Waste produced by different sources is partly collected by formal sector municipal street cleaners and garbage collectors, and partly as a result of the private initiative of municipal waste collectors, and the activities of the informal sector waste pickers, dump pickers and itinerant waste buyers.

Waste from households and small enterprises is collected by the municipal cleansing department through their regular service in a limited part of the city, or by private collection firms. Intermingling with these services are the municipal workers who sell part of the waste they collect to dealers who have their shops near a dump, and the itinerant waste buyers collecting waste from door to door. Larger industries usually recycle the major part of their own post-industrial waste in their own plant. They know the composition of the waste and are able to recover it before it becomes contaminated with other waste materials.

Recovery in Bamako, Mali also has the form of a network. The network 'scouts' are teenage buyers and sellers who have left school and choose to collect instead of getting a formal job. These collectors are usually capitalised by their parents.

The network also includes semi-wholesalers, who buy and sell intermediate products, such as rubber chunks or crumb rubber. The actual production is done by producers specialised in specific types of recycling. These are usually either blacksmiths or craftsmen. The final step in the recovery network is the consumers of finished products, who choose to purchase in the low-grade market, rather than purchasing the equivalent goods produced by the formal manufacturing sector.

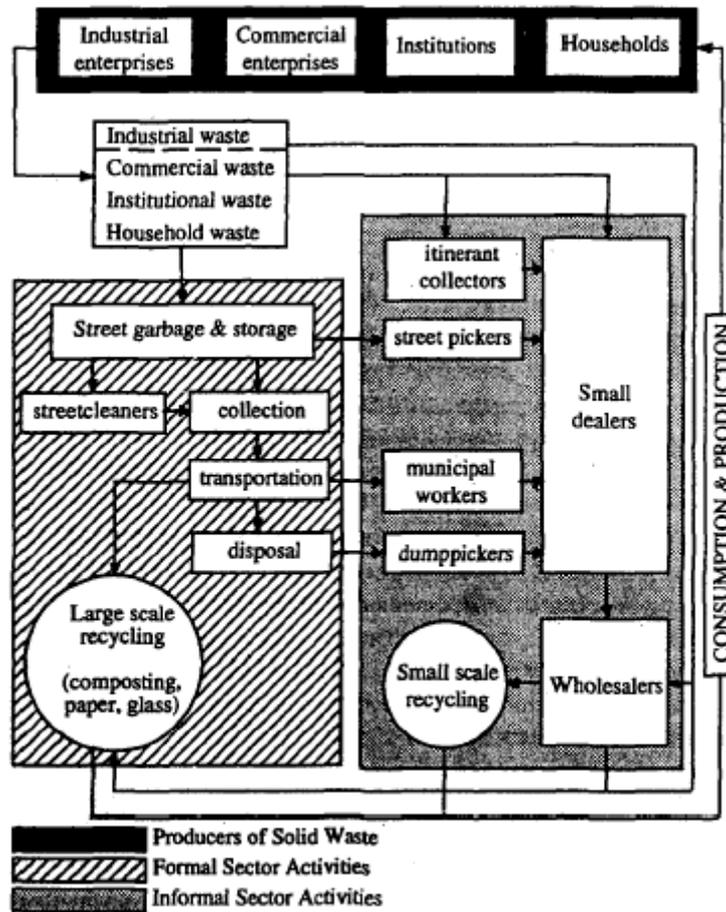


Figure 6.1 Interlinkages between formal and informal recovery, re-use and recycling of solid waste.

Source: Baud, 1994.

6.3 The Role of NGOs

Non-governmental Organisations (NGOs) have a relatively important role to play in the catalyzing of change in developing countries. Frequently, the presence and/or interest of an NGO can lend credibility to an activity which would otherwise remain unrecognized and marginalised.

During the UN Water and Sanitation Decade (1981 - 1990), the concept of community participation as a means to the improvement of water supplies and services proved to be so critical that the decade's goals could only be achieved through involving communities in the management of their own water and sanitation services. The emphasis in this period shifted from the seeking of community assistance to supplement government initiatives, to an appeal for government assistance to supplement community initiatives. A similar approach can be applied to urban solid waste management. The role of the community - in particular, the women and children in the community - is as the heart of many informal waste recovery systems. Although tyre and rubber recovery enterprises are somewhat specialized and predominantly male, appropriate NGO intervention is quite likely to have a significant positive effect on development of sustainable systems. The example of NGO participation in the case of the Calcutta Ragpickers

illustrates the ways NGOs can involve themselves to improve the lives and working conditions of poor people.

Box 6.1. The Ragpickers of Calcutta

In recent years Calcutta (12 million inhabitants) has seen enormous growth caused by a migratory influx from rural areas, natural growth, and politically motivated migration. Between two and three million people live in so-called 'shanty towns', and many earn their living by scavenging, or 'rag picking'. There has never been and still is not enough legal and formal work for the large numbers of newcomers, and this form of livelihood provides important subsistence income for upwards of 60,000 people.

During the 1980s, the Calcutta municipal government developed ambitious master plans for the squatter communities, including planning for sewage facilities and water supplies; the improvement of 'slums'; the purchase and deployment of waste collection trucks; and siting community refuse bins throughout the town. Like many such plans, it considered mostly only the formal public and private recovery activities, and left the economic life of the slum dwellers and squatters almost completely out. Although an occasional economic programme was set up to provide small loans for 'slum entrepreneurs', this programme was limited to the small fraction of legal residents (non-squatters) who already had secured certain legal rights such as Trader's Licenses, Ration Cards etc.

In recent years, this has shifted, and both public sector planners and donors, among them UNICEF, have started paying attention to the large numbers of women and children among the rag pickers. The majority of slum and squatter families depend on some kind of child labour, whose income adds to the family subsistence income base. Often these children are working in hazardous and noxious industries, putting their health in jeopardy, in technical violation of the Prohibition and Control of Child Labour Act. Yet if this Act were rigidly applied, thousands (estimated 70,000) of young boys and girls living in the slums and squatter colonies would be restricted from employment, putting their survival and that of their families at risk.

Source: Mukherjee, 1993

Although certain NGO interventions are designed to get children out of waste work, the alternative approach is of more relevance to rubber recycling enterprises. It involves organizing the children in their waste work, largely through developing alternative working methods. This legitimizes waste picking and gives it the status of a trade in which money can be made. Related activities undertaken by NGOs include informal education, vocational training and job placement, issuance of identity cards to protect children from police harassment, giving children access to health and nutrition programmes and hygiene education, and in some cases even the setting up of 'non-exploitative shops' to protect the children from exploitation by traders and to train them in entrepreneurial skills.

6.3.1 NGOs and CBOs in Solid Waste Recycling

Apart from their role as advocates for women and children, both Non-Governmental Organizations (NGOs) and Community based Organizations (CBOs) are involved with waste issues in a wide variety of locations and on a number of different bases. This involvement ranges from advocacy, to political intervention, to providing financing, to direct engagement in waste collection and recycling-related income generation activities. Some examples include:

Waste Wise, an NGO in Bangalore, India, has set up a pilot project for composting of household waste by waste pickers in a specific area. They have also created several small workshops which

process other waste materials. Discussions were held with households, waste pickers and dealers, the Bangalore Corporation, and the ward office and the Housing and Urban Development Authority. Households were issued with baskets for dry waste materials, and they pay a fee (US \$ 0.16-0.30) for waste collection. The organic matter was composted in the park to show residents what became of their waste and to show people how including non-organic matter hinders the composting process.

In Nairobi, the Undugu Society of Kenya, an NGO working with street children for more than 20 years, has been running the so-called Machuma schools. Street children who are taken care of by the organization attend morning classes in basic education, including the ordinary school subjects besides practical exercises; these are adapted to be suitable for the street children. In the afternoons the children continue with their regular work, collecting scrap metal to sell to scrap dealers.

In Manila, the Philippines, two examples show the growing interest and importance of community based groups in waste activities; the so-called Balikatan (Women) Movement involved with waste pickers and junk dealers (Linis Canda), and the activities of a middle class CBO, the IRREN Foundation. In the first case, eight previously established junk shop dealers work with 62 push-cart boys supplied with identity cards, uniforms and push-carts paid for by both the project and the junk dealers. The Balikatan Movement held an educational campaign in the area, distributing information at schools and community groups; they also facilitated loans to junk shop dealers and organized collection of materials which had previously gone unrecovered, including rubber scrap. Now 60% of the 18,000 households in the area participate. The push-cart boys are no longer harassed by the police, and the recovery rate has gone from 10% of solid waste to 35%. Initial cooperation from City officials was critical to the successes that marked the project's early stages; this support has cooled with a succeeding administration.

IRREN, a group of middle-income residents, has set up a collection scheme and a 'redemption centre' in their neighbourhood. Various waste materials are collected separately and stored in a redemption centre near an important 'exit road' of the neighbourhood. The waste materials are regularly collected by itinerant waste buyers, who earn their living from these materials.

6.3.2 Women and Waste

In addition to working with (street) children, several community organizations and NGOs in cities in India are working with women waste pickers. Their goals are to increase women's income levels, reduce their work burden, and improve the working conditions by mitigating the occupational health hazards associated with picking from the streets. Although rubber recovery is generally dominated by men, the activities of these types of organisations may nevertheless have relevance for its increasing development. Activities of NGOs that have become involved with women paper waste pickers include the following:

- Arranging exclusive access to waste paper from commercial establishments, government offices and to dry waste materials from residential areas.
- Opening non-exploitative waste buying shops to increase the income of the women waste pickers.
- Organizing the women waste pickers to form a cooperative and to sell the material directly to a dealer to increase the margin they obtain.

- Uniting the waste pickers to fight against the vested interests of private contractors and government officials, to bargain for higher prices, better working conditions and to seek solutions for other social problems they face.

These attempts have met with varying success, and both success and failure are instructive for future efforts in other areas in terms of organizing women and small entrepreneurs. Increasing the sources through making contacts may be time-consuming and detract from direct income-producing activity. Institutionalizing an activity may open the door to competition from better-equipped or more influential social actors, and may end up taking the source of income away from the very people it was intended to help.

In addition, maintaining an enterprise such as a waste buying unit, which is known to be under the auspices of a 'women NGO', faces on an institutional scale the same type of gender barriers that women face in their daily lives. Examples of these barriers include:

- Lack of finances or land constraints
- Discrimination related to the women's gender (and caste)
- Husbands who try to pressure their wives to stay away from 'awareness and educational' activities related to the role of women
- Confusion about the role of the NGO, which is cast by the waste pickers as their employer: thus the NGO staff members find themselves spending a lot of time and energy on the administrative and financial activities the shop
- Buyers and wholesalers who boycott such initiatives because they consider it as a threat to their business
- Lack of support from the government, and the negative societal perception of waste and (women) waste workers, which leads organizations to start projects to 'rehabilitate' women waste pickers by placing them in other occupations.

