United Nations Environment Programme
International Environmental Technology Centre

Compendium of Technologies for the Recovery of Materials/Energy from End of Life (EoL) Tyres
Final Report

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ABBREVIATION

ABS	Anti-skid Braking System
ARF	Advanced Recycling Fee
ATM	Asian Tiger Mosquito
BAT	Best Available Techniques
BEP	Best Environmental Practices
BOE	Board of Equalization
CAA	Clean Air Act
CONAMA	Brazilian National Commission of the Environment
DFAT	Department of Foreign Affairs and Trade
DOC	Dissolved Organic Compounds
DTIE	Division of Technology, Industry, and Economics
EAF	Electric Arc Furnace
EH&S	Environment, Health and Safety
ELT	End of Life Tyres
ELV	End of Life Vehicles
EPA	Environmental Protection Agency
EPD	Environmental Protection Department
EPDM	Ethylene Propylene Diene Monomer
EPGS	Electric Power Generating System
EPHC	Environment Protection and Heritage Council
EPR	Extended Producer Responsibility
EPU	Equivalent Passenger Unit
ESPs	Electrostatic Precipitators
ETRMA	European Tyre and Rubber Manufacturers' Association
EU	European Union
FBR	Fixed Bed Reactors
FCI	Fixed Capital Investment
FIRST	Financial Incentives for Recycling Scrap Tyres
FTS	Fischer-Tropsch Fuel Synthesis
GRE	Global Recycling Equipment
GVW	Gross Vehicle Weight
HGR	Hydrogasification
HH	Household
HP	High Pressure
IETC	International Environmental Technology Centre
IGCC	Integrated Gasifier and Combined Cycle
IIWTM	Integrated Industry Waste Tyre Management
ITRA	International Tyre and Rubber Association
JATMA	Japan Automobile Tyre Manufacturers Association
JSRA	Japan Shipbuilding Research Association
KMB	Kowloon Motor Bus
KOTMA	Korean Tyre Manufacturers' Association
MCDA	Multi-Criteria Decision Analysis
MRT	Metal Recovery Technology
NGO	Non Government Organization

OECD	Organisation for Economic and Cooperative Development
OTR	Off-the-Road
PAHs	Polyaromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PEPA	Pakistan Environmental Protection Agency
PIT	Polymer Injection Technology
PRO	Producer Responsibility Organization
PRS	Producer Responsibility Scheme
PTE	Passenger Tyre Equivalent
REDISA	Recycling and Economic Development Initiative of South Africa
RMA	Rubber Manufacturers Association
RPM	Revolution Per Minute
RTR	Rotary Tyre Re-shredder
SATRP	South Africa Tyre Recycling Plant
SAyDS	Argentine Secretariat of Environment and Sustainable Development
SCEW	Standing Council on Environment and Water
SMR	Steam Methane Reformer
SPR	Steam Pyrolysis
SsCyFAyPC	Secretariat of Pollution Prevention and Environmental Surveillance and Control
SSM	Sydney Steel Mill
TB	Terminal Blend
TDA	Tyre Derived Aggregates
TDF	Tyre Derived Fuel
TSA	Tyre Stewardship Australia
TSBC	Tyre Stewardship of British Columbia
UK	United Kingdom
UNEP	United Nations Environment Program
UNSW	University of New South Wales
URC	Unlimited Resources Corporation
USA	United States of America
USEPA	United States Environment Protection Agency
UV	Ultraviolet
VMT	Vehicles Miles Travelled
VOCs	Volatile Organic Compounds
WBCSD	World Business Council for Sustainable Development
WRAP	Waste Reduction and Prevention Act
WT	Waste Tyre
WTP	Waste Tyre Pyrolysis

EXECUTIVE SUMMARY

The development of tyre industry, indicates that almost one billion tyres are manufactured worldwide every year. Nearly almost equal quantity of waste tyres is generated annually. How to deal with this amount of waste tyres has been a challenge to all the countries. Quite often, waste tyres are stockpiled in "tyre dumps". In some cases, it is disposed off in landfills and sometimes just abandoned in general areas. If not disposed off properly, waste tyres could cause health and environmental risks, including fires, act as a breeding ground for vector-borne diseases and release heavy metals. Several cases of the stockpiles causing fire and burning sometimes for years have been reported. On the other hand, tyres contain metal, natural rubber, synthetic rubber, carbon black and various additives, presenting opportunities for materials and energy recovery. Various technologies are available to exploit this opportunity. International Environmental Technology Centre (IETC) of United Nations Environment Program (UNEP), with its focus on waste management, has developed the compendium to provide information on such technologies for the recovery of materials/energy from waste tyres. Based on the concept of "waste is resource", the compendium aims to provide an overview of technologies for recovery of materials/energy from waste tyres and an introduction of waste tyres management practices in different countries. This information could be of reference for countries who are considering to establish a waste tyre management system or improve the existing system. The compendium has been prepared based on data from secondary sources including publications from scientific journals, reports and websites.

This compendium describes, the environmental soundly way to recover materials and energy from waste tyres. General and specific technologies for the recovery of materials/energy from waste tyres are introduced to the target audience. In terms of recovery of materials, ground rubber, metal and devulcanised rubber could be recovered through different technologies including tyre derived aggregates (TDA) as products. For recovery of energy, there are technologies for direct use as a fuel, conversion to conventional type fuel and recycling waste tyres in steel production. Detailed process description, environmental and social aspects, investment and operating costs, institutional and regulatory requirement, pros and cons with respect to developing countries have been discussed. Further specific technologies present, a brief introduction of the technologies, mainly shredding and pyrolysis technologies are discussed. Selected list of the technology supplying companies with their contact and special features, including companies in both developing countries and developed countries are given in Annexures. A framework for effective waste tyre management system worked out by waste tyre management organizations is illustrated and the waste tyre management practices in Argentina, Australia, Brazil, Canada, Europe Union, Hong Kong, Japan, South Africa, United States of America, Thailand & India are discussed.

The compendium is spread over 7 chapters. Chapter 1 gives introduction, overview & history of tyre and waste tyres, objectives, scope & format. A basic understanding of the issue of waste management has been provided in the initial chapters.

Chapter 2 describes classification of tyres & waste streams. The "Definition" of waste varies across the continents and countries. These definitions have been discussed to assist policy makers and practitioners to set the boundaries for tyre waste management. Tyre waste is a "tradable commodity" and its "mechanism of trading" are usually described in terms of tyre waste composition, potential for material recovery, tyre waste trade value chain (starting from manufacture, production, import, consumption, tyre waste generation, treatment and disposal), sources of generation. This chapter will assist target audience about the tyre waste stream identification, their classification & composition, likely waste streams and planning for identifying scale of tyre waste management in a particular geography.

Chapter 3 describes Methodology for Assessment of Quantity of Waste Tyres Generated in a Country. Methodologies for tyre waste inventory vary as per their application, constraints, advantages, data requirements and sources of data. Before selecting a particular methodology, it is important to evaluate its constraints, advantages, data requirement and whether sources for collecting such data are available. The compendium describes different tools and techniques for data acquisition, review and stakeholder engagement. This chapter gives guidance on the usage of results obtained as part of tyre waste inventory assessment for planning and implementation of tyre waste management i.e. scale & level of technology and guidance notes provides assistance to target audience to assist in identification of problem, its extent & capacity required to manage it.

Chapter 4 describes Perspective of Tyre & Waste Management. The "perspective" of tyre waste and the mechanism of tyre waste trade varies across the continents and countries. These different perspectives and mechanisms along with a material flow model have been discussed to provide conceptual understanding of tyre waste management. Review of current practices of tyre waste management in different countries provides an understanding of policies/ laws/ regulations and institutional framework for tyre waste management. Institutional mechanisms for management system have been described which will be useful in developing a roadmap for setting up institutions and policy/laws/ regulations for tyre waste management chain covering collection transportation and treatment including material recovery and disposal. This chapter provides guidance to assess whether tyre waste is addressed in the existing environmental/ related legislation of the country, identify the gaps and the regulations where tyre waste can be addressed and whether there is a need to address it in a new law.

Chapter 5 describes Compendium of Technologies for the Recovery of the Materials / Energy from Waste Tyres. Technologies or technical interventions are vital for tyre waste management chain to maximize material recovery and minimize the risks. Technical interventions for collection and transportation of tyre waste are commonly known as treatment channels and infrastructure. Technical interventions for treatment of tyre waste are generally knows as treatment technologies. Environmental impacts of treatment technologies are vital to be addressed during design and operation of these technologies. Guidance notes will be useful for technical personnel as well as for the responsible agencies/organizations and other stakeholders to identify appropriate technical options & specification for collection, transportation, treatment and disposal of tyre waste in order to comply with policy/ laws/ regulations.

Chapter 6 describe Tyre Waste Management Models. This chapter provides a broad framework to assist in assessment and development of viable model for waste tyre management system.

The financial viability of all the stages of tyre waste management chain is vital for its implementation. Financing mechanism of collection, transportation, treatment and disposal of tyre waste may include market-based instruments (economic instruments) including recycling fee and environmental tax based on amount and type of waste. To assist policy makers in understanding financial mechanism for tyre waste management, examples from developed and developing countries have been discussed.

Chapter 7 describes case studies from developed & developing countries. This will provide target audience examples of successfully implemented waste tyre management systems.

Different countries are at different stages of implementation of waste tyre management system. Therefore, the countries and target audience need to first assess the level of their existing system & their requirements system. For example countries, which have already carried out inventory assessment and have regulations in place can directly refer to chapter 5, 6 & 7. Guidance notes at the end of each chapter will assist them to carry out this assessment. This will also assist them to fix their objectives and decide on the extent of intervention required to achieve these objectives. Finally they can prepare work plan and allocate resources to complete the required activities.

CHAPTER 1: INTRODUCTION

1.0 Introduction

Rapid increase in volume and types of solid waste and hazardous waste generation is becoming a burgeoning problem for national and local governments to ensure a sustainable management of waste. Waste management has a strong bearing on environment and quality of human life. The adverse impacts of improper waste management are very serious and well known. Waste management also requires resources both financial as well as sound technologies. For example, in low income countries, collection alone drains up 80 to 90% of the municipal solid waste management budget. Waste management is high on the national and international agenda due to severe negative impacts on environment, lack of resources to effectively manage it and loss of resources which could be saved and / or recovered through its proper management based on the waste hierarchy, circular economy and 3R (reduce, reuse and recycle) approach.

End of life (EoL) tyres or waste tyres is one of the waste streams, which is growing steadily and is expected to continue in future. It has been reported 15.85 million tones of tyres have been produce in the world in 2014[1]. About the same number that reach the end of their useful lives every year. These reach the end of their useful lives every year. These EoL tyres are either dumped illegally landfilled or enter waste stream for material recovery. In all the three situations, they pose environmental & health risk if not managed scientifically in the absence of regulatory regime it becomes difficult to design & implement an appropriate EoL tyre waste management system. Further, technology selection for recovery route has been identified as one of the major factor to support waste management system.

The United Nations Environmental Programme (UNEP) through International Environmental Technology Centre (IETC), Division of Technology, Industry, and Economics (DTIE) is implementing Waste Management program based on principle of 3R (reduce, reuse and recycle). IETC aims to promote identification and implementation of environmentally sound technologies (ESTs) for collection, storage, treatment, disposal, recovery & recycling of different waste streams. In this context, UNEP DTIE-IETC has prepared compendium of environmentally sound technologies for EoL tyres. The key audience of this compendium will be technology selection decision makers. This work will compliment the work being done globally and regionally, on the subject by UNEP and other related agencies. In this chapter, the following sections describe overview & history of tyres & EoL tyres, objectives, scope and format of the compendium

1.1 Overview & History of Tyres and Waste Tyres

Rubber tyres have been in use since the mid-1800s. They have been an integral part of transport for many years, changing and adapting to the shifting needs of society. The history of the development

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[1] *Tyre Industry of Japan 2015, http://www.jatma.or.jp*

of tyres informs contemporary efforts to overcome the challenges of their disposal, as each step in the evolution of their properties and performance introduced new complexities, and hence barriers to, reprocessing or reuse.

The first automobile tyres were solid rubber. Due to their durability, solid tyre were initially preferred over pneumatic tyres filled with pressurised air. However, although solid tyres were patented in 1845 they fell into disuse, because of their tendency to damage roads. Pneumatic tyres for automobiles were pioneered by brothers Andre and Edouard Michelin, and soon replaced solid rubber tyres, which were eventually legislated against because of their damaging impact on public roads.

The original bias-ply pneumatic tyre was an inner tube containing compressed air and an outer tube for traction that was reinforced with 'plys' of cords of fabric coated in rubber. These tyres dominated the market until the introduction of radial tyres, which are still in use today. Radial tyres utilize cord belts that radiate at a 90-degree angle from the wheel rim and are reinforced by a belt of steel fabric that runs around the circumference.

In the 1900s, the average recycled content of all rubber products was 50%. By 1960, it was reduced to 20%. The introduction of steel belted radials in the late 1960s and early 1970s made it increasingly difficult to slice and grind EoL tyres. Consequently, the old infrastructure for processing EoL tyres was almost completely lost. By 1995, the tyre and rubber industry only used approximately 2% recycled rubber. As such, the current rubber recycling market is relatively new. The complexity of the composition of contemporary tyres significantly affects how they are processed and recycled. Contemporary tyres are made of vulcanised rubber, a more stable form of rubber which results from combining natural and synthetic rubber with sulphur. This modifies the rubber, forming cross-links between individual polymer chains. Vulcanised rubber overcomes many issues associated with natural rubber, such as a tendency to become sticky at high temperatures, and to become brittle in the cold. However, the structural changes that vulcanisation brings about makes the recycling of tyres more difficult. This complex composition further contributes to the challenges of tyre recycling[2].

Although modern tyres are still, fundamentally, rubber products, they are a complex mix of natural and synthetic rubbers, and various structural reinforcing elements including metals and chemical additives. This complexity significantly influences the way EoL tyres can be handled, and has led to stockpiling, dumping and diversion to landfill due to the various barriers to recycling or reprocessing. This, in turn, has exposed communities to negative environmental and health impacts and has squandered potentially valuable resources locked up in EoL tyres stockpiles. Consequently, many governments worldwide are seeking to clean up EoL tyres and industries are increasingly utilising waste tyres as a source of materials or energy.

1.2 Objectives

The main objectives of this compendium include: To facilitate the technology decision makers in making more informed decisions for technology selection; Develop criteria to facilitate the assessment of various

[2] *Reschner, K. (2008). Scrap Tyre Recycling: A Summary of Prevalent Disposal and Recycling Methods. Entyre Engineering, Berlin*

technology options to shortlist most relevant and suitable technologies and prepare compendium of commercially available or near commercially available technologies and associated techniques for recovery of materials and energy from used tyres.

1.4 Scope

The scope of this compendium covers information on commercially available or near commercially available technologies and associated techniques for recovery of materials and energy from waste / hazardous waste and subsequent treatment of residual wastes. The key fields of information in the compendium are: Type of technology – detailed process description, type of waste handled, products (if any), emissions, job potential and capacities available; Operational / technical details including parameters for specifications for procurement, operation and maintenance requirements, and specific aspects for developing countries; Environmental and social considerations; Investment and operating costs; Institutional and regulatory requirements; Pros and Cons with respect to developing countries; Examples of real life applications; Photographs and sketches and Suppliers.

The preparation of this compendium has involved collection of data from secondary sources including publications from scientific journals, reports and web sites. A case study based approach has been adopted to provide the practitioner examples of live situations so that it can be adopted in a country/ geographical region or city. The compendium should be usable in all the countries, where EoL tyre projects have been initiated.

1.4 Format of the Report

This **Compendium** has been compiled in seven chapters. **Chapter 1** gives introduction, overview & history of tyre and EoL tyres, objectives, scope & format of the report.

Chapter 2 gives Classification of Tyres & Waste Streams consisting of tyre making and its constituents, Types of tyres (passenger vehicle tyres, truck tyres, aircraft tyres, bicycle tyres, off-the-road (OTR) and mining tyres), lifecycle of a tyre and tyre life span, EoL tyres (definition, source of EoL tyres) and environmental and health impact of EoL tyres followed by guidance notes. These notes will assist target audience about the EoL tyre waste stream identification, their classification & composition, likely waste streams and planning for identifying scale of EoL tyre waste management in a particular geography.

Chapter 3 Methodology for Assessment of Quantity of Waste Tyres Generated in a Country describes methodology for the estimation of EoL quantities; Model generation for assessing EoL tyres; Quantitative approach; Qualitative analysis of the data and Methodology to estimate the quantity of EoL tyres in a stockpile. The chapter gives insight on the usage of results obtained as part of tyre waste inventory assessment for planning and implementation of EoL tyre waste management i.e. scale & level of technology. Guidance notes provides assistance to target audience to assist in identification of problem, its extent & capacity required to manage it.

Chapter 4 Perspective of Tyre & Waste Management (WT) describes National and social policies / laws / regulations / institutional roles in developed countries (policies / laws / regulation, institutional mechanism) and national and social policies / laws / regulations / economic /

institutional roles in developing countries. Guidance notes also provide a broad road map to assist target audience in assessing & developing enabling policy/ laws/ regulations and institutional framework for EoL tyre waste management. Guidance notes provide insights to assess whether EoL tyre waste is addressed in the existing environmental/ related legislation of the country, identify the gaps and the regulations where EoL tyre waste can be addressed and whether there is a need to address it in a new law.

Chapter 5 Compendium of Technologies for the Recovery of the Materials / Energy from EoL Tyres describes Generic technologies & specific technologies for the recovery of materials / Energy from EoL tyres; Material recovery technologies (Rubber recovery technologies—Recovery of ground rubber , Technologies for tyre derived aggregates , Metal recovery technologies , Technologies for recovery of devulcanised rubber, Energy recovery processes and technologies, Technologies for direct use as a fuel, Technologies for conversion to conventional type fuel , Technologies for recycling EoL tyres in steel production); Specific technologies for recovery of materials/energy from EoL tyres (Introduction, Material recovery technologies, Shredding process of material recovery from EoL tyres, Budgetary cost estimates for shredders, Companies practicing shredding process in developed countries) and Other specific technologies used in EoL tyres. Guidance notes provide a broad framework to assist in design and development of technical specifications for EoL tyre waste management system. This will assist technical personnel/ EoL tyre waste implementation agencies/ other stakeholders to identify technical options for EoL tyre waste collection, transportation, treatment and disposal systems.

Chapter 6 EoL Tyre Waste Management Models describes management practice of EoL tyres; Stakeholders' responsibilities (Tyre industry responsibility, Government responsibility, End User Responsibility); Existing EoL management models (Free market approach, EoL tyres management associations and conferences) and Framework for effective EoL management systems. Further, guidance notes provide a broad framework to assist in assessment and development of viable model for EoL tyre management system.

Chapter 7 Case Studies of EoL Tyre Management by Country/Region describes Case Studies: Developed Countries (EoL tyre management in Australia, EoL tyre management in Canada, EoL tyre management in European Union, EoL tyre management in Hong Kong, EoL tyre management in Japan EoL tyre management in United States of America); Case Studies: Developing Countries (EoL tyre management in Argentina, EoL tyre management in Brazil, EoL tyre management in South Africa) and Conclusions.

CHAPTER 2: CLASSIFICATION OF TYRES & WASTE STREAMS & MARKET ASSESSMENT

2.0 Introduction

EoL tyre is a significantly growing waste stream in the world. It is discarded at an estimated rate of approximately one per year per capita in industrialized nations (EPA, 2010). As the world's population grows and becomes more industrialized, the number of tyres produced and eventually discarded, is growing rapidly. Each year, approximately 100 million tyres are processed by the recycling industry. The conversion of these EoL tyres into items of economic value requires an understanding of EoL tyre as a "tradable commodity" and its "mechanism of trading". EoL tyre as a "tradable commodity" can be described in terms of tyre classification, composition and its potential for material recovery. "Mechanism of Trading" can be described in terms of life cycle, starting from raw material, manufacturing / production / import, consumption, waste generation, sources of generation, waste disposal and facilities of material recovery. The impact of material recovery and their conversion into items of economic value can be assessed from environmental, occupational health and safety issues which would have occurred either in their absence or under uncontrolled conditions. The following sections describe each of these items to facilitate an understanding of EoL tyre market followed by guidance notes to assess EoL tyre market in a country/ geographical region/ city. This will help the target audience in identifying the problem, assessing the existing waste value chain & relevant stakeholders in a geographical area / country.

2.1 EoL Tyre as a Tradable Commodity

EoL tyre as a tradable commodity has been described in terms of tyre making & its constituents & tyre classification, which contain items of economic value. At first, tyre making & its constituents have been described, which are easily "identifiable" and "recoverable", followed by description of composition for material and energy recovery. These are classified into different types based on usage e.g. Passenger Vehicle Tyres, Truck Tyres, Aircraft Tyres, Bicycle Tyres, Off-the-Road (OTR) and Mining Tyre.

2.1.1 Tyre Making and its Constituents

Rubber composite acts as the primary material and plays an important role in tyre manufacturing. The composite is typically a combination of natural and synthetic rubbers, carbon black and sulfur. Tyre rubbers include 85% carbon, 10 to 15% iron material and 0.9 to 1.25% Sulphur[3].

Natural rubber is an essential material used in tyres & tubes manufacturing. Natural rubber is derived from the sap of the Hevea brasiliansis tree. Its molecular structure primarily consists of

[3] *TNRCC (1999). Composition of a tyre. Texas Natural Resource Conservation Commission, Austin*

hydrocarbon with the molecular weight range of 50,000 to 3,000,000. **Figure 2.1** shows a schematic representation of the molecular structure of natural rubber[4].

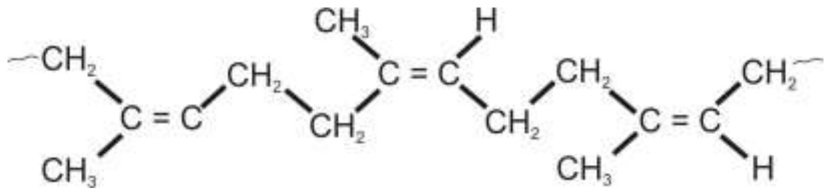

Figure 2.1: Molecular Structure of Natural Rubber

Tyres are produced using synthetic and natural rubber, steel, textiles and chemical additives[5]. The ratio of these different components varies depending on what the tyre will be used for, as different ratios produce different characteristics. The synthetic rubber is manufactured using petroleum or coal as a primary resource. Zinc oxide, the chemical that serves as an activator, is added to the rubber. Carbon black, very finely-powdered carbon, usually makes up about 30% of the tyre and is added to reinforce the tyre, making it stronger and more resistant to abrasions, and ensuring that the tyre wears out slowly. It also makes the tyre easier to process and helps protect it from UV light[6]. These different components are **mixed and homogenised** in a Banbury mixer. In addition to chemicals, different additives are also used depending on the tyre type. The most common additives and their roles on the process are listed in **Table 2.1**[7].

Table 2.1: Common Additives and their Roles in the Process

Additive	Characteristics
Calcium oxide	Improves strength and Durability
Zinc oxide and titanium oxide	Speeds up the vulcanization process
Copper oxide	Bonding agent
The zinc oxide/ stearic acid accelerator/ organo-sulfur	Aids the vulcanization process and enhances the physical properties of rubber
Antioxidant	Prevents deterioration of the rubber complex

Other elements in a tyre's composition include iron and titanium from the tyre's steel belts and sulfur from the vulcanization or cross-linking process. Tyres also contain very small amounts of silicon, aluminum, magnesium, sodium, potassium and phosphorus[8].

Certain chemicals, when combined with rubber and heated, produce certain characteristics such as high friction for racing tyres. These materials are mixed and then vulcanized by adding sulfur. **Vulcanization** is a thermo chemical process that creates cross-links between individual polymer chains[9]. This process greatly stabilizes the rubber, but can make end-of-life processing more difficult.

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[4] *Audley, B. G. and Archer, B.L. (1988). Biosynthesis of rubber. In Natural Rubber Science and Technology (ed. Roberts, A. .D.). 35-62. Oxford University Press, London*
[5] *OECD (2007). Improving recycling markets. Organisation for Economic and Cooperative Development, Paris*
[6] *OECD (2007). Improving recycling markets. Organisation for Economic and Cooperative Development, Paris*
[7] *Cummings R.C. (1998). Preparation, characterization, and uses of tyre-derived particles. Dissertation for the Degree of Doctor of Philosophy. The University of Southern Mississippi, Mississippi*
[8] *Evans, A. and Evans, R. (2006) The Composition of a Tyre: Typical Components. The Waste and Resources Action Program, Oxon, UK.*
[9] *OECD (2007). Improving recycling markets. Organisation for Economic and Cooperative Development, Paris*

Once the rubber is prepared it is sent to the tyre-building machine where the layers of rubber are **wrapped** to form the tyre. The other components are then taken to the machine and once all are in place, are **pressed** together. At this point the tyre is a 'green tyre' as it has not yet been cured and does not have a tread pattern[10].

For **curing**, the tyre is placed inside a mould containing a bladder that fills with steam, inflates the tyre, and presses a blank tread against the sides of the mould imprinting it with the tread pattern. During this process the tyre is heated up to 149ºC, curing the rubber and binding all the components together[11].

2.1.2 Types of Tyres

Depending on their size and function, tyres vary in design, composition, and total weight. The rubber composition of different types of tyres is given in **Table 2.2**.

Table 2.2: Rubber Composition of Different Types of Tyres

Synthetic Rubber	Natural Rubber
Passenger Vehicle Tyre	
55%	45%
Light Truck Tyre	
50%	50%
Racing Car Tyre	
65%	35%
Off-Road Tyre	
20%	80%

Some different areas of application include high performance tyres for passenger vehicles, trucks, bicycles, aircraft and numerous forms of mobile heavy machinery and agricultural tools.

Radial Vs Bias tyres

Radial tyre

In radial tyres, side wall flex is not transmitted to the tread. There is little transversal slip. The radial tyre allows the machine to transfer more power to the ground. Due to flexibility and strength of the tyre, the tyre absorbs shocks, impact and bumps. The result is a better ride and better operator comfort.

Bias tyre

In bias tyre, all sidewall flex is transmitted to the tread. The footprint deforms and there is an increase in tyre slip. The tyre does not contact as much ground as a radial tyre, leading to a loss of engine power transmission and greater ground damage. Due to the stiffness of the tyre, it does not absorb bumps on the ground. All impact and shaking is felt by the driver and machine.

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[10] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*
[11] *Continental AG (2008), Tyre Basics: Passenger Car Tyres. Continental AG, Germany*

Passenger vehicle tyres

These are typically composed of vulcanised rubber compound (47%), carbon black (21.5%), steel (16.5%), and nylon/fibre (5.5%)[12]. The carbon black, steel and textiles reinforce the tyres. A typical passenger tyre will weigh up to 7kg, and these make up 85% of the tyre market in the USA and the UK[13]. The vulcanization of rubber in tyres makes them stronger, more durable, but also more difficult to break down and reuse. Steel is generally utilized within the tyre in the beads, belts and structural body. The steel is treated with metal cobalt and coated with a brass formulation to help the rubber and steel stick together. This is important for the function of the tyre, because if the steel is not properly adhered to the rubber, it can move independently and destroy the structural integrity of the tyre. However, this creates problems in recycling as the steel and rubber cannot be easily separated.

The main features of a passenger car tyre are the tread, the body with sidewalls and the beads. The tread, made up of a mixture of natural and synthetic rubber, is the raised pattern that comes in contact with the road. It has a pattern of grooves and this pattern is often specifically tailored to the use of the tyre. For example: a snow tyre has a tread pattern which compacts the snow and funnels it out from the tyre's sides. The body supports the tread and gives the tyre its specific shape. The beads are rubber-covered, metal-wire bundles that hold the tyre onto the wheel[14]. The body of the tyre is made of fabric – the plies. The material is coated in a combination of natural and synthetic rubber to help hold air inside and to help the fabric bond to the other parts of the tyre. The material of the plies can vary depending on the type of tyre. **Figure 2.2** shows the rubber tyres integral part of a passenger tyre.

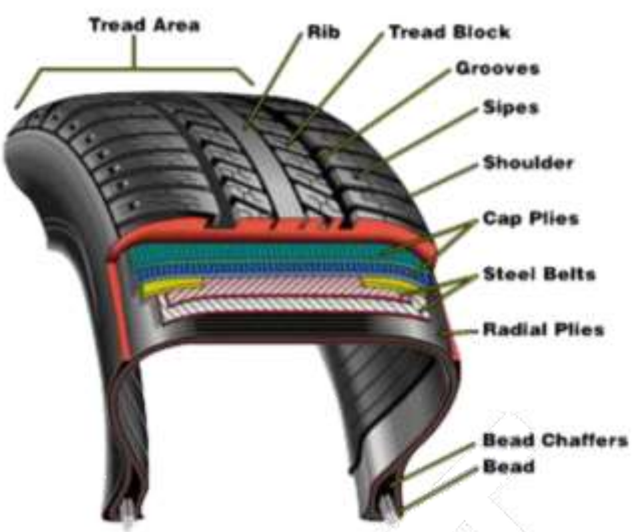

Figure 2.2: Schematic Representation of Rubber Tyres Integral Parts of a Passenger Tyre

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[12] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*
[13] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*
[14] *Miller, R.C. (1985). Tyres: A Century of Progress. Popular Mechanics, 60-64.*

Truck Tyres

Truck tyres are much larger than those on passenger vehicles and are typically used in the commercial sector. Generally, they are composed of a rubber compound with a higher ratio of natural rubber than that used on passenger vehicles. They are reinforced with carbon black, textiles and steel, like passenger tyres; however, in truck tyres more steel wire is used to ensure adequate reinforcement. They serve larger, heavier vehicles and, as such, the average truck tyre will weigh 55 kg compared to 7kg for a passenger tyre. These commercially used tyres need greater reinforcement because of the distances they cover, the heavier payloads and the greater stresses imposed by large vehicles. Truck tyre generally utilize a rubber compound that allows for lower friction and higher mileage and are designed to be easily re-treaded (in comparison to passenger tyres) by the retailers. Truck tyres are designed to have a longer life span that the average passenger tyres, often with a heavier tread, which is appropriate for longer commercial journeys[15]. Material composition of truck and passenger tyres by weight in the EU is presented in **Table 2.3**.

Table 2.3: Material Composition of Truck and Passenger Tyres by Weight in the EU

Material	Truck Tyres	Passenger Tyres
Natural Rubber	27%	14%
Synthetic Rubber	14%	27%
Metal	16.5%	25%
Carbon black	21.5%	22%
Textile	5.5%	--
Zinc oxide	1%	2%
Sulphur	1%	1%
Additives	7.5%	5%

Additives consists of reinforcing agents like clays and chemicals mentioned in **Table 2.1**.

Aircraft tyres

Aircraft tyres are built to cope with much more challenging conditions than road tyres, and are subjected to extreme temperature differences, with runways heating up to 50ºC during take- off (due to friction), and sub-zero temperatures reached during flight. They must also be resistant to impact and to the elements, often exposed to winds of 160 kmph during descent, and can hit the runway at 130 kmph[16]. Because of this, the material used for the plies of an aircraft tyre must be very strong. Kevlar is often used for their reinforcement, to give them the stability and strength necessary to deal with the pressures of take-offs and landings. Kevlar is able to resist and maintain its integrity in the extreme temperatures experienced. Aircraft tyres also have specific rubber compound formulations to provide maximum protection against ultraviolet light and the ozone. Further, it may also contain magnesium hydroxide as flame retardants. The most common way of dealing with damaged or aged aircraft tyres is retreading. Of all aircraft tyres, 80% are retreaded[17]. The use of retreaded tyres is common in commercial aircrafts – each tyre is marked and tracked by a serial number, so the carcass history of the tyre is known from the point of manufacture to retyrement[18]. Once aircraft tyres can

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[15] *Miller, R.C. (1985). Tyres: A Century of Progress. Popular Mechanics, 60-64.*
[16] *Freeman, L. (2005). What Makes Airplane Tyres So Special? Planet and pilot, 35-40*
[17] *ITRA (2001). Understanding Retreading: Guidelines. International Tyre and Rubber Association Foundation Inc., USA*
[18] *Santerre, K. (2006). Aircraft Tyre Selection and Management. http://www.avweb.com/news/maint/193372-1.html (accessed 17 April 2013)*

no longer be retreaded, they are generally shredded. Aircraft tyres are processed separately from passenger tyres or truck tyres because they contain different levels of steel and reinforcing fabrics[19].

Bicycle tyres

Bicycle tyres differ from both automobile and aircraft tyres, with three basic parts: the carcass, the bead core and the tread. The carcass is a rubberised fabric that is laid around the bead cores. Typically, the carcass is made of nylon fabric which is then coated with a rubber compound: the denser the fabric, the more resistant it will be to punctures. The tyre tread will then be applied, and the entyre tyre is vulcanised[20]. The bead core determines the diameter of the tyre and is generally made of steel wire. For foldable tyres, the steel wire is replaced with a bunch of Kevlar fibre forming a hoop; allowing the flexibility needed for folding, but making the tyres more difficult to recycle. The majority of bicycle tyres, however, are standard and are relatively easy to dispose of, as they can be broken down into their components and have a much thinner tread than automobile or aircraft tyres[21]. This means they can be easily shredded or crumbed.

Off-the-Road (OTR) and mining tyres

Off-the-road (OTR) tyres include heavy industrial tyres primarily designed for the wheels of mining or agricultural vehicles, trailers or trailed appliances. Mining and other OTR tyres are typically very large, and are manufactured to suit a wide range of conditions. They must cope with different surfaces (from surface and underground mining), extreme temperatures and heavy payloads[22]. Mining tyres are generally radials, and are reinforced with steel cord and beads[23]. OTR mining tyres differ from passenger tyres in both their size and rubber composition. Unlike passenger tyres, which often contain a significant ratio of synthetic rubber, off-the-road mining tyres have a rubber content of nearly 100%[24]. The difference in rubber composition may be due to the fact that passenger vehicle tyres are required to meet higher performance standards (low rolling-resistance, improved skid-resistance and good wear) to succeed in the competitive market. OTR tyres, on the other hand, have to cope with heavy loads and longer distances. The fibre content in passenger tyres can be as much as 5% of the total weight, whereas OTR tyres tend to have little or no fibre content and contain approximately 15% steel[25]. Given the large size of mining tyres, the rubber they are made of represents a significant resource and should be recovered where possible. By pulling the tread off an off-the-road mining tyre, the buffing of pure rubber (with no steel or fibre contamination) can be used to retread other off-the-road tyres[26]. Retreading off-the-road tyres is half the cost per unit of manufacturing new tyres. However, a retreaded tyre has a lifespan 20% shorter than a new tyre[27]. If OTR mining tyres cannot be retreaded, they can be used in the production of tyre derived fuel, and the steel recovered can be recycled as scrap steel[28]. There are a number of innovative solutions available for dealing with end-of-life mining tyres, due to their size. Large OTR mining tyres have

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[19] *ITRA (2001). Understanding Retreading: Guidelines. International Tyre and Rubber Association Foundation Inc., USA*
[20] *Schwalbe Tyres (http://www.schwalbetyres.com/tech_info/tyre_construction (accessed 17 April 2013)*
[21] *Schwalbe Tyres (2011). Tyre Construction. http://www.schwalbetyres.com/tech_info/tyre_construction (accessed 17 April 2013)*
[22] *Bridgestone Tyres (2013). Tyre specifications. www.bridgestone.com (accessed 17 April 2013)*
[23] *International Mining (2012). Mining Tyres. http://www.im-mining.com/2012/09/01/mining-tyres/(accessed 20 April 2013)*
[24] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*
[25] *Dunn, J.R. and Jones, R.H. (1991). Automobile and Truck Tyres Adapt to Increasingly Stringent Requirements. Elastomerics July, 11-18*
[26] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*
[27] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*
[28] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*

been modified and used as water tanks, road bases for temporary roads, as well as feed containers and other livestock/farm items[29]. These modifications usually involve cutting off the sidewalls of the tyre, and forming a tank or bunk. Most tanks will then have a concrete base poured[30]. The cut-off sidewalls can also be used as windbreak fences[31].

2.2 Mechanism of EoL Tyre Trade

Mechanism of EoL tyre trade can be explained in terms of three elements. These are

1. Material Flow
2. Life Cycle
3. Geographical Boundary

"Material Flow" along the "Life Cycle" of a tyre within a "Geographical Boundary" forms the basis of EoL tyre generation in cities/ countries. The following sections describe a conceptual understanding of material flow, along the life of a tyre, its conversion into a "waste" item followed by its transformation into new material or its reuse.

Conceptual life cycle of a Tyre is shown in **Figure 2.3**.

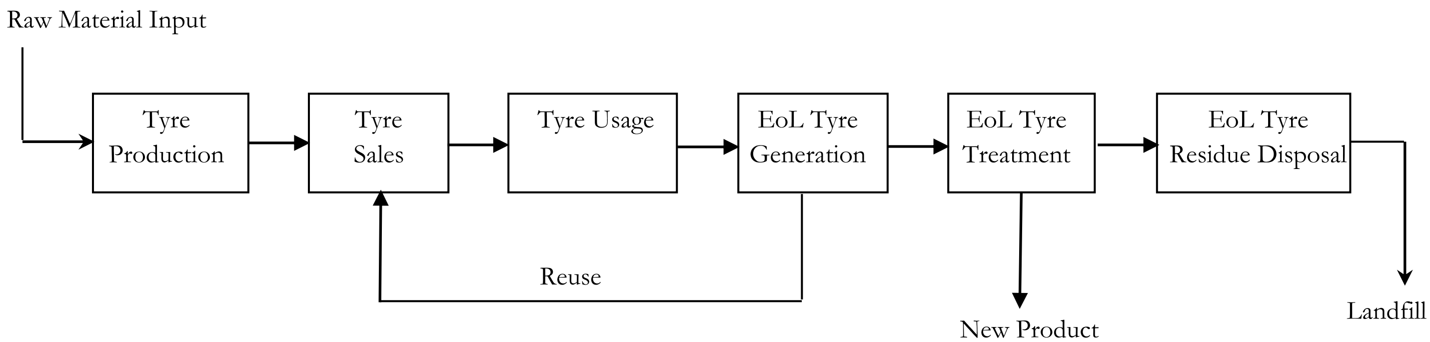

Figure 2.3: Conceptual Life Cycle of Tyre

2.2.1 Life cycle of a tyre

The various stages in the life of a tyre, starting from raw material input through to manufacture, use and disposal, are shown in **Figure 2.4**. It shows in particular that retreading may take place in the prevention phase as a re-use measure or in the waste recovery/disposal phase where tyres that have been discarded may undergo retreading or other environmentally sound disposal operations, thus increasing the useful life of tyres through retreading in both phases[32].

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[29] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*
[30] *Essadiqi, E. and Pehlken, A. (2005). Scrap Tyre Recycling in Canada. CANMET Materials Technology Laboratory, Canada*
[31] *Scrap Tyre News (2004). Scrap OTR's Spin their Way into Other Uses. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.minerals-metals/files/pdf/mms-smm/busi-indu/radrad/ pdf/scr-tir-rec-peh-eng.pdf (accessed 17 April 2013)*
[32] *UNEP, Revised technical guidelines for the environmentally sound management of used and waste pneumatic tyres*

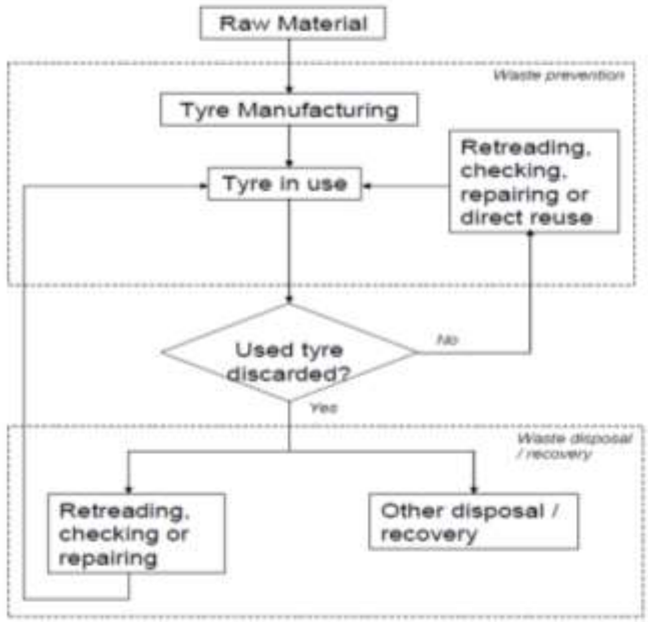

Figure 2.4: Stages in the Life of a Tyre[33]

(1) Used tyres

Different agencies use different terms for used tyre as per their regulatory framework. According to California's Department of Resources Recycling and Recovery (CalRecycle), 30 Public Resources Code (PRC) 42806.5 defines[34] "used tyre" as a tyre that meets all of the following[35]:

1. The tyre is no longer mounted on a vehicle but is still suitable for use as a vehicle tyre.
2. The tyre meets applicable requirements of the Vehicle Code and Title 13 of the California Code of Regulations.
3. Tyre Storage:

   (a) The used tyre is stored by size in a rack or a stack, but not in a pile in a manner approved by the local fire marshal and vector control authorities and in accordance with state minimum standards.

   (b) A used tyre stored pursuant to this section shall be stored in a manner to allow the inspection of each individual tyre.

(2) Retreaded tyres

The term "retreading" refers to replacing the wearing surface of the tyre. Where tyres that have been previously discarded are retreaded, retreading is a waste recovery operation. Where used tyres that have not been discarded are retreaded, retreading is considered a form of waste prevention. In both

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[33] UNEP, *Revised technical guidelines for the environmentally sound management of used and waste pneumatic tyres*
[34] *http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=42001-43000&file=42800-42808*
[35] *http://www.calrecycle.ca.gov/tyres/enforcement/inspections/wasteorused.htm#WasteOrUsed*

cases retreading enables the tyres to be reused and extends their useful life. Further information on retreading technologies is presented in Chapter 4 of the present compendium[36].

(3) Waste tyres

A waste tyre is a tyre that is not brand new, nor is it mounted on a vehicle, and it is not stored in a manner for display and sale that allows for inspection of the tread. A waste tyre is not intended for use on a vehicle again. A tyre intended for use on a vehicle again may still be considered as a waste tyre if it does not meet all of the requirements[37].

2.2.2 Tyre lifespan

Annually, almost one billion tyres for passenger cars, utilities, trucks and off-road vehicles are manufactured worldwide, while an almost equal quantity of tyres are permanently removed from vehicles[38]. The lifespan of a passenger car tyre varies widely, with some lasting only 40,000 km while others remain functional for over 80,000 km[39]. The quality of the tyre, individual driving or usage styles, road or ground-surface conditions, exposure to sunlight and other elements, mechanical stress and tyre maintenance all impact on its lifespan. In particular, a lack of proper and regular inflation increase surface stress on a tyre, shortening its lifespan. The lack of inflation increases the pressure on the tyre's structure and contact with the ground surface produces excessive heat. These both affect the structural integrity of the tyre, making it degrade more quickly[40].

Tyres used for commercial trucks are handled differently. Truck tyres are used on vehicles with a Gross Vehicle Weight (GVW) exceeding 10,000 pounds (approximately 4,500kg)[41] and are designed to travel hundreds of thousands of kilometers on their original treads, before re-treading. They last much longer because of their design and the strict maintenance guidelines for long haul vehicles.

Truck tyres contain more natural rubber than synthetic rubber (27% natural rubber, 14% synthetic rubber)[42] whereas passenger car tyres are mostly made from artificial rubber - Styrene and Butadiene copolymers, (14% natural rubber, 27% synthetic rubber). This helps truck tyres cope better with the weight of the vehicle. In addition, commercial trucks are, typically, professionally maintained which eliminates much of the wear resulting from poor maintenance. In many countries, drivers are also required to perform daily pre-trip vehicle inspections, including the checking of tyres and their inflation levels. Re-treading of tyres is more common in commercial trucks.

Bicycle tyres are smaller and lighter than all other types of tyres. A high quality bicycle tyre can last up to 4,000km,[43] but bicycle tyres are more vulnerable to puncture because they are relatively much thinner and are more exposed to debris.

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[36] UNEP, *Revised technical guidelines for the environmentally sound management of used and waste pneumatic tyres*
[37] *http://www.calrecycle.ca.gov/tyres/enforcement/inspections/wasteorused.htm#WasteOrUsed*
[38] *Rubber Manufacturers Association*
[39] *Continental AG (2008), Tyre Basics: Passenger Car Tyres. Continental AG, Germany*
[40] *Continental AG (2008), Tyre Basics: Passenger Car Tyres. Continental AG, Germany*
[41] *ETRMA (2010), End of life tyres: A valuable resource with growing potential. European Tyre and Rubber Manufacturers' Association, Brussels*
[42] *O'Shaughnessy V. And Garga V. K. (2000). Tyre-reinforced earthfill. Part 3: Environmental assessment. Can. Geotech. J. 37, 117-131*
[43] *Nabeel, A. (2011). Bicycle Tyres Information and Selection Guide. http://www.everybicycletyre.com/tyres/tyreguide.asp (accessed 20 April 2013)*

2.2.3 EoL Tyres (Definition, Source of Waste Tyres)

2.2.3.1 Definition

There are various definitions of what constitutes a 'EoL tyre'. This compendium defines a EoL tyre as one that can no longer serve its original intended purpose, that is, a product that is at the end-of-life[44]. As used tyres can re retreaded and so reused not all used tyres are, by definition, EoL tyres. However, it is a common practice in Europe and Japan to include both re-treaded and EoL tyres in the definition of 're-used' tyres. In the US, EoL tyres are commonly referred to as scrap tyres.

The United States Environment Protection Agency (USEPA) defines a EoL tyre as a "worn, damaged, or defective tyre, which is not mounted on a vehicle". They class EoL tyres as a form of solid waste. There are drawbacks with this definition as it initially allowed EoL tyres to be dumped in landfill with other solid waste products. This definition is used to describe all tyres that have been disposed of, legally or illegally. As such, it does not distinguish between end-of-life tyres and those disposed of prematurely and which could, otherwise, have been retreaded. This distinction is important because the majority of tyres have the potential for re-treading, while those that have reached their end-of-life do not.

The EU definition of EoL tyres includes those retreaded and re-used, as well as those that have reached their end-of-life. This is seen in the 'ladder' of valuation in the EU for how tyres are reused. Those at the bottom of the ladder end up in landfill (despite a ban on tyres in landfill that was imposed in 2003, some dumping still occurs in places); the middle tier comprise EoL tyres used for energy purposes or 'materials compensation'; the top tier is made up of EoL tyres used as a source of rubber that is re-formed for products with similar properties, such as retreading[45]. This definition is useful in that it provides a clear understanding of the total number of EoL tyres generated by the EU annually and their secondary use. **Defining different categories of tyres at disposal helps in identifying the appropriate energy and materials harvesting techniques to be utilized. A snapshot of different definitions of EoL tyres is given in Table 2.4.**

Table 2.4: Snapshot of Definitions of Waste Tyre

Name	Definition	Remarks
Waste tyres	A tyre that's no longer mounted on a vehicle and is no longer suitable for use as a vehicle tyre due to wear, damage, or deviation from the manufacturer's original specifications	Definition by CalRecycle[46]
Used tyres	A tyre that is no longer mounted on a vehicle but is still suitable for use as a vehicle tyre.	Definition by CalRecycle
End-of-life (EoL) tyres	Tyres which can no longer be used on vehicles including passenger cars,	Definition by ETRMA

[44] *Rubber Manufacturers Association*
[45] *EcoRub AB (2010). The mountain of tyres. http://www.ec orub.eu/ecology/the-mountain-of-tyres/ (accessed 20 April 2013)*
[46] *http://www.calrecycle.ca.gov/tyres/enforcement/inspections/wasteorused.htm*

	trucks, airplanes and motorcycle tyres (after retreading or regrooving)[47]	
Scrap tyres	A worn, damaged, or defective tyre that is not a repairable tyre.	Definition by CalRecycle

2.2.3.2 Source of EoL Tyres

EoL tyres are mainly generated through replacement. An average car will need its tyres replaced every 40,000-80,000km[48]. The average serviceable lifespan of a car is 300,000km[49] meaning one car can produce 30+ waste tyres in its lifetime. Automobile disposal is another source of waste tyres, as these tyres may not necessarily be at the end of their life, but because of the nature of disposal, will often end up in stockpiles. The car is dismantled and the different components are collected or sold. Tyres may be recycled or discarded, depending upon the country[50].

There are also a number of tyres residing in so-called **'legacy' stockpiles** that have been established over many years and house huge numbers of tyres. Although these stockpiles do not produce new tyres, they can be viewed as a source of future recycling initiatives.

Finally, many tyres have been dumped with other solid waste in landfill. This practice is banned in many countries, including the USA and all countries in the EU[51], because of their slow degradation and the disturbances caused: they can trap methane gas that is produced in landfills, causing tyres to become buoyant and rise to the surface[52]. This movement can damage the lining of the landfill that is supposed to prevent the landfill contents contaminating the surrounding environment. These tyres need to be removed for proper disposal.

It is difficult to calculate the number of waste tyres generated globally, as many countries do not have mechanisms for collecting or analyzing data. However, the World Business Council for Sustainable Development estimated in 2008 that around one billion end-of-life tyres were generated globally, a further four billion are in stockpiles and landfills around the world and about 1.5 billion new tyres are manufactured a year[53]. Similarly, it is difficult to quantify how many tyres were successfully recycled because waste tyre management differs from country to country.

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[47] *ETRMA, Tyre Generic Exposure Scenario, End of Life Tyre Guidance, http://www.etrma.org/uploads/Modules/Documentsmanager/chemrisk--09-12-16-end-of-lifetyre.pdf*

[48] *Continental AG (2008), Tyre Basics: Passenger Car Tyres. Continental AG, Germany*

[49] *Elliott, H. (2010). Cars that will make it past 200,000 miles. http://www.forbes.com/2010/12/08/mostreliable-cars-2010-business-autos-reliable-cars.html (accessed 24 April 2013)*

[50] *Bressan Mühlbeier, D. (2010). Tyre Recycling becomes riving force in Brazil. http://infosurhoy.com/cocoon/saii/xhtml/en_GB/features/saii/features/society/2010/10/14/feature-02 (accessed 6 April 2013)*

[51] *USEPA (2013). Scrap Tyres. http://www.epa.gov/osw/conserve/materials/tyres/ (accessed 24 April 2013);*
ETRMA (2010), End of life tyres: A valuable resource with growing potential. European Tyre and Rubber Manufacturers' Association, Brussels

[52] *USEPA (2013). Scrap Tyres. http://www.epa.gov/osw/conserve/materials/tyres/ (accessed 24 April 2013)*

[53] *Messenger, B. (2013). Tackling Tyre Waste. http://www.waste-managementworld. com/articles/print/volume-14/issue-2/features/tackling-tyres.html (accessed 10 June 2013)*

Case Study: Example of Material Flow Analysis in Japan

Material flow analysis (MFA, also known as Material Flow Accounting) has become one of the basic tools in industrial ecology. "Material flow analysis (MFA) refers to the analysis of the throughput of process chains comprising extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal of materials". In addition to national accounting of material flows, MFA has been increasingly used as a basis for analyzing and planning waste management and recycling systems[54].

MFA essentially flows the principles of mass conservation, where, total input (mass or energy) within a system boundary is equal to the sum of stock and outflow from the system. This can be depicted by using the following equation, adapted from (Brunner and Rechberger, 2004)[55]:

$$\sum_{K_1} in_{input} = \sum_{K_o} in_{output} + in_{stock} \qquad (1)$$

Where the number of system flow is denoted by $_k$, $_I$ and $_o$ are input and output, and in denotes flow or flux. In general, in_{stock} is calculated by the difference input and output from the overall system.

Conceptual MFA application to waste management in Japan is shown in **Figure 2.5.**

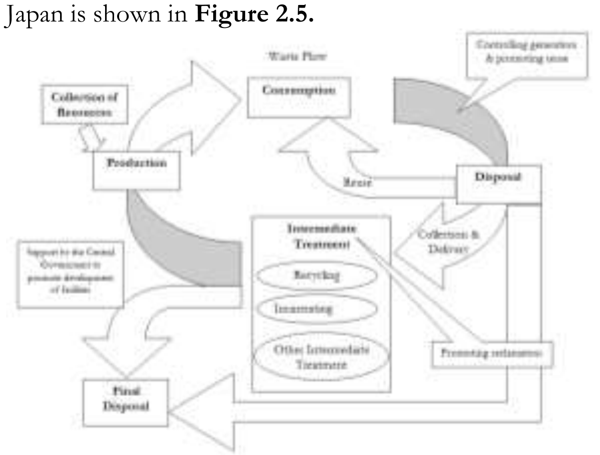

Figure 2.5: MFA Application to Waste Management[56]

Conceptual MFA application to waste tyres in Japan is shown in **Figure 2.6**.

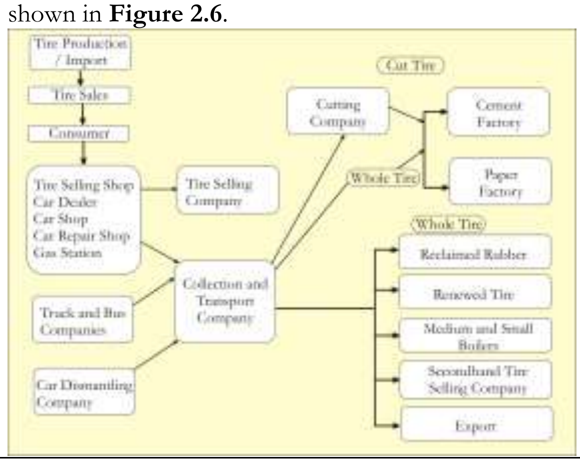

Figure 2.6: Flowchart of Recycling Waste Tyres[56]

System Boundary: Japan
Input: Waste Tyre
Output: Reprocessing use of original form (Reuse)
Thermal Recycle
Abroad Export (Used tyres, cut tyres)
Others

Processing flow of scrap tyre recycling in Japan is shown in **Figure 2.7.**

[54] *Chapter 12: Material Flow Analysis and Waste Management by Yuichi Moriguchi and Seiji Hashimoto*

[55] *Research Gate: Dealing with emerging waste streams; Used tyre assessment in Thailand using material flow analysis*

[56] *Prepared from the Report on Establishing a sound material-cycle society Creating economic development through the establishment of a sound material-cycle society, 2009; Ministry of Environment Government of Japan*

Figure 2.7: Processing Flow of Scrap Tyre Recycling[57]

As per JATMA Volume of scrap tyres generated is given below.

1. The sum of scrap tyres (used tyres) generated at the time of "tyre replacement" and "vehicle scrapping" in 2014 (January to December) was: 99 million tyres in quantity, 1,052,000 tons in weight; increased by 2 million tyres, approximately 30,000 tons respectively from the previous year.

2. At "tyre replacement"
   The volume of newly scrapped tyres at "tyre replacement" increased by 2 million tyres from the previous year to 84 million tyres in quantity, and by approximately 30,000 tons from the previous year to 924,000 tons in weight. It is mainly attributed to an increase in the sales of replacement tyres.

3. At "vehicle scrapping"
   The volume of newly scrapped tyres at "vehicle scrapping" increased by 1 million tyres from the previous year to 15 million tyres in quantity but slightly decreased in weight to 127,000 tons from the previous year.
   The reason of the weight decrease in spite of a increase in the quantity is a decrease of the proportion of heavy duty vehicles.

Status of the recycling in 2014 is given below & graphically shown in **Figure 2.8**.

The total recycled volume increased by 22,000 tons from the previous year to 921,000 tons in 2014. However the recycling rate remained same in 88% as generation of scrap tyres (used tyres) increased. The composition of waste generation by type of business hasn't changed much from the previous year.

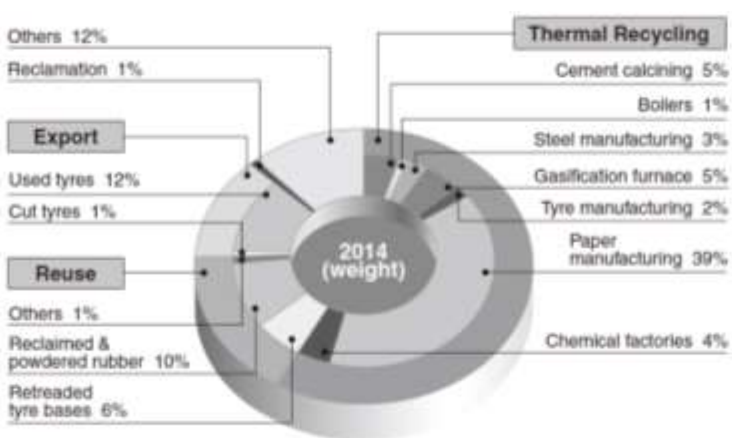

Figure 2.8: Recycling of scrap tyres in 2014[57]

[57] *Tyre Industry of Japan, JATMA 2015*

2.4 Environmental and Health Impact of Waste Tyres

The health and environmental risks posed by waste tyres have been well documented[58] and include fires, various health impacts and environmental contamination due to fires in stock piles[59]. The following describe these issues followed by case studies of health & environmental aspects related ot waste tyres.

2.4.1 Environmental impacts due to fires in stockpiles

Tyre stockpiles, whether regulated or illegal, are associated with high fire risks. Tyre fires are difficult to extinguish, generate toxic smoke and fumes, and cause environmental contamination through residue left after the fire has burnt out. As with all fires involving hydrocarbon products, the presence of carbon monoxide and sulphur oxides represents the greatest immediate threat to human health, with risks of carbon monoxide poisoning and suffocation; however this threat drops rapidly with distance from the seat of the fire[60].

There have been numbers of devastating stockpile fires, such as in Hagersville, Ontario,[61] which lasted 17 days. The residual chemicals leached into the ground, contaminating the water table. As the world's largest automobile market, North America was the first to feel the serious impacts of waste tyres and now both the USA and Canada have programs in place for dealing with them and minimising the risks they pose, including fires. Though tyre fires are difficult to ignite, once they are lit they are very hard to control or extinguish. They burn very hot, and the cylindrical casings allow air drafts to feed and stoke the fire[62]. In the United Kingdom, the huge Heyope tyre dump, near Knighton, Powys, was still smouldering almost 15 years after fire first broke out in 1989 when a stockpile of 10 million waste tyres were packed too densely for fire fighters to extinguish and although no flames were visible, temperature readings confirmed the intense heat generated below the surface[63]. Tyre fires also release toxic fumes of ultra-fine particles that are often contaminated with metals like nickel and tin, coming from the beads within tyres, which can have a widespread impact on the surrounding areas. These toxic emissions can also contain sulphuric acid and gaseous nitric acid, which can irritate the skin, eyes and mucus membranes; can affect the central nervous system; cause depression; have negative effects of the respiratory system; and in some extreme cases, cause cancer and mutations[64]. Air pollution threatens human health: even after fires are extinguished the oily residue left behind is difficult to eliminate from the environment and can impact the local

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[58] *See: USEPA (2013). Scrap Tyres. http://www.epa.gov/osw/conserve/materials/tyres/ (accessed 24 April 2013); Australian Government Department of Sustainability, Environment, Waster, Population and Communities (2013). Product Stewardship for end-of-life tyres. http://www.environment.gov.au/settlements/waste/tyres/index.html (accessed 19 April 2013);*

[59] *Liu H.S.; Mead J.L. and Stacer R.G. (1998). Environmental impacts of recycled rubber in light fill applications: Summary and evaluation of existing literature. Technical Report #2. Plastics Conversion Project. Chelsea Center for Recycling and Economic Development, University of Massachusetts, Lowell*

[60] *USEPA (2010). Scrap Tyres: Handbook on Recycling Applications and management for the US and Mexico. United States Environmental Protection Agency, USA*

[61] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*

[62] *Rowe, M. (2002). Dumped On: Waste Tyres. http://www.guardian.co.uk/society/2002/may/15/environment.waste (accessed 23 April 2013)*

[63] *UK Parliament Hansard (1990). Heyope, Knighton (Fire). http://hansard.millbanksystems.com/commons/1990/jul/26/heyope-knighton-fire (accessed 16 April 2013)*

[64] *USEPA (2010). Scrap Tyres: Handbook on Recycling Applications and management for the US and Mexico. United States Environmental Protection Agency, USA*

soil[65], contaminating the surrounding area. If water is used to fight these fires, it can result in serious ground- and surface-water contamination[66].

2.4.2 Hazards with adverse health issues

Illegally dumped tyres and waste tyre stockpiles pose other threats to human health. This is because their doughnut shape allows them to easily collect water and become an ideal breeding ground for mosquitoes, vermin and snakes[67]. Mosquitoes in particular carry diseases that are dangerous to humans and can spread malaria, dengue fever, yellow fever, encephalitis and West Nile virus[68]. Stockpiles can markedly increase the number of these vectors, with a single tyre able to nurture hundreds of larvae[69].