However, in general the experience is that NGO interventions leading to increasing organization among waste workers have a beneficial effect. In Colombia, 84 groups of recyclers have joined together to create the National Association of Recyclers (ANR)

Since its establishment it has protected and defended the interest and the rights of all recyclers in the country and promoted national policies to the interests of the union.

6.4 Small Waste and Rubber Recycling Enterprises

An important set of informal sector actors consist of small and micro-enterprises which process waste materials. These businesses are generally unregistered and unlicensed, and operate under conditions that differ greatly from those in the medium- and large-scale formal sector recycling industries.

The dividing line between the formal private sector of a country and its informal sector may be difficult to determine. Although there is still no generally accepted definition of the term 'informal sector,' this publication follows the International Labour Office (ILO), in using the term 'informal sector' to refer to very small scale units which typically:

- Produce and distribute goods and services
- Consist largely of independent, self-employed producers

- Sometimes employ family labour and/or a few hired workers or apprentices
- Operate with very little capital, or none at all
- Utilize a low level of technology and skills
- Therefore operate at a low level of productivity
- Generally provide very low and irregular incomes
- Are for the most part unregistered and unrecorded in official statistics
- Have little or no access to organized markets, to credit institutions, to formal education or training institutions
- Are not recognized, supported or regulated by the government
- Are almost invariably beyond the pale of social protection, labour legislation or protective measures at the workplace
- Are generally unorganized and in most cases beyond the scope of action of trade unions and employers' organizations

Although these characteristics are generally associated with the informal sector, in practice this sector manifests itself in many different ways. Production, processing and/or manufacturing facilities are greatly influenced by circumstances and commercial characteristics of the country in which they are actually operating.

Despite considerable local variation, the characteristics of the informal sector listed here tend to obtain for most small and medium-sized rubber repair and/or recycling enterprises. Several examples are presented below.

Box 6.2. Sme's in Rubber Recovery in Calcutta

In Calcutta, India, waste rubber is generated in households, petrol stations, and automotive shops. Housewives sell small rubber articles, especially chappal (sandal) straps, to itinerant dealers. Specialised dealers purchase truck and heavy equipment tyres in bulk, for resale to manufacturers. About 90% of the waste rubber is returned via recovery networks to the formal sector tyre manufacturers, who reduce it to crumb and reclaim used in their manufacturing processes.

About 40 small and micro-enterprises are involved in secondary manufacturing of the remaining 10% of the rubber waste, not including those involved in making chappals. Most of these enterprises process four to six tonnes per month. Their activities include shredding and granulating the rubber for reuse into small wheels (for wheelbarrows and tricycles), bicycle pedals, and vibration absorbers.

Chappal strap recycling is a specialised activity, where the straps are colour-coded and reused into new rubber sheeting (to be cut into new straps) in a low-tech, largely manual process.

Source: PTR, 1992

Box 6.3. Sme's in Rubber Recovery, Bamako, Mali

In Bamako, Mali, the recovery of tyres is accomplished by small entrepreneurs who pay standard prices for bicycle, passenger vehicle, and heavy equipment tyres. They then sell these tyres to professional recyclers, who are primarily involved in three types of activities:

- the separation of steel wires (through burning) to make springs, nails, and metal clips;
- the use of the tyres as fuel for stripping paint;
- primary recycling of the tyres in cutting shons which cut the tyres into pieces which can be sold to

craftsmen and small secondary manufacturers.

Source: GERAD 1994

Box 6.4. Informal Sector Rubber Recovery, Manila, the Philippines

In Manila, the Philippines, street scavengers are the first actors in the tyre recovery chain: they collect the tyres and sell them to traders for retreading, or to backyard micro-enterprises for secondary production. Tyres which are suitable are retreaded, and the buffings (resulting from this process) is considered valuable, and are exported to Taiwan.

Small backyard entrepreneurs may produce rubber wheels, doormats, garbage containers, plant pots, rubber bushings, engine supports, or footwear. Nylon cord and steel wires are also separated and used as weaving materials or for baling.

Source: CAPS, 1992

Rubber recycling in developing countries tends to be the province of small and micro-enterprises (sme's). Activities performed by these sme's range from repairing punctures to regrooving, retreading, and numerous forms of secondary manufacture. These enterprises tend to cluster at the top of the recovery hierarchy, which means that they are recovering the retained value added in the tyres and tubes. Most enterprises are either performed in the open-air or in small buildings, sometimes associated with related formal-sector businesses, like garages.

Micro-enterprises tend to be owner-operated, with one to three (male) employees. Little investment is generally required for start-up, and the cost of the raw materials (tyres or tubes) remains low. The skill level varies, but in most cases techniques can be easily learned by new entrants. Retreading and regrooving, both of which are small (8-15 employees), rather than micro-enterprises, combine a retention of value added with operations that add new value. Both require a substantial investment in equipment and some level of technical sophistication.

CHAPTER 7 ECONOMICS OF RUBBER RECOVERY

Chapters 3, 4 and 5 deal with the different technical approaches which can be used to recover products, materials, and energy from tyres, tubes, and conveyor belts. Information in these chapters illustrates the range of technical sophistication and capital intensity associated with different approaches to rubber recovery. There are simple processes which require only hand tools and can be performed by semi-skilled crafts people in the open air. Intermediate approaches require electricity, basic machinery and tools, and therefore require some sort of protected shelter or workshop. There are also large industrial facilities with complex plants, which are clearly out of the reach of small entrepreneurs.

For each of these enterprise classes, the level of skills, the intensity of capital investment and the kind and quality of products differs. This affects the financial situation of the enterprise as much as the economic environment in which the enterprise operates does.

Section 7.1 describes the economic environment in which rubber recovery enterprises in developing countries operate and discusses the benefits of the sector to the economy. Section 7.2 present the framework for business-economic analysis of rubber recovery activities, comprising a profit and loss statement and a number of ratios. Section 7.3 presents three case studies of rubber recovery enterprises in Mali, Egypt and India respectively. In section 7.4 a financial/economic analysis of the cases is conducted and the cases are compared with respect to financial ratios.

7.1 Economic environment of the rubber recovery sector

The waste recovery sector in developing countries has the potential to 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 the public health. Improved recovery processes reduce the amounts of waste materials that have to be collected and disposed of by the municipal service, and thus the costs of municipal waste management. Also, the reduction of the volume of waste accumulated in the street is likely to result in a reduction of the risk this poses to public health.

The scale and type of resource recovery in economically less developed countries differs fundamentally from this sector in industrialized countries. For some waste materials, including rubber, this sector is larger in terms of the number of enterprises and persons involved than in industrialized countries. Some of the characteristics of the market in which recycling enterprises in less developed countries operate are listed below:

- Recovery activities result in the retention of value-added in the recovered products and materials. The investment of labour and capital captured in these products and materials is thus conserved, providing economic benefit to the society.

- Resource recovery in economically less developed countries is dominated by informal sector entrepreneurs. A large number of traders and reprocessors have managed to set up feasible businesses that generate reasonable or high profits.
- One of the prime factors that determine the feasibility of waste recovery is the price of the virgin material. The price of the recovered material is equal to the price of the virgin material less a reduction for a difference in quality. Therefore, fluctuations in the price of the virgin material have a direct impact on the price of the recovered material. This makes the waste recovery sector very dependent on developments on the world market for the virgin material.
- Virgin materials often have to be imported, are therefore relatively expensive and consume foreign currency. The use of recovered waste materials as industrial inputs for the formal sector relieves this financial burden for the enterprises concerned as well as for the economy as a whole. Rubber processing in particular can substitute for import of bituminous or oil-related materials, and thus can, over the long term, have a positive effect on the country's balance of payments.
- Labour costs in economically developing countries are low. Also, because of high unemployment rates, there is very little opportunity for income generation in the formal sector. Therefore, the informal waste sector provides employment for many people, although it is often the activity of last resort in their daily struggle for survival. This means that the normally labour-intensive processes associated with the recovery of waste materials, such as collecting, washing and sorting waste, become financially feasible. The dark side of this is that incomes are usually minimal, and working conditions often appalling.
- Consumer products made of or containing recycled materials generally have a lower quality than products made exclusively of virgin material. However, the market for the low-cost consumer items made of non-virgin materials is extensive, in the first place, because there are large numbers of low-income consumers, who cannot afford the higher priced virgin-made products. Secondly, the products made of recycled materials can meet the quality standards required by this group of customers.

In economic terms, these small-scale producers are operating in a completely different market and supplying products for a completely different demand than the producers in the formal sector. This otherwise unsupplied market is nevertheless a form of productive economic activity whose existence can be attributed to recycling in the informal sector, and to the availability of secondary materials at low cost.

- Regulations and quality standards for recycled products are largely or completely lacking. In the industrialized countries, such 'inferior' quality products may not pass standard quality tests, but in less industrialized countries they are tolerated.

Although the specific economics of rubber recovery differ per individual enterprise, the economic and social factors listed above may be a source of benefit in any particular situation. The justification to promote or support the development of rubber recycling may be based on these factors.

7.2 Framework for Financial Analysis

The financial and economic aspects of waste recovery activities have hardly ever been adequately documented. However, this report contains three case-studies of small waste recovery enterprises regarding waste recovery. These enterprises are analyzed on their profitability and how vulnerable they are with respect to fluctuations in the market. For this purpose the following format is used:

Profit and Loss Statement

- Gross sales price of the product or service
- Sales commission to traders
Net sales price of the product or service
- Purchase price of the waste material
Product margin
- Cost price of other material inputs
Value added
- Costs of labour (based on the # of labourers)
Gross profit margin
- Cost of depreciation (based on investments) and rent
Net profit margin (before interest)
- Costs of interest
Net profit margin (after interest)

A number of financial/economic ratios can be derived from such a Profit and Loss Statement. In this report, the following ratios are used in the analysis:

1. Investment per labourer =
 $\text{capital invested} / \# \text{ of labourers}$

This ratio shows whether the production process is capital intensive (high ratio) or labour intensive (low ratio).

2. Value added per labourer =
 $\text{value added} / \# \text{ of labourers}$

This ratio gives an indication of the income generation capacity of the enterprise. The higher the ratio, the higher the income that is generated by each employee.