Although tyres remain substantially intact for decades, some components can break down and leach. The leachates from tyre rubber contain heavy metals such as cadmium, chromium, lead, zinc, copper, molybdenum, selenium, sulphur, 2-mercaptobenzothiazole and extremely toxic polyaromatic hydrocarbons (PAHs), causing skin problems and eye irritations to major organ damage and carcinogenesis[70]. In the research done by Karanfil *et al.*[71], iron showed the highest level of metal leaching (up to ~800 mg/ 100g tyre) when tyre chips were exposed to acidic environments. The incorporation of organic compounds increases iron concentrations in water, for instance, it becomes ~ 20 mg/L at pH 4. Magnesium was the second highest leaching metal at acidic conditions at amounts of 2 -5 mg/ 100 g tyre. When the tyre was exposed to a leaching solution, at pH 10.0, the leaching of the Dissolved Organic Compounds (DOC) significantly increased (reaching 27 mg/ 100 g tyre). The leaching of inorganic compounds such as iron, Cr, Cu, Mo, Se, Ni and Pb was considerably lower over one month of leaching experiments.

Although waste tyres were proposed for use in landscaping and other earthworks, up until the late 1990s, it is now recognized that waste tyres can contaminate soil, making them unsuitable for agriculture or small scale kitchen gardens.

Case Study 1: Asian Tiger Mosquito[72]

There are numerous reports describing the dangers of tyre stockpiles, particularly as a breeding ground for disease carrying vectors such as mosquitoes. The cylindrical shape of the tyre easily captures water and creates an ideal environment for mosquito larvae to grow. However, while many

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[65] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*
[66] *USEPA (2010). Scrap Tyres: Handbook on Recycling Applications and management for the US and Mexico. United States Environmental Protection Agency, USA*
[67] *USEPA ; Manchon-Vizuete E., Marcias-Garcia A., Nadal Gisbert A., Fernandez-Gonzalez C. And Gomez-Serrano V. (2004). Preparation of mesoporous and macroporous materials from rubber of tyre wastes. Microporus and Mesoporous Materials 67, 35-41*
[68] *USEPA (2010). Scrap Tyres: Handbook on Recycling Applications and management for the US and Mexico. United States Environmental Protection Agency, USA*
[69] *SAEPA (2010). Waste Guidelines: Waste Tyres. South Australia Environment Protection Agency, Adelaide*
[70] *Guo, Q. (2011). Recycling helps tyred-out rubber hit the road again. http://theconversation.com/recycling-helps-tyred-out-rubber-hit-the-road-again-3982 (accessed 23 April 2013)*
[71] *Karanfil et al. The feasibility of tyre chips as a substitute for stone aggregate in septic tank leach fields. Clemson University and South Carolina Department of Health and Environmental Control, South Carolina*
[72] *New York Times News Service (1992). Asian Tiger Mosquito carrying fatal disease. http://articles.chicagotribune.com/1992-07-24/news/9203060705_1_tiger-mosquito-dengue-fever-encephalitis (accessed 6 April 2013)*

of these reports focus on the danger to human health that stockpiles pose to nearby communities – they do not usually consider the risk tyres can pose to the health of people half a world away.

But there is evidence that tyres can spread disease significantly further than was ever imagined. The Asian Tiger Mosquito (ATM), native to South East Asia, entered the USA in 1985. During the 1980s there was a large increase in the number of tyres imported into the USA from regions where the ATM is common. The ATM is thought to have made a home in tyre stockpiles that were waiting to be shipped.

The mosquito was first sighted in Houston, Texas, and is believed to have arrived in the water pooled in a tyre imported from Japan for America's re-treaded tyre market. The mosquito carries Eastern equine encephalitis, a disease that can be transmitted to humans and can cause brain damage. This disease is fatal to 80% of humans who contact the virus. The ATM is regarded as one of the most dangerous mosquitoes because of its tendency to live in closer proximity to humans than other mosquito species, its aggression and its feeding habits. The ATM feeds on a wide variety of animals that carry diseases that can be passed onto humans. Other than the Easter equine encephalitis, the ATM can carry several other forms of encephalitis, as well as dengue fever. The ATM has also shown to be a vector of many tree-related diseases (arboviruses) under experimental conditions, demonstrating its potential to become a threat to the native flora of the USA as well as human health.

How did the ATM spread across the US? During the 1980s tyres imported for the re-tread market came in container shipments that were not adequately inspected for mosquitoes when they entered ports. These tyres were then sent to many different locations, where they were often stored outdoors and those that were found to be unsuitable for retreading often ended up in illegal dump sites.

As a result, the mosquito spread and is now found in Texas, Florida, Illinois and 22 other US states. What is even more concerning is that the ATM has now adapted to local climatic conditions in the USA. Initially, ATM eggs would not hatch if the day length was shorter than 13.5 hours meaning it was suited to its native tropical and subtropical regions. However, rapid selection has occurred in the ATM community and the mosquito is active in South and Central Florida for a significant part of the year, despite daylight hours typically far less than 13.5 hours.

Case Study 2: The world's longest burning tyre fire

In Wales in the autumn of 1989, on one of the wettest days of that year, unknown arsonists managed to set fire to a massive tyre dump in wooded glen near the Welsh border with England. It would be 15 years until the blaze at Heyope – where 10 million or so tyres had been progressively dumped by a local tyre retreading business over the preceding 20 years was finally extinguished.

The irony that world's longest continually burning tyre fire was ignited in such miserable, wet conditions in an apparently random act of vandalism was repeatedly noted in the considerable volume of commentary which followed, around the globe. More significant, though, was the impact the fire had on the local community, both at the height of the blaze and as the fire smouldered on, and the consequent political storm of debate. The Heyope fire revealed to the world the extent to which fire tyres threaten the natural environment and people's health and led to protests and activism and, eventually, new laws and regulations controlling or banning the dumping of tyres.

"The resulting pollutants from the burning tyres ran into the brook and the fire and fumes polluted the air. The brook flows into the River Teme, and approximately 50 miles downstream, water is extracted for drinking purposes," the local Member of Parliament, Richard Livsey, told the UK House of Commons in July, 1990, describing the damage to "the precious environment in this lovely part of my native Wales".

"I am told four million consumers in the western Midland depend on that supply," he said of the impact on local waterways.

The House heard that phenol (also known as carbolic acid) contamination was found far downstream, after initially peaking at 2,000 mg/litre, well in excess of the European Commission's water quality guidelines of the time. Cyanide and carcinogenic polyaromatic hydrocarbons were also identified downstream. A maximum level of 0.00005 g/L^2 is the current safe environmental limit for phenol approved in Australia and other similar jurisdictions.

The Australian Government's National Pollution inventory lists acute toxic effects for phenol including the death of animals, birds and fish and the slowing of grow rates in plants, with longer term impacts on fertility in natural ecosystems. For humans in contact with phenol, health impacts range from local to systemic toxicity, such as irritation of the skin and airways to burns to respiratory problems, muscular weakness and respiratory collapse.3

Although the UK National Rivers Authority installed filters in the bed of the stream as the fire smouldered on, and while some politicians spoke out about protecting the 110 or so jobs provided by the local tyre processors, the fire spurred on national activism and a flurry of Government inquiries, working groups and reports promoting tyre recycling. By 2003, European Union legislation covering the UK banned the disposal of whole tyres in landfill and by 2006 banned shredded tyres in landfill.

2.5 Guidance Notes

Objective: The major objective of guidance notes is to assist the target audience to carry out waste tyre market assessment, which includes identification, their classification and their tentative composition and likely waste stream. It will also assist in planning for inventory assessment & selection of type of technology. This planning will include delineating the area, establishment of waste trade value chain & identification of stakeholders in a geographical area.

Guidance Procedure: Guidance procedure includes completion of following eight steps. The schematic representation of these steps is given in **Figure 2.9**.

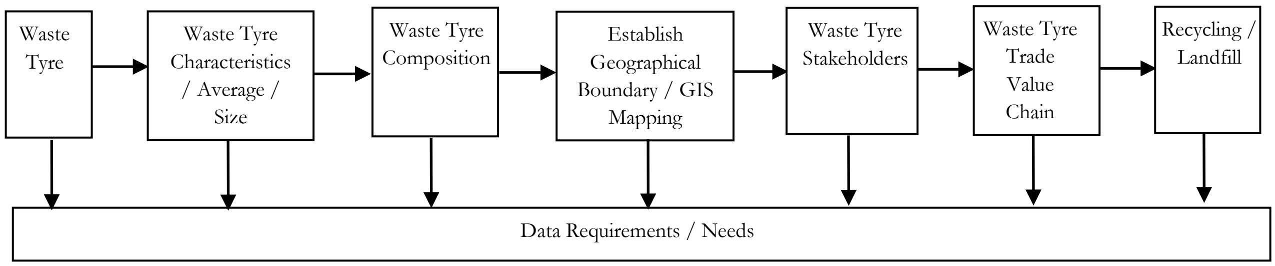

Figure 2.9: Guidance Procedure for Defining Waste Tyre Classification & Market Assessment

Step 1: Determine source of waste tyres & type of tyres as per section 2.1.2. This will assist in studying the tyres of interest. Determine the brands, local, national and international, which are available in the market for each tyre and the year of their introduction in the market. This can be determined through review of secondary data from industry association or by interacting with local dealers. If the product is manufactured under a brand name, the broad feature of technology used to manufacture item is generally disclosed. This will also assist in identifying its dealer's network, existing facilities for item's manufacture / import and its membership with local industry association.

Step 2: Determine average weight and size of local, national and international waste tyre from each brand. The variation in size of each item should be documented under each brand.

Step 3: Determine broad composite on as per table. **Table 2.3** for each type of tyre from available source like dealers / industry association / manufacturer. Determine approximate quantity of recoverable elements from each item based on outputs of step 2.

Step 4: Establish geographical boundary/ system boundary of study area (country / city/ region). Procure maps of the area and prepare base map of the area with physical features marked on it. This mapping will give an insight into the possible sources of waste tyre and assist in carrying out the waste tyre inventory assessment.

Step 5: Identify different stakeholders like importers, manufacturer, businesses / dealers / retailers, consumers who could be tyre waste generators and mark them as layer two on the base map. Physically verify by carrying out preliminary reconnaissance survey of the identified locations of the stakeholders. Mark the tentative locations by taking latitudes and longitudes of the identified locations through GPS instrument. Identify the stakeholders, which are in the formal/ organized sector and which are in the informal sector.

Step 6: Prepare a tentative waste tyre trade value chain as per conceptual life cycle shown in **Figure 2.3** and waste tyre trade value chain given in **Figure 2.4**. These figures should be customized as per preliminary survey, which will be confirmed and established during field survey.

Step 7: Identify waste tyre repair sites, dismantling sites, recycling sites and landfill/dump sites. Physically verify these sites by preliminary reconnaissance survey and marking the tentative locations by recording their latitudes and longitudes through GPS instrument.

Step 8: Identify data needs from these stakeholders based on identified stakeholders in step 5 and trade value chain identified in step 6.

CHAPTER 3: METHODOLOGY FOR ASSESSMENT OF QUANTITY OF WASTE TYRES GENERATED IN A COUNTRY

3.0 Introduction

As waste tyres are expected to grow about 4% annually, their management is becoming a priority in overall waste management. In order to make strategies that suit the local condition most properly, decision makers need to consider the local market, legislative framework, culture, etc. The assessment of quantity of waste tyres discussed in this chapter will help to understand the local condition: how many tyres are generated locally every year and will assist the target audience to fix size, scale & selection of technology for recovery of materials and energy.

3.1 Model Generation for Assessing Waste Tyres

A model can be designed with some basic assumptions to determine the waste tyres generated. The output of guidance notes given in chapter 2 will assist to develop this model. An example of the Californian State model is given in **Figure 3.1**. The basic model should consider the following important set of agendas in order to complete the onerous task of estimating the waste tyre generation.

- Calculate the number of new tyres sold in or entering the state every year.
- Assign these to tyre categories by weight.
- Estimate the length of time before they enter the waste stream.
- Tabulate the weight of these waste tyres.
- Compute the results in PTEs (Passenger Tyre Equivalent) 291 and Tons.

- PTEs (Passenger Tyre Equivalent) is a notional term using a standard weight of 10kg to represent the average weight of a passenger tyre.
- The weight of various tyre types can be expressed in PTEs.
- For example, a Medium Truck tyre, which weighs approximately 50kg, is considered equivalent to 5 PTE in weight.

Basic Weight Units by Tyres

Kind	Size, construction, etc.	Basic weight unit (kg.)
For truck and bus	Bias Radial	37.0 45.0
For Small truck	Over 7.50 to 16 equivalent Under 7.50 to 16 equivalent	16.0 9.0

	Total	12.5
For light weight trucks		5.1
For passenger cars		7.4
For light weight passenger cars		4.3
For construction vehicles		102.5
For industrial vehicles		8.3
For agricultural machinery		5.0
For two-wheeled motor vehicles		1.5
Source: Waste Tyre Recycle and Collection System; Nippon Steel Technical Report No. 86 July 2002 by Yasuyuki Nakao and Kunihiro Yamamoto		

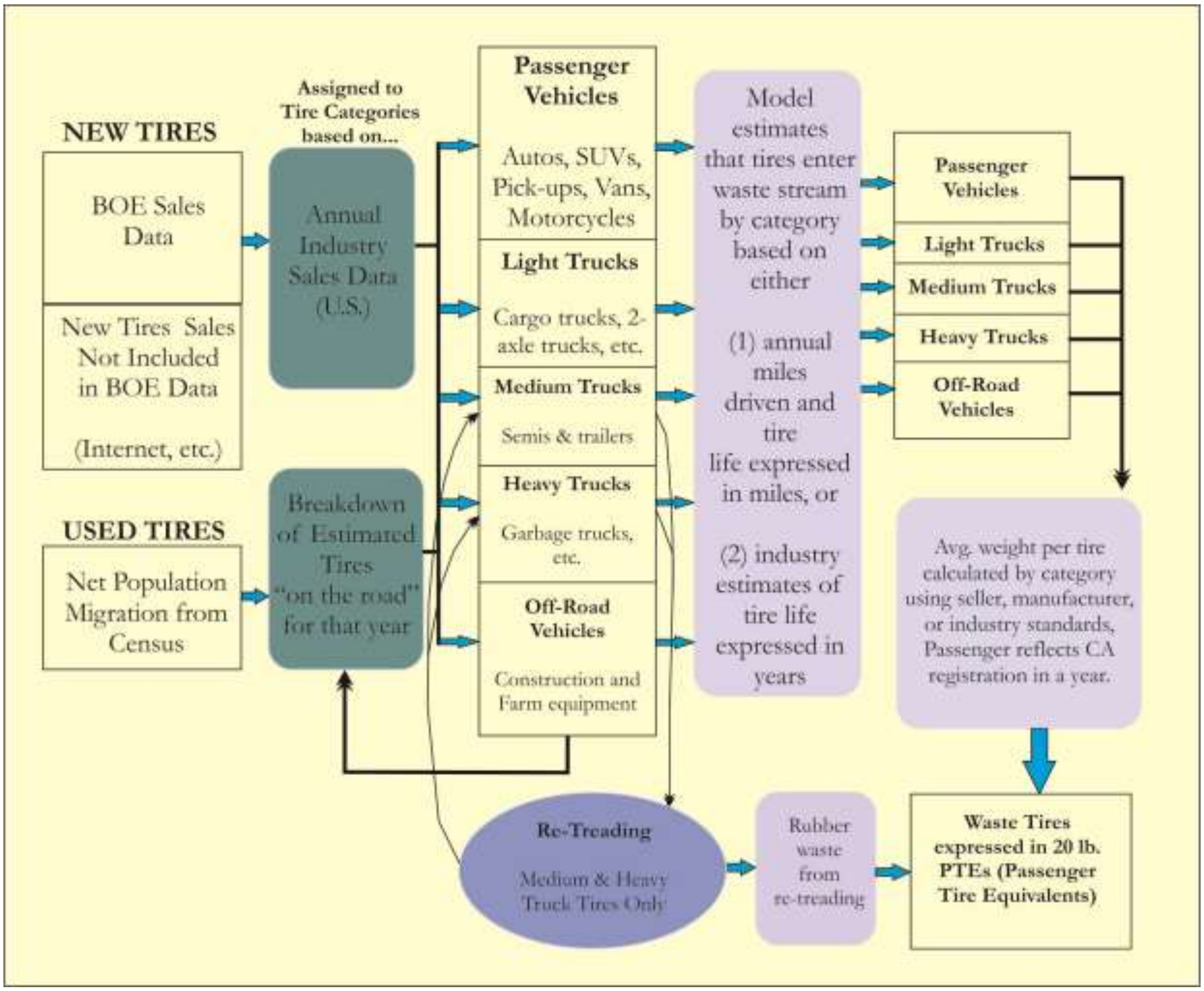

Figure 3.1: A Californian State Model to Assess the Used Tyre Generation

Source: Rubber Manufactures Association (RMA)

3.2 Quantitative Approach

This section describes the sources that can be used to form an accurate survey of the number and type of WTs. The data is based on Australian case, as an example to better illustrate the approach.

3.2.1 Calculate the number of tyres

When considering the number of tyres, an assessment model should be mostly based on two aspects - new tyre production and tyre allocations for various designated vehicles. Both these parameters will enhance the model so that the assessment of waste tyres can be made to maintain an effective and standardized output. Sources of information for New Tyre production are given below.

- No. of new tyres sold: BOE (Board of Equalization) Revenue.
- No. of tyres sold on internet: modern tyre dealer.
- No. tyres sold to government entities: Federal Highway Administration, CA registration stats.
- No. tyres brought in from Out-of-State: Net migration, No. of people/Household (HH), No. of vehicles per HH.
- Tyre life (**Figure 3.1** will be used as reference).
- VMT (Vehicles Miles travelled) for Passenger, Light Truck and Medium Truck: Federal Highway Administration.
- Tread life for all types: National Highway Traffic Safety Administration.
- No. of Retreads for all types: Tyre Retread Information Bureau.
- Annual maximum life: Industry recommendations, RMA.

Tyre allocation parameters

- No. of Passenger: Light Truck, Medium & Heavy Truck, Off-Road average tyre weight
- Passenger: Tyre size sale statistics, distributor specifications, CA vehicle registration
- Light truck: Tyre Size Sale Statistics, Distributor Specifications
- Medium truck: Manufacturer Specifications
- Heavy truck, Off-Road: Scrap Tyre reports
- Percentage difference from new weight: sources from RMA, UK Environment Agency report could be of help.

After developing a model for waste tyres generated in a region/state/country the resultant data can be graphed as below (**Figure 3.2**) The figure illustrates the percentage of different sources of tyre distribution for various classifications of vehicles in use both domestically and commercially.

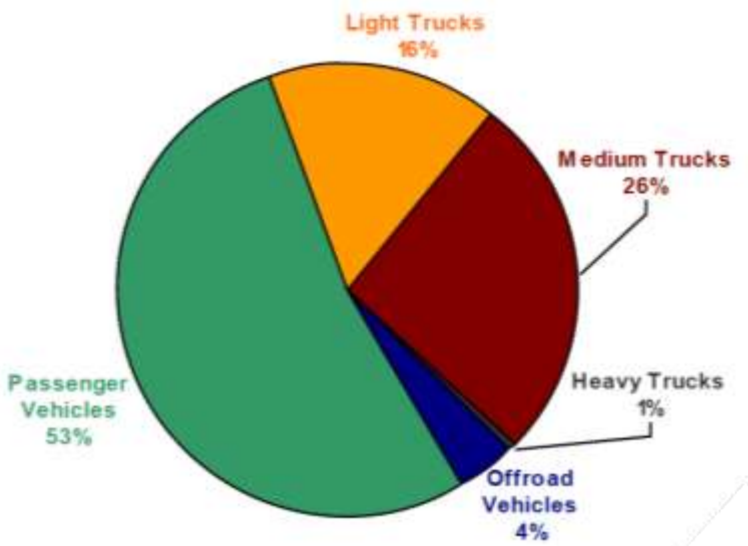

Figure 3.2: An Example to Illustrate the Source of Waste Tyres with Help of a Model

Source: CIWMB

3.2.2 Assign the tyres to categories by weight

Tyre data is generally expressed in equivalent passenger units (EPUs)[73]. Where data collected can be provided by weight, the obtained data can be converted into EPUs for generating reports as shown in **Table 3.1**.

Estimating WT can be based on the following set of data and assumptions. An EPU shall be taken to be 9.5 kg for a new tyre, and 8.0 kg for a waste tyre. Accordingly, the EPU for a tyre in-use, and for a tyre put into re-use, will be taken to be the midpoint between the EPU for a new tyre and the EPU for a waste tyre, being 8.75 kg. Retread tyres will be assumed to enter their intermediate destination at an EPU of 8.0kg. It is also assumed that this EPU will then be reduced by a further 0.5kg during the buffing of tyres prior to retreading. (This 0.5kg of buffings will be attributed to an end-of-life destination). It will then be assumed that 2.0kg will be added back onto the tyre as retread casing[74]. These assumptions will be tested during the course of the survey of tyre retreaders.

Table 3.1: EPU Tyres at Different Stages in the Lifecycle of a Tyre

Stage of Use	EPU (kg)	
Consumption	New	9.50
	Second Hand	8.75
	Retreads	9.50
In-Use	8.75	
Intermediate destination	8.75	
End-of-life destination	8.00	

[73] *Tyre Stewardship Australia, Department of the Environment, Australia Government http://www.environment.gov.au/topics/environment-protection/national-waste-policy/tyres*

[74] *Sharma, H.; Reddy, K. (2004). Geoenvironmental Engineering - Site Remediation, Waste Containment and Emerging Waste Management Technologies. Wiley John Wiley & Sons, Inc. ISBN 0-47121599-6.*

There is a possibility that the weight of an average passenger tyre is now higher than 9.5kg as a result of increases in the size of an average passenger tyre. During the course of the study any examiner can examine the weight of an average passenger tyre. This will include the examination of specification sheets on common passenger tyres and input from the tyre industry.

Irrespective, the EPUs stated above will be retained for the purposes of report generation. However, the conversion of some data on tyre numbers into EPUs may be adjusted if it is found that there has been a change in the weight of an average passenger tyre.

Tyres can be classified as being passenger, truck or off-the-road (OTR) tyres. Passenger tyres include those used on passenger vehicles including motorcycles and caravans, as well as trailers for domestic use. Truck tyres are those used on buses, light and heavy commercial Vehicles, prime movers, trailers and semi-trailers, and fire fighting vehicles. OTR tyres are those used on machinery or equipment used in areas such as agricultural, mining and construction and demolition.

Table 3.2 shows the classification of tyres for vehicle types taken from the Draft *Tyres Product Stewardship Agreement* (May 2008) published by *Environment Protection and Heritage Council* (EPHC)[75]. The number of tyres per vehicle type and the indicative EPUs per vehicle is also shown. The values and terminologies shown in this table shall be verified and refined during the course of data collection. This will include an evaluation of average weight of tyres for different vehicle types during the survey of the tyre industry, in particular truck tyres and passenger vehicle tyres.

Table 3.2: EPU Values for Tyre Types

Tyre Classification	Vehicle Tyre/Type		EPU/ tyre	Industry
Passenger	Motor cycles		0.5	
	Passenger vehicles		1	
	Campervans		1.5	
	Light commercials		1.5	
Truck	Light truck		2	
	Truck		5	
	Super single		10	
Off the road	Solid	Small	3	
		Medium	5	
		Large	7	
		Extra Large	9	
	Tractor	Small	15	Agriculture
		Large	25	
	Fork lift	Small	2	
		Medium	4	Whole sale and retail Trade
		Large	6	
	Grader		15	
Off the road	Earth Mover	Small	20	Mining
		Medium	50	
		Large	100	
		Extra large	200	
		Giant	400	

[75] *Environmental Agency. Waste Management: The Duty of Care, A Code of Practice. UK.*

Tyre Classification	Vehicle Tyre/Type		EPU/ tyre	Industry
	Bobcat		2	
	Aircraft	Small	2	
		Medium	4	
		Large	10	

The calculation of EPUs per vehicle can be made on the assumption that all vehicles, either assembled or unassembled, have a full complement of tyres fitted, including spare tyres. The calculation of EPUs through the lifecycle of tyres should include both the outer tyre and the inner tube for pneumatic tyres.

This example does not cover tyre types smaller than those classified as passenger tyres. Examples of tyres excluded from the study are tyres from bicycles and other cycles; mowers and wheelbarrow; carriages for disabled persons; baby carriages; etc.

3.2.3 Geographic distribution of used tyres

Data on the consumption and use of tyres, and the domestic source and fate of end-of-life tyres can be reported by jurisdiction (state or territory) and by remoteness classification (metropolitan, regional or remote). Remoteness classification can be made using the Remoteness Structure from the *Australian Standard Geographical Classification 2005* published by the Australian Bureau of Statistics (ABS)[76] for this analysis, the Remoteness Structure will be used for local government areas, and will be refined to a three-tiered remoteness classification as shown in **Table 3.3**.

Table 3.3: Remoteness Classification

Major cities	Metropolitan
Inner regional	Regional
Outer regional	Remote
Remote	
Very remote	

The remoteness classification for each local government area in Australia has been mapped for easy classification. Details on the method for attributing data according to jurisdictions and by remoteness at each stage in the life cycle of a tyre should be studied for detailing. The confidentiality of data and identity of companies and organizations involved in the study must be maintained. This is of particular importance to companies involved in UT management who work in collaboration with government.

3.2.4 Data Output

Table 3.4 provides an overview of the data output that could be generated while doing the quantitative analysis of WT.

Table 3.4: Data Output Categories

[76] *Australian Bureau of Statistics, Australian Standard Geographical Classification 2005 (Cat. No. 1216).*

Life cycle base			Break down
Consumption		Domestic Manufacture	
		Net importation	Loose fitted New/second-hand
		Retread	
		Total	Loose fitted New/second-hand
In-use			
End of life	Domestic Destination	Recycling	Tyre derived product
		Energy recovery	Whole /shredded
		Landfill	Whole /shredded
		Illegal dumping	
	Export Destination	Reuse	Destination
		Retreading	
		Recycling	Baled/shredded/crumbed/powdered
		Energy recovery	Destination

Source: A report on domestic and international fate of end-of-life tyres (2012).

3.2.5 Consumption of tyres

For the purposes of analysis and report generation in a country or state, consumption refers to the sale of whole tyres for the purpose for which they were designed. Also for the purposes of the estimation, it can be assumed that all tyres made available for purchase during the period of estimation were also sold during the period of study. That is, tyres will be considered to be either inuse or at end-of-life. The holding of tyres before, or in between these two stages in the lifecycle of a tyre will be considered only for the purpose of data collection on the number of tyres in-use or at end-of-life. **Figure 3.3** describes lifecycle pathways of tyres including data collection fields.

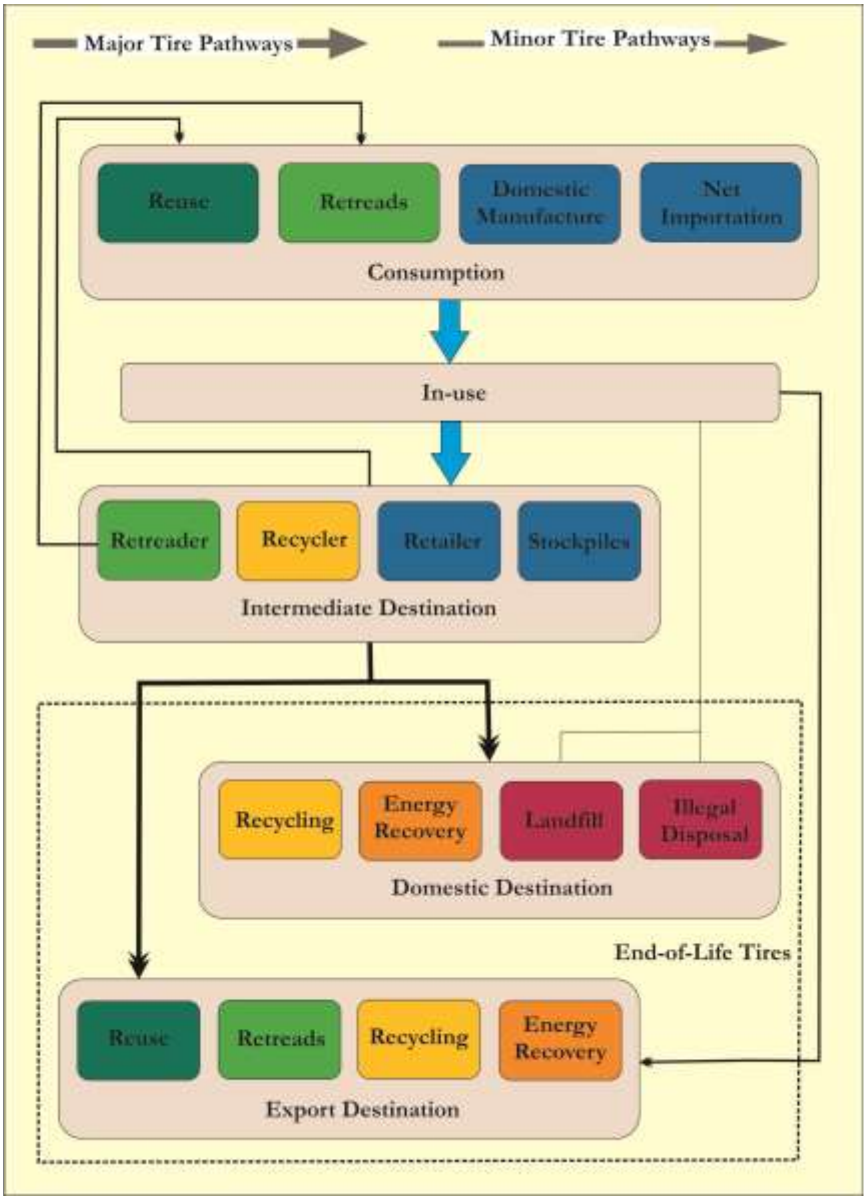

Figure 3.3: Life Cycle Pathway of Tyres Including Data Collection Fields

Source: COAG Standing Council on Environment and Water Study into domestic and international fate of end-of-life tyres Final Report; Hyder Consulting Pty Ltd
http://www.scew.gov.au/system/files/resources/023a5607-0964-47e0-92cd-78fc0e6bb14e/files/hyder-end-life-tyres.pdf

3.2.6 Domestic manufacture

As stated in the Hyder report[77], domestic manufacture of tyres in Australia has ceased. (South Pacific Tyres closed its manufacturing facility in Melbourne at the end of 2008, and Bridgestone closed its manufacturing facility in Adelaide in early 2010.)

It is assumed that there will still be some domestically manufactured tyres entering the market during the course of time and analysis. Both South Pacific Tyres and Bridgestone will be contacted regarding their manufacturing activity in Australia during this period.

3.2.7 Net imports

Data on the net imports of loose and fitted tyres entering Australia can be sourced from the Department of Foreign Affairs and Trade (DFAT). The net import of tyres can be calculated by balancing the import of loose and fitted tyres with the export of loose and fitted tyres in corresponding import and export product categories. Data on the import of loose and fitted tyres could be obtained for the relevant categories in the *Combined Australian Customs Tariff Nomenclature and Statistical Classification* (Working Tariff). The environmental consulting group has relevant import data for consecutive times over the years. The broad, four-digit categories that cover the relevant codes are shown in the following examples. The highest level of detail within these categories is the ten-digit statistical codes. These codes can be assessed to determine their relevance to the WT estimation[78]. The relevant ten-digit statistical codes have also been assessed to determine:

- which classification of tyre the code relates to the EPU for a typical tyre,
- the number of tyres to be attributed to each unit within the code

The full list of the relevant ten-digit statistical codes and their assessment is detailed in the Tyres Product Stewardship Agreement. Statistical codes that were not considered relevant to this study include those that relate to vehicle parts, rather than whole vehicles.

Some relevant sample codes that have been used in ELT management are listed below;

4011: New pneumatic tyres, of rubber.
4012: Retreaded or used pneumatic tyres of rubber; solid or cushion tyres, tyre treads and tyre flaps, of rubber.
8426: Ships' derricks; cranes, including cable cranes; mobile lifting frames, straddle carriers and works trucks fitted with a crane.
8427: Fork-lift trucks; other works trucks fitted with lifting or handling equipment.
8429: Self-propelled bulldozers, angledozers, graders, levellers, scrapers, mechanical shovels, excavators, shovel loaders, tamping machines and road rollers.

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[77] *Atech Group for Environment Australia, A National Approach to Waste Tyres, June 2001.).*
[78] *Australian Bureau of Statistics, Motor vehicle census (Cat. No. 93090) to 31 March 2009.*

8430: Other moving, grading, levelling, scraping, excavating, tamping, compacting, extracting or boring machinery, for earth, minerals or ores; pile-drivers and pile-extractors; snow-ploughs and snow blowers.

3.2.9 Retread sales

Data on the domestic sales of retreaded tyres can also be obtained through a survey of industry groups, major national retailers and retreaders.

Figure 3.5: Retreaded Tyres

3.2.10 Total sales

The number of new and retreaded tyre sales should include imported second-hand tyres in the calculation of the net importation of tyres. The number of new and retreaded tyre sales is the number of tyres entering the Australian market for the first time. The calculation of the total sales of tyres in Australia can be made by adding the number of new and retreaded tyre sales to the number of second-hand tyres sold. The distribution of the sales of passenger and truck tyres between each state and territory is assumed to be the same as that for the distribution of tyres in-use, being aligned to the distribution of vehicle registrations. The distribution of the sales of OTR tyres can be also be done on the basis of the distribution of the OTR tyres in-use.

3.2.11 Passenger and truck tyres

The total number of tyres in-use for passenger and truck tyres can be determined by the extrapolation of data on the number of passenger vehicles and trucks registered for use in each state and territory. This extrapolation could be undertaken using the classification of tyres and indicative EPUs for vehicle types. Passenger vehicle and truck registration data can be built using the ABS publication *Motor vehicle census in track accordance* to 31 March 2009. Data from the *Motor vehicle census* should be cross checked and updated with vehicle registration data from individual states and territories where it is available.

Data from the 31 March 2009 census, and individual states and territories can further be used, in combination with ABS's *Australian Demographic Statistics* to generate figures for the number of passenger vehicles and trucks in-use[79] for the entyrety of the estimation, the distribution of passenger and truck tyres in-use between states and territories can be done on the basis of vehicle registrations in each state and territory. The distribution of passenger and truck tyres in-use by remoteness shall also be done on the basis of population distribution by remoteness within each state, using the ABS publication *Regional Population Growth.*

3.2.12 Off-the-road tyres

Data on the number of OTR tyres in-use can be calculated using the average lifespan of OTR tyres and historic sales figures for OTR tyres. The average lifespan of OTR tyres can be determined during the course of the survey of various industries. Different lifespans may be determined for different types of OTR vehicles. The average lifespan could be used to determine the point in time which is equal to the average lifespan of tyres prior to the end of the study period. A normal distribution of the expected lifespan of OTR tyres can be generated around annual data sets. This distribution will minimise the impact of any short term fluctuations in OTR tyre sales. The proportion of each distribution could fall within the estimation period, which can later be added together to determine the number of OTR tyres considered to be in-use.

The distribution of OTR tyres between states and territories, and by remoteness, can be done on the basis of population distribution, using the ABS's *Australian Demographic Statistics,* except for tyres identified as being used in a particular industry. The distribution of OTR tyres used in a particular industry between states and territories could also be done on the basis of the distribution of that particular industry between jurisdictions taken from the ABS publication *Australian Industry.* All OTR tyres used in mining could be assumed to be in-use in remote locations. OTR tyres used in agriculture can be assumed to be in-use in regional or remote locations. The remoteness distribution for OTR tyres used in agriculture on the basis of the population distribution between regional and remote areas within a jurisdiction[80]. OTR tyres used in wholesale and retail trade can be assumed to be distributed to the same extent as population across all remoteness classifications. Other uses of tyres include furniture, dustbins, flower pot / rooftop or kitchen garden, making bund at river banks as shown in **Figure 3.6**.

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[79] European Union, Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste, December 2000.
[80] European Tyre and Rubber Manufacturers' Association (ETRMA), End of Life Tyres: A valuable resource with growing potential 2010 Edition.

Figure 3.6: Reuse Options of Use Tyres

3.2.13 Recycling

Data can be collected for tyres reprocessed into a tyre-derived product, and for whole tyres used for a purpose other than for which they were designed, specifically, civil works.

Data will be collected through a structured survey of the tyre industry associations and major tyre recyclers. The estimation of WT could ascertain information about the source and form of tyres received for recycling, and the destination and form of tyres being recycled and reprocessed, including for export. Industry associations and recyclers that could to be contacted include:

- Australian Tyre Recycling Association
- Australian Tyre Industry Association
- Tyre Cycle
- Reclaim

- Chip
- Aus Tyre Crumb
- EcoFlex

An estimate can be made of the proportion of the Australian market covered by the survey for both the recycling of whole tyres and the reprocessing of tyres. Data collected can then be adjusted to account for that component of the market not covered by the survey e.g. pulverization, rubber grounds and other material recovery / recycling options (except energy recovery).

3.2.14 Energy recovery

Data on the use of tyres as an energy source in cement kilns could be collected through a survey of the Cement Industry of Australia and cement kilns identified as using tyres for an energy source. Data on the pathway of end-of-life tyres used for energy recovery can also be collected during the collection of data on the retreading and recycling of tyres.

To date, the use of end-of-life tyres as an energy source has been limited to cement kilns. This can be confirmed during the course of the survey of the tyre industry regarding the fate of end-of-life tyres. The survey of cement kilns can be done on an ad hoc basis as it is understood that there are only a small number that use tyres for energy recovery. As such, it is also anticipated that the entyrety of the domestic use of end-of-life tyres for energy can be accounted for during this study.

3.2.15 Landfill

Data can be collected on the disposal of tyres to landfill as whole tyres, shredded tyres, and as shredder flock from the disposal of whole vehicles. Relevant state and territory departments and agencies, major landfill operators, and the Waste Management Association of Australia could be contacted to determine the number of tyres disposed of to landfill. Waste audit data can also be used to confirm the proportion of material being disposed of to landfill which are tyres. The Minerals Council of Australia can be contacted regarding the landfilling of OTR tyres.

3.2.16 Illegal dumping

Data on the amount of tyres being stockpiled will be determined by a survey of state and territory government departments and agencies, select local governments, and major anti-littering organization[81], [82] on the extent of stockpiling as stated in the above mentioned methodologies. A determination can then be made of the balance of tyres that are unaccounted for that are being stockpiled or illegally dumped. **An example of waste tyre generation & material flow analysis 9MFA) in a developing country context is given in section 7.2.4 chapter 7.**

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[81] *European Union, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, April 1999.*

[82] *European Union, Commission Regulation (EC) No 1418/2007 of 29 November 2007 concerning the export for recovery of certain waste listed in Annex III or IIIA to Regulation (EC) No 1013/2006 of the European Parliament and of the Council to certain countries to which the OECD Decision on the control of transboundary movements of wastes does not apply, November 2007.*

3.3 Methodology to Estimate the Quantity of WT in a Stockpile

The quantity of tyres in a stock pile can be estimated by calculating the cubic yards of the area covered by the stack pile of waste tyres.

Step 1: Determination of volume of a stock pile

The volume of stock pile can be obtained by measuring or estimating the length, width and height of the tyre pile and converting it into cubic yards of tyres:

Volume (in m3) = [Length (m) x Width (m) x Height (m)] ÷ 27

Step 2: Determining the number of tyres

After determining the cubic yards of a tyre pile, multiply cubic meters by the tyres per cubic meters (tyres/m3) as listed in the conversion tables below (**Table 3.5, Table 3.6** and **Table 3.7**) for whole or altered tyres. This following chart can be used as the reference[83] in calculating the number of tyres.

Table 3.5: Number of Whole Tyres in a Stockpile

Whole Passenger/Light Truck Tyres (tyres/ m^3)			
Storage Type	**Height of Tyre Pile**		
	<3 m	3-5 m	>5 m
Stored less than 15 years			
Loose (Stacks)	10	12	14
Barrel (Stored)	12	14	16
Laced (Shredded / trimmed)	14	16	18
Stored 15 years or more			
Loose (Stacks)	12	14	16
Barrel (Stored)	14	16	18
Laced (Shredded/ trimmed)	16	18	20

Table 3.6: Number of Whole Semi/Truck Tyres in a Stockpile

Whole Semi-Truck Tyres (tyres/ m^3)			
Storage Type	**Height of Tyre Pile**		
	<3 m	3-5 m	>5 m
Stored less than 15 years			
Loose (Stacks)	2.5	2.75	3.0
Barrel (Stored)	4.2	4.4	4.6
Laced (Shredded / trimmed)	4.1	4.3	4.5
Stored 15 years or more			
Loose (Stacks)	3.0	3.5	4.0
Barrel (Stored)	4.4	4.6	4.8
Laced (Shredded/ trimmed)	4.3	4.5	4.7

[83] *International Rubber Study Group, Statistical Summary of World Rubber Situation, 2010.*

Table 3.7: Number of Altered Tyres in a Stockpile

Altered Tyres (Tyres / m³)		
Type	**Tyres**	**Description**
Sidewalls or treads	20	The photo below shows cut out sidewalls and treads.
Primary shreds	20	Tyres that have been run through a shredder one time.
Shreds 2 inches or smaller	40	Tyres that have been run through a shredder more than once to create pieces two inches or smaller.
Crumb rubber (less than ¼ inch in size)	NA	Not regulated by the California Department of Resources Recycling and Recovery.

Step 3. Calculation of weight of tyres in the stock pile

Average weight of one whole passenger tyre = 9 kg = 1 PTE*

Average weight of one whole semi-truck tyre = 45 kg = 5 PTEs

Whole passenger tyres 10 PTEs/ m3

Whole "semi" truck tyres 3 semi-truck tyres/ m3

Single pass/rough shreds 27-30 PTEs/ m3

2-inch shreds 42-47 PTEs/ m3 (850-950 lbs/ m3)

*1 PTE = 1 x Passenger Tyre Equivalent

See Table 3.8

Table 3.8: Approximate Range of Numbers of PTEs

	Whole PTEs	**Single pass rough shreds**	**2-inch shreds**
One 2500 ft² pile (50'x50'x14)	12,963	34,992-38,880 (36,936 avg)	54,432-60,912 (57,672 avg)
One 2500 ft² pile (50'x50'x8')	7,410	20,007-22,230 (21,118 avg)	31,122-34,827 (32,974 avg)
10,000 ft² pile (4-2500 ft2 piles)	51,852	140,000-155,520 (147,760 avg)	217,728-243,648 (230,668 avg)

Caution: Factors that may produce a low estimate;

1. A high percentage of truck tyres will increase the total PTEs and total tonnage of tyres in a site. For example: a site that contained 50% truck tyres had a 100% increase in the total PTEs in the site. The original estimate using the standard factors produced an estimate of 240,000 PTEs while the total actual number equalled 450,000 PTEs.

Passenger car tyres = 10 whole tyres/ m^3 @ 9 kg each = 90 kg/m^3

Truck tyres = 3 whole truck tyres/ m^3 @ 45 kg each = 135 kg/m^3

2. Rolling or hilly terrain makes it very difficult to estimate the height of piles. As a general rule, estimate the height while on the down side of the hill. It is better to overestimate than under estimate when it comes time to contract for a cleanup.

3. Watch for any signs of gullies or ravines under tyre piles. Also, look for any signs of excavation at a site. All of these can lead to an under estimation 304 of the number of tyres at a site due to hidden conditions.

4. Piles over ~4.3m high can contain more tyres due to compaction by the weight of the tyres. Compaction at the Kirby site in piles approaching 12m high has produced an average of 75% more tyres than estimated using an aerial survey and triples the standard estimating factors of 10 PTEs per cubic meter. Truck tyres have been about 20% of the total tyres removed from the Kirby site and actual experience has been 35 PTEs per cubic meter.

3.4 Qualitative Analysis of the Data

A qualitative analysis of the reliability of the data sets could be undertaken during the process of data collection and collation.

3.4.1 Data entry

All data collected during the process can be requested in, or entered into a spreadsheet database. This should include the use of formal templates for the surveys of industry. Data entered should be cross checked by different project team members. A preliminary data validation process should be undertaken during the entry and cross checking of data to confirm that the results are within the expected range of findings.

Data collection and calculation can be undertaken with the intention of building the *Tyres Data Aggregation* model around the worksheets developed for the collection and calculation of data for the calculation.

3.4.2 Qualitative confidence rating

A quality confidence rating should be developed to identify and manage any areas of weakness in the data collected, or the method of data collection and calculation. The quality confidence rating could use a Multi-Criteria Decision Analysis (MCDA) to provide an overall confidence rating for data sets at each stage in the lifecycle of tyres, for different tyre types and for different geographic distribution[84].

The MCDA in general scores data sets for their performance against the following key characteristics:

[84] *European Union, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, November 2008.*

- Accuracy
- Credibility
- Sample size
- Consistency
- Appropriateness
- Comparability
- Sensitivity of dependent calculations

3.5 Guidance Notes

The objective of guidance notes is to assist the waste tyre investigation team to apply the customized approach and methodology using the above tools and techniques to assess existing and future waste inventory. Guidance procedure for carrying out waste tyre inventory assessment includes completion of following activities. The schematic representation of these steps is given in **Figure 3.5**.

Activity 1	:	Establishment of the study area and its geographical limit
Activity 2	:	Identification of tyre waste and establishment of waste trade value chain
Activity 3	:	Estimate waste tyre quantities and obsolescence average lifespan through secondary data
Activity 4	:	Verification of average lifespan through primary data
Activity 5	:	Identify the products, by products and waste products (e.g. retreaded tyres, recycling, energy, recovery, landfill & illegal dumping)
Activity 6	:	Establish tyre waste trade economics
Activity 7	:	Identify and assess the impacts

Activity 1: Establishment of the study area and its geographical limit

This activity will include the establishment of geographical limits of study area i.e. geographically defining the area. This will include assessment of landuse maps of the study area, fixing of rural and urban boundaries and mapping of tentative locations of stakeholders as described in step 4 to step 5, guidance notes of Chapter 2. The investigation team will geographically verify the tentative locations where generation, stockpiling, collection, handling and brokering, processing and production of other items from tyre waste are taking place by using transect walk.

Activity 2: Identification of tyre waste and establishment of waste trade value chain

This activity will include identification of specific waste tyre item and complete tracking followed by mapping of its life cycle considering sales, consumption, storage, treatment / disposal.

The different stakeholders as identified in step 4 and step 5, guidance notes of Chapter 2 will form key links in the material flow chain to facilitate input/ output analysis. A typical, waste trade chain will be established in a geographical context after verification of the tentative trade value chain (example **Figure 2.3 & 2.4** given in Chapter 2) obtained as an output of activity 1 and activity 2. This superimposition of waste trade value chain on a map will facilitate spatial analysis.

Activity 3: Estimate the average life through secondary data by following "approach and methodology mentioned in Section 3.2. This will include secondary data e.g. market research data like market supply and import data, installed base etc.

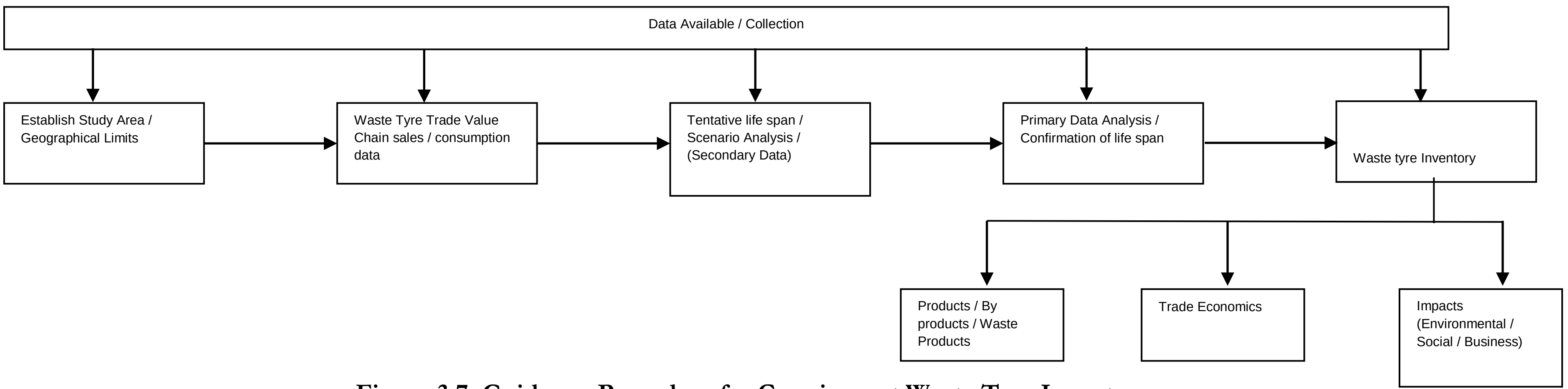

Figure 3.7: Guidance Procedure for Carrying out Waste Tyre Inventory

The key to estimate waste tyre inventory is fixing of average life span based on market research data, industry data or on consumer behaviour. Since average life span is dynamic in nature, therefore, a range is fixed with upper and lower limits. Carry out sensitivity analysis for waste tyre inventory using upper and lower limits of average life span.

Activity 4: Verification of average lifespan through primary data

The average life can be verified through identification of waste tyres stream reaching the storage for treatment / dispoal. Quantification at the storage can be carried out using tools / techniques given in section 3.3. Data availability, reliability, its amount & range & completeness can be carried out through tools & techniques described in section 3.4..

Activity 5: Identify the products, by products and waste products and back calculate waste tyre generation.

Note: Activities 3, 4 & 5 are iterative in nature till a reasonable range is achieved in order to develop criteria for selection of technology.

CHAPTER 4: PERSPECTIVE OF TYRE WASTE MANAGEMENT

4.0 Introduction

Current practices of tyre waste management provide an understanding of policy/ laws/ regulations and institutional framework related to its management. In this context, at first, existing policy/ laws/ regulations and institutional framework related to tyre waste management in developed countries is presented. This is followed by current policy / laws / regulations & institutional framework in developing countries. Finally, guidance notes provide a broad road map to assist in developing enabling policy/ laws/ regulations and institutional framework for tyre waste management.

4.1 National and Social Policies / Laws / Regulations / Institutional Roles in Developed Countries (Policies / Laws / Regulation, Institutional Mechanism)

Waste tyres are not considered a hazardous waste but as there are numerous issues associated with their collection and process, and as there are a wide range of local, state and national environmental, land use, business and financial regulations that may impact a tyre processing business.

The Technical Guidelines for handling waste tyres published by Secretariat of the Basel Convention in 2011 state that although tyre components have no hazardous properties and are therefore not intrinsically hazardous, if improperly managed and disposed of, they may pose risks to public health and the environment. Consequently, waste tyres come under various local and national environmental regulations in many jurisdictions and processors may be required to meet various requirements to demonstrate how waste tyres will be collected, recycled and stored. The following sections describe national & social policies / laws / regulations / institutional roles in developed countries.

4.1.1 WT management in European Union

Major regulations related to tyre waste management and their major features in EU are given below.

(a) 1993 Regulation on supervision and control of trans-border shipment of waste 259/93/EEC

(b) **1999 directive on the Landfill of Waste - 1999/31/EC**

- Ban on used tyres (whole tyres) in landfill starting July 2003
- Ban on shredded tyres in landfill starting July 2006

(c) 2000 European Waste List - 2000/532/EC and further amendments
End of life tyres are classified under code '16 01 03'
(d) 2000 directive on Incineration of Waste - 2000/76/EC

- Fixes emission standards for all cement kilns starting in 2002
- Older cement kilns prohibited from burning end-of-life tyres after 2008
- From December 2008, new provisions apply to cement kilns co-incinerating waste including end of life tyres. The cement kilns currently burning ELT in Europe are already complying with this Directive.

(e) 2000 directive on End of Life Vehicles (ELV) - 2000/53/EC
- 85% of scrap cars to be recovered starting 2006
- tyres to be dismantled from vehicles (increasing ELT arising by 10%).

(f) 2001 EC decision on EU list of wastes - 2001/118/EC, end of life tyres are classified under entry 16.01.03. This text applies from 1st January 2002 in EU Member States.

(g) 2005 EC Thematic strategy on prevention and recycling of waste - COM(2005)
- provides an holistic analysis of the major achievements in the waste management area for the past 30 years.
  It stresses a need to further developing approaches for the determination of best environmental options and for the setting of targets for recycling and recovery of waste, taking into account the differences between products and materials and the possible alternative.
- encourages the principle of producer responsibility- strategy proactively applied by the tyre manufacturers since late 90’s in anticipation of EU regulatory requirements.

(h) 2008 Waste Framework directive - 2008/98/EC

- sets the basic concepts and definitions related to waste management and lays down waste management principles such as the “polluter pays principle” or the “waste hierarchy”.
- introduces the concept of end of waste, by which selected waste streams could cease to be considered as waste if they comply with end of waste criteria.

The criteria for it to be considered as a resource could be:

- A market or demand for ELT derived materials should exist
- ELT derived materials should be commonly used for specific purposes and meet related technical requirements
- ELT derived materials should meet existing legislation and standards applicable to products
- The use of ELT derived materials should not lead to overall adverse environmental or human health impacts

In May 2010, a Quality standard CEN TS14243 “Materials produced from end of life tyres – Specification of categories based on their dimension(s) and impurities and methods for determining their dimension(s) and impurities” was published. This technical specification aims at characterizing the different materials derived from end of life tyres in terms of dimensions (ELT cuts, shreds, chips, granulates and powders) and impurities (steel & textile) using harmonized methods of sampling and testing.

EU Member States have to be in compliance with the EU legislation in transposing the Directives into local legislation. They are free to set national initiatives to reach the EU targets. In regard to the development of waste management policies at national level, the landfill of waste Directive has been a major driver for setting ELT management systems in Europe. Today within the EU there are three different systems for managing end of life tyres as described below.

- Producer responsibility
- Tax system
- Free market system

Producer responsibility

The law defines the legal framework and assigns the responsibility to the producers (tyre manufacturers and importers) to organise the management chain of end of life tyres. This has led to the setting-up of a not-for-profit company financed by tyre producers aiming at managing collection and recovery of end of life tyres through the most economical solutions. A reporting obligation towards the national authorities provides a good example of clear and reliable traceability. A schematic presentations of the producer's responsibility scheme is given in **Figure 4.1**.

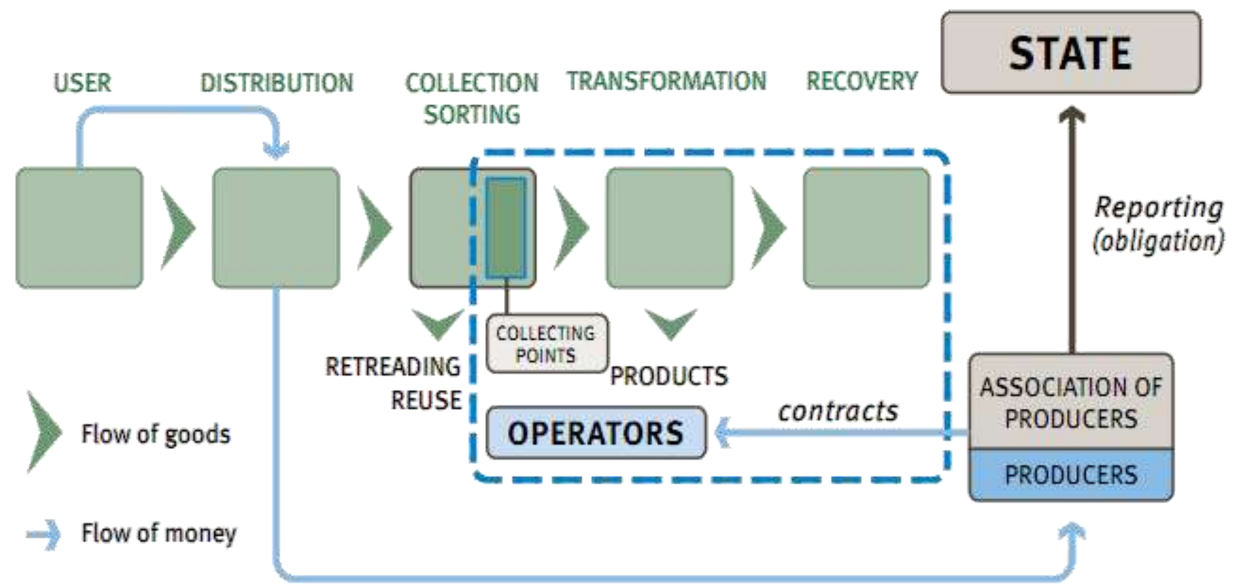

Figure 4.1: Producer Responsibility Scheme

Source: End of life tyres, A valuable resource with growing potential 2011 edition by European Tyre & Rubber manufacturers association (ETRMA) http://www.etrma.org/uploads/Modules/Documentsmanager/brochure-elt-2011-final.pdf

Salient features of this scheme are given below.

- PROs (national associations, voluntary consortia, joint companies and boards) that were set up jointly by tyre producers/importers to take responsibility for end of life tyres are financed in different manners according to the legal system prevalent in the country.
- PROs organisations in turn organise and manage the end of life recovery chain in different ways.

- PROs are mandated to collect and organize the treatment of an equivalent amount (according to the principle 'one new tyre sold one worn tyre recovered') of the volumes of tyres sold collectively by tyre companies.
- The process is financed through an environmental fee generally applied to the product price, regardless of the location of the collection point.
- PROs manage the chain from collection to recovery or recycling, with the support of a reliable and transparent traceability or auditing system.

Countries: Belgium, Estonia, Finland, France, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden and Turkey.

Tax system

Each country is responsible for the recovery and recycling of the end of life tyres. The system is financed by a tax levied on (tyre) production and subsequently passed on to the customer. This is an intermediate system whereby the producers pay a tax to the State, and in turn state is responsible overall for the organisation and remunerates the operators in the recovery chain.

Countries: Denmark, Slovak Republic

Free market system

Under this system, the legislation sets the objectives to be met but does not identify those responsible. In this way all the operators in the recovery chain contract under free market conditions and act in compliance with legislation. This may be backed up by voluntary cooperation between companies to promote best practices.

Countries: Austria, Bulgaria, Croatia, Germany, Ireland, Switzerland. Operating under a freemarket system, United Kingdom has a hybrid system as collectors and treatment operators have to report to national authorities.

4.1.2 WT management in Australia

The stewardship Australia (TSA) is a system based on producer's responsibility. *Tyre Stewardship Australia (TSA)* is a voluntary, industry-led scheme that aims, primarily, to increase the recycling rate of WT. Tyre product stewardship scheme generally acts as an organising committee between parties in the tyre supply chain to share responsibility for the long term management of WT in Australia. The major objectives of the Tyre Product Stewardship Scheme are to: i) Increase the resource recovery and recycling and minimise the environmental, health and safety impacts of WT generated in Australia, ii) Develop Australia's tyre recycling industry and markets for tyre derived products. These objectives can be achieved through the following steps:

- a series of commitments requiring tyre importers, retailers, collectors, transporters, recyclers, governments, fleet operators and other consumers to play an active part in ensuring WT are designated to their respective applications and ELT are disposed in a way which is environmentally friendly and sustainable.

- enterprise to enterprise agreements or contractual arrangements between individual businesses and organisations, which give effect to the industry wide long range withstanding commitments.
- a tyre stewardship fund used to support the activities of the scheme and for investment in research and development for new technologies and market development
- a company called Tyre Stewardship Australia, funded by tyre manufacturers and importers, which will be responsible for administering the scheme and for working to remove impediments to the development of a sustainable domestic tyre recycling industry. Tyre Stewardship Australia (TSA) has been established in January 2014 by tyre importers to administer the national tyre product stewardship scheme.

As key elements of the strategy of TSA:

- Tailor its activities and investment strategies to ensure increased recycling and resource recovery on a local, regional and national basis, in recognition of the unique geographical and regional challenges in Australia, and
- Work with governments to remove impediments to the establishment of a sustainable domestic tyre recycling industry and markets for tyre derived products.
- Through the scheme, TSA aims to increase domestic tyre recycling, expand the market for tyre-derived products and reduce the number of Australian end-of-life tyres that are sent to landfill, exported as baled tyres or illegally dumped.
- TSA is responsible for administering the scheme and conducting education, communication and market development activities.

The scheme was developed through extensive consultation with a broad range of stakeholders to design a voluntary, industry-led, operated and funded scheme. Guidelines outlining the operations of the scheme were established in consultation with industry and Australian and state and territory governments. Key features of the scheme are:

- any stakeholder in the tyre supply chain, including tyre and vehicle importers, retailers, fleet operators, local governments, collectors, recyclers and the mining industry, may apply to become a participant in the voluntary scheme.
- participants commit to play their part in ensuring end-of-life tyres go to an environmentally sound use.

4.1.3 WT management in Canada

Canada has implemented tyre extended producer's responsibility (EPR) laws. While these Canadian policies use the term product stewardship rather than EPR, they embody to varying degrees the basic principles of EPR in that they assign a significant degree of responsibility for fuunding, planning, and / or implementing tyre programs and achieving goals to industry. PROs have been formed in each province to administer these programs.

The Canadian EPR programs involve, to varying degrees, government oversight and in some cases stakeholder involvement on governing boards. In some instances, retailers are considered to be stakeholders, and producers are involved more peripherally.