3. Return on investment ratio =
 $\text{annual net profit margin} / \text{capital invested} * 100\%$

What eventually remains after all the costs are deducted is the net profit. The return on investment ratio relates this profit to the money invested in the activity, and is therefore the most suitable indicator to assess the degree of profitability. The percentage should be compared with the rentability (profitability) of other investment possibilities in order to assess whether investing in other opportunities should get a higher priority. In general, the ratio should be in the range of 10 - 15% for developing countries.

4. Net profit to minimum wage ratio =
annual net profit margin / annual minimum wage

This ratio relates the income of the owner of the enterprise, *i.e.* the net profit, to the minimum wage rate. It puts the reward that the entrepreneur gets for his venture into perspective. In the North this ratio ranges from 2-10 for small enterprises. However, it should be considered that minimum wage rates in the North are relatively higher and are more based on meeting basic needs, than in the South. Therefore, a ratio between 10 and 30 is not uncommon for countries in the South.

5. Net profit ratio to sales ratio =
net profit margin / sales price * 100%

The net profit ratio assesses the vulnerability of the profit with respect to sales price fluctuations. The smaller the ratio, the higher the vulnerability. This is obvious because, in that case, a small decrease in the sales price can result in a losing business.

6. Secondary quality ratio
price of secondary product or material / virgin price * 100%

This ratio shows the price gap between the secondary and the virgin product or material. This gap can mainly be explained by differences in quality, although other factors like perceptions of customers may have an impact too. The higher this ratio, the better the prospects are for recovery activities.

7.3 Case Studies of Small-scale Rubber Recovery and Recycling

The cases in this section attempt to show three different levels of rubber recovery enterprises in a range of approaches to rubber recycling. The purpose here is not comparison *per se*, but rather to show, within each case, the social and economic factors which contribute to the viability of small enterprises.

7.3.1 Rubber Recovery in Bamako, Mali

In Bamako, Mali, several workshops exist which recover the rubber material from tyres for production of secondary products. Rubber is manually re-worked by hand to make animal traction harness, rubber seat springs, shock-absorber bushings, V-belts for grain mills, sandals, and similar products etc. All products can be manufactured by hand using hand tools.



Figure 7.1. Bags Made from Inner Tubes, Bamako, Mali.

Source: GERAD



Figure 7.2. Gaskets Punched from Tyres, Bamako, Mali.

Source: GERAD



Figure 7.3. Cords from Waste Tyres, Bamako, Mali.

Source: GERAD

Each of these workshops is run by one owner-craftsman who employs a few labourers and/or apprentices. The next table gives insight into the profitability of the workshop with a capacity of handling 20 waste tyres per week, which equals approximately 2,000 kg of rubber.

Table 7.1. Profit and loss statement per ton of waste rubber for a rubber recovery workshop in Bamako, Mali, 1991 (prices in US\$).

	US\$/ton waste rubber	Description
Sales revenue of secondary products	34.63	900 kg of harnesses, seat springs, bushings, V-belts, sandals against a sales price of US\$ 0.035 per kg
Purchase price of rubber waste	13.30	10 tyres of 10 kg per week @ US\$ 1.33
<i>Product margin</i>	21.33	
Other materials	0.73	fuel

<i>Value added</i>	20.60	
Cost of labour	10.50	3 working days for: 1 owner/craftsman @ US\$ 2.5 per day 3 apprentices @ US\$ 0.33 per day
Taxes and fees	1.23	Municipal tax 1.15; Cooperation fee 0.07
<i>Gross profit margin</i>	8.87	
Cost of depreciation	1.03	Simple hand tools (hammers, pincers, chisels, anvil, bellows, forge) and self-made shed, investment US\$ 320, life time 3 yrs or 310 ton waste rubber
<i>Net profit margin</i>	7.84	Before interest

Source: GERAD, 1994

Table 7.1 shows a net profit of US\$ 7.84 per ton of waste rubber per week. With a capacity of 2 ton per week, this equals an annual profit of US\$ 815, which is retained by the owner. This is a little bit more than the annual minimum wage rate of US\$ 750 (based on US\$ 2.50 per day), at which the owners' labour input is valued in the 'costs of labour' component. So, the owner has a total earning of just over twice the minimum wage rate from this business. However, interest payments and the workshop rent still have to be deducted. The cost price of making the secondary products is US\$ 26.79 (34.63 - 7.84) per ton of waste rubber. Note that the wages of the apprentices, i.e. US\$ 0.33 per day, are much lower than the minimum wage rate. If they would receive a minimum wage, the labour costs would increase with US\$ 19.53 (3 lab.* 3 days * (2.50 - 0.33)). In that case the net profit would disappear completely and a *loss* of US\$ 11.69 would be the result. Therefore, the conclusion is that rubber recovery in Bamako is only a profitable business because extremely low wages are paid to labourers.

7.3.2 Rubber Recovery in Cairo, Egypt

The second example presents a case in Cairo of a rubber waste recycling workshop where gaskets and rubber seals are made from tubes. In this workshop not only hand tools are used, but also electric and mechanical equipment, including a locally made 50-tonne hydraulic electric press and punching knives. In this workshop two people run the whole process, a skilled and a semi-skilled labourer. Table 7.2 shows the profitability of a workshop with a production capacity of 1,200 kg of waste tubes per week.

Table 7.2. Profit and Loss Statement per Ton of Waste Rubber for a Rubber Recovery Workshop in Cairo, Egypt, 1991 (prices in US\$).

	US\$/ton waste rubber	Description
Sales revenue of secondary products	720.00	960 kg of gaskets and seals, sales price of US\$ 0.75 per kg
Purchase price of rubber waste	500.00	1 ton of tubes @ US\$ 0.50 per kg
<i>Product margin</i>	220.00	
Other materials	25.00	fuel
<i>Value added</i>	195.00	
Cost of labour	62.50	5 working days for: 1 skilled labourer @ 7.5 per day 1 semi-skilled labourer @ 5.0 per day
<i>Gross profit margin</i>	132.50	
Cost of depreciation	7.17	50 tonne hydraulic electric press and hand tools, investment US\$ 4,300, life time 10 years or 600 ton of waste rubber
<i>Net profit margin</i>	125.33	before interest

Source: EQI, 1992



Figure 7.4 Cutting Inner Tubes into Elastic Cords, Cairo, Egypt
Source: EQI.

Table 7.2. shows a net profit of say US\$ 125 per ton of waste tubes processed, which makes an annual profit of say US\$ 7,500. However, the workshop rent and interest payments still have to be deducted. The wage rates are at a fair level, considering a minimum wage rate of US\$ 3.50 per day or 1,100 per year. The income of the owner is about seven times this minimum wage, which seems a fair remuneration. The cost price of making the gaskets and seals amounts US\$ 595 per tonne of waste rubber input (720 - 125), the costs of interest excluded.

7.3.3 Rubber Recovery in Calcutta, India

This case illustrates the economics of a larger workshop or small factory in which rubber waste (reclaimed rubber, waste rubber and rubber crumbs) is used as an input to produce secondary solid rubber moulded products such as rubber trolley wheels, pads and bushings. This case differs from the previous two, in which waste rubber is turned into secondary products without processing the rubber.

For the production of moulded rubber products, mechanized equipment and machinery is needed to mix the raw materials and to mould them under pressure and heat. Operation and maintenance of this equipment also requires skilled personnel. In this case the personnel operates in two shifts of ten hours each per day in order to use the equipment efficiently. The production capacity is 200 kilograms of waste rubber per day, or 60 ton per year. About 75% of the total raw material input is converted into products. This means that a raw material input of 1,000 kilograms of waste rubber and 560 kilograms of other raw materials results in 1,170 kilograms of secondary products. Table 7.3 evaluates the profitability of the workshop.



Figure 7.5. Sorting of Rubber Waste, Calcutta, India.

Photo: PTR



Figure 7.6. Mastication of Rubber Waste in Low-Cost Rubber Mixing Mill, Calcutta, India.

Photo: PTR

Table 7.3. Profit and Loss Statement per Ton of Waste Rubber for a Rubber Processing Workshop in Calcutta, India 1991 (prices in US\$).

	US\$/ton waste rubber	Description
Sales revenue of secondary products	702.00	1,170 kg of trolley wheels, pads, bushings @ US\$ 0.6 per kg
Purchase price of rubber waste	362.00	400 kg of reclaimed rubber @ 0.67/kg 400 kg of industrial rejects @ 0.20/kg 200 kg of rubber crumbs @ 0.07/kg
<i>Product margin</i>	340.00	
Other materials	110.20	560 kg of chemicals, clay, oils, consumables and whiting @ US\$ 0.16/kg fuel, electricity, water: US\$ 20.6
<i>Value added</i>	229.80	
Cost of labour	51.75	5 working days for: 2 supervisors @ US\$ 1.55 per day 4 operators @ US\$ 1.00 per day 5 helpers @ US\$ 0.65 per day
Cost of maintenance	6.60	
<i>Gross profit margin</i>	171.45	
Cost of depreciation	25.00	Mixing mill of US\$ 3,700; hand-operated moulding press of US\$ 1,500; moulds of US\$ 1,700; tables, scales, trimming tool together US\$ 600; Total investment US\$ 7,500, life time 5 years or 300 ton of rubber waste
Cost of rent	18.60	workshop
<i>Net profit margin</i>	127.85	before interest
Interest	11.25	16%/yr on average investment (US\$ 7,500/2) and working capita (US\$ 362.00 + 110.20)
<i>Net profit margin</i>	116.60	after interest

Source: PTR, 1993

Table 7.3. shows that a net profit after interest of US\$ 116.6 per ton of waste rubber is generated. On a yearly basis this results in an income of about US\$ 6,000 after interest or 7,540 before rent and interest. The latter is about thirty-seven times the minimum wage of US\$ 0.65 per day or US\$ 203 per year, which may be regarded as a relatively high income for the owner. The cost price of the secondary products is US\$ 585.4 (702 - 116.6) per ton of waste rubber, including the costs of interest.

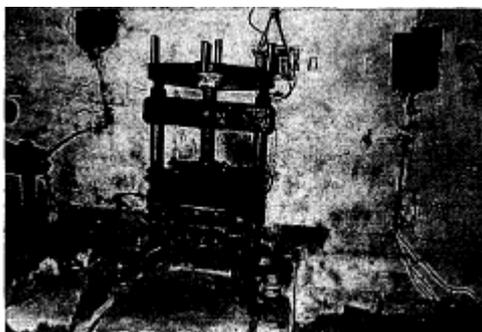


Figure 7.7. Low-Cost, Hand-Operated Electrically Heated Moulding Press for Wheelbarrow Tyres, Calcutta, India.

Source: PTR



Figure 7.8. Hand-Moulded Rubber Wheelbarrow Tyres from Recycled Rubber, Calcutta, India.

Source: PTR.

7.4 Financial and Economic Analysis of the Case Studies

The case studies give a sense of the level and variety of rubber recovery costs in small enterprises. There are obvious and significant differences between the three cases in terms of capital intensity, labour costs, availability of (raw) materials, skill levels of the personnel and pressure on the labour market, and costs of fuel and energy (this last is of increasing importance as the scale and reliance on purchased energy increases).

The specifics of the three cases are not directly comparable, but nevertheless they provide certain degree of insight into small-scale rubber recovery in general, and into these three types of recovery in particular.

The relevant financial ratios have been calculated for the three cases, and compared to each other. Differences and similarities cannot in all cases be fully or completely explained, since other factors lying outside the scope of research, such as regional and national economic circumstances, may differ.

7.4.1 *Virgin and Secondary Prices*

In all three cases, the entrepreneurs are paying for the input materials, but at a fraction of their value as tyres or tubes. In the Bamako and Cairo cases, the price paid is based on the tyres or tubes being a waste material. In the Calcutta case the price paid is for intermediate products which have already been through a recycling process.

Table 7.4. gives an indication of the relationship between the prices of secondary products and the virgin products they replace. These prices are reported as they were encountered during some field visits in Africa. They are not intended to show a representative, nor an average picture.

Table 7.4. Product Unit Prices for Virgin and Secondary Products in Africa in US\$, early 1990's.

Town	Secondary Product	Price virgin products	Price secondary products
Bamako (Mali)	animal traction harness	20.-	7.- (35%)
	seat springs	4.-	2.50 (63%)
	shock absorber bushing	17.-	4.20 (25%)
	V-belt	105.-	8.30 (6%)
Accra (Ghana)	engine seats	75.-	7.5 (10%)
	bearing housing	100.-	11.- (11%)
	suspension bushing	40.-	5.- (13%)
Cairo (Egypt)	general	-	- (30-50%)

Note: Parentheses indicate the secondary price as a percentage of the virgin price.

Source: AB&P/Ghana, EQI/Cairo, GERAD/Mali

Table 7.4. shows the wide range in the relation of prices of secondary products to virgin products. In Bamako secondary prices vary from 6-63% of the virgin price. Most likely the quality of the secondary products compared to the virgin product will account for the difference. Accra shows a stable picture with secondary prices being around 10-13% of the virgin counterparts.

The Table 7.5 relates the price of recovered, secondary materials to the price of the virgin material.

Table 7.5. Prices of Raw and Secondary Materials in Calcutta in US\$ per kg, 1991.

Material	Virgin	Secondary material (calculated per kg total material)	Secondary Material (calculated per kg rubber only)
Reclaimed rubber	-	0.40-0.80	0.80-1.60
Rubber crumbs	-	0.07	0.14
Synthetic Rubber	2.00		-
Natural Rubber	1.30		-

Note: One kilogram of reclaim or crumb contains about 50% rubber only.

Source: PTR, 1993

A comparison of the price of raw materials shows a similar picture: the price of reclaimed material is considerably lower than the price of the virgin material. This is certainly true for crumb rubber, in part because the secondary material has limitations that the virgin material does not. The price of rubber reclaim is substantially higher than the crumb rubber price and approximates the virgin price of natural rubber. The difference between it and the virgin price for synthetic rubber is larger.

Other Business Indicators

Other indicators of the financial conditions of the enterprises in the three case studies are summarised in Table 7.6.

Table 7.6. Business Indicators for Rubber Recovery Enterprises.

Business indicator	Bamako Mali	Cairo Egypt	Calcutta India
1. Total investment	320	4,300	7,500
2. Investment per labourer	80	2,150	680
3. Value added per labourer ratio	535	5,850	1,080
4. Return on investment ratio	255%	175%	100%
5. Net profit to minimum wage ratio	2	7	37
6. Net profit to sales price ratio	23%	17%	21%

Note: Net profit used in indicators 4, 5 and 6 is before deduction of the costs of rent and interest.

The total investment is the highest in the Calcutta case. This is obvious because this is an intermediate manufacturing enterprise in which rubber is moulded into secondary products. The Bamako case is a manual workshop in which little capital is involved. The Cairo case lies in between these two, and is a semi-manufacturing workshop. However, note that in none of the cases the investment in land is included, which may increase the capital investment dramatically.

The investment per labourer ratio gives an indication of the capital-intensity or, from a different perspective, the labour-intensity of the production process. In Bamako, the process is labour intensive, as expected for a handicraft enterprise. This results, on the one hand, in a low productivity (a low value added per employee), but on the other hand in a high profitability (a high return on investment). The high profitability ratio is present in all the three cases. It appears that capital invested in rubber recovery enterprises may be expected to generate a satisfactory return.

The semi-manufacturing Cairo workshop appears to be more capital intensive than the manufacturing Calcutta enterprise, the latter being relatively labour intensive. The reason is that in the Cairo case only two labourers are involved in contrast to the Calcutta case in which eleven labourers find employment. Subsequently, the value added per labourer is much higher in Cairo compared to Calcutta, which makes the former more productive. However, the difference in profitability between the two cases, indicated by the return on investment ratio, is not so striking, *viz.* 175% for Cairo versus 100% for Calcutta. The reason for this is that the labour costs, which are paid from the value added, are much lower in Calcutta than in Cairo. From the tables in the sections on Cairo and Calcutta it can be seen that the labour costs for eleven labourers in Calcutta (US\$ 52) are even smaller than for two labourers in Cairo (US\$ 63).

In other words, the enterprise in Calcutta can afford to be labour intensive and nevertheless make a good profit. This conclusion is confirmed by the net profit to minimum wage ratio. This ratio relates the profit to the local setting of labour incomes and therefore puts the profit more into perspective. In Calcutta the entrepreneur has an income that is 37 times the minimum wage rate, which is extremely high, but not abnormal in the Indian context. In Cairo this ratio is 7, still high, and for Bamako it is 2, which is a marginal income.

The vulnerability to sales price fluctuations, measured by the profit to sales price ratio, can not be characterized as high in any of the cases. The ratio lies around the 20% which means that the profitability of the enterprises is not endangered by minor sales price fluctuations.

CHAPTER 8 ENVIRONMENTAL EFFECTS OF RUBBER RECOVERY

There are three types of environmental effects associated with rubber tyres: first, the environmental effects (primarily neutral or negative) of disposal; secondly, the environmental impacts (both negative and positive) associated with recovery and recycling of waste tyres; and third, the effects on worker health and safety for those working in recycling enterprises. This chapter considers these three types of environmental impacts separately.

The environmental effects of discarding and disposal of tyres depend on the manner of disposal, and the degree to which environmental mitigation and control measures are taken. The environmental profile of recycling and recovery operations for rubber can affect the local and global environment in a number of ways. Choice of technology and scale of operations influence the environmental impact of recovery activities. In this chapter, the types of environmental effects associated with rubber recovery activities are discussed.

The purpose of this discussion is to review what is known about both types of potential effects, to assess the extent to which these are factors in economically less developed countries and to identify potential policy or technical activities which can improve the environmental aspects of recovery activities. It is not the intention either to quantify the environmental impacts or to associate these narrowly with specific processing technologies. In spite of this, the discussion of worker health and safety will, where possible, relate potential impacts to specific kinds of operations.

8.1 Negative Environmental Effects of Tyre Disposal

As is discussed in Chapter 1, the growing quantity and variety of rubber applications, together with shifts in tyre composition and technology, is creating a growing volume of waste rubber tyres; these are resistant to decomposition at ambient temperatures; are bulky and consume landfill volume; trap air and water when buried or discarded; and are associated with breeding of mosquitoes and other water-incubating insects and bacteria.

The rate of tyre disposal is growing in industrialized countries, at the same time that the rate of recovery of rubber from waste tyres is declining due to both economic and technological factors. Tyre recovery in industrialized countries is, therefore, usually recognized as an environmental benefit, as the case study of the Netherlands, below, indicates.

8.2 General Environmental Benefits of Recovery

i Conservation of Value Added

The process of manufacturing and adding value to materials has environmental effects at each step in the production process. Thus there are environmental impacts from making rubber from caoutchouc sap (which adds value), environmental effects from making tyres from latex (which adds even more value), and so on through the entire production cycle. By conserving the value added of a particular step, recycling makes the material available while avoiding the environmental effects associated with production.

ii Raw Material Conservation

The raw material of natural rubber is latex sap from rubber trees. Rubber plantations are a form of monoculture in much of the tropical developing world, where they frequently displace diverse virgin or regenerated rainforest. The flora and fauna of plantations is greatly impoverished, and they are artificial ecosystems vulnerable to outbreaks of pests and to changes in weather patterns. To the extent that rubber is a necessary and valued substance in modern life, the availability of rubber from secondary sources limits the need for new rubber plantations and thus their negative environmental consequences.

Furthermore, synthetic tyres are made from petroleum products. The extraction of oil and other petroleum products is also environmentally damaging, and the supplies of these materials are limited. Thus recycling has benefits to the global material supply.

iii Limitation of Disposal

Although frequently unrecognized in economically less developed countries, landfilling of waste materials has a negative environmental effect, discharging toxic and/or unsightly materials to the environment. To the extent that recovery activities keep materials out of the landfill, this has an environmental benefit.

Although tyres are almost inert, they are difficult to dispose of, unsightly, and may provide a breeding ground for mosquitoes. To the extent that prevention, reuse, repair, and retreading reduce disposal, this is also an environmental benefit.

BOX 8.1 Waste Tyre Recovery in the Netherlands

Fout! Bladwijzer niet gedefinieerd.In the Netherlands each year 4.5 million automobile tyres are discarded. At present 92% of the waste tyres find their way into some type of recovery or recycling process. The remaining 8% (360,000) tyres are dumped or incinerated without energy recovery. Tyres are collected by licensed tyre-collecting firms, which collect all tyres, whether or not they have residual economic value.

This high rate of recovery, perhaps the highest in the world, is largely a product of deliberate policy making on the part of the Netherlands government, whose strategy for achieving national recycling goals is to enter into agreements with each branch of industry, and to let the branch choose its own strategy for implementation.

The ultimate destination of all the 4.5 million tyres that are discarded yearly in the Netherlands are shown in Table 8.1.