Most provinces in Canada decided to levy a tax on new tyres in order to fund recycling programs. These programs are run privately under stewardship programs, with each province having its own program. The stewardship boards are responsible for tax collection, as well as distributing incentives to the tyre tax recyclers.

4.1.4 WT management in Hong Kong

Hong Kong plans to bring waste tyres under part of the Producer Responsibility Scheme (PRS) program. It's a policy stating that producers and users of products should be held responsible for the products they produce and consume. According to the government, "Producer Responsibility schemes (PRSs) place the obligation for managing certain products on the producers, distributors, or sellers of the products. Hong Kong's government plans to bring waste tyres as part of the PRS program in the year
2016 to 2018.

4.1.5 WT management in Japan

Japan does not have specific laws regarding the recycling of tyres, unlike many other developed countries, and they have been treated as part of solid waste recycling. In Japan, "The Fundamental Law for Establishing a Sound Material-Cycle Society". Like stewardship programs in Australia and the USA, Japan has a cooperative program between tyre manufacturers, the government and other industry players to facilitate their recycling provides the guiding principles for tyre waste management. The Japan Automobile Tyre Manufacturers Association Inc. (JATMA) promotes the 3Rs - "Reduce, Reuse and Recycle" to coordinate the collection and recovery of used tyres, and to encourage further research and development. JATMA has also implemented a program for the removal of legacy stockpile sites.

4.1.6 WT Management in South Korea

Korea has adopted a similar methodology to the EU for tyre management. In Korea manufacturers and importers pay a deposit fee that is refunded if they collect the used tyres.

4.1.7 WT management in United States of America (USA)

Waste tyres are managed primarily at the state level in the USA. Each state employs different legislations and governance to maintain and manage the WT flow.

State and Local Governments

Scrap tyres, as a solid waste, are regulated primarily by state governments. In 1985, Minnesota enacted the first state law for the management of scrap tyres. By now, 48 states have enacted laws that address scrap tyre management. While each state has its own program, some common features include:

- Source of funding for the program;
- Licensing or registration requirements for scrap tyre haulers, processors and some end users;

- Manifests for scrap tyre shipments;
- Limitations on who may handle scrap tyres;
- Financial assurance requirements for scrap tyre handlers; and
- Market development activities.

Local municipalities help educate the public about illegal dumping and enforce anti-tyre dumping laws. Local agencies are also usually responsible for tyre pile cleanup

Some local jurisdictions encourage proper disposal by allowing local citizens to drop off limited numbers of tyres at recycling centres, or conduct tyre amnesty days where any local citizen can bring a limited number of tyres to a drop-off site free of charge. State scrap tyre programs may provide financial help to fund such events.

Local municipalities also play big role in procuring products made with scrap tyres including playground/park applications. And in many states, local government agencies are also large users of rubberized asphalt in public paving projects. The Federal government is also a large purchaser of products made with recycled rubber, and has established purchasing guidelines.

4.2 WT Management in Developing Countries

4.2.1 WT management in Argentina

In May 2013, Resolution No.523/2013 on Sustainable Tyre Management throughout their Useful Life, particularly Waste Tyres, was published in the Argentine Official Gazette. This resolution provides the conceptual framework to further develop a national strategy for sustainable tyre management throughout their life cycles, especially after they have become wastes, during the post-consumption period. Steps preceding this resolutions are given below.

- The Argentine Secretariat of Environment and Sustainable Development (SAyDS, as per its Spanish acronym) started to develop a Draft Common Policy Decision on retreaded and waste tyres in 2008. The SAyDS hosted the 1st and 2nd "Seminar on Sustainable Waste Tyre Management" to discuss comprehensively the issue of waste tyre management. Concurrently, they gathered information from various institutions, involving government agencies and private sector institutions. The purpose was to assess and develop logistics and technology proposals to design a national program for the recovery/reuse of tyres as they reach the end of their useful lives, and to promote specific environmental legislation so that they may be sustainably managed.

- The technical assessments conducted by the Undersecretariat of Pollution Prevention and Environmental Surveillance and Control (SsCyFAyPC, as per its Spanish acronym) led to the conclusion that waste tyres should be considered as special universal waste. If the waste tyres are not properly and sustainably managed, they will pose a significant risk of environmental damage or pollution and may affect the health of the population.

- The INTI-Caucho Centre also participated in the development of draft regulations to create a "comprehensive Waste tyre environmental management System", which includes a list of definitions and recommended uses to ensure waste tyres are sustainably managed.

4.2.2 WT management in Brazil

Waste tyre management system is based on producer's responsibility conceptually similar to EU's system. There is some formalized infrastructure within Brazil for the collection of used tyres. The Brazilian National Commission of the Environment (CONAMA) determined, in 1999, that tyre manufacturers and importers were responsible for the environmentally friendly collection and management of waste tyres. The regulation has evolved over time, but has in essence maintained that recycling tyres is mandatory by law and is, therefore, the responsibility of the manufacturers. Brazil requires importers to demonstrate the disposal of 20% more tyres per annum than they import.

4.2.3 WT management in China

In China, scrap tyres have a great potential market in China. From this perspective, scrap tyres have been regarded as an important renewable resource and have played an important role to promote rubber industry development. In recent years, relevant regulations on scrap tyres management have been issued as described in **Table 4.1** shown.

Table 4.1: Relevant Regulations on Scrap Tyres Management in China

Sr. No.	Management Sectors	Laws or Regulations	Issued Departments	Main Contents
1.	Planning	Suggestions Concerning on the Establishment of an Integrated and Advanced Collection System of Waste and Second-hand Products	General Office of State Council (〔2011〕 No. 49)	Focus on collection of main waste and second-hand products. Adequately utilizing function of market mechanism, enhance collection rate of main waste and second-hand products ,such as scrap metals, waste papers, waste plastics, car scraps and electromechanical equipment, scrap tyres
2.	Collection	The Measures for Administration of Renewable Resources	National Development and Reform Commission Ministry of Public Security Ministry of Construction State Administration for Industry and Commerce State Environmental Protection Administration	Article 2 Renewable resources include metallic scrap, discarded electronic products, mechanical and electric equipment and parts, waste paper making materials (such as waste paper and cotton), waste materials for light chemical industry (such as rubber… Article 15 Departments of commercial administration is in charge of the industry of renewable resources recovery, and responsible for stipulation and implementation of industrial policies of renewable resources recovery, recovery standards and program of recovery industry development as well.
3.	Transport (out- of-province for storage or	Law of the People's Republic of China On the Prevention and	The Standing Committee of the National People's Congress	Article 23 To transport any solid waste out of the administrative region of a province, autonomous region or municipality directly under the Central

Sr. No.	Management Sectors	Laws or Regulations	Issued Departments	Main Contents
	disposal)	Control of Environmental Pollution by Solid Wastes		Government for storage or disposal, one shall apply to the environmental protection administrative department of the people's government of the province, autonomous region or municipality directly under the Central Government where the solid waste is to be moved out for approval, which shall grant its approval after consulting with and obtaining permission from the province, autonomous region or municipality directly under the Central Government where the solid waste is to be accepted.
		Circular Economy Promotion Law (Jan.1st, 2009)	The Standing Committee of the National People's Congress	Article 38 The dismantlement and recycle of special products, such as used electric and electronic products, used motor vehicles and ships, waste tyres and waste lead-acid batteries, shall comply with the provisions of relevant laws and regulations.
4.	Recycling and Disposal	Tyre Industry Policy	Bulletin of Ministry of Industry and Information Technology (Industry Policy No.2, 2010)	Article 53 Enterprises engaging in tyre retreading and scrap tyre recycling should adapt cleaner production technology and technological equipment meeting environmental protection requirements and energy-saving .pollution reduction standards and prevent second pollutions. Illegal oil refining of scrap tyres is strictly prohibited. Illegal oil refining equipment of scrap tyres will be banned according to law.
5.	Import	Bulletin on Adjusting Import Waste Management Catalogue	Ministry of Environmental Protection Ministry of Commerce National Development and Reform Committee General Administration of Customs General Administration of Quality Supervision, Inspection and Quarantine	Restriction Import: 400400009 Non-vulcanizated rubber scrap,powder Forbidden Import: 4004000010 Waste tyre and stripping 4004000020 Vulcanizated rubber scrap,powder (excluding hard rubber) 4017001010 All kinds of hard rubber scrap
6.	Export	Management Measures on Approval Notification for Hazardous Waste Export	State Environmental Protection Administration (No. 47 Order)	Article 3 Export approval notification of "Hazardous wastes" and "other wastes" stipulated under Basel Convention and hazardous wastes defined by laws of import parties or transit parties will comply with this management measures.

Source: Comparison Study of Scrap Tyres Management between China and the USA, http://www.allconfs.org/img1/_2013117174041182.pdf

For scrap tyres collection, enterprises which meet the registration requirements of industrial and commercial administration can engage in collection activities and don't need other special license. For scrap tyres transportation, haulers also don't need apply any licenses only when they want to transport out of the administrative region of a province, autonomous region or municipality for storage or disposal purpose.

For scrap tyres recycling or disposal, relevant environmental protection requirements should be met and illegally oil refining is strictly prohibited. For scrap tyres import, only non-vulcanizated rubber scrap or powder can import.

4.2.4 WT management in India

Currently, waste tyre management in India is regulated by the Solid Waste Management Rules 2016, while its export & import is regulated under Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016.

4.2.5 WT management in South Africa

The South African government, seeking alternative and ecologically friendly waste tyre disposal options, has accepted the Recycling and Economic Development Initiative of South Africa (REDISA plan)(311) in accordance with the National Environmental Management Waste Act, (Act 59), 2008 (Government Gazette, 17April 2012). This initiative is based on stewardship system a type of Extended Producer Responsibility (EPR) system.

4.3 Guidance Notes

Objective: The major objective of guidance notes is to assist policy makers/ other stakeholders to assess whether tyre waste is addressed in the existing environmental/ related legislation of the country. This assessment will assist them to identify the gaps and the regulations where tyre waste can be addressed or whether there is a need to address it in a new regulation. Nine steps have been identified in guidance notes to assist in development of an enabling policy/ laws/ regulations and institutional framework for tyre waste management.

Guidance Procedure: Guidance procedure includes completion of following seven steps as given below

- *Step 1:* Identify the environmental legislation, where Municipal Solid Waste/ Hazardous Waste or items related to trans-boundary movement of hazardous waste/ Basel Convention are addressed.
- *Step 2:* Identify the sections and subsections where any item related to waste tyres / tyres are mentioned.
- *Step 3:* Look for following words in the legislation/ regulation and their definition and interpretation:

    - Discarded / Disposal
    - Used tyres/ Scrap tyres/ Waste tyres

- Recycle/ Reuse
- Treatment

- *Step 4:* Prepare tyre waste definition reference matrix with respect to three drivers like definition of "waste tyres", description of its "loss of utility" and "way of disposal" using the following matrix.

Regulation/ Drivers	**Drivers**		
	Definition of Used / Scrap / Waste Tyres (Yes/ No)	**Definition of loss of utility (Yes/ No)**	**Definition of way of disposal (Yes/ No)**
"Hazardous" waste			
"Non-Hazardous" waste			
Regulation related to Basel Convention			
Any other regulation e.g. end of life vehicle			

In case of "Yes" specify the reference, its coverage and application in domestic and transboundary trade.

- *Step 5:* Incase tyre waste is mentioned either directly or indirectly in any regulation, specify roles and responsibility of following stakeholders
  - Generator/ Producer
  - Exporter/ Importer
  - Collector/ Transporter
  - Waste Treatment Operator
  - Regulatory Agencies (Local/ National)

- *Step 6:* Identify the gaps from the matrix and recommend tentative content, extent and coverage of tyre waste definition.

- *Step 7:* Carry out due diligence on tyre waste policy/ laws/ regulations eg. EPR other country policy and regulatory framework. Identify the gaps with respect to existing environmental regulations (outputs of step 1 to 3) and recommend tentative content, extent and coverage of tyre waste policy/ laws/ regulatory framework. Organize a workshop of major stakeholders like line ministries/ government agencies (IT/ Electronics/ Consumer Durables/ Electrical/ Industries/ Environment/ Forests/ Finance/ Economy and Commerce), industry associations, retailer's associations, municipalities, formal and informal recyclers, transporters, operators for incinerators/ hazardous waste management facilities and NGOs to arrive at an acceptable tyre waste policy/ laws/ regulations.

CHAPTER 5: COMPENDIUM OF TECHNOLOGIES FOR THE RECOVERY OF MATERIALS / ENERGY FROM WASTE TYRES

5.1 Introduction

Waste tyres can be re-used, recycled and harnessed as sources of materials and energy. Tyres contain metal (bead wires and steel cords), latex (natural) rubber, styrene-butadiene (synthetic) rubber, carbon black and various additives as discussed previously; presenting opportunities for materials and energy recovery. Uses range from civil engineering (whole tyres and tyre-derived aggregate) and the numerous applications for crumb and ground rubber to the burning of waste tyres as fuel and processing of waste tyres to reclaim rubber or to extract oil, gas and char. These processes, their applications and the technology required to support them are described in the following sections. At first, generic technologies for the recovery of materials/energy from waste tyres have been described. This is followed by specific technologies and guidance notes. Guidance notes assist the target audience to carry out stepwise due diligence in order to decide the technology required for tyre waste management.

5.2 Generic Technologies for the Recovery of Materials / Energy from Waste Tyres

The feasibility & economic viability of a technology depends on supply, demand, current costs and prices and local conditions. Key issues include the availability of a steady supply of waste tyres, regulations discouraging or preventing stockpiling or disposal in landfill, the availability of infrastructure to support processing, the costs of the technology and power required and, particularly, the market demand (and sales price) for the materials and energy recovered. **Figure 5.1** gives an overview of the main use of waste tyres. **The following sections describe technologies in the hierarchy of tyre reuse, tyre recycling energy recovery from waste tyres.**

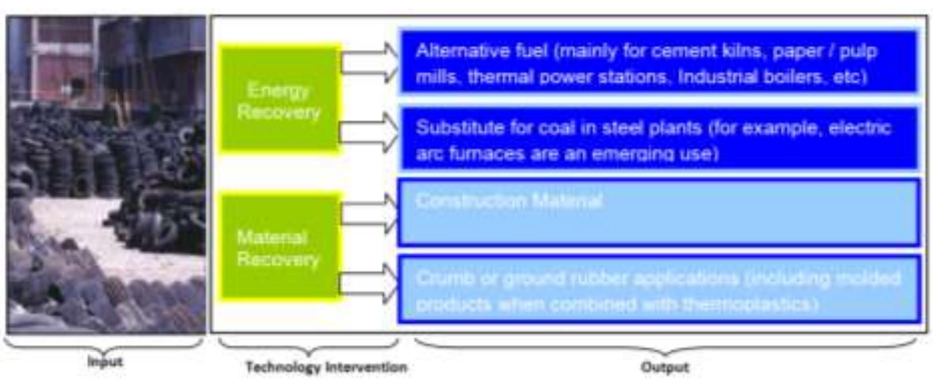

Figure 5.1: Main Use of Waste Tyres[85]

[85] *World Business Council for Sustainable Development, Managing End of Life Tyres, 2008.*

5.3 Tyre Reuse

5.3.1 Products Manufactured from Waste Tyres

A number of products can be manufactured from tyres e.g. flower pots, furniture & shoes. Process description is given below.

1. Cutting
2. Shaping / Moulding
3. Weaving / Knitting
4. Finishing

Figure 5.2 describes stepwise process flow for these ptoducts

Figure 5.2: Products Manufactured from End of Life Tyres

Major specifications:

1. Input / type of tyre (Number)
2. Output (Number)
3. Area Requirement
4. Labor Requirement

5.3.1.1 Environmental & Health Impacts

Since the process is a dry process major environmental impacts include solid waste generation. This solid waste mainly consists pieces of tyres & tyre cuttings, which can again be used for recycling & recovery.

5.3.1.2 Investment & Operating Costs

Majority of these activities fall in category of micro and small scale enterprises mainly consisting of costs of land, labor & input raw material.

5.3.2 Tyre Derived Aggregate (TDA) & Whole Waste Tyres

Tyre derived aggregate (TDA) is a product made by cutting waste tyres into pieces ranging from approximately 50-300mm. These pieces are larger than rubber crumb and have different applications. TDA is useful because it is lightweight, is a good thermal insulator, is highly permeable, can absorb vibrations, produces low lateral pressure on walls and has good shear strength. It is able to provide a solution for many geotechnical challenges. In virtually all civil engineering applications the waste tyre material replaces some other material currently used in construction, including soil, clean fill, drainage aggregate, and lightweight fill materials such as expanded shale and polystyrene insulation blocks. Therefore, TDA has the potential to greatly reduce construction costs, while providing a recycling option for waste tyres. **Each cubic meter of TDA is equivalent to approximately 100 passenger tyres.**

5.3.2.1 Process Description

There are two types of TDA: Type A with a maximum size of 3 in. (75 mm) and Type B with a maximum size of 12 in. (305 mm). While these are the most commonly used sizes, TDA specifications are determined by the end use and will differ based on the contractor's technical, environmental and economic requirements for the project. TDA has become the commonly accepted description for this material because it better conveys the engineering value of the geometrically, size-reduced waste tyre pieces, compared to tyre crumb, chip or shred used for other purposes, as previously discussed[86].

In general, tyre derived aggregate can be made from car and truck tyres or a mixture of tyre sizes. To produce TDA, tyres are fed into a primary shredder that cuts the tyres using knives that rotate at slow speed. The most popular type of primary shredder utilizes groups of spaced circular blades mounted on pairs of counter-rotating shafts. This type of primary shredder has hooks on the knives that help pull the tyre into the blades and cut the tyre lengthwise (see Figure 5.3). The corners of the knives act as cutting edges that together with the adjoining blade edges of the knives on the opposing shaft create the scissor action needed to cut the tyres. Another type of primary shredder utilizes knife rotors and rotor spacers that are permanently attached to the knife rotors. The machine has detachable blade sections bolted to the knife rotor. Wear plates or liners are also secured to each side of the rotor to protect against wear. This machine

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[86] *Recycling Research Institute Scrap Tyre News http://www.scraptyrenews.com/tda.php, accessed Aug 7, 2013.*

design permits closer spacing tolerance between the edges of the adjacent blade than can be achieved with conventional hook and shear machines[87].

Figure 5.3: Popular Type of Primary Shredder

The quality of TDA is determined by the sharpness of the shredder knives and maintenance of the blades. Machines with sharp knife edges and close clearances between the blades produce a clean cut TDA with few exposed steel belts, tyre cords or wire, whereas dull knives can lead to wire remaining embedded in the TDA. While wire removal can be accomplished in several ways, some methods such as de-beading tyres prior to shredding are expensive and not economical for a high volume product for civil engineering applications. Usually processors use magnets mounted over a conveyor belt or vibrating table to remove wire pieces. **Figure 5.4** shows a system used to produce TDA of various sizes in two stages.

Major specifications include:

1. Input capacity / Output capacity (tons/hr)
2. Output (Size in mm)
3. Power requirement
4. Area requirement

[87] *Recycling Research Institute Scrap Tyre News http://www.scraptyrenews.com/tda.php, accessed Aug 7, 2013.*

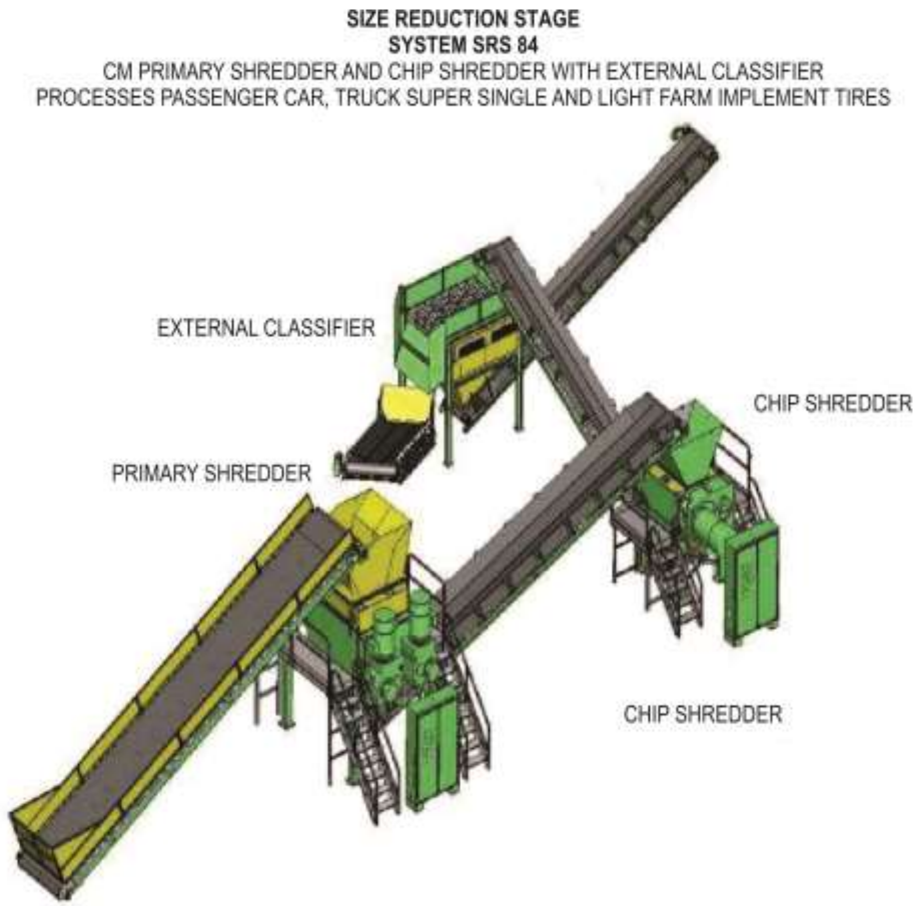

Figure 5.4: System Used to Produce TDA of Various Sizes, in Two Stages[88]

5.3.2.2 Products and Application for Tyre Derived Aggregates and whole Waste Tyres

a) Tyre Derived Aggregates

Tyre derived aggregate has many civil engineering applications as shown in **Figure 5.5**. Since 1992, when TDA was first utilised in the US, the range of uses for waste tyres and waste tyre derived materials has grown. In virtually all civil engineering applications, the waste tyre material replaces some other material currently used in construction, including soil, clean fill, drainage aggregate, and lightweight fill materials such as expanded shale and polystyrene insulation blocks. This means it can reduce construction costs and deliver environmental benefits, by reducing demand for virgin raw materials. **TDA also has properties which are particularly advantageous in some civil engineering applications.**

- **Lightweight (weighs 1/3 of what soil weighs)**
- **Low earth pressure (1/2 that of soil)**
- **Good thermal insulation (8 times better than gravel)**

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[88] *Courtesy: CM Tyre Recycling Systems and Solutions,* *http://www.cmtyrerecyclingequipment.com/CompleteSolutionsDetails.aspx?pid=4601*

- **Good drainage (10 times better)**
- **Compressible**
- **Vibration mitigation**
- **Low cost**

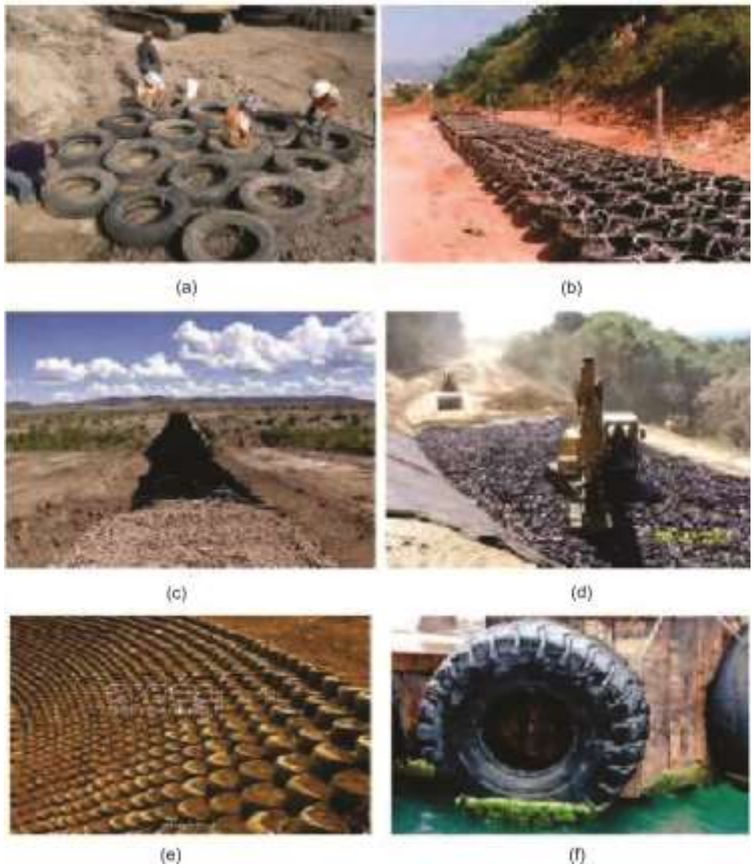

Figure 5.5: Innovative Uses of Scrap Tyre (a,b,c) Road Sub-layer Stability,(d) Tyre Pieces as Fill Material, (e) Slope Stability,(f) Ship Bumper at Warf[89]

For projects that need materials with these properties TDA is often the most cost effective solution. In addition, TDA offers a high volume use for waste tyres. **Typically, one cubic meter of TDA fill consumes 100 tyres. Civil engineering projects can consume from 20,000 waste tyres per application to over 2 million tyres per application,** so is attractive to many contractors and favored for public works, particularly those undertaken by governments or authorities also seeking to concurrently reduce the burden of waste tyres on landfill sites.

In road works, TDA can be used as lightweight fill replacing soil in the construction of highway embankments, as bridge abutment backfill and as thermal insulation to limit frost penetration beneath roads in cold climates[90]. TDA has also been used as backfill for retaining walls and sheet pile walls, with its low weight and high permeability making it a perfect replacement for

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[89] *Image Source: Ahmet Turer (2012). Recycling of Scrap Tyres, Material Recycling - Trends and Perspectives, Dr. Dimitris Achilias (Ed.), ISBN: 978-953-51-0327-1*
[90] *Humphrey, D. and Blumenthal, M. (2010) The Use of Tyre-Derived Aggregate in Road Construction Applications. Green Streets and Highways 2010: pp. 299-313. doi: 10.1061/41148(389)25*

conventional fillers[91]. The permeability of TDA has seen it used successfully in drainage layers in landfill, septic systems drain fields, and high way edge drains[92]. Research has also shown that using a layer of TDA beneath railway lines can greatly reduce vibrations, improving conditions for adjacent residences and businesses[93].

b) Whole Waste Tyres

Highway Crash/Sound Barriers

Whole waste tyres can also be used to construct crash or sound barriers for highways, by stacking and binding whole waste tyres in steel cable and then enclosing them in fibre glass. A study by the Texas Transport Institute[94] determined that crash barriers made from waste tyres would be able to absorb the impacts of automobiles travelling at up to 71 miles per hour (approximately 115 km per hour). This option provides a cost effective way of using tyres in infrastructure at their end of life. Though sand barriers are more common, because of the ease with which they are assembled and their excellent absorption characteristics, waste tyres provide a viable alternative.

Artificial Reefs

Artificial reefs made of waste tyres were proposed as a solution to the burgeoning mountains of used tyres in stockpiles in the United States in the 1950s and 60s. The Goodyear Tyre and Rubber Company researched alternative uses for waste tyres and advertised tyre reefs as a major outlet for used tyres[95]. It was thought that from artificial tyre reefs coral reefs would grow and fish would throng. In 1974, a Goodyear pamphlet boasted: "Worn out tyres may be the best things that have happened to fishing since Izaak Walton (the author of the classic, *Compleat Angler*)[96]. By 1978, Goodyear claimed to have built over 2000 reefs[97].

Artificial tyre reefs are made by splitting tyres lengthwise, creating two circular halves that are left attached by about 6 inches of rubber. They are then stacked in a triangular formation. Holes are drilled into these tyre stacks, and then concrete is poured into the hole to anchor the reef. A 36 inch (90cm) reef weighs approximately 1,800 pounds (816 kg). A reef is installed by being hauled by a barge into the water, and placed in water that is 60 – 100ft deep. The cost of constructing a tyre reef is approximately USD$3.50 per tyre[98]. Configuration of the artificial reef and of the "rubber rock", large and small tetrahedral tyre modules are shown in **Figure 5.6**.

Artificial tyre reefs were intended as an environmental "win, win"; they were supposed to create habitat for a variety of marine life while utilizing a mass waste that would otherwise have ended up

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[91] *Tweedie, J.J., Humphrey, D.N., and Sandford, T.C. 1998b. "Tyre TDA as Retaining Wall Backfill, Active Conditions." Journal of Geotechnical and Geoenvironmental Engineering. ASCE, Vol. 124, No. 11. pp. 1061-1070.*

[92] *Jesionek, K.S., Humphrey, D.N., and Dunn, R.J. 1998. "Overview of Shredded Tyre Applications in Landfills." Proceedings of the Tyre Industry Conference, Clemson University, March 4-6. 12 p. in http://www.rma.org/scrap_tyres/EPA%20Scrap%20Tyre%20Handbook%20on%20Recycling%20%20Management%20publication.pdf*

[93] *Wolfe, S.L., Humphrey, D.N., and Wetzel, E.A. 2004. "Development of Tyre Shred Underlayment to Reduce Groundborne Vibration from LRT Track." Geotechnical Engineering for Transportation Projects: Proceedings of GeoTrans 2004. ASCE. pp. 750-759 http://www.rma.org/scrap_tyres/EPA%20Scrap%20Tyre%20Handbook%20on%20Recycling%20%20Management%20publication.pdf*

[94] *Texas reference: http://www.epa.gov/osw/conserve/materials/tyres/tyres.pdf p.33, accessed June 29, 2013.*

[95] Environmental Protection Agency, Markets for Scrap Tyres http://www.epa.gov/osw/conserve/materials/tyres/tyres.pdf

[96] *The Washington Post, Oct 2, 2006, Bright Idea of Tyre Reef Now Simply a Blight, accessed June 26, 2013*

[97] *Environmental Protection Agency, Markets for Scrap Tyres http://www.epa.gov/osw/conserve/materials/tyres/tyres.pdf*

[98] *Environmental Protection Agency, Markets for Scrap Tyres http://www.epa.gov/osw/conserve/materials/tyres/tyres.pdf*

in landfill. Initially, they attracted government and community support. However, the reefs proved to have a significant environmental impact on sea and ocean environments where they were adopted around the world[99]. Malaysia and Indonesia, for example, launched massive tyre reef programs. By 1995, there were 67 artificial tyre reefs off Malaysia alone[100].