Table 8.1. Destinations of Discarded Tyres in the Netherlands. Source: VROM-VACO, 1993

Destination	In %	In no's per year
Sold to be re-used as tyre	35%	1,575,000
Re-use after retreading	28%	1,260,000
Re-use after granulation or regeneration	6%	270,000
Used as fuel in e.g. cement industry	18%	810,000
Incinerated	3%	135,000
Landfilled	5%	225,000
Various other uses	5%	225,000
Total	100%	4,500,000

Ninety percent of all tyres are collected by a large number of authorized firms, which inspect and select the used tyres for various types of reuse and recycling. The firms must be licensed to prevent the illegal and unsafe return to the market of poor quality tyres by dishonest collection companies, which in turn can give recycling a bad reputation.

Less than 1% of collected passenger vehicle tyres are retreaded: only one company is active, retreading approximately 5,000 tyres per year. In contrast, approximately 30 firms are involved in retreading of truck and bus tyres, often under contract to the tyre owner, who can monitor the age and quality of the retreaded tyre. Furthermore, nearly 2/3 of airplane tyres, which are regularly subjected to high speeds and forces, have been retreaded, a fact attesting to the quality of the retreaded tyres.

In the Netherlands the large quantity of bicycles in use, approximately 15 million, or one per capita, generates one million used bicycle tyres per year. A recent development is the collection and recovery of these tyres. Customers have to pay a US\$ 0.65 to the collector or the bike-repair shop for the used or discarded tyre. The steel wire is melted; nylon goes for the manufacturing of carpets and other uses; and the rubber is made into crumb and re-used in other rubber products.

The production or repair of tyres from the waste stream, conserves energy and materials, since there is less energy used in recycling than in new manufacture of tyres, rubber, or formal sector consumer products that would compete with the recycled ones. Also, the environmental effects of most operations, from retreading to secondary manufacture, are qualitatively similar to those from the use of virgin materials, but far lower in quantity, giving a net benefit. Thus there is a net resource and energy benefit to the use of secondary rubber.

v *Risk Reduction*

One of the environmental dangers associated with tyres is the danger of fire from stockpiled tires. Recovery projects have a two-way effect on this risk. On the one hand, recovery enterprises may stimulate the stockpiling of tyres as part of building up an inventory of raw materials, although these are usually more carefully managed than piles of tyres that are not destined for use. On the other, recovery projects may regularly use stockpiled tyres, with the result that there are fewer piles at risk.

8.3 Specific Environmental Benefits

The impacts of disposal of tyres and rubber are just as problematic for non-industrialised countries as they are for industrialized ones. The main differences are that landfilling in non-industrialized countries is still largely uncontrolled; it is generally regarded as being free; and its environmental and public health dangers are not as likely to be recognized by the sanitation or public works authorities; even where these dangers are well understood, adequate control may be technically unfeasible or economically out of reach. Thus the benefit of reduction in disposal is a largely unrecognized one.

Reclamation of rubber from tyres conserves materials and energy. In economically less developed countries, this may translate into import substitution, reducing the need for foreign exchange for the purchase of raw materials. It may also translate into conservation of locally produced or exploited resources, avoiding both costs and environmental impacts associated with local production and exploitation.

A more direct environmental and economic benefit of rubber recovery in developing countries is its tendency to create a supply of useful and necessary products in a lower price class than those created by formal manufacturing processes. This results in second-level conservation of the energy and materials that would have gone into making the "normal" products. It also provides an economic benefit in terms of making necessary products available to those who could normally not afford them.

Avoidance of nuisance and public health problems associated with tyre dumping and disposal do represent a benefit for developing countries, even though the local public health authorities may neither recognize these problems nor be positioned to remediate them.

8.4 Negative Environmental Impacts

Recovery itself represents an environmental plus, both to industrialized and non-industrialized countries, although the latter are less likely to realize that benefit or let it influence their actions. The second set of environmental considerations associated with recovery and recycling are the environmental impacts -- both positive and negative -- of the recovery activities themselves. Unlike the general benefits of recycling, these tend to be specific to the type and scale of the recycling activities themselves. This section concerns the environmental effects, and the following section the effects to worker health and safety. The discussion which follows considers only those environmental impacts associated with recycling and recovery in non-industrialized countries, and is focused primarily on small- and micro-enterprises of the informal sector.

i Smoke and Hydrocarbons from Burning of Rubber in Recycling Operations

Most recovery operations involve burning of tyres or rubber at some stage of processing. "Burning tires emit carcinogenic poly-nuclear aromatic hydrocarbons, carbon monoxide, sulphur dioxide, nitrogen oxides, and hydrochloric acid. In addition, because tires melt as they burn, these fires [can] create an oily, liquid leachate (pyrolytic oil) that can contaminate surface [and] groundwater." (Dimino 1994, p. 16). The ash from burning of tyres may also be a hazardous substance.

Given the fact that most burning operations are manual and small, there seems to be no available strategy to mitigate this effect. With adequate resources, the substitution of mechanical processes for burning could reduce smoke generation in certain circumstances.

ii Release of Rejected Tyres, Buffings and Dust to the Environment

Most types of reclamation, from puncture repair to remoulding, involve a pre-selection of usable tyres and/or tubes, with the unusable ones to be discarded. At this point, a quantity of tyres must be disposed of, and this may occur through dumping, the hazards of which have been discussed above.

Regrooving, retreading, and certain kinds of manual production involve rasping, buffing, sanding, shaving, or other cutting processes which produce small fragments, buffings, and dust. Mechanical grinding, milling, and rasping also produce dust and buffings, which create a strong odour of rubber, and may contaminate the immediate surroundings.



Figure 8.1. Steel Recovered by Burning Tyres, Nairobi, Kenya.

Source: WASTE

Avoidance of release of these items and substances will generally require an alteration not only in the operations involved, but also in the mentality of the workers. Certain logistical support mechanisms, for example the placing of special bins or containers or the installation of systems to remove fugitive dust or catch the discards, may alleviate the problem. Emission of this dust to the air can be avoided with filters in a closed environment, but is unavoidable when the operation is done, as in most non-industrialized countries, with free air movement.

iii Use and Discharge of Hazardous Substances

Most products, by-products, and ingredients of rubber production are hazardous to a greater or lesser extent. The use of glues and binders in manual processes is one example, as is the use of adhesives, binders and fillers in retreading, and/or additives in moulding. Where these are ingredients, discharges involve leftovers, production wastes, and damaged or obsolete materials.

Reclamation processes also produce waste in the form of residues and by-products, many of which may also be hazardous. Recompounding processes (mixing of regenerate with special polymer compounds, prior to moulding or (re)-vulcanization processes) generate residues. The production of reclaim has a large potential for emissions to water, air, and soil, as there are a great many petroleum-based additives and other substances which are both used and generated in the process. Retreading involves the use of certain petroleum products, which are vaporized during the revulcanization process. There is a high probability that these are to some degree hazardous; the likelihood, in a micro-enterprise in a non-industrialized country, that they are handled appropriately to their level of hazard and complexity, is extremely small.

The capital-intensive process for producing rubber reclaim has potentially detrimental environmental effects, depending in part on the process used. Wet processes produce a highly contaminated waste water containing sulphur derivatives, organic oils, softeners and suspended solids. The effluent has a high chemical oxygen demand and is often acidic or alkaline. When the wet digester process is used there are considerable amounts of metal chlorides, and a sludge of hydrolysed fibre and fine rubber particles in the effluent. The process also produces an unpleasant odour.

The environmental risks from improper use or release of these substances to the environment are difficult to assess. Mitigation measures include training and education, as well as providing appropriate receptacles and collection systems for these substances and materials. Over the longer term, research into less hazardous equivalents (either less hazardous substances or the same substances in a less hazardous form) might prove helpful.

iv Hazards of Recycled Tyres or Recovered Products

In certain cases, the tyres, tubes, and secondary products which are produced by small-scale manufacturers, retreaders, regroovers, and the like, may themselves form an environmental hazard. The clearest example of this is improperly regrooved tyres, or retreads made on casings which have deteriorated too far to retain their integrity.

In the larger picture, the environmental hazard represented by these products is relatively small. Still, their effects can be constrained by introducing measures of quality control, as well as by providing free disposal for tyres and casings that are inappropriate for reuse.

v *Environmental Losses Due to Pre-Emption of a More Environmentally Beneficial Recovery Strategy by a Less Beneficial One*

This is the situation that results when one recovery strategy -- for example regrooving -- pre-empts retreading or secondary manufacture whose net environmental benefit might be higher. Given that the local marketplace determines, in part, which products are marketable, and which aspects of retained value are most commercially viable, this risk seems unavoidable.

8.5 Risks to Worker Health and Safety

A third category of risks and problems is threats to worker health and safety. According to the literature, there are several sources of both air pollution and environmental hazards in relation to various types of rubber recovery operations. These include primarily the following:

- rubber dust from physical processes, including abrasion of rubber during manufacture or recycling, or during punching, polishing or buffing final preparation of products. This is associated with re-grooving, retreading, and virtually all forms of manual secondary manufacture. Dust can be hazardous upon inhalation, if ingested (during eating or drinking in a dusty space) or through contact with the skin.
- dust from additives and chemicals, which are frequently used in powder form. This is associated with glues used in manual manufacturing processes, as well as with chemicals used in recompounding for moulding of shoe soles and the like.
- fumes from chemical processes, which contain airborne solvents and aromatics. These are associated with manual gluing and vulcanization; any time something can be smelled, there are fumes of some sort in the air.
- vapours, consisting of particles adhering to airborne droplets of liquid, from most of the "hot" processes, where rubber is moulded or pressed at high temperatures. This includes moulding, calendaring, vulcanization, and curing stages of manufacture or retreading.
- smoke and resulting airborne hydrocarbons and other particles associated with burning of tyres. This burning may occur during pre-production, for example to allow wire cord to be extracted, or as a means of disposing of wastes.
- physical injury to workers due improper use of tools and machinery on the one hand, and to excessive lifting, carrying, and pulling on the other.

i Danger from Dusts, Buffings, and Powders

The danger for workers from dusts, buffings and powders varies by type of exposure. Both inhalation and contact with skin can be dangerous, causing illness or cancer. In addition, ingestion through eating or drinking in a dusty area can cause particles to be absorbed into the stomach, causing poisoning and stomach cancer.