Dr William Alevizon, who conducted a review of Malaysia's reefs, said in his 1990 submission to the Malaysian Government;[101] "Of all materials now in reasonably common use in the construction of artificial reefs, automobile tyres are by far the least satisfactory, particularly in ocean environments". He argued that arrays of tyres, no matter how they are constructed, have proven highly unstable structures in the sea. "Their inherently low specific gravity gives them a propensity to shift under relatively slight conditions of water movement. This continual movement eventually defeats whatever binding method has been used to join them together. In large storms, tyre arrays can be (and have been) moved considerable distances, only to eventually break apart. The individual tyres then become undersea juggernauts wreaking havoc on sensitive benthic habitats for many years."

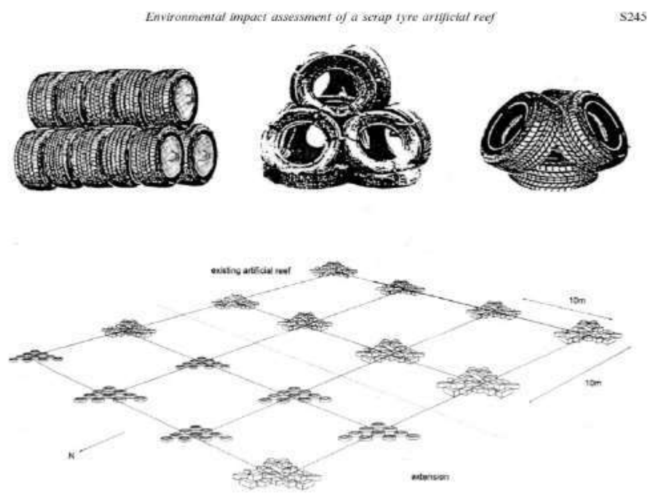

Figure 5.6: Configuration of the Artificial Reef and of the "Rubber Rock", Large and Small Tetrahedral Tyre Modules[102]

He also noted that in terms of "forming substrate for colonization by marine life, the relatively smooth surfaces of tyres are also the least satisfactory material, often becoming covered by a "community" consisting of little more than filamentous algae". In conclusion, he recommended that of artificial reefs "be immediately discontinued and that they should be properly considered a threat - not a benefit - to the cause of fisheries or habitat enhancement in the marine environment."

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[99] *Brian Skoloff, Tyre reef off Florida proves a disaster http://usatoday30.usatoday.com/news/nation/2007-02-17-florida-reef_x.htm?csp=34, accessed May 7, 2013.*
[100] *Geoffrey Lean, Why divers have to remove 2m tyres, one by one http://www.independent.co.uk/environment/nature/why-divers-have-to-remove-2m-tyres-one-by-one-437799.html, accessed June 26, 2013*
[101] *William Alevizon , Statement on Tyres as Artificial Reefs For Malaysia by Dr. Bill Alevizon, A Scientific Expert on Artificial Reef http://www.reefball.com/map/malaysiatyres/Statement%20on%20Tyres%20as%20Artificial%20Reefs%20For%20Malaysia%20by%20Dr.htm, accessed June 26, 2013*
[102] *ICES Journal of Marine Science, 59: S243–S249. 2002*

Example 2:

Osborne Reef - the fate of the world's largest artificial tyre reef

In the spring of 1972 the dumping of millions of tyres off the Florida coast seemed like an ecological triumph. So much so that Goodyear launched a blimp amid much fanfare to christen the site by dropping a gold-painted tyre, as hundreds of private boats formed a ceremonial flotilla below.

The project in Fort Lauderdale was put together by Ray McAllister, the professor of ocean engineering at Florida Atlantic University, with the approval of the US Army Corps of Engineers. Thousands of dollars were raised towards the project, and hundreds of volunteers were organized with boats and barges. The tyres were received from Goodyear. Goodyear also donated the equipment – and the nylon and steel -- that was used to bind and compress the tyres into bundles for deployment. At the time, Goodyear released a press release that said the reef would "provide a haven for fish and other aquatic species" and detailing the "excellent properties of scrap tyres as reef material." Such reef projects were actively promoted "as the next best thing to recycling".

"What happened instead is a vast underwater dump – a spectacular disaster spawned from good intentions," the Washington Post reported in 2006. "Today there are no reefs, no fishy throngs, just a lifeless underwater gloom of haphazardly dropped tyres stretching across 35 acres of ocean bottom. It is not just a matter of botched scenery. Because they can roll around, the tyres are pounding against natural reefs nearby" Tyres have also washed up on beaches around the area and have become wedged in the nearby natural reef, affecting the growth of coral and other marine life.

Breakwaters

Breakwaters are built to protect harbours or shorelines from the impact of the waves. The breakwater absorbs some of the impact of the waves. Breakwaters made of waste tyres were found by the US Army Corps of Engineers to be most effective on small-scale waves[103]. **Waste tyres used in breakwaters and other floats are filled with a material that increases their buoyancy, usually foam. They are able to displace up to 200 pounds of water. They are used to float marinas and docks, as well as serving as a barrier against waves.**

Erosion Control

Several different erosion control applications have been developed using waste tyres. In the USA, the California Office of Transportation Research has developed several of these applications, including banding waste tyres together and partially or completely burying the unstable slopes. They found that tyres, with other stabilizing materials, can provide stability and immediate economic solutions for problems such as unstable highway shoulders. **Using waste tyres can reduce construction costs by 50-75%, compared to using other low cost alternatives such as rock, gabion (wire mesh/stone matting) or concrete.**

There have been similar problems reported with other tyre reefs worldwide. William Nuckols, the coordinator of Costal America, describes the tyre reefs as a "constantly killing, coral-destruction machine". In 2007, the state government of Florida announced a $2 million budget to help gather and remove the tyres from the ocean, and in 2010 a full-scale salvage operation was put in place at the cost of $3.4 million. "It's easy to throw something in the water – what we are finding is it's extremely expensive to remove something from the water," the Washington Post reported a Florida official as saying.

[103] *Markets for scrap tyres, United States Environmental Protection Agency Office of Solid Waste* http://www.epa.gov/osw/conserve/materials/tyres/tyres.pdf

Tyre removal was carried out by US Army and Navy divers from 2007. Divers gathered and bundled the tyres which were then buoyed to the surface. The project served not only as an environmental initiative but as a military training exercise. The US Army provided a landing craft utility (LCU) accommodating a crane used to transfer the tyre bundles from the water's surface to on-board tractor-trailer units. Full trailers were off-loaded for recycling. A 2009 review of progress concluded that "when conditions were ideal (i.e. calm seas, no equipment failures), the divers were able to recover approximately 2,500 tyres during a single day. This appears to be the maximum daily productivity that can be expected during the operation". By the end of 2010, some 73,000 tyres had been retrieved of an estimated two million strewn across the ocean floor.

5.3.2.3 Environmental and health impacts of tyre derived aggregates and whole tyres

TDA and whole waste tyres reduce the use of raw virgin materials in many civil engineering applications and exhibit a number of useful properties for construction and earthworks. However, although their use has become common over the past two decades, questions remain about their potential to negatively impact the environment. **A significant literature review reported[104] in 2007 concluded differences in the environmental impact of TDA or tyres installed above the water table and those utilised below the water table, or in aquatic environments. Leaching above the water line, usually caused by rain, led to an increase in level of certain metals such as iron and manganese but the impact of tyre leachate on drinking water did not exceed safe levels for human consumption. In contrast tyres and TDA placed in water, in ground water, surface water, rivers, ponds, oceans etc, have been shown to be toxic to aquatic life.**

Another literature review on the water quality and environmental toxicology effects of tyre-derived aggregate (TDA), carried out by University of Maine and summarised by the US EPA, found[105]; **"TDA has a limited effect on drinking water quality and fresh water aquatic toxicity for a range of applications including lightweight backfill for walls and bridge abutments, insulation and drainage layers beneath roads, free-draining and insulating backfill for residential foundations, vibration damping layers beneath rail lines, landfill leachate collections systems, drainage layers in landfill caps, landfill gas collection systems, and drainage aggregate for drain fields for on-site waste water treatment systems. TDA is unlikely to increase the concentration of substances with primary drinking water standards above those naturally occurring in the groundwater. It is likely that TDA will increase the concentration of iron and manganese, but the data indicates that these elements have limited ability to migrate away from the TDA installation."**

The EPA also reported that: "Several environmental studies have been performed to assess the potential for toxics to leachate from tyres when placed in wet soils. The impact of waste tyres on the environment varies according to the local water and soil conditions, especially pH value"[106]. Generally, TDA and whole tyre applications that are not subject to immersion in water have been found to impact the environment within levels considered safe for human. However, the

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[104] *International workshop on scrap tyre derived geomaterials, 2007, Yokosuka, Japan, proceedings; http://books.google.com.au/books?id=yMrELXFfxZ0C&printsec=frontcover#v=onepage&q&f=false*
[105] *Dana N. Humphrey, Michael Swett Literature Review of the Water Quality Effects of Tyre Derived Aggregate and Rubber Modified Asphalt Pavement http://www.epa.gov/osw/conserve/materials/tyres/tdastudy.pdf*
[106] *Environnemental Protection Agency http://www.epa.gov/osw/conserve/materials/tyres/civil_eng.htm*

demonstrated toxicity of tyres in aquatic environments has led to a range of recommendations from various authorities discouraging their use.

5.3.2.4 Investment and Operating Costs

The economic advantages of using whole tyres and TDA are dependent on the cost of producing TDA and the cost of collecting waste tyres plus the costs of transporting both, compared to the local cost of sourcing and transporting conventional or alternative building materials. Generally, if there is sufficient local supply of waste tyres, TDA is a cost effective option for projects that need lightweight fill material for construction, and the use of TDA in drainage is cost effective in areas where there is a limited supply of conventional drainage aggregate. **Some of the planning, practical and business considerations outlined for ground/crumb rubber are also applicable for TDA.**

TDA is produced using a mechanical shredder. Unlike rubber crumb or ground rubber, TDA can be produced using a single shredding line, whereas crumb and ground rubber requires multiple size reduction steps and more equipment. Nonetheless, a considerable initial investment in equipment is required as in an adequate budget for maintenance and operations.

A study into the feasibility of tyre shredding facilities carried out by George Washington University (2003)[107] stated that **market analysis and its implications for the type of shredder needed was critical for investment decisions.** There are many types of tyre shredders available on the international market but the smaller, cheaper models only process smaller car tyres and cannot be used for truck tyres even at low volumes because truck tyres contain a higher percentage of reinforcing wire and, so are, considerably more difficult to process. Therefore, investment decisions needs to take into account the type of waste tyres available locally and **the potential benefits of spending more on flexible equipment that can process all tyres types.**

Secondly, it may be more economical in the long term to purchase a larger plant that is capable of doing the initial first shred of tyres to produce TDA, but can also subsequently further reduce the size of the shred to meet any local demand for crumb or ground rubber. By having the flexibility to switch from producing TDA to crumb or ground rubber, and vice a versa, or to produce both, diversifies market risk.

Thirdly, as TDA is considered a low cost, high volume civil engineering solution in most markets, equipment of sufficient size must be purchased to produce volumes consistent with the demands of civil engineering. For example, although smaller portable tyre shredders are available (transportable) they are unlikely to meet high volume demands. The US shredder manufacturer BCA industries[108] lists the price of shredders capable of handling car tyres as starting from USD 115,000 for a base model. All other equipment needed to feed tyres into the shredder and magnet systems to remove metal are extra.

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[107] Scrap tyres to crumb rubber: feasibility analysis for processing facilities, Nongnard Sunthonpagasit, Michael R. Duffey, The George Washington University, April 2003.

[108] BCA Industries, http://www.bca-industries.com/shredders/model_ES1000ST.php Accessed August 5, 2013.

The 2011 EPA Scrap Tyre Handbook details a number of costs to achieve shreds of different sizes. **For Type B TDA, a simple shredding system, plus the minimum of supporting equipment such as a Bobcat and Front end loader would total US $706,000. To achieve smaller 5cm shreds costs rise to US $928,000 to US$ 1,396,000. For 2.5 cm shreds, equipment set up costs (excluding land etc) total approximately US $988,000 to US $1,506,000[109].**

The most expensive single component of any shredder is the shredding head which, if replacement is necessary, cost close to $50,000. Kurt Reschner, however, recommends new industries should expect to investment of USD5 million for a turnkey operation capable of processing 2-3 tonnes of tyres an hour[110].

The George Washington University study[111], which undertook first hand research with waste tyre processors, commented that **actual throughput yields are generally lower and maintenance requirements higher than the optimistic assessment of equipment manufacturers. The study said maintenance costs can reportedly be 200–300% more than the costs estimated by equipment manufacturers.** Worn equipment can reduce processing capacity and production rate. Service lives of perishable items, such as shredder knives, are also generally shorter than those projected by the manufacturers. "One producer claimed that his shredder machine processes 10 tons per hour when the knife is new, but only 5 tons per hour when near the end of the knife's life. Shredder knives have to be replaced after 60,000 car tyres or 10,000 truck tyres while toothed rolls in the ambient grinding process have to be recoated after processing about 1500–2000 tyres," the study reported[112].

5.3.2.5 Institutional and Regulatory Requirements

As TDA is produced using a similar process and equipment to crumb rubber and ground rubber institutional & regulatory requirement remain the same.

5.3.2.6 Pros and cons with respect to developing countries

From a technical point of view both whole tyres and TDA can provide low cost civil engineering solutions for developing countries. Lessons learned worldwide about the applications of both TDA and whole tyres in infrastructure development assist **developing economies in achieving low cost construction while absorbing waste.** Increasing urbanization across the globe means large supplies of waste tyres are likely to be available across small distances, making centralized, large scale processing practical. However, local conditions must always be taken into account when assessing the feasibility and economic viability of tyre recycling technologies.

Developing countries already have well established and dynamic informal waste sectors and high rates of reusing or reclaiming materials from waste tyres, many of which are carried out at very low cost using hand tools[113]. As many waste tyres are currently being utilized the same 'push factor' that

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[109] *Scrap Tyres: Handbook on Recycling Applications and Management for the U.S. and Mexico, December 2010*
[110] *Kurt Reschner, Scrap Tyre Recycling, A Summary of Prevalent Disposal and Recycling Methods, 2008.*
[111] *Scrap tyres to crumb rubber: feasibility analysis for processing facilities, Nongnard Sunthonpagasit, Michael R. Duffey, The George Washington University, April 2003.*
[112] *Scrap tyres to crumb rubber: feasibility analysis for processing facilities, Nongnard Sunthonpagasit, Michael R. Duffey, The George Washington University, April 2003.*
[113] *Columbia University, Recycling Rubber*

supports mechanized tyre recycling in newly industrialized and advanced industrial economies may not exist. In higher income economies large scale waste tyre processors are paid a small fee to accept each tyre, which becomes one important income stream for a viable business model. In developing countries, informal waste collectors usually pick up small numbers of tyres to break them down into more manageable parts by hand, particularly separating out metal and the division of the tyre into the rim and the tread sections, and then sell them for reuse. This suggests it would be unlikely that a large scale tyre processor would be paid to accept tyres; conversely the processor may need to pay waste collectors to supply tyres. As economies grow, however, waste generation increases markedly and there is growing demand for larger scale solutions and more funding available to support them.

Innovation Case Study: Waste tyres to save lives in earthquake zones

Waste tyres may prove a cheap means of protecting poor populations living in vulnerable low cost structures from the devastating impact of earthquakes on such brittle structures. Work by Associate Professor Ahmet Turer, Middle East Technical University, Civil Engineering Department, Turkey, and colleagues over the past decade has returned promising results for the use of waste tyre strips as reinforcements for walls and for waste tyre pads as seismic base isolators – flexible systems sitting between the ground and the upper structure to isolate the building from earthquake inducted seismic forces. In 2004, the World Bank announced the funding of the research, pointing out that strong earthquakes regularly affect Turkey, causing widespread destruction and death, and often leaving the poor in even more precarious situations. In Turkey, 95 % of the population lives in earthquake-prone areas. The majority of poor people live in self-constructed masonry (brick, adobe, stone) houses (45% of total housing stock in major cities) that rarely withstand the impact of significant earthquakes. With no access to engineering services to improve designs and without sufficient resources to build using reinforced concrete, such communities are susceptible to heavy damage or the total collapse of their homes during earthquakes as they disintegrate in a sudden (brittle) manner, without leaving the "life pockets" that form during the collapse of reinforced concrete houses.

Results reported in 2005 showed that a waste tyre strengthened house model (1/10 scale) set up on a tilt/shake table collapsed at 18 degrees (0.31 g) whereas house strengthened using waste tyres resisted 34 degrees (0.56 g) of tilting; an approximately 80 percent of strength increase. The performance of the building also changed from sudden collapse (brittle) to more flexible (ductile) behaviour. The researchers reported the following advantages: the steel mesh within waste tyres gives them a high tensile strength, making them a suitable reinforcement material; they can be obtained at low cost or free; reinforcing strips can be prepared using simple tools (e.g., a utility knife) and the application of waste tyres to walls is simple and easy, and does not require complicated tools or expert skills. Post-tensioning is a well-known technique used in modern civil engineering. The theory is based on applying a compressive stress field on usually a brittle material (such as concrete), which has weak properties under tensile forces. In 2012, results were reported of experiments on brick walls reinforced using waste tyre rings in the form of chains tied around the walls to generate compression stresses for post-tensioning. The experimental studies showed that the nominal lateral load capacities of the brick walls can be improved up to about 10 times by applying 100 kN (per 0.885m of length) axial post-tensioning force using waste tyre chains.

The use of waste tyres pieces has also been tested for use in a pad formation for seismic base isolation. Experiments including "shaking table tests and analysis" have shown that the use of waste tyre pads is viable within certain constraints. Waste tyres using as pads as shown in **Figure 5.7**. Softer types of waste tyres, such as winter tyres, may be used with additional recycled steel plates placed between each layer to increase the vertical load capacity while maintaining a relatively low

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http://www.seas.columbia.edu/earth/RRC/documents/recycling_rubber.pdf, accessed Aug 5, 2013.

horizontal stiffness. Waste tyre pad based seismic base isolation can also be used for rural bridge supports as a low cost and practical material while recycling a waste material[114].

Figure 5.7: Waste Tyre Pieces Used as Pads

5.4 Tyre Recycling

Material recovery technologies have been described in terms of rubber recovery technologies consisting of recovery of ground rubber, Technologies for tyre derived aggregates, metal recovery technologies, technologies for recovery of devulcanised rubber. Energy recovery processes and technologies have been described in terms of technologies for direct use as a fuel, technologies for conversion to conventional type fuel and technologies for recycling waste tyres in steel production.

5.4.1 Recovery of ground rubber/Crumb rubber

Ground rubber, or crumb rubber, is produced by shredding waste tyres to produce small pieces. Tyre crumb rubber has a granular texture and ranges in size from very fine powder to approximately one cm pieces and has a density of between 1.13 and 1.16 kg/L[115]. Typically, 4–5 kg of tyre crumb rubber can be derived from one passenger tyre. Typical product yield from waste tyres are given in **Table 5.1**. This process was not common until 1985, when specific legislation regarding the disposal and recycling of waste tyres was introduced in Minnesota, USA[116]. Minnesota introduced a program that directed waste tyres away from scrap piles and landfills, into a new rubber recycling industry. In 2012, 34 million waste tyres[117] were processed into ground rubber in the US, representing 26.2% of the annual US waste tyre processing market[118].

[114] *Ahmet Turer (2012). Recycling of Scrap Tyres, Material Recycling - Trends and Perspectives, Dr. Dimitris Achilias (Ed.), ISBN: 978-953-51-0327-1, page 207.*
[115] *Zinc Leaching from Tyre Crumb Rubber, Emily P. Rhodes , Zhiyong Ren , and David C. Mays, Environ. Sci. Technol., 2012, 46 (23), pp 12856–12863*
[116] *http://www.rma.org/scrap_tyres/EPA%20Scrap%20Tyre%20Handbook%20on%20Recycling%20%20Management%20publication.pdf p.21,accessed May 4, 2013*
[117] *eCycling USA, Chuck Vollmer & Peter Soriano 26 February 2013, presentation, eCyclingUSA-Tyre-Recycling-Businesses-26-Feb-2013.pdf, accessed May 20, 2013.*
[118] *2011 Rubber Manufactures Association, Inc.*

Table 5.1: Typical Product Yield from Waste Tyres

	Truck Tyres	Car Tyres
Crumb Rubber	70%	70%
Steel	27%	15%
Fibre and Scrap	3%	15%

Processing waste tyres into rubber granules is one of the most useful disposal options for used tyres, because of the wide variety of uses for crumb rubber. However, the usefulness of this material is dependent on the local and regional market for recycled rubber and the cost and technical challenges of processing. As tyres are built for durability and stability, their properties can make size reduction a difficult, energy and cost intensive process. The prevalence of steel belted radial tyres further complicates this process; machinery is needed that must both reduce the size of the tyres and ensure that the ground rubber is both steel and fibre free.

Ground rubber processing involves the reduction of tyres, mechanically or cryogenically, through a system that cuts, grinds or shatters the tyre into smaller pieces[119]. The main piece of equipment required is the tyre shredder, which uses powerful, interlocking knives to chop tyres into smaller pieces[120]. As tyres are highly engineered and extensively designed products that are meant to be virtually indestructible under a variety of conditions[121], the recycling of modern tyres was originally challenging. Tyres were originally processed in the 1980s using metal or wooden shredders but this early equipment was not technically or economically efficient, as it was easily damaged while waste tyres were processed. Since then, technologies and hardware have been developed and refined to effectively process waste tyres. Tyres were originally processed in 'ambient' systems, that is, at ambient room temperature. However, in the past few years there has been a shift towards the use of cryogenics in the production of ground rubber. In this process, the rubber is frozen at sub zero temperatures in a bath of liquid nitrogen, dramatically altering the physical properties of the tyres to make them very brittle. The frozen tyres are then struck with an impact device, effectively shattering the rubber into small particles, 10 mesh (2mm) and smaller[122].

The initial shredding process involves breaking the waste tyres down into chips of approximately 5cm in size, with additional processing producing smaller particles. This reduces the space needed for storage and transport as, in this form, waste tyres are much easier and cheaper to handle and relocate.

5.4.1.1 Process description

There are two main processes for producing ground rubber from waste tyres. The main difference is the temperature at which the processes are carried out, however, ambient processing generally produces coarser crumb than cryogenic processing. The main processes for producing ground rubber from waste tyres are shown in **Figure 5.8**.

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[119] *Producing Ground Scrap Tyre Rubber: A Comparison Between Ambient and Cryogenic Technologies M. H. Blumenthal, Senior Technical Director, Rubber Manufacturers Association, accessed online May 4, 2013.* http://www.rma.org/download/scrap-tyres/processing/PRS-005%20(1).pdf

[120] *Institute of Scrap Recycling Industries (ISRI), Inc., Yearbook 2012, pg 43.*

[121] *Institute of Scrap Recycling Industries (ISRI), Inc., Yearbook 2012, pg 43.*

[122] *Institute of Scrap Recycling Industries (ISRI), Inc., Yearbook 2012, pg 44.*

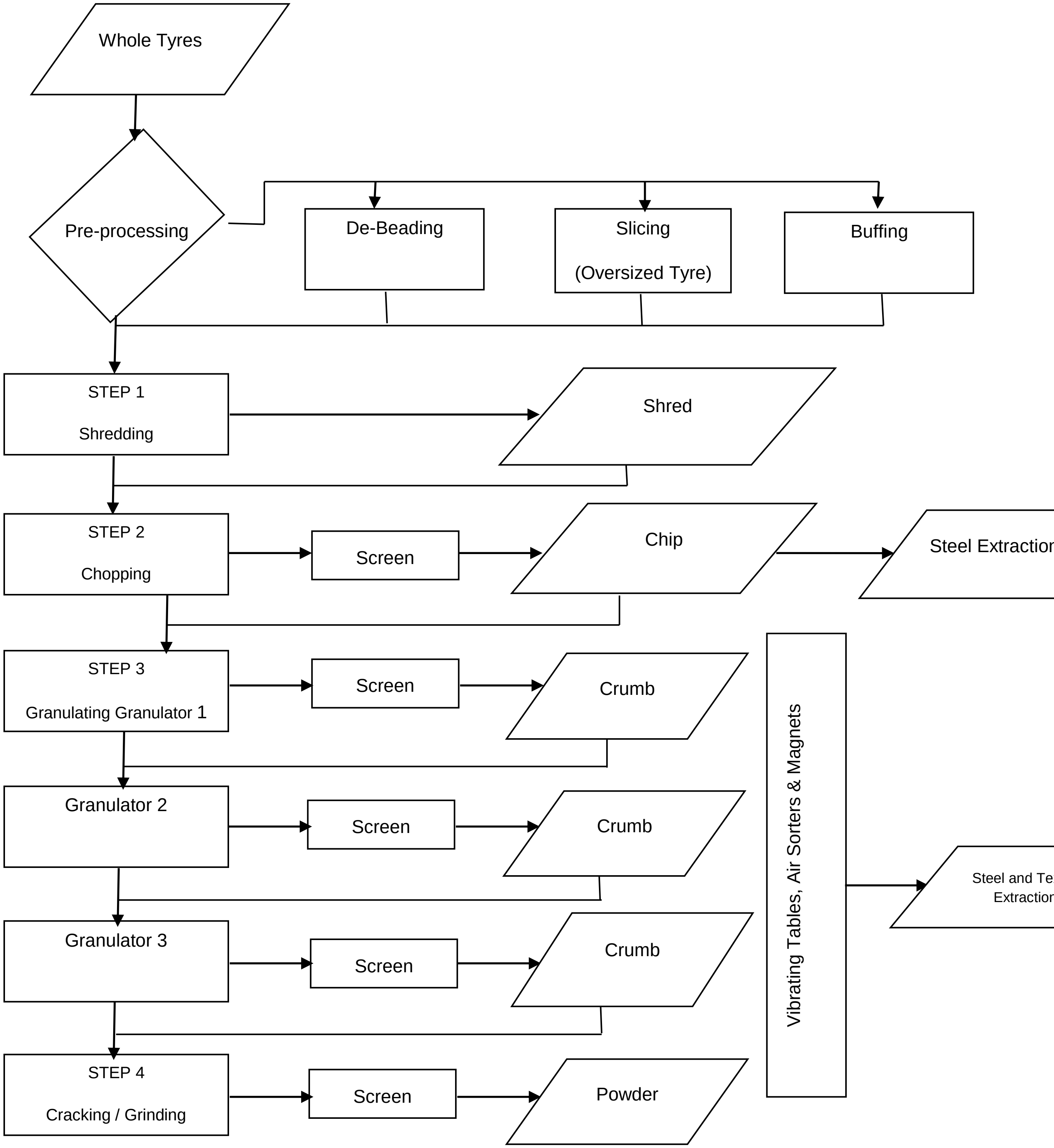

Figure 5.8: Main Processes for Producing Ground Rubber from Waste Tyres[123]

[123] *Financial and Economic Analysis of the Proposed National Used Tyre Product Stewardship Scheme, URS Australia Pty Ltd, December, 2005.*

Source: Personal Communication, 2005, and URS Analysis

a. Ambient Processing

Ambient tyre recycling refers to the processing of waste tyres at room or air temperatures. Rotary shear shredders are the most common machines used for shredding tyres at ambient temperatures. They have two counter-rotating shafts and are able to shred many different types of tyres, including car tyres, truck tyres and farm equipment tyres. Rotary shear shredders operate at a low rate of revolutions per minute (RPM), typically between 20 RPM and 40 RPM, with a high torque. The majority of shredders are powered by electric motors, and have the ability to process 2 – 6 tons per hour, depending on the input material and the desired size of the chips. Ambient tyre processing can take place in large, fully automated plants with capacities of up to 65,000 tons/inputs a year.

Depending on the operation, the steel beads in the tyre can be removed before or after shredding. In operations which do not have shredders that can cope with steel beading, a de-beader is used to remove the steel beads from tyres before shredding commences. This reduces the wear on the shredder, and the subsequent size reduction processors. Although steel beads usually make up only 10-15% of a (car) tyre, it is estimated that they are responsible for approximately 70% of the damage to the processing machines in shredding. To extend the lifespan of the crumbing processors, de-beading before shredding is recommended. In some operations, tyres are shredded with the steel beads in place, and the metal is later removed magnetically.

Ambient tyre shredding can be considered a relatively mature process, though it was not a common practice until the mid-1980s. There are a number of different companies that provide reliable machines throughout North America and Western Europe. This form of tyre recycling is one of the easiest ways to produce crumb rubber. It allows waste tyres to be transformed into a waste product with minimal processing in a cost-effective manner. Although there are variations in the size of the crumbs produced, the crumbs can be subsequently sorted or further processed until the desired particle size is achieved.

As shown in **Figure 5.9**, the tyres are processed first into 50mm chips in the preliminary shredder (A), and then entered into the granulator (B). In the granulator, the chips are reduced to approximately 10mm, and the majority of the steel and fibre are removed from the rubber granules. After this, the rest of the steel is removed magnetically and the fibre is removed with shaking screens and wind sifters (C).

The majority of applications for ground rubber require granules smaller than 10mm, and for this reason most ambient grinding plants have a number of consecutive grinding steps (D), using machines such as:

- Secondary granulators
- High speed rotary mills
- Extruder or screw presses
- Cracker mills

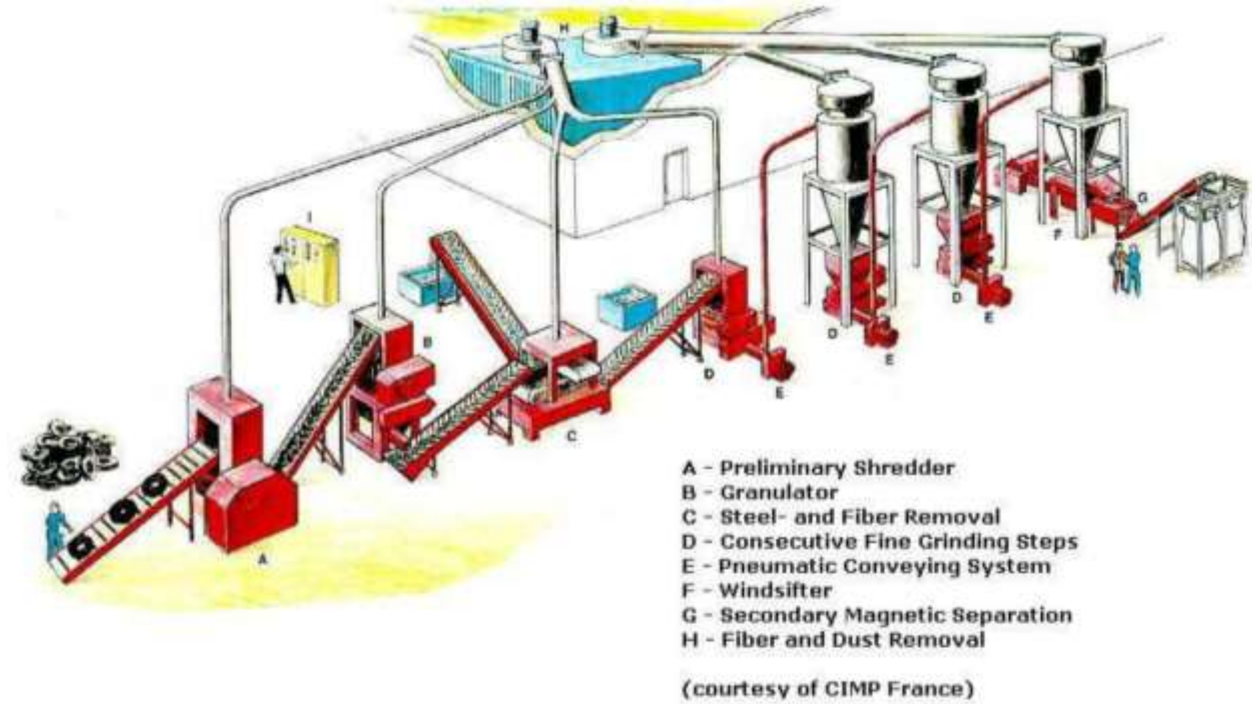

Figure 5.9: Ambient Waste Tyres Recycling[124]

b. Cryogenic processing

The initial de-beading and pre-shredding process is the same in cryogenic processing as it is in the ambient process. As shown in **Figure 5.10**, once the 50mm chips are produced, they are cooled in a continuously operating freezing tunnel (B), before being inserted into a high RPM hammer mill (C). This machine shatters the chips into a variety of particle sizes, simultaneously removing the steel and fibre particles. The steel is removed magnetically, and the fibre is removed through the use of shaking screens. The granules are still very cold, and may be damp, when they exit the hammer mill, so they are dried (E) before they are sorted into different particle sizes (F). The different sized particles are sorted through a number of screens[125]. Fine grinding can reduce the particles further, if this is necessary.

[124] *Kurt Reschner, Scrap Tyre Recycling:A Summary of Prevalent Disposal and Recycling Methods http://www.entyre-engineering.de/Scrap_Tyre_Recycling.pdf, accessed May21, 2013.*

[125] *Department of Civil Engineering, CLEMSON University http://www.clemson.edu/ces/arts/cryogenic.html, accessed May 20, 2013.*

Figure 5.10: Cryogenic Tyre Recycling

Major specifications includes:

1. Input capacity / Output capacity (tons/hr)
2. Output (Mess Size
3. Power requirement
4. Area requirement

5.4.1.2 Products and Applications for Ground Rubber

Ground rubber is considered as one of the most useful rubber products derived from waste tyres because of its wide range of applications and is the most economically viable sector of the waste tyre processing industry[126]. As shown in **Table 5.2**, applications include: Athletic surfaces and fields, mats for agricultural uses and equestrian footing, automotive parts and tyres, construction/indoor, landscaping, trails and walkways, moulded and extruded products, playground and other safety surfaces, rubber modified asphalt and sealants, rubber and plastic blends[127].

Table 5.2: Ground Rubber Applications[128]

Mesh	Application
4 – 40 mesh	Playground surface material, mulch, animal bedding, molds, surface materials (playgrounds, race tracks), carpet padding, rubber products, road enhancement material, manufacture of

[126] *ReCycling USA, Chuck Vollmer & Peter Soriano 26 February 2013, presentation, eCyclingUSA-Tyre-Recycling-Businesses-26-Feb-2013.pdf, accessed June 29, 2013.*
[127] *Recycling Research Institute Scrap Tyre News http://www.scraptyrenews.com/crumb.php, accessed Aug 8, 2013*
[128] *eCycling USA presentation, Chuck Vollmer & Peter Soriano 26 February 2013.*

Mesh	Application
	reclaimed rubber, matting, paste and sealing materials, modified rubber products, road pavement.
40 120 mesh	Rubber plastic materials, rubber products (such as railway and subway ties), brake pads, modified asphalt, solid tyre production.
120 200+ mesh	Textile material coating, special paper coatings, painting materials and additives, special rubber products, medical devices, high level water proofing, materials for military uses.

Ground rubber in rubber compounds

One of the most obvious uses for ground/crumb rubber is as a compound ingredient in tyre manufacturing, introducing an element of recycling into new tyres. Advances in technology and machinery in recent years has led to an improvement in the quality of ground rubber, resulting in an increasing number of manufacturers using this recycled material in their rubber compounds. Using ground/crumb rubber in tyre compounds can achieve substantial savings, as it is cheaper than other compounding materials, without reducing the quality of the tyre. It is mainly used in tyres where speed and high performance are not crucial characteristics e.g. farm tyres. Kurt Reschner's paper on waste tyre recycling[129] also identifies other advantages including:

- Improved degassing during vulcanisation
- Improved mould release
- Reduced cure times leading to increased plant efficiency
- Better mixing properties and improved stability of uncured parts

Crumb rubber may also reduce the cost of producing items, if the crumb rubber is more cost effective than conventional materials. This is largely dependent on the size of the ground rubber industry (and economies of scale), the availability of tyres and the cost of the material/s the crumb is replacing.

Moulded products

Crumb rubber can be used in the production of moulded rubber products. The increase in the supply of crumb rubber in many markets, and the development of the moisture-curing urethane binder, has led to an increase in the range and number of products that can be made with simple compression moulding[130]. This method of binding rubber crumbs is typically used to produce low

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[129] *Kurt Reschner, Scrap Tyre Recycling:A Summary of Prevalent Disposal and Recycling Methods http://www.entyre-engineering.de/Scrap_Tyre_Recycling.pdf, accessed May 20, 2013*

[130] *Kurt Reschner, Scrap Tyre Recycling:A Summary of Prevalent Disposal and Recycling Methods http://www.entyre-engineering.de/Scrap_Tyre_Recycling.pdf, p 14, accessed May 22, 2013.*

tech products in bulk, such as livestock mats, railroad crossings and athletic mats. The use of crumb rubber and a urethane binder reduces the time and cost of manufacturing rubber products. However, these materials are not suitable for making all rubber products – only products that require a moderate level of resistance to abrasion and similar tension strength.

The urethane binder used to cure ground rubber is a type of polyurethane. Polyurethane is made by mixing two or more liquid streams. There are two main components that make up polyurethane; isocyanate and polyol. These are combined with a number of catalysts, surfactants and blowing agents. This mixture may be referred to as a "resin", as many different types of polyurethane are used as binders.

Wet Poured Layers

Crumb rubber can also be used in ground surfacing for playgrounds or athletic facilities, to create a softer surface to reduce the risk of injuries. This is most commonly achieved by mixing moisturecuring urethane with mesh crumb rubber (very fine crumb rubber, which has been forced through mesh in order to create small particles) to create a compound that is poured in a similar way to pavements. This layer is softer than the compressed, moulded mats that are discussed above.

Sprayed Layers

This use of crumb rubber is similar to the wet poured layers. The rubber crumb is combined with urethane binder, and can then be sprayed onto surfaces in order to make them waterproof, elastic, impact absorbing and resistant to vibration and corrosion.

Thermoplastic-Elastomer Compounds

Rubber crumb can also be combined with a thermoplastic binder at high temperature to produce a material that has similar qualities to a thermoplastic compound, in addition to the elasticity of rubber. Thermoplastics are easy to use in injection moulding, and have the potential to be recycled as they can be moulded, and extruded. They also need little as no compounding, with no need for reinforcing or stabilising agents, and can be easily coloured by most dyes. The use of thermoplastic-elastomer compounds consumes less energy than making products from virgin raw materials, and offers more control of the product quality[131]. This material can be used for products such as acoustic insulation in cars, in pallets and at railroad crossings. However, compared to conventional rubber or thermoset, thermoplastic-elastomer compounds have less thermal stability.

Rubber Modified Asphalt

Rubber modified asphalt, also known as rubberized asphalt concrete, is a material used in paving roads. It is made by combining ground rubber from waste tyres with asphalt – producing a binder that is then blended with typical aggregate materials, such as broken or crushed stone. There are two main binders used in rubber modified asphalt; asphalt-rubber and terminal blend.

Asphalt-rubber is made by combining hot asphalt with rubber, in order to react the two together. It is defined as "a blend of paving grade asphalt cement, ground recycled tyres (that is, vulcanized) rubber and other additives, as needed, for use as a binder in pavement construction. The rubber shall be blended and interacted in the hot asphalt cement sufficiently to cause swelling of the rubber

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[131] *Goldenplast s.p.a. http://www.goldenplast.com/thermoplastic-compounds.php, accessed May 23, 2013.*

particles prior to use"[132]. Crumb rubber typically makes up 18-22% of the blend, using rubber that is in the 10-16 mesh range. Other components or additives may be added if specific characteristics are required.

The blending must take place in the field, and requires specialised, mobile equipment. The paving grade asphalt is heated to 190^{0}C (375^0 F) then crumb rubber (at ambient temperature) is mixed into the hot asphalt. During this process, the rubber particles swell, transforming the compound into a gel-like material[133]. The rubber-asphalt is then pumped into a holding tank, which keeps the material at 177^{0}C at least. The material must be kept hot before it is used. Within the tank, the rubber-asphalt will also be agitated, ensuring that it can be poured easily.

Waste tyres serve as a potentially vast resource of durable recycled rubber that exhibits many of the same properties as the oil-based polymers conventionally used as asphalt additive[134]. Rubberised asphalt has a number of advantages. One of the main benefits is that it is cost effective. Generally, rubberised-asphalt does not need to be applied as thickly as conventional materials, cutting down on materials used and costs. Rubberised asphalt also typically has a longer life span (often 50% longer) than regular asphalt or other conventional materials, reducing the rate of replacement[135]. It is also more resistant to rutting, as well as reflective and thermal cracking, minimising maintenance costs. Approximately, 1,500 tyres are used for every lane mile[136] (1.67 kms) of rubberising paving, or approximately 8,000 tyres for a one mile (1.67kms) section of a four-lane highway[137].

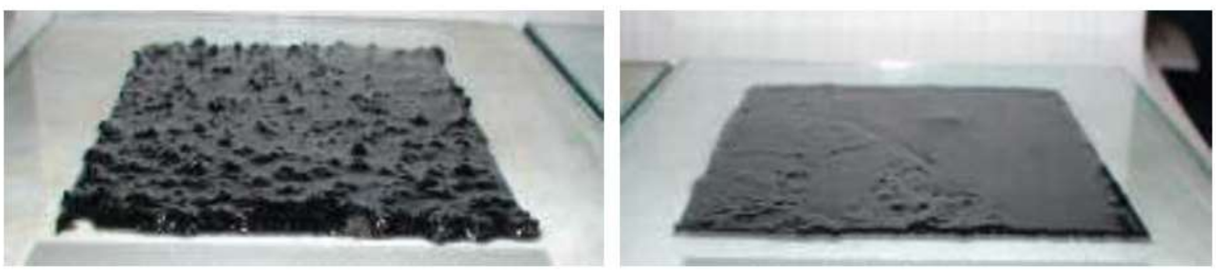

Figure 5.11: Asphalt-Rubber Binder (left) and Terminal Blend Binder (right)

Terminal Blends are binder materials in rubberized asphalt concrete that use finely ground (less than 40 mesh) crumb rubber. It is typically blended at the asphalt refinery, and the component materials are heated over an extended period of time. The main difference between terminal blend and asphalt rubber is the amount of crumb rubber used in the binder (TB less than 10%; AR 15-20%) and the use of specialized mixing equipment for asphalt rubber. In Terminal Blends, the extended heating of the rubber dissolves it into the binder, as seen in **Figure 5.11**. The Terminal Blend binder has a good

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[132] *American Society for Testing and Materials (ASTM) Standard D6114 - http://www.calrecycle.ca.gov/tyres/RAC/, accessed May 24, 2013.*
[133] *George B. Way P.E Asphalt-Rubber Standard Practice Guide http://www.rubberpavements.org/Library_Information/AR_Std_Practice_Guide_20111221.pdf, accessed April 22, 2013.*
[134] *Rubberized Asphalt Foundation http://www.ra-foundation.org/faq/, accessed June 26, 2013.*
[135] *California Department of Resources Recycling and Recovery (CalRecycle) http://www.calrecycle.ca.gov/tyres/RAC/, accessed May 7, 2013.*
[136] *Arizona Department of Transportation http://www.azdot.gov/quietroads/what_is_rubberized_asphalt.as, accessed June 26, 2013.*
[137] *Rubberized Asphalt Foundation http://www.ra-foundation.org/faq/, accessed June 26, 2013.*

storage life, with no separation due to the process that integrates the rubber into the asphalt, and it is manufactured similar to polymer modified asphalt[138].

5.4.1.3 Environmental and Health Impacts of Ground Rubber

The main concerns about the use of ground/crumb rubber, particularly in playgrounds or sport fields, are the potential for health and environmental impacts. **Beyond the emissions and energy used in the ground rubber production process, issues with crumb rubber include:**

- **The potential release of chemicals into surface and ground water – and their associated environmental impacts**
- **The release of chemicals into the air – and their associated public health and environmental Impacts**
- **Heat retention in ground rubber surfaces and associated illnesses e.g. heat stress**

These issues relate mainly to ground rubber used in surfacing, as such applications come into contact with people and the surrounding environment. Crumb rubber contains numerous toxic and potentially carcinogenic compounds including polyaromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), zinc, iron, manganese, nickel, PCB, copper, mercury, lead, cadmium, volatile nitrosamines, benzothiazole, isononylphenol, and more. These chemicals are of concern for various reasons. Many of the metals have been associated with damage to the nervous system, as well as irritation of the eyes, nose, and throat. PAHs have been identified as a cancer risk and as causing substantial organ damage. VOCs have been implicated as a cause of organ damage and in less severe consequences such as nausea, headaches, and sensory organ irritation[139]. However, the presence of these substances is only a problematic if there is sufficient human or environmental exposure to toxic elements – via direct contact or the contamination of surrounding areas -- to elevate levels in the human body or in ecosystems to unsafe concentrations.

There have been a number of studies into the potentially adverse health and environmental impacts of using crumb rubber. A study done by University of California, Berkley in 2010 concluded: "A review of existing literature points to the relative safety of crumb rubber fill playground and athletic field surfaces. Generally, these surfaces, though containing numerous elements potentially toxic to humans, do not provide the opportunity in ordinary circumstances for exposure at levels that are actually dangerous. Numerous studies have been carried out on this material and have addressed numerous different aspects of the issue. For the most part, the studies have vindicated defenders of crumb rubber, identifying it as a safe, cost-effective, and responsible use for tyre rubber". The study included independent product tests on cryogenic crumb rubber for synthetic turf, concluding it was safe for use in sports fields.

A New York State Department of Health Review (revised in 2012)[140] assessed public concerns relating to the risks of heat stress, injury, infection, latex (natural rubber) allergies and chemical

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[138] *Shakir Shatnawi, COMPARISONS OF RUBBERIZED ASPHALT BINDERS:Asphalt-Rubber and Terminal Blend*

[139] *"Review of the Impacts of Crumb Rubber in Artificial Turf Applications," Rachel Simon, University of California, Berkeley. February 2010*

[140] *New York Statement Department of Health http://www.health.ny.gov/environmental/outdoors/synthetic_turf/crumb-rubber_infilled/fact_sheet.htm, accessed June 26, 2013*

exposure. It concluded that crumb rubber in filled synthetic turf fields absorbs heat, resulting in surface temperatures that are much higher than the temperatures of the surrounding air. Such temperatures pose a risk of discomfort and heat stress and warranted a warning that users should stay hydrated and seek shade to relieve heat stress. No increased risk, when compared to natural grass fields, was found for injury or infection, or any significant risk of latex allergies. The review concluded that -- based on the available information -- chemical exposure from crumb rubber in synthetic turf does not pose a public health hazard. However, research is continuing and concerned groups continue to collate various studies that suggest the use of crumb rubber for various purposes can pose a health risk, such as exposure to lead in playgrounds if crumb rubber is gradually ground down into dust later picked up on children's clothes and the leaching of zinc into the environment[141].

For example, in a 2010 study[142], ten organic compounds in the vapour phase were identified in the head space (that is, the space between the surface and the typical head height of a person potentially breathing in the vapours) of all tested samples of commercial crumb rubber materials used in sports fields. Volatile benzothiazole (BT) was detected at the highest level in all commercial CRM samples, in the range 8.2–69 ng g^{-1} CRM. Other volatile PAHs and antioxidants were also quantified in the vapour phase. A decrease of volatile compounds was noted in the headspace over CRM samples from 2-years-old fields when compared with CRM at installation. Zinc was the most abundant element in the acidified leachate (4.4–260 µg g^{-1}) and leachable BT was detected in the range 0.6–5.4 µg g^{-1}.

A 2012 study[143], noting that tyres contain approximately 1-2% zinc by weight, assessed 14 studies of zinc leaching in the published literature and then assessed the impact of crumb rubber size on the dynamics of such leaching. Results indicate that zinc leaching increases with smaller crumbs of rubber and longer exposure times and that leaching occurs with an initial pulse of elevated zinc concentration followed by more constant leaching rate.

Consideration of off gases and leachates are important in assessing both health and environmental impacts of crumb rubber materials and take into account both direct human contact over time and the run-off of leachates into the surrounding areas. One other consideration is the type of binder used[144]. In terms of safety, fully reacted polyurethane is chemically inert, and there is no exposure limits associated with it. However, polyurethane polymer is combustible, and when ignited it can produce carbon monoxide, as well as traces of nitrogen oxides and hydrogen cyanide[145].

5.4.1.4 Investment and Operating Costs

The processing of waste tyres to produce crumb rubber requires:
(1) an initial investment in technology;
(2) a large suitable site
(3) ongoing operational and maintenance costs.

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141 *Guive Mirfendereski, PhD, JD http://www.synturf.org/crumbrubber.html and The Crumb Rubber under the new playground http://www.lifeaftercrumbrubber.blogspot.com.au/, accessed, June 26, 2013*

142 *Xiaolin Li, William Berger, Craig Musante, MaryJane Incorvia Mattina, "Characterization of substances released from crumb rubber material used on artificial turf fields" [Chemosphere 80 (3) (2010) 279–285]*

143 *Zinc Leaching from Tyre Crumb Rubber, Emily P. Rhodes , Zhiyong Ren , and David C. Mays, Environ. Sci. Technol., 2012, 46 (23), pp 12856–12863*

144 *G. Avar, Polyurethanes (PU), Kunststoffe international 10/2008, 123-127)*

145 *G. Avar, Polyurethanes (PU), Kunststoffe international 10/2008, 123-127)*

The economic viability of any operation depends on a number of key factors, which will vary depending on local conditions. **Generally, current shredding and grinding technology requires relatively high capital investment and maintenance costs, is energy intensive and depends on other costs like the transportation of waste tyres to the plant. Processing equipment and systems are designed to cope with high volumes of waste tyres and profitability often depends on being able to maintain a high rate of throughput[146].**

Generally cryogenic processing is the more economical option if a fine, mesh rubber powder is required. If coarser rubber crumbs are suitable, ambient rubber processing is more economically viable.

For cryogenic processing less energy and less machinery is needed in comparison to ambient size reduction. It is also much easier to separate the steel and fibre from the rubber at low temperatures. However, the cost of liquid nitrogen can make this technique more expensive.

The main costs associated ambient processing are the costs of equipment and the energy used in processing. **Table 5.3** below shows a breakdown of the energy used in producing ground rubber, as compared to some other options.

Table 5.3: Comparing Energy Usage in Different Tyre-related Processes[147]

Process	Energy needed (kWh/kg)
Manufacture a tyre	32.0
Produce tyre rubber compound	25.0
Energy release from incineration of scrap tyres	9.0
Energy consumed in grinding waste tyres into crumb rubber (particle size between 0.5 – 1.5mm)	1.2

There's also a table comparing the ambient and cryogenic processing in **Table 5.4**.

Table 5.4: Comparing Ambient and Cryogenic Processing[148]

Parameter	Ambient	Cryogenic
Operating temperature	Ambient, maximum of 120ºC	Below – 80ºC
Size reduction principle	Cutting, shearing, tearing	Breaking cryogenically embrittled rubber pieces
Particle morphology	Spongy and rough, high specific surface	Even and smooth, low specific surface
Particle size distribution	Relatively narrow particle size distribution, only limited size reduction per grinding step	Wide range particle distribution (ranging from 100 mm to 0.2 mm) in just one processing step
Maintenance cost	Higher	Lower

146 SBIR Phase I: Improved Technology for Recycling Tyres, Rubber Recovery Solutions, LLC http://center.ncet2.org/index.php?option=com_patents&controller=awards&tmpl=component&view=awards&layout=award&frame=awards&user=29700&id=50993_nsf

147 Specific energy values. Sources: W. Dierks: Incorporating the Use of Recycled Rubber, Robert Snyder: Scrap Tyre Disposal and Reuse, compilation by Kurt Reschner in http://www.entyreengineering.de/Scrap_Tyre_Recycling.pdf, as above.

148 Rubber Recovery Solutions, LLC , SBIR Phase I: Improved Technology for Recycling Tyres http://www.irevna.com/pdf/Industry%20report.pdf, pg 22, accessed July 2, 2013.

Parameter	Ambient	Cryogenic
Electricity consumption	Higher	Lower
Liquid nitrogen consumption	-	0.5 – 1.0 kg liquid nitrogen per kg of tyre

The US Rubber Manufacturers Association provides some general guidelines. These include:

- **Initial considerations: investigate the supply of waste tyres in your area. Are there enough tyres to ensure supply and to offset investment costs?**
- **Market analysis: What tyre derived products can be produced from your rubber crumb and what prices can you achieve?**
- **Transport: Do you have access to suitable, cost effective transport to get waste tyres to the processing plant and to deliver your product?**
- **Land Use planning: Do you have a site suitable for large scale equipment (approx 2 hectares), tyre stockpiles, vehicles and administrative offices and is this land zoned for such use?**
- **Capital investment and ongoing costs: Calculate purchase prices of processing equipment, plus ongoing maintenance costs[149].**

The multi-national supplier of shredding technology, SSI[150] (Shredding Systems Inc) recommends a supply of at least one million tyres within a 150 mile (250km) radius is required to start up a viable business.

Tipping fees: Many countries pay waste tyre processors to take tyres and so divert them away from landfill. As a rule of thumb, according to SSI, these tipping fees will roughly cover the overhead costs of processing and profits will be derived from sales. Without a fee to take waste tyres, businesses are unlikely to be viable in mature markets such as the US.

In 2013, the international purchase price of tyre shredding machines to make crumb rubber began at approximately USD500K[151]. SSI estimated operating costs on top of initial capital investment of USD12 to USD25 per ton of waste tyres to cover power required, maintenance, spare parts, labour etc. The company noted that as start-up operations is unpredictable many processors are not profitable until they have been running for 9-12 months, meaning new businesses require sufficient funding to cover this period. The US-based multinational shredding systems supplier, Global Recycling Equipment, lists (2013 quotation) the components of a system required to reduce waste tyres to 10 mesh, while removing metal and fabric waste. As processing required multiple stages, this includes four shredders, two raspers and four granulator raspers, plus all intermediate equipment linking the steps. A 2,000 kg system is listed at USD 1.26 million and a 4,000kg system at 1.733 excluding shipment from China.

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[149] From Considerations for Starting a Scrap Tyre Company, A Blueprint for Planning a Business Strategy, published by the RMA, accessed Aug 7, 2013.
[150] SSI Shredding Systems, Inc. http://www.ssiworld.com/ accessed Aug 7, 2013
[151] SSI Shredding Systems, Inc. http://www.ssiworld.com/applications/applications3-en.htm, accessed Aug 7, 2013.

The not-for-profit South African waste tyre recycler, SATRP, estimates the costs of establishing a waste tyre processing facility at between USD2 million and USD25 million[152]. Most shredder systems originated in the US or Europe, but many are now produced in China. Purchase and operational costs may differ depending on shipping cost and local economic conditions.

5.4.1.5 Institutional and Regulatory Requirements

Waste tyres are not considered a hazardous waste but as there are numerous issues associated with their collection and process, and as there are a wide range of local, state and national environmental, land use, business and financial regulations that may impact a tyre processing business, a full regulatory check is required.

Shredding machinery of any type is potentially dangerous and local regulations may include specific guidelines for ensuring worker safety and the fencing of the site.

The Technical Guidelines for handling waste tyres published by Secretariat of the Basel Convention in 2011[153] state that although tyre components have no hazardous properties and are therefore not intrinsically hazardous, if improperly managed and disposed of, they may pose risks to public health and the environment. Consequently, waste tyres come under various local and national environmental regulations in many jurisdictions and processors may be required to meet various requirements to demonstrate how waste tyres will be collected, recycled and stored.

Due the known fire risk there are likely to be limits to the volume of tyres stored for processing at any one time. According to the US RMA a waste tyre business will come under the purview of environmental regulation and, depending on the market area, could include a series of regulations from local, state and/or federal agencies. Depending on the market, permits and/or registrations may be required for; solid waste (recycling), tyre transport, waste tyre storage, waste water discharge, public health, fire. As processing equipment is potentially dangerous to employees, regulations may similarly cover health and safety.

5.4.1.6 Pros and Cons with respect to Developing Countries

Ground rubber recovered from waste tyres is a low-cost material with many of the performance characteristics and properties of virgin rubber, making it a potentially attractive resource for developing economies. However, the production of ground rubber involves multiple steps – and therefore a series of shredders and associated equipment in size reduction. This requires **substantial capital investment in processing technology, equipment, product testing, distribution, and marketing and industry reports suggests costs and timeframes are often underestimated in establishing ground rubber plants.** Incorporating recovered ground rubber into existing formulations to reduce the use of more expensive virgin rubber can pose similar challenges, especially in process optimization and product testing[154]. These issues are critical if access to capital is limited. Likewise, **ground rubber processing requires reliable power supplies and for a local skills base to ensure imported shredding equipment can be effectively operated, maintained**

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152 *SATRP Company* *http://www.rubbersa.com/processors.html*
153 *Revised technical guidelines for the environmentally sound management of used and waste pneumatic tyres,* UNEP/CHW.10/6/Add.1/Rev.1
154 *Scrap Tyres: Handbook on Recycling Applications and Management for the U.S. and Mexico, December 2010*

and repaired. Blunt knives and blades greatly, for example, dramatically reduce machine performance and eventually cause equipment failure[155].

The viability of any ground rubber processing business depends on demand for its product and the price the market is willing to pay. Ground and crumb rubber is used in manufacturing as a substitute for other virgin materials, including rubber. **Unless local industries exist with the potential and skills to produce viable new products using recovered ground rubber there will be little market demand and given the low value of recovered ground rubber export opportunities are currently limited.** In addition, many developing countries have established informal waste sectors and high rates of reusing or reclaiming materials from waste tyres, based on low labour costs and the use of simple hand tools[156]. This may mean there is insufficient economic incentive to move to mechanised tyre recycling.

Example 1:
In their 2010 "Scrap Tyre Handbook" for the US and Mexico, the US EPA notes that although "tremendous financial, technical, and creative resources have been devoted to developing tyre processing technology to make ground rubber and applications to use it" results have been mixed. **The US Rubber Manufacturers Association estimates that even after more than 20 years of concerted effort only 17 per cent of the waste tyres generated in the US in 2007 were processed into ground rubber, despite the availability of range of creative application in the mature US market.** Since these applications have developed slowly and do not consume large enough volumes of waste tyres, the EPA recommends that ground rubber processing be developed in tandem with lower cost applications for waste tyres such as energy and civil engineering. This advice is not specific to developing countries, but is aimed at new markets in Mexico, suggesting similar issues for new waste tyre businesses elsewhere.

5.4.2 Metal Recovery Technologies

Tyres contain between approximately 15% (cars) to 27% steel (truck tyres) by weight. This equates to approximately 1.2 to 1.4 KGs of steel belt and bead wire in a passenger car tyre, which, when recovered, is a marketable resource for use in world's mature metal recycling industry. Known as tyre wire scrap, this recovered material, is a malleable high tensile carbon steel. The typical composition for steel belts and bead wire includes: carbon, manganese, silicon, phosphorus, sulfur and traces of copper, chromium and nickel. Wire coating is typically a mix of copper and zinc or a mix of brass and tin[157]. The metal recovered is usually processed into specification grade products used by steel mills for the production of new steel[158]. Scrap steel is a valuable material and is widely recycled back into the production of new steel: electric arc furnace steelmaking utilizes up to 100 per cent scrap steel, producing 100% recycled new steel, and oxygen furnace steelmaking can use up to 30 per cent scrap steel with iron ore and limestone to manufacture new steel. Steel is the world's most recycled material, with a post-consumer recycling rate of about 80 per cent. Steel is also one of the few magnetic materials meaning it can be recovered relatively easily from waste streams[159].

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155 *Scrap tyres to crumb rubber: feasibility analysis for processing facilities, Nongnard Sunthonpagasit, Michael R. Duffey, The George Washington University, April 2003.*
156 *Recycling Rubber http://www.seas.columbia.edu/earth/RRC/documents/recycling_rubber.pdf, accessed Aug 5, 2013.*
157 *Considerations for Starting a Scrap Tyre Company, A Blueprint for Planning a Business Strategy http://www.rma.org/download/scrap-tyres/general/GEN-060-Considerations%20for% 20Starting%20a%20Scrap%20Tyre%20Company%20A%20Blueprint%20for%20Planning%20a%20Business%20Strategy.pdf*
158 *Institute of Scrap Recycling Industries (ISRI), Inc., Yearbook 2012, pg 44.*
159 *World Steel Association, Steel and raw materials, http://www.worldsteel.org/dms/internetDocumentList/fact-sheets/Fact-sheet_Rawmaterials2011/*

5.4.2.1 Process Description

As described in previous sections detailing shredding, crumbing and grinding, the metal in waste tyres is either recovered before processing or magnetically extracted during processing. As metal is integrated into the tyre for durability separation requires work and energy; which can be done mechanically or manually, both of which are either energy or labour intensive, or both. **In larger automated tyre shredding operations metal recovery is incorporated into process.** By contrast, in developing countries with large informal waste collection sectors metal will likely be removed by hand prior to the recovery of rubber.

a) Debeading

The tyre bead usually consists of multiple strands of high tensile, brass-plated steel, coated with rubber and formed into hoops to seal the tyre against the rim and provide hoop tension to prevent air leakage[160]. It acts as a load transfer mechanism between the tyre and the rim. The other source of steel is the belt wire, comprised of cords of thin, high tensile wire[161]. This metal, particularly the bead, presents a problem for the cutting tools of shredding and granulating machinery because it means that they wear relatively quickly and so have to be regularly reground and replaced. Debeading significantly reduces wear and tear on the primary shredder and consecutive size reduction machines. While the steel beads represents only relatively small component of a waste tyre by weight, they are responsible for about 70% of the wear and tear in the initial shred as well as in the consecutive grinding machines[162]. If processing continues with blunt tools, equipment can be seriously damaged. This wear, repair and replacement cycle is costly to the operator, as is the downtime associated with each change of tools. Also, once the tyre with its rubber and steel content is shredded, it is still necessary to remove the steel. This means that additional processing is needed (see below).