Adequate ventilation and strict industrial hygiene is the most commonly deployed mitigation strategy. Providing workers with gloves, masks, and protective clothing and footwear may also mitigate the problem, but only when accompanied by a policy of ensuring that these become a part of normal everyday operations. The providing of a separate area for eating and/or protected storage for foodstuffs would also be useful. Technical innovations that can be helpful include installing blowing systems in the machinery itself, and orienting vacuum blowers right over the process. In certain cases, it is recommended to substitute liquid additives in place of those in powder form.

ii Danger from Fumes or Vapours Containing Carcinogenic or Hazardous Substances

These dangers, like those of dust exposure, may occur from inhalation, ingestion, or skin contact. Vapours from rubber production include carcinogenic substances, as well as embrytoxins, which are harmful to fetuses.

Exhaust ventilation is a key ingredient of almost any strategy for control of vapours. The exclusion of pregnant women from locations where vapours are formed is also advisable. Masks and protective equipment, especially gloves, can assist in the protection of individuals, but only if these are regularly and properly used.

In certain cases changes in the process may be useful as well. In relation to both retreading and moulding, the choice of certain compounding ingredients may have the effect of reducing vapour formation. A fairly high level of technical sophistication is necessary to precisely identify the problems and propose and implement solutions, and would probably require not only external financing, but also external expertise. Even then, there is no guarantee that the proposed changes could be implemented at the informal sector micro-enterprise level.

iii Injury from Physical Processes, Including Cutting Tools or Processing Machinery

There are three sorts of risks to workers under this category. First, there is the risk of cutting with cutting tools. Secondly, there is a risk of injury through improper use of machinery. Third, the literature frequently mentions the risk to workers of excessive lifting, that can result in back strain.



Figure 8.2. Entrepreneurial Tyre Collector, Bamako, Mali.

Source: GERAD

All three of these risks be mitigated by a relatively long period of apprenticeship before workers are allowed to use sharp tools or operate the machines on their own. Careful maintenance of tools and equipment is also a factor in injury reduction. In terms of lifting, the use of pallet jacks or other leverage tools can reduce the burden on individual workers. The specific relevance of these measures must of course be assessed for each individual case.

iv Dangers from Smoke from Burning Rubber

Both smoke from burning rubber and the dust from buffings can be dangerous to the health of workers. Smoke inhalation, particularly when the smoke contains products of combustion from complex polymers, as is the case with tyres, can cause various lung ailments and can be carcinogenic. It can also cause eye and throat irritation.

Good ventilation is one generally recommended mitigation strategy. Protective masks, goggles, or clothing could be helpful, as long as these become a part of regular operations.

These risks can be significantly reduced through careful project planning and design. The location of most small workshops in partially open-air buildings or out of doors minimises direct risks to workers, although it disperses potential contaminants more quickly into the environment.

v Health and Safety Risks of Scavenging and Collection of Tyres

Health and safety risks in the scavenging of tyres can range from back and muscle strain to contact with septic or contaminated substances. Scavengers frequently lack any protective equipment, such as gloves or shoes, that would make scavenging safer. Also, tyres are quite heavy for a child to lift, and truck or bus tyres can easily strain an adult's back.

The dangers from lifting and carrying can be significantly reduced by providing scavengers with pallet jacks, lifting hooks, and carts. These come under the general category of collection and transportation improvements, and are usually associated with some type of formal recognition of the collectors. In some cases, set-up of collection points can make the acquisition of equipment for these points worthwhile.

8.6 Role of External Financing and Institutionalization

Maximizing the benefits and minimizing the negative effects of rubber reclamation represents a complex set of tasks. Neither the problems nor the indicated solutions lie within the scope of most of the small entrepreneurs who scavenge tyres and repair or recondition them, or use them for innovative manufacturing enterprises.

In the first place, the long-term health threats to his health from exposure to dust, fumes, and the like may appear far less important to a worker than the more immediate threat to survival of loss of livelihood. The consequences for the environment are even less likely to be of concern.

Secondly, the relationship between largely invisible fumes or barely perceptible dusts and cancer or illness are seldom recognized even in industrialized countries, where access to the background information is far more available. Thus even when workers are made aware of a danger, they may find it difficult to believe or to understand. This may undercut the internal motivation for making use of protective clothing or equipment, and may also undermine the interest in improving ventilation or workplace conditions.

Thirdly, even in the cases where there is understanding of and belief in the problems, the marginal economic viability of many small- and micro-enterprises would probably prevent there being any action taken to rectify problems.

For all of these reasons, external financing offers perhaps the only reasonable path to environmental improvement in rubber recovery activities. In particular, the financing of new equipment or operations can with relative ease incorporate technical or mechanical features that improve the environmental performance of the enterprise. External financing for protective

equipment and/or preventive equipment maintenance may also contribute to decreased risks and improved environmental performance.

CHAPTER 9 FUTURE DIRECTIONS FOR RUBBER RECOVERY

Rubber and tyre recovery has limited but interesting potential in terms of both waste handling and economic development in developing countries. New projects are interesting when they are motivated by the resource value of the tyre; in most cases, the viability of a project based exclusively on avoided disposal lies far off in the future.

In general, the higher up the value added hierarchy it is possible to go in planning an activity, the greater the market for its products and the higher return per investment (see Chapter 7). For example, retreading, which preserves the value added of the casing, is higher in this hierarchy than making containers, which only preserves the value added of the rubber. Thus, projects involving repair and retreading are likelier to prove economically feasible than those involving secondary manufacture.

The level of technology which is appropriate for the type of entrepreneurs dealt with in this publication remains low. High-technology capital-intensive projects match neither the supply of tyres nor the needs of the locality and may cause an exodus of labour.

9.1 Locally Generated Tyres

The quantity of locally used and generated tyres in developing countries will likely remain low, but grow gradually as the number of automobiles per capita grows. The greatest environmental and economic benefit will involve maximum conservation of value added through recovery of tyres as tyres (and tubes as tubes), through either repair, regrooving (despite its dangers and quality problems), or retreading.

The scale of investment possible should dictate the choice for repair or retreading. Repair, and the development of new tools and techniques, is a micro-process, and is likely to be affordable in most circumstances. It is important to check if this market is already saturated before beginning new projects, since any new activity could disturb or displace existing entrepreneurs.

Retreading lies beyond the capability of most informal-sector entrepreneurs, but in and of itself it is neither particularly capital-intensive nor difficult to learn. It represents an interesting potential for a group of organized small-scale secondary manufacturers, for example, to combine their efforts and jointly develop retreading. Some external financing is likely to be needed in this case. Here too, a careful exploration of the market is necessary to see if there is adequate demand for the retreaded tyres and to ensure that current players are not displaced. Sometimes, government actions are required to ensure that retreaded tyres are permitted on vehicles and that there are no barriers to their entering the market.

Secondary manufacturing (new products from tyres) is also potentially interesting, but if it is not already taking place, there may be legitimate reasons why it is not, and the risk that the resulting products will not sell is therefore high.

A careful examination of the import market may provide ideas for import substitution using secondary rubber, with the resulting local manufacturing taking market share away from the corresponding import. This could occur on a small scale, such as with developing local harness shops from waste rubber, or on a larger scale, with the development of crumbing or reclaim plants to feed a local industry currently using imported virgin rubber. If this is desirable in macro-economic terms, the development of secondary manufacturing or processing may be interesting; here again, it is important to pay attention not only to the potential benefits of the new project, but to the activities it will supplant both domestically and internationally.

9.2 Import of Waste Tyres

In the economically highly developed countries, the high vehicle and tyre safety standards cause tyres to be discarded after a relatively short use life; this increases the rate of disposal, with the associated problems already discussed. The abundance of waste tyres -- many with good casings and even a significant tread profile -- has created a significant waste tyre export trade to economically less developed countries. This trade is motivated in the North by the search for cheap disposal, and in the South by the demand for inexpensive rubber resources. In Ghana, for example, this trade is even advertised on billboards.

The reputation of this trade has been tarnished by concerns about export ("dumping") of hazardous wastes on developing countries, without adequate safety regulations, together with the perception that a number of economically less-developed countries are willing to import developed country wastes in order to earn "hush money", without reference to the problems that this may cause for the local environment or the health of the local populations.

Concern over the waste trade in general has produced a flood of regulatory initiatives, with the two most important in respect to waste being the Basel Convention and the Bamako Convention.

- The Basel Convention (1989) determines the conditions under which waste may and may not be exported from developed to developing countries. Among its provisions are assignment of liability to the exporter and the requirement for involvement of the importing nation's authorities. Export is forbidden unless explicit and legally binding permission for import is given by the importing nation.
- The Bamako Convention (1991) is an agreement by 51 African countries not to allow the importation of any waste materials into their countries.

These international agreements have not, in fact, caused an end to the movement of waste materials; throughout the world, there is a great deal of both legal and illegal activity in this highly lucrative enterprise. Furthermore, more than 100 countries have neither signed the conventions nor instituted their own protective measures, and thus are free to trade in (hazardous) wastes.

There is a plausible case to be made for the exemption of the used tyre trade from these measures, since tyres are not in principal a hazardous waste, and have recognized and provable resource value. Only when imported for pure dumping in uncontrolled piles are tyres a health and environmental hazard.

On the other hand, there is resistance to the import of tyres to economically less-developed countries partly out of ideological principles, among them the conviction that until the rich countries have to swallow their own wastes within their borders, they will make no serious commitment to reducing those wastes and/or moderating excessive consumption. This reasoning has produced the idea that waste export is an ideologically objectionable form of recolonization.

Where a political consensus nevertheless exists in the importing country in favour of import of waste tyres for use as a feedstock, the following factors should be carefully considered before proceeding with such a scheme:

- The potential for recovering tyres for local uses as tyres
In the first instance, the potential for using the tyres locally should be considered. If used tyres were to be repaired, regrooved, or retreaded for local use, what local or import sources of tyres would they be supplanting? How many tyres can the local, regional, or continental market reasonably absorb? What percent of the tyres would be suitable for reprocessing as tyres, and how many would have to be handled through other, lower-value options?
- The potential for recovering tyres for use as tyres and returning them to the country of origin or a third country.
If the local market for tyres is already saturated, the risks of dumping those tyres on the local market are great, and any investment in retreading is unlikely to pay off. In this case, there is some possibility for shipping the retreaded (but certainly not regrooved) tyres back to the country where they were used. Here, the market questions become even more difficult, as these tyres would be competing with new tyres in generally saturated markets. The availability of policy instruments to promote the retreaded tyres, combined with some form of price supports from the country of origin, might make this a financially viable, but hardly a sustainable, option.

Still another approach would be to retread tyres for re-export to a third country, which had an excess of demand for tyres, perhaps backed up by foreign aid credits or price supports from the country of origin . This too involves high financial risks for the processing country, and its economic sustainability over the long term is open to question.

- The potential for secondary recycling combined with reclamation as tyres
Diversifying the strategy in the importing country increases the potential for success of a tyre importation and processing scheme. In particular, if there are good local markets for retreaded tyres, secondary products, and crumb rubber, the chances of success increase significantly.

9.3 Tyre Recovery as an Industrial Development Strategy for the South

Given the foregoing discussion, it should be clear that the viability of recovery activities depends upon a number of technical, socio-economic and political relationships. Macro-economic influences such as international price and trading policies; laws and government policies ranging from environmental controls to import regulations; and municipal sanitation priorities all have an effect on the type and level of recovery that will be feasible.

In the industrialized countries of the North, recovery of tyres is sandwiched between several conflicting factors and priorities: the need to find safe and environmentally sound disposal for used tyres, strict technical, safety and performance standards for vehicle tyres, emissions restrictions to land, air and water from industrial processes, increasingly open global trade, and minimum wage and worker health and safety laws. These factors, in combination, create a situation where used tyres become almost impossible to dispose of. Older recycling technologies such as the production of reclaim cannot meet environmental standards. New uses for tyres cannot get started because of environmental restrictions; and products which could compete in a local economy are out-competed by inexpensive synthetic imports. As a result, Northern countries expect to pay high prices for legal tyre disposal. In the US, it is virtually unheard of to be able to dispose of an old tyre for less than US\$1.00. These costs get passed along to consumers, where their impact on the total price of running an automobile is extremely small.

This situation suggests that not only may entrepreneurs in developing countries be able to set up cost-effective recovery of tyres generated in their region, but there may also be a potential market for 'disposal through recovery' of imported used tyres from the North.

This potential for importing used tyres has many implications. First, many developing countries have no indigenous or inexpensive source of rubber for their industrial needs, so the imported used tyres could provide that resource at an affordable price. Retreading operations and other secondary production enterprises may provide an affordable source of good quality tyres for local markets, and in countries without any domestic tyre production (and therefore no local tyre industry to compete with) this could boost the local economy.

On the other hand, creating a rubber recycling industry that depends on imports can have some disadvantages. In some countries, import duties may adversely affect local industries that depend on imported raw materials. In the Philippines, the 9% import levy for goods of foreign origin in addition to the usual tariff tax that is assessed against foreign products, was therefore reduced to 5%, despite the fact that imposition of the levy would boost recovery of local resources. Although there are limits to import duties, they will certainly influence the ability to develop an import-based reprocessing industry.

A careful scrutiny of the social, economic, and political context prior to committing to a particular recovery enterprise will assist in avoiding costly mistakes, disruption of locally functioning systems, and loss of credibility.

9.4 Waste Tyre Prevention Strategies

Recovery is not the only way to reduce disposal of tyres. Actions taken during the use phase can prolong the life and quality of the tyre, resulting in a longer period of productive use. This results in a reduction in the rate of disposal. Factors that contribute to prevention of tyre disposal include:

- Improvement in the construction and quality of the tyres: it is claimed that tyre life could be extended from 100,000 km to almost 160,000 km per year.
- Moderating the style of driving, avoiding rapid acceleration, taking corners at high speed, sudden braking, driving at high speeds on poor roads, and bumping onto the kerbstone all accelerate the degradation and of tyres and hasten their disposal. Optimal use and maintenance of a tyre could extend its life by 35%.
- Raising the passenger-kilometre ratio, through encouraging carpooling, shared automobile ownership, the use of mini-vans, and the like.
- Limitation of the number of cars or the quantity of kilometres driven, through taxes and other policy measures. Promotion of the use of bicycles for inner city transportation is an option which deserves more attention in this respect.

9.5 Technology Transfer and Development

Until now, the transfer of technology for tyre and other forms of recycling has mainly taken place from the industrialized countries to the economically less developed ones, with the transferred technology seldom being either appropriate or directly applicable. In contrast to this, in Asian cities such as Calcutta, Manila and Karachi, many small enterprises which are involved in the recovery of waste tyres based on the application of many ingenious manual techniques, may have made important advances in small-scale recovery which could be of great benefit to their colleagues in other economically less-developed countries. In small and micro-enterprises with some access to investment capital, hydraulically driven cutting tools may increase productivity. Moulding of shoe soles or rubber mats requires still more technical sophistication and high-quality electrical power for continuous processes like milling and extrusion. Retreading requires still more expertise and capital equipment.

This would suggest that South-South exchange and technology development have not yet received the attention they deserve. Entrepreneurs, especially in Asian countries, have shown themselves to be able to invent and adapt recycling technology to local circumstances. These adaptations are usually at an intermediate level of technology, making them more suitable and eminently more affordable for the informal sector than machinery designed in the North. This type of technology is far more suitable for transfer to, for example, Sub-Saharan African countries. However, in most cases the workplace and environmental hazards have not been addressed, and the task for those promoting South-South transfer is how to factor these aspects into South-South transfers.

There is also a need for information on environmental protection and workplace safety innovations which be of value to economically less developed countries. In more industrialized countries, such as the Netherlands, the national and local government frequently takes the initiative to assist small businesses in applying technical innovations which improve their environmental performance. One approach which would address the real needs of waste

entrepreneurs in the economically less-developed countries is the application of technical expertise to the question of improvements in equipment design, directed to the most pressing technical and environmental problems. This presents an interesting potential to Northern development agencies and local policy makers alike. This is a role frequently taken by government subsidized research institutes in the North, particularly when it involves assistance to indigenous small businesses and industries. The set-up of local innovation centres oriented to the recycling and waste handling sector is also a means to promote the development of appropriate technical improvements.

9.6 Public Authorities and Private Initiatives

From the viewpoint of environmental protection and out of concern for public health, the collection and disposal of waste is usually considered to be the responsibility of the government or municipal institutions. However, municipalities in many low-income countries are unable to cope with the ever-growing volumes of waste because of inadequate public funds, increasing populations, the lack of equipment and spare parts, and staff which is not specifically trained for the task of modern city cleansing.

A difficulty in municipal solid waste management is that the total costs of safe and environmentally acceptable solid waste disposal are poorly documented and are usually underestimated. Most financial resources, furthermore, have long ago been fully committed to the more obvious tasks of collection and transport of waste materials. As a result, the economic and environmental potentials of recovery activities are seldom fully realized, because their economic, social and environmental benefits are not fully recognized and valued. It is against this background that the need to support and expand informal sector recovery activities arises, as a means to improve existing practices of this sector and to integrate them into the municipal waste management systems. Various recycling potentials can and should be incorporated on both the implementation and the policy level. The challenge here is to achieve integration without destroying, displacing, or co-opting the existing operations, most of which are both financially and politically extremely vulnerable.

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 (formal and informal) companies and community-based organizations are increasingly participating in various aspects of municipal solid waste management. International organizations like the UN, together with donors and NGOs, are increasingly adopting this integrative approach as the most fruitful strategy for future waste management system development.

Government authorities continue to play an important role in the promotion and viability of recovery activities, not only by their local waste management approach but also by their economic policy. For example, regulations on the importation of (waste) tyres virtually determine its feasibility on the local level. Modern and progressive governments which are committed to environmental and workplace safety, are increasingly setting up regulatory and institutional frameworks for sustainable waste management. The success of the entire system

depends on a clear articulation and adoption of policy goals and practical measures to pursue the overall goal of sustainable municipal waste management:

- the political priorities in favour of environmental support must be clearly articulated in order to gain the support of the public. The roles of the various social actors -- generators, public and private waste services, formal and informal-sector actors -- must be explicitly considered and articulated in a broad social discussion; when this has been determined, clear and enforceable regulations must be put into effect to support the decisionmaking.
- In financial and economic terms, a full accounting of all costs, including hidden costs to the environment and the health of the population and workers, must be made. Once this is done, there should be an attempt to bring income and expenditures from the waste system into balance with each other, and these must be continually monitored.
- In economic terms, the trade-offs between capital- and labour-intensive waste management systems must be carefully weighed, as must the benefits and costs of reduction in natural resource use, import substitution, the use or conservation of foreign exchange, and the like.
- The acquisition of technologies and equipment must be considered in conjunction with the prevailing local conditions, human and technical resources, supply of tyres, and the appropriate and sustainable levels of scale and technology.
- In institutional terms, it is critical to formulate goals, strategies, and specific practical tasks clearly and unambiguously; to clarify lines of responsibility and liability; to disambiguate contested bureaucratic jurisdictions, and the like. Then it becomes possible to consider the benefits of assigning certain functions to the private sector, both formal and informal; to decentralize functions and services, and to strengthen expertise and knowledge within the locally present waste sectors.
- Finally, in social terms, it is important to achieve the participation of all residents receiving waste services, as well as to involve all of the stakeholders, including those informal-sector actors directly or indirectly participating in waste activities, in any planning or alterations in the current system.

Some specific issues which governments and intermediary organizations should address, depending on their resources and responsibilities, include:

- The potential for discouraging and/or forbidding the burial or incineration of waste tyres
- The need to recognize and integrate the existing informal recycling networks within municipal solid waste management systems
- Stimulation of the development and implementation of appropriate technologies for waste tyre recovery
- Formulation of policies to protect and encourage the horizontal growth of small-scale resource recovery initiatives
- The need to create legal frameworks and controlling mechanisms that will enhance safety in the workplace as well as protect the environment
- The dissemination of information regarding preventive and recycling aspects directed at the population and the enterprises.

The problem in integrating small-scale (informal) resource recovery activities in a sustainable urban waste management system, is more a matter of perception than one of technology. It requires interdisciplinary cooperation at different levels among various actors, such as municipal departments; official councillors; national governments; non-governmental organizations

(varying from welfare to environmental organizations); research institutes; scholars; community representatives; and the like.

Many questions are still to be answered, especially as to how small-scale recycling activities can be optimized under local conditions to best fit into a broader perspective on waste management. However, from the practical experiences already gained all over the world, some of which are shown in this book, important lessons can be learned and conclusions can be drawn, which may result in more appropriate and sustainable solid waste management systems including the increased and improved recycling of rubber waste.

ANNEXES

ANNEX 1 EXCHANGE RATE CALCULATIONS

In 1991-1992, the years 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)
Pakistan	\$1 = 30 Rupees (Rp)
Mali	\$1 = 300 Francs (CFA)

ANNEX 2 LIST OF RESOURCE ORGANISATIONS

Institutions with Information on Rubber Waste Recycling

Appropriate Technology Development Association

P.O. Box 311, Gandhi Bhawan
Lucknow-226001, U.P. India

Association Francaise des Ingenieurs du Caoutchouc et des Plastiques

60 Rue Auber
94400 Vitry sur Seine, France
+33 (1) 46 71 92 22

A research institute involved in development and diffusion of research and scientific information about rubber and plastics.

Center for Neighborhood Technology

2125 West North Avenue
Chicago, Illinois, 60647 USA
+1 312 278 4800

A community-based technical assistance organization specializing in small- and intermediate-scale technologies for recovery and recycling. They have a project to promote the use of crumb rubber in road construction.

Deutsche Kautschuk-Gesellschaft eV

Zeppelinallee 69
D-6000 Frankfurt (M) 90
Germany
tel: +49 69 79 36 153
fax: +49 69 79 36 150
telex: 411 254 WDK D

An organisation for the promotion of scientific and technical knowledge of rubber, centred on chemistry, physics, and engineering.

Institut de Recherches sur le Caoutchouc (IRCA)

42 Rue Scheffer
75116 Paris, France

tel: +33 (1) 47 04 32 15
telex: 620871

A division of the Centre for International Cooperation and Research on Agronomy and Development. Specializes in research and dissemination of information on production techniques involving natural rubber.

RAPRA Technology Limited

Shawbury, Shrewsbury
Shropshire, SY4 4NR England
tel: +44 1939 250 383
fax: +44 1939 251 118
telex: 35134

An international technical information centre for rubbers and plastics; offers consulting and technical analysis services. Also does business planning and market research for business clients.

SIRI, Small Industry Research Institute

P.O. Box 2106, 4/43,
Roop Nagar, Delhi, 110 007 India

tel: +91 11291 81 17

A consultancy specializing in small business and intermediate technologies. They provided information for this study.

TNO Plastic and Rubber Institute

P.O. Box 6031
2600 JA Delft, the Netherlands
tel: +31 15 269 6900
fax: +31 15 256 6308
telex: 38067 cpm nl

A research institute which carries out research on plastics and rubber, an affiliated of the Division for Industrial Research of TNO, the Dutch organization for applied scientific research. They have a number of experts on rubber recycling on their research staff. 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.

ANNEX 3 JOURNALS

Rubber Technology, Manufacture, Processing, and Recycling

European Rubber Journal (ERJ)

Cowcross Court (2nd Floor)
75-77 Cowcross Street, London EC1M 6BP, England
tel: +44 171 608 1116
fax: +44 171 608 1173
telex: 28544 CRAINS G.

KGK Kautschik Gummi Kunststoff, Germany

Journal of Natural Rubber Research

Maylasian Rubber Producers' Association
Tun Abdul Razak Laboratory
Brickendonbury
Hertford SG 13 8NL, England
tel: +44 1992 584 966
fax: +44 1992 554 837
telex: 817449 MRRDBL

Progress in Rubber and Plastics Technology

RAPRA Technology Limited
Shawbury, Shrewsbury
Shropshire, SY4 4NR England
tel: +44 1939 250 383
fax: +44 1939 251 118
telex: 35134

Resource Recycling

P.O. Box 10540
Portland, Oregon 97210-0540 USA
tel: +1 503 227 1319
fax: +1 503 227 6135

Rubber Chemistry and Technology

Institute of Polymer Science, the University of Akron
Akron, Ohio 44325 USA
tel: 1 216 375 6831 (Editor, G.R. Hamed)
tel: +1 216 375 6938 (Managing Editor, R.H. Gerster)

Rubber World

P.O. Box 5485, 1867 W. Market St.
Akron, Ohio, 44313-6901 USA
tel: +1 216 864-2122
telex: 297690 RWMAG UR

Solid Waste Management, General

African Environment

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

Environmental Sanitation Reviews

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

GATE: questions, answers, information

- * Published quarterly
- * Free of charge for readers in Africa, Asia and Latin America. Readers from the industrialized countries pay DM 24 (\$ 17) per year
- * Offers a free information service on appropriate technologies for all public and private development institutions in countries dealing with the development, adaptation, application and introduction of technologies. Each number covers a special theme; at regular intervals numbers appear on solid waste (hospital waste, recycling, solid waste management etc.).

SWM-Info

UNCRD (UN Centre for Regional Development)

Environmental Planning Unit

1-47-1 Nagono, Nakamura-ku

Nagoya 450, Japan

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

WARMER Bulletin

83 Mount Ephraim,

Turnbridge Wells, Kent TN4 8BS, UK

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

Waste Management & Research

(for address, Appendix 4: ISWA)

- * Published bimonthly
- * Annual subscription price including postage: \$ 198
- * Publishes from a broad cross-section of researchers and workers in the field; from academic institutions, governments and the private sector. The main focus is on the discussion of solutions to problems that arise primarily with municipal wastes.

ANNEX 4 CONSULTANTS INVOLVED IN 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-Hagggar
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 and 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 person: Mr Aloys Opiyo
Tel. +254 (2) 55 22 11
Fax: +254 (2) 54 58 88

WASTE
Crabethstraat 38 F
2801 AN Gouda, the Netherlands
Tel: +31 (182) 522 625
Fax: +31 (182) 584 885
E-mail Internet: waste@tool.nl

ANNEX 5 INSTITUTIONS WITH INFORMATION ON SOLID WASTE MANAGEMENT

Several institutions run data bases on e.g. solid waste management, recycling, production processes, technology, legislation and case studies. Below a selection.

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 Centre (WMC)

(for address, see CAPS in list of consultants involved in WAREN project) has a programme called Infowaste focusing on solid waste.

- On-line recycling inquiry system, training & 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

United Nations Centre for Human Settlements (Habitat)
PO Box 30030, Nairobi, Kenya
tel: +254 (2) 621 234
Fax: +254 (2) 624 266/624 267
Telex: 22996 UNHAB KE

Waste Management Information Bureau,
Enquiry Service and Waste Information,
AEA Environment & Energy, B 7.12
Harwell Laboratories, Oxfordshire OX11 0RA, UK
Tel: +44 - (235) 43 34 42
Fax: +44 - (235) 43 28 54
- Database service covering 60,000 abstracts from literature published worldwide; short enquiries free.

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.

Anti-oxidant: an additive that inhibits plastic or rubber from chemically reacting with oxygen.

Bead: that part of the tyre which is shaped to fit the rim, consisting of a steel wire reinforcement protected by wrappings.

Belt: a layer or layers of material underneath the tread, laid mainly in the direction of the tread centre line, to restrain the circumference of the casing.

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

Buffings: the particles of tread removed from the casing of a tyre by an abrasive tool as preparation for retreading. Also called **raspings**.

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.

Casing: the laminated ply and bead structure of a tyre, consisting of reinforced materials, joined with rubber compounds; could also be considered the body of the tyre.

Colourant: a dye or pigment added to rubber to impart colour

Crumb rubber: finely granulated rubber scrap, also called **powder**. the term is used for particles finer than 1 mm

Cushion: a thin intermediate rubber layer between the tread and the casing.

Discard: to throw something away, irrespective of where.

Extrusion: process of forming continuous shapes by forcing molten rubber 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 typified by kitchen residues and other organic wastes.

Granulate: granulated vulcanized rubber scrap, larger than 1 mm and smaller than 20 mm.

Granulation: the size reduction of rubber materials into small particle sizes using a granulator.

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

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

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

Labour-intensive: needing a large workforce.

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

Market: processor or end-user.

Marketing: processing by which buyers and sellers are brought together.

Monomer: a molecule which typically contains carbon and is of a low molecular weight (compared to 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.

Moulding: the process of shaping rubber in a heated mould, under pressure.

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

PE: polyethylene.

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

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 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.

Prevention: avoiding the generation of waste.

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

PS: polystyrene.

PVC: polyvinyl chloride.

Raspings: the particles of tread removed from the casing of a tyre by an abrasive tool as preparation for retreading, also called **buffings**.

Reclaim: (1) a sheeted, de-vulcanized polymeric material obtained by subjecting vulcanized rubber (particles) to a chemical process. Also, to produce reclaim. (2) to recover rubber or other waste materials and redirect them to productive use.

Reclamation: the process of recovery of materials or energy, **not** specifically related to the production of **reclaim**.

Recovery: the process of directing to reuse, reprocessing, recycling, or the like materials which would otherwise be thrown away.

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

Reduce: convert into a simpler form.

Regroovable: The characteristic of a commercial (truck, bus, aeronautic or agricultural) vehicle tyre that is designed with sufficient undertread to allow the regrooving of the original tread pattern after this is worn down.

Regroove: to cut a fresh tread pattern by deepening the original pattern and extending it into the undertread, with the aim of prolonging the use life of the tyre.

Regranulate: tyre particles, generally with a dimension of 4 to 20 mm, produced by grinding, milling, shredding or cutting tyres; (vt) to produce these particles.

Reuse: the use of a product more than once in its original form; (vt) to promote or effect this second or further use.

Refuse: rubbish, mixed waste materials.

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

Scrap tyre: a used tyre for which no use is found in retreading or regrooving, but which can be recovered or recycled.

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 for the size reduction of tyres or rubber chunks into smaller particles.

Thermoset: a characteristic of plastic or rubber 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. Vulcanization produces a thermoset.

Used tyre: a tyre which has been removed from a vehicle after it is no longer considered to be functional in its original purpose as a vehicle tyre.

Virgin rubber: rubber material in the form of sheets, blocks, granules, powder, floc, or liquid, from natural or synthetic sources, that is not been subjected to use or processing other than that required for its initial manufacture.

Vulcanization: the chemical reaction, usually involving sulphur, whereby a rubber compound is changed into a tough, resilient, and durable material. The process usually is performed under heat and pressure.

Waste tyre: a tyre which has entered the waste stream because of a perceived end to its primary usefulness as a vehicle tyre; a tyre which has been removed from a vehicle after it is no longer considered to be functional in its original purpose as a vehicle tyre.

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

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Abstract

Rubber waste documents recovery and recycling activities in cities in economically less developed countries. This publication describes how rubber waste is recovered in informal small-scale enterprises and turned into end-products ready for use by other (small) entrepreneurs and general customers.

Attention is paid to the various technologies used in rubber recovery. Financial aspects, marketability of products, environmental problems and government policies are also dealt with.

The book is based on data and seven research reports compiled by consultants in six cities: Cairo, Nairobi, Accra, Bamako, Calcutta and Manila.

This is the third title in the Urban Waste Series. It is co-published by TOOL Publications and WASTE.