To reduce the amount of steel in the tyre shred, one option is to debead tyres before the scrap tyre is passed to the shredding and granulating machinery. There are various methods for doing this and equipment of different levels of mechanization and automation is available, from debeaders which are loaded manually and which use single or double hooks to literally tear the beading out of the tyre, to fully automatic systems which are fed with tyres, and which remotely move and position the tyres in line with the hook/s for separation, like as shown in **Figure 5.12**[163]. Other systems cut out the strip of tyres containing the bead. However this leaves a significant amount of rubber around the steel, which must then be removed to render the scrap steel suitable for sale and recycling. Debeading prior to processing usually add an additional separate step prior to processing as there is no easy "conveyor belt" from debeading into shredding. Once tyres have been debeaded they normally need to be loaded into the shredding systems.

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document/Fact%20sheet_Raw%20materials2011.pdf, accessed Aug 6, 2013

[160] *Walter.H.Waddell, Pneumatic Tyre Compounding,http://www.rma.org/download/scraptyres/processing/PRO-006%20-%20Pneumatic%20Tyre%235B.pdf, accessed Aug 5, 2013.*

[161] *Debeading scrap tyres, Patent, WO 2005070639 A1 , Tom Hogg & John Stewart, 2005. Description.*

[162] *Kurt Reschner, Scrap Tyre Recycling , A Summary of Prevalent Disposal and Recycling Methods http://www.entyre-engineering.de/Scrap_Tyre_Recycling.pdf, accessed Aug 2, 2013.*

[163] *Debeading scrap tyres, Patent, WO 2005070639 A1 , Tom Hogg & John Stewart, 2005. Description.*

Figure 5.12: Automated Debeading System, AAA Engineering, Ontario, Canada

In developing economies the recovery of metal from waste tyres is often carried out manually, as shown in **Figure 5.13**. In most small-scale applications in developing countries, waste tyres are initially cut by hand with very sharp knives. First the two sidewalls are removed, and the tread is torn from the tyre, then the remaining rubber is cut into pieces. The resulting blocks, chunks, strips or pieces of rubber are then further shredded into smaller pieces or used in the production of new products. The side walls, which contain the beads, are burnt to remove the steel from the rubber. This poses a risk to the environment and health locally as tyre smoke from tyre fires contains noxious chemicals and there is potential for toxic run off in rain[164].

Figure 5.13: Manual Separation of the Tread from the Sidewalls, Karachi, Pakistan © PCSIR – WASTE (left) Manually-loaded tyre debeader manufactured in Jiangsu China, Careddi Technology Co., Ltd.(right)

b) Magnetic removal

Other processing equipment operates without debeading, but incorporate metal removal into the shredding and subsequent size reduction processing. For example, in one hi-tech operation in Jeddah, Saudi Arabia[165], multiple mechanical shredding stages are utilized to process

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[164] RUBBER WASTE, *Options for Small-scale Resource Recovery, Urban Solid Waste Series 3, WARENproject, http://www.bvsde.paho.org/bvsacd/cd48/rubber-waste.pdf, accessed Aug 11, 2013.*

[165] *Process description source: Tyre recycling is no news in the Emirates, Sharjah National Crumb Rubber Industries http://www.eldan-recycling.com/content/tyre-recycling-no-news-emirates, accessed Aug 11, 2013.*

whole car and truck tyres. Initially, tyres are shredded to approx. 50-300 mm, this shredded rubber then enters the first granulation stage at which they are reduced to 12 mm. The rubber chips and steel are moved past an Over band Magnet (a large magnet suspended above the mix on the conveyor belt as shown in **Figure 5.14**) which removes 90-98% of the metal from the mix.

Figure 5.14: Overband Magnets – These are Used in the Initial Shredding Process to Separating Steel from Rubber

As shown in **Figure 5.15**, the steel is diverted to one side. The chips are sent to fine granulators for further size reduction. The material is then run past Drum Magnets that removes the remaining steel component (1-10%) in both the first and second fine grinding processes.

Figure 5.15: Drum Magnet and Metal Separated Magnetically and Baled[166]

Major specifications include:

1. Input/Output capacity (Size in mm)
2. Separation Efficiency (%)
3. Power Requirement
4. Area Requirement

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[166] *EuroRec Srl: http://eurorec.en.ec21.com/Steel_Tyre_Wire_Scrap--2641515_2641516.html*

5.4.2.2 Products and applications for recovered metal

Scrap steel is a globally traded product and useful in all markets for the production of new steel.

5.4.2.3 Environmental and health impacts of recovered

Scrap steel is a stable, useful and valuable resource. Its removal from waste tyres poses no direct environmental or health threat. However, there are health and safety considerations for workers loading tyres into machinery and in handling steel wire and for workers using extremely sharp hand tools. The most detrimental environmental and health impacts on communities are created through the recovery of steel by cutting off the side walls of tyres and liberating the metal by burning off the rubber. As detailed in Chapter 2 burning tyres generates toxic smoke and fumes and cause environmental contamination through residue left after the fire has burnt out.

5.4.2.4 Investment and operating costs

The recovery of metal from tyres can be achieved manually in developing nations requiring little investment or ongoing cost beyond labor and hand tools. Alternatively, it can be achieved through the use of relatively simple machinery or very sophisticated automated systems requiring substantial capital investment. **As metal recovery is usually a secondary process in the shredding of tyres or the liberation of rubber for reuse, investment and operating costs will be directly linked to the primary purposes for the recycling of waste tyres.**

The scrap steel market shifts with the business cycle. As waste tyre-derived steel is more difficult to recover than many other types of post-consumer scrap steel due to the need to separate it from rubber, it is most economically attractive as a recovered material at times when global prices for scrap steel are high. The resale of scrap steel recovered from waste tyres also depends on its 'cleanliness' – which refers to the amount of rubber contamination and whether a waste tyre processor is producing sufficient volume for steel furnaces. As the primary use for scrap steel is the manufacture of new steel product, too much residual rubber will cause problematic sulfur emissions in steel making[167]. **A Canadian study[168] published in 2005 reported that although the steel used in tyre production is of very high quality, steel recovered from waste tyres is currently of inconsistent quality due to varying levels of rubber contamination and so tends to lose market share at times when the scrap market is oversupplied.** Another problem for the sale of tyre derived scrap steel is lack of uniformity of the resource due to alloying (bronze or brass) and different extraction techniques including chopping and shredding. Metal extracted by melting the rubber away around it is close to 99.9% pure, but other techniques result in more contamination. **Recovered steel should have a purity of at least 97 per cent to be an attractive resource for the steel recycling industry and can be readily sold**[169].

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[167] *University of California Riverside, Technology Evaluation and Economic Analysis of Waste Tyre Pyrolysis, Gasification, and Liquefaction* *http://www.calrecycle.ca.gov/publications/Documents/Tyres%5C62006004.pdf*
[168] *CANMET Materials Technology Laboratory, Scrap Tyre Recycling in Canada, 2005.*
[169] *PALLMANN Industries, Inc. Machines and Systems for the Recycling of Scrap Tyres* *http://www.pallmannindustries.com/Recycling%20of%20Tyres.htm, accessed Aug 5, 2013*

Demand is also closely linked to the proximity of a steel mill requiring scrap steel as transport costs erode profitability. In some markets tyre derived steel is not in great demand as high quality postconsumer steel is easy to access, however, demand is generally high in most areas of Asia and some parts of the US[170]. All these factors need to be taken into account when assessing the potential viability of tyre derived scrap steel.

5.4.2.5 Institutional and regulatory requirements

Institutional and regulatory requirements are directly linked to the process by which metal is extracted from waste tyres; **if extraction is part of a shredding or grinding operation metal recovery will be covered by the same local, state or national regulations which are relevant for that industry. The sale of scrap steel may be subject to regulations on export.** Due to high demand for scrap steel in the rapidly growing Chinese and Indian economies some national governments of developing countries have banned the export of scrap steel to ensure sufficient supplies for local steel mills[171] [172].

5.4.2.6 Pros and cons with respect to developing countries

There is good demand for metal recovered from waste tyres and rubber in developing economies. While more industrialized economies may extract metal as a by-product of shredding or grinding to create crumb rubber, TDA or tyre derived fuel, many developing economies utilise waste tyre rubber for the production of other products.

For example, one factory in Indonesia recently installed a debeader as the heart of its operation as shown in **Figure 5.16**. As reclaimed rubber sells for about 25% of the cost of new rubber it is in demand locally, in this case by the footwear industry. Rather than debeading using old manual equipment it has upgraded to a Chinese built mechanical debeader, but continues to sell pieces of rubber cut directly from the remainder of the tyres into the footwear industry[173].

Figure 5.16: Debeader and Cut Rubber for the Footwear Industry, Surabaya, Indonesia[174]

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[170] *University of California Riverside, Technology Evaluation and Economic Analysis of Waste Tyre Pyrolysis, Gasification, and Liquefaction* *http://www.calrecycle.ca.gov/publications/Documents/Tyres%5C62006004.pdf, accessed Aug 6, 2013.*

[171] *Ghana: Gov Won't Lift Scrap Metal Exports Ban – Iddrisu* *http://allafrica.com/stories/201305171010.html?page=2, access Aug 6, 2013.*

[172] *Masahudu Ankiilu Kunateh, Ghana: Gov Won't Lift Scrap Metal Exports Ban - Iddrisu* *http://allafrica.com/stories/201305171010.html?page=2*

[173] *Leshan Tyrupro Import & Export Co.,Ltd, Surabaya, Indonesia (Production line modificaton) http://www.tyrerecycleline.com/info-221.html, accessed Aug 11, 2013.*

[174] *EuroRec Srl http://eurorec.en.ec21.com/Steel_Tyre_Wire_Scrap--2641515_2641516.html*

5.4.3 Technologies for recovery of devulcanised rubber

Devulcanization is the process in which vulcanization, a chemical process that converts rubber into a more durable form, is reversed. This involves reversing the crosslink bridges formed by polymers during vulcanization. Vulcanization was developed in the 19th century and involves adding sulfur, heat and carbon to the rubber "curing" it so that it is structurally sound, able to hold its shape and withstand temperature fluctuations. When rubber is devulcanized, the crosslink polymer bridges are severed, completely or partially.

A truly devulcanized elastomer can be characterized as an elastomer that is as pliable and as processable as its virgin counterpart, maintaining as much physical and structural integrity as possible. However, current processes do not yet achieve this ideal. Generally, the quality of devulcanised rubber is still inferior to new rubber as the reclaiming process not only severs the sulfur-crosslinks but the main polymer chains are also broken[175].

5.4.3.1 Process description

Step 1: The process of devulcanization can generally be broken down into two distinct steps. The first of these is size reduction, which must be carried out before the devulcanization process. This can be achieved using method previously discussed, such as ambient or cryogenic grinding. The use of small, finely sized rubber particles is common to nearly all devulcanization processes. Metal should also be extracted[176]. This reduces the size of the waste so that it can be easily fed into a system that breaks the chemical bonds.

Step 2: The second step is the actual devulcanization process, or the breaking of the chemical bonds (primarily sulfur bonds). De-vulcanization aims to reverse vulcanization as far as possible without damaging the polymer. In sulfur vulcanization, formation of a rubber network by both carbon-sulfur bonds (C–S) and sulfur-sulfur bonds (S–S) takes place, therefore only these bonds should be broken during de-vulcanization. To create a high performance reclaimed product, de-vulcanization should literally be the reverse process of vulcanization. In reality, extensive polymer scission and a partial re-combination of these links occurs, resulting in highly branched chain segments that differ greatly from the virgin rubber.

Methods of devulcanization include:

a) Chemical Devulcanization

Chemicals have been used as part of the devulcanization process since the 1960s. Generally, chemical devulcanization processes (shown in **Figure 5.17**) involves mixing the ground rubber particles with chemical reactants in a temperature and pressure controlled mixer. Once the reaction time has elapsed, and the majority of bonds have been broken, the contents of the mixer are rinsed, filtered and dried to remove any remaining unwanted chemical components. The products can then be packaged or otherwise prepared for sale.

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[175] *DE-VULCANIZATION AND RE-UTILIZATION, OF PASSENGER CAR TYRES, Doctoral thesis, Sitisaiyidah Saiwari, University of Twente, 2013, http://doc.utwente.nl/86036/1/thesis_S_Saiwari.pdf*

[176] *Scrap Tyre Recycling in Canada, CANMET, Materials Technology Laboratory, 2005.*

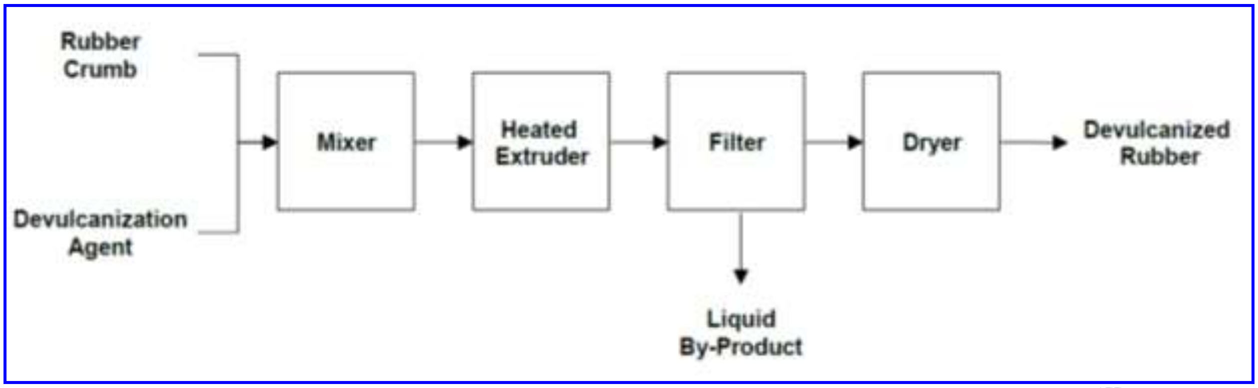

Figure 5.17: Schematic Diagram of a Chemical Devulcanization System[177]

There are a number of different chemical agents that can be used in the devulcanization process. These include **petroleum-based solvents** (e.g. toluene), thiol-amine reagents, hydroxide, disulphide compounds or chlorinated hydrocarbons[178]. Depending on the **chemical agent, a catalyst** may also be required to garner the desired reactions. For example, POLYMERight Inc., **California, is developing a process of reclaiming rubber where a measured amount of the devulcanizing chemical agent (DB-26) is added to the mixer and heated with the ground rubber. After the necessary exposure time, the slurry is then forced through an extruder at temperature between 500° and 600°F (260° and 315°C)**[179]**. The rubber is then cooled, and readied for sale.**

b) Ultrasonic devulcanization

Ultrasonic devulcanization processes were first studied in 1973 in a batch process by immersing bulky rubber articles in a liquid and then applying ultrasonic radiation in the range of 20 kHz59. The similar method was patented in 1987. A small piece of vulcanized rubber was devulcanized using 50 kHz ultrasonic waves. It was claimed that breakdown of C-S and S-S bonds occurred in this process, but that C-C bonds remained intact. The properties of the revulcanized rubber were reported to be very similar to those of the original vulcanizates[180].

Ultrasonic devulcanization involves the use of a devulcanization system, consisting of extrusion and ultrasonic components, as shown in **Figure 5.18**. In this type of devulcanization, the ground rubber is loaded into a hopper, and fed into an extruder. The extruder pushes and pulls the rubber, heating it and causing it to soften. The rubber is then transported through the extruder cavity, where it is exposed to ultrasonic energy. **The combination of heat, pressure and mechanical mastication acts to devulcanized the rubber**[181]. After passing through the extruder, the rubber goes through a cooling bath and is then dried.

[177] *CalRecovery, Inc. (2004). Evaluation of Waste Tyre Devulcanization Technologies. CalRecovery, Inc., California*
[178] *CalRecovery, Inc. (2004). Evaluation of Waste Tyre Devulcanization Technologies. CalRecovery, Inc., California*
[179] *CalRecovery, Inc. (2004). Evaluation of Waste Tyre Devulcanization Technologies. CalRecovery, Inc., California*
[180] *Devulcanization and reutilization of passenger car tyres, Doctoral thesis, Sitisaiyidah Saiwari, University of Twente, 2013, http://doc.utwente.nl/86036/1/thesis_S_Saiwari.pdf*
[181] *CalRecovery, Inc. (2004). Evaluation of Waste Tyre Devulcanization Technologies. CalRecovery, Inc., California*

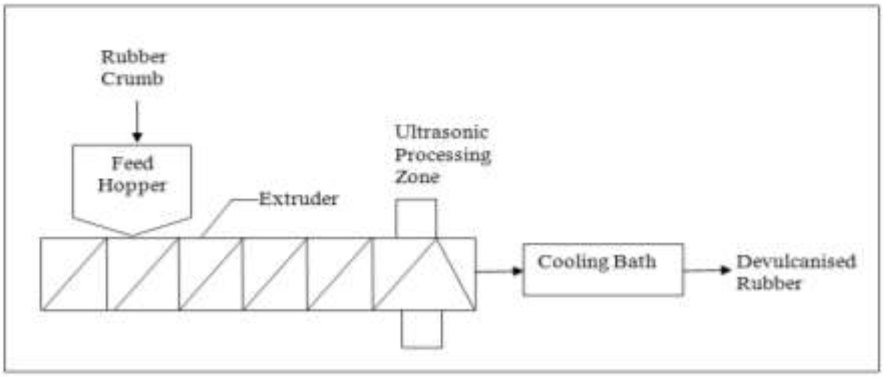

Figure 5.18: Schematic Diagram of an Ultrasonic Devulcanization System[182], [183]

c) *Microwave devulcanization*[184]

In the microwave technique, a controlled amount of microwave energy is used to cleave the bonds in a rubber vulcanizate network. The rubber to be used in this process must be polar enough to absorb energy at a rate sufficient to generate the heat necessary to cut down the network structure. Microwave energy causes molecular motion in rubber molecules creating heat and thus raising the temperature of the material resulting in bond scission on the basis of the relative bond energies of C-C, C-S, and S-S bonds. In theory, scission of the S-S and C-S crosslinks should occur first before CC scission, according to their bond energies. However, the process is difficult to control due to the fast temperature increase in the microwave unit. Therefore, a cooling unit following the reclaiming step is essential. **Figure 5.19** shows the process diagram of a microwave process.

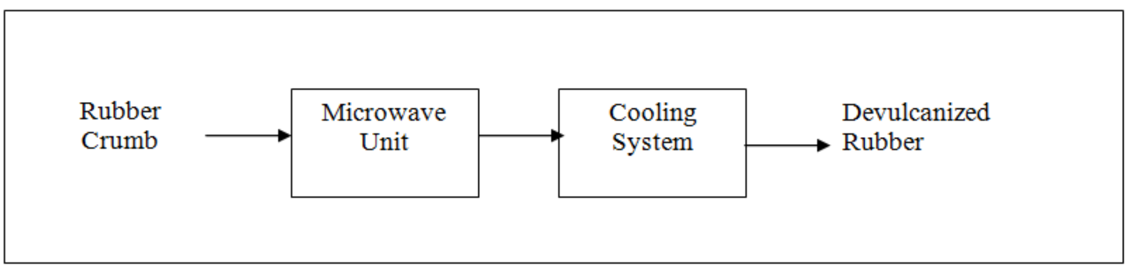

Figure 5.19: Schematic Diagram of a Microwave Devulcanization System[185]

While this is significantly faster than other devulcanizing processes, **the microwave process is only effective on a small percentage of waste tyres (less than 5%).** The best use for this form of devulcanization is with compounds containing mainly polar rubber, such as EPDM (ethylene propylene diene monomer (M-class) rubber) hose.

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[182] *CalRecovery, Inc. (2004). Evaluation of Waste Tyre Devulcanization Technologies. CalRecovery, Inc., California*
[183] *Saiwari, 2013*
[184] *DE-VULCANIZATION AND RE-UTILIZATION, OF PASSENGER CAR TYRES, Doctoral thesis, Sitisaiyidah Saiwari, University of Twente, 2013, http://doc.utwente.nl/86036/1/thesis_S_Saiwari.pdf*
[185] *Saiwari, 2013*

d) Microbial devulcanization

Thiobacillus-bacteria are able to oxidise the sulfur in polysulfonic bonds to sulphate. This reaction is limited to a surface layer of the rubber with a thickness of less than 1 µm and the oxidation takes several weeks. The thiophilic bacteria Sulfolobus Acidocaldarius is able to split carbonsulfur bonds in a stepwise oxidation reaction of the carbon-bound sulfur into a sulfoxide, a sulfone and finally to a sulphate. The disadvantage of these processes is the low devulcanization rate. According to 2011 research into the state of devulcanization technologies, these types of biological devulcanization processes are exclusively or primarily limited to the surface layers of the elastomers which may explain the overall low rates of desulfurization based on total mass processed[186]. This is, therefore, currently not an option for achieving the kind of bulk devulcanization required for recovering materials from waste tyres.

5.4.3.2 Products and applications for devulcanised rubber

Devulcanised rubber is not yet generally considered commercially viable, although research into more efficient and cost effective processes is continuing. Worldwide, only a very small number of low-capacity devulcanization systems are operating in the United States (at approximately 50 Kg /hr). These are on an R&D scale and are either mechanical or ultrasonic systems). Center plastics 2011 study[187] concluded no proven commercial capacity units could be found that are currently devulcanizing waste tyres, for example, at 500 Kg/hr or greater. The likely reasons include insufficient product quality and the high costs of production.

5.4.3.3 Environmental and health impacts of devulcanization

Little information is available in the literature on the environmental impacts of waste tyre devulcanization technologies. As business developers and researchers have concentrated their efforts primarily on technology improvements and achieving satisfactory properties for devulcanized rubber, an estimation of emission rates and a detailed environmental analysis of various technologies are not available. However, Center plastics undertook a qualitative analysis of using data and information from some other types of tyre manufacturing processes (for example, extrusion of rubber). This environmental analysis was limited to chemical and ultrasonic devulcanization and assumed that control of emissions would be required[188].

Chemical: The chemicals that would be vented from the batch reactor are dependent on the characteristics of the waste tyre feedstock and on the chemical agent(s) used in devulcanizing the crumb rubber. For example, if disulfides are used in the process, they could result in formation of hydrogen sulfide (H2S) or methyl or other mercaptans (RSH). If the chemical agent orthodichlorobenzene is used, chlorinated hydrocarbons could potentially be released in the form of air emissions. Methyl iodide is volatile, and if used as a devulcanization agent, it could be vaporized. Since tyre manufacturing utilizes zinc oxide and zinc carbonate, chemical devulcanization might also produce airborne metal particulates. These vent gases would need to be treated prior to release to

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[186] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*
[187] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*
[188] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*

the atmosphere. These vapours cannot be effectively treated by vapour phase carbon so would need to be thermally oxidized.

Ultrasonic: Process losses from ultrasonic devulcanization would primarily be emissions of fine particulate or of gases. Since the typical operating temperature of an ultrasonic devulcanization reactor is about 230°F (110°C), less vapour emission would be expected than from chemical devulcanization. Vented vapours would need to be treated by one of two methods. 1. The use of a small thermal oxidizer. 2. The use of vapour phase carbon[189].

5.4.3.4 Investment and operating costs

Generally, reliable information and data on devulcanization of waste tyre rubber is difficult to obtain due to proprietary claims, the reluctance of industry and developers to release information relating to poorly performing processes and poor quality products, as well as the limited number of technology researchers and developers and a commensurate scarcity of peer-reviewed data[190].

A study commissioned for the Californian state government and published in 2004 found: "The economic cost of devulcanization technology is a critical barrier to developing and commercializing the process. The price spread between the selling price of crumb rubber and the price of virgin rubber is substantially less than current estimates of devulcanization cost. Crumb rubber is the raw material for the devulcanizing process. Further aggravating the problem is the expected discount sales price of devulcanized rubber. Based on current estimates, the processing cost must be reduced by 80 to 90 percent (to 10 to 20 percent of current estimates) before the process could be operated profitably. This represents a substantial reduction in the estimated processing cost[191]. There have since been no significant technological advances to achieve cost reductions of this magnitude. **Table 5.5** shows the center plastics report estimates set up and operating costs.

Table 5.5: Center Plastics Report Estimates Set up and Operating Costs (2011)[192]

	Mechanical	**Chemical**	**Ultrasonic**
Capacity (lb/hr)	100	75	75
Capital Cost ($)	92,000	166,000	163,000
O&M Cost ($)	135,000	172,000	136,000
Amortized Capital and O&M ($)	143,000	186,000	150,000

5.4.3.5 Institutional and regulatory requirements

No known commercial devulcanization processes in operation.

5.4.3.6 Pros and cons with respect to developing countries

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[189] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*
[190] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*
[191] *Evaluation of Waste Tyre Devulcanization Technologies, CalRecovery Inc., 2004*
[192] *M.S. Laura Fontana, CenterPlastics Enterprise Ltd, GuangDong, P.R.China, Internal Research report, The Present State of Desulpurization Technologies (2011)*

This is a high cost, technology-dependent process so would not be suitable for developing economies.

5.5 Energy Recovery Processes and Technologies

Tyres can be used as fuel either in shredded form known as tyre-derived fuel (TDF) or whole, depending on the type of combustion device. Scrap tyres are typically used as a supplement to traditional fuels such as coal or wood. Generally, tyres need to be reduced in size to fit in most combustion units. Besides size reduction, use of TDF may require additional physical processing, such as de-wiring. Unlike tyre fires, which can cause substantial air and ground pollution, the incineration of whole tyres or tyre chips for fuel is relatively environmentally safe.

Waste tyres can be incinerated to provide an alternative source of energy. Although open fires containing tyres or accidental fires in tyre stockpiles produce noxious pollutants, the incineration of waste tyres in high temperature furnaces with proper flue gas cleaning system achieves good results[193]. Consequently, energy applications are currently the dominant means of managing waste tyres in the United States, Japan and Europe and approximately 50% of waste tyres processed worldwide are utilised as fuel[194].

While incineration to release energy is not considered recycling as the tyre is entyrely consumed in the process it is preferable to landfilling or illegal dumping. The incineration of tyres replaces virgin fuel resources, therefore reducing pressure on the natural environment. The use of TDF in combustion units is typically limited to blends of less than 30 percent of total energy input due to the high rates of heat release and the low moisture content of TDF. TDF is able to replace higher-cost oil and gas in some cases where oil, gas and solid fuel are co-fired in the same furnace. More typically, however, TDF is used as a supplementary fuel in combustors to complement other energy sources such as coal and biomass[195]. As TDF is a relatively efficient source of energy, overall performance can be enhanced with the addition of TDF to the fuel mix. In addition, as the carbon content per unit of energy for waste tyres is less than the carbon content per unit of energy for coal and petroleum coke, TDF offers potential reductions in greenhouse gas emissions[196]. Likewise, ash production and several other key emissions are reduced. However, there are other environmental issues associated with the incineration of TDF and the installation of air pollution control equipment is essential if these potential benefits are to be realised (see *2.2.1.1.3)*. **Table 5.6** shows the comparison of energy values of tyre-derived fuel (TDF) to other fuels.

Table 5.6: Energy Content of Fuel

Fuel	Heating Value
Heating oil	42 MJ/kg
Natural gas	38 MJ/m^3
Coal	25 MJ/kg
Wood biomass	20 MJ/kg
Tyres	36 MJ/kg

[193] *Recycling of Scrap Tyres, Ahmet Turer, Middle East Technical University, Civil Engineering Dept. Turkey. www.intechopen.com accessed Aug 22, 2013.*
[194] *Developing a Sustainable Waste Tyre Management Strategy for Thailand, National Science and Technology Development Agency (Mar 2013)*
[195] *Materials Characterization Paper, In Support of the Final Rulemaking: Identification of Nonhazardous Secondary Materials That Are Solid Waste -- Scrap Tyres, EPA. Feb 2011*
[196] *Managing End-of-Life Tyres, World Business Council for Sustainable Development, page 6, 2008.*

Mixed plastic waste	43 MJ/kg

The chemical characteristic of any energy source determines how it will perform both technically and environmentally. The composition of the wide range of tyres used worldwide varies as does the composition of various coal types, so precise comparisons are difficult to make. **However, a typical passenger tyre contains about 30 types of synthetic rubber, eight types of natural rubber, eight types of carbon, black, steel cord, polyester, nylon, steel bead wire, silica and 40 different kinds of chemicals, waxes, oils and pigments. They typically contain 85% hydrocarbon, 10-15%[197] metal (in the bead wire and steel belts) and a variety of chemical components.** A comparison of the **proximate** analysis of coal and tyres by the United States Environmental Protection Agency in 2010 indicated that tyres offer efficiency advantages over coal. **Tyres have a heat content of 7,800 – 8,600 kilocalories per kilogram, depending on the type of tyre and the amount of wire and beading that has been removed. The energy value of tyre-derived fuel is 36MJ/kg, whereas coal produces an average of 25MJ/kg.**

As tyres have much lower moisture content than coal and since the energy required to heat and vaporize water is generally non-recoverable in the energy conversion process, lower moisture content can translate into higher combustion efficiency. **The (90%+) wire free TDF analyzed also had lower ash content than coal, offering efficiency advantages, and reducing the cost of ash disposal associated with incineration.** The higher volatile-to-fixed carbon ratio in tyres also enhances its ability to combust rapidly and completely.

Analysis of the environmental aspects of ash generated by TDF indicated that tyres generally contain metals at concentrations comparable to, or lower than coal. However, there is one notable exception, with zinc. Zinc is added as part of the rubber vulcanization process in the manufacturing of tyres, and therefore, zinc levels in tyres are much higher than in coal. Applications that use TDF must be able to control zinc emissions to prevent negative environmental impacts.

5.5.1 Technologies for direct use as a fuel

Waste tyres have been used as a source of energy in Japan, Europe and the United States since the 1970s. TDF (Tyre Derived Fuel) was initially mostly used in paper manufacturing mills, but in the past 15 years waste tyres have become more widely recognized as an alternative fuel for combustion processes, and are now used in cement kilns, industrial boilers, utilities and in dedicated electricity generating facilitates. The contribution of tyre derived fuels in various individual sections in USA is shown in **Figure 5.20**.

[197] *World Business Council for Sustainable Development, Managing End-of-Life Tyres, 2008. Full report.* *http://www.wbcsd.org/Pages/EDocument/EDocumentDetails.aspx?ID=57&NoSearchContextKey=true*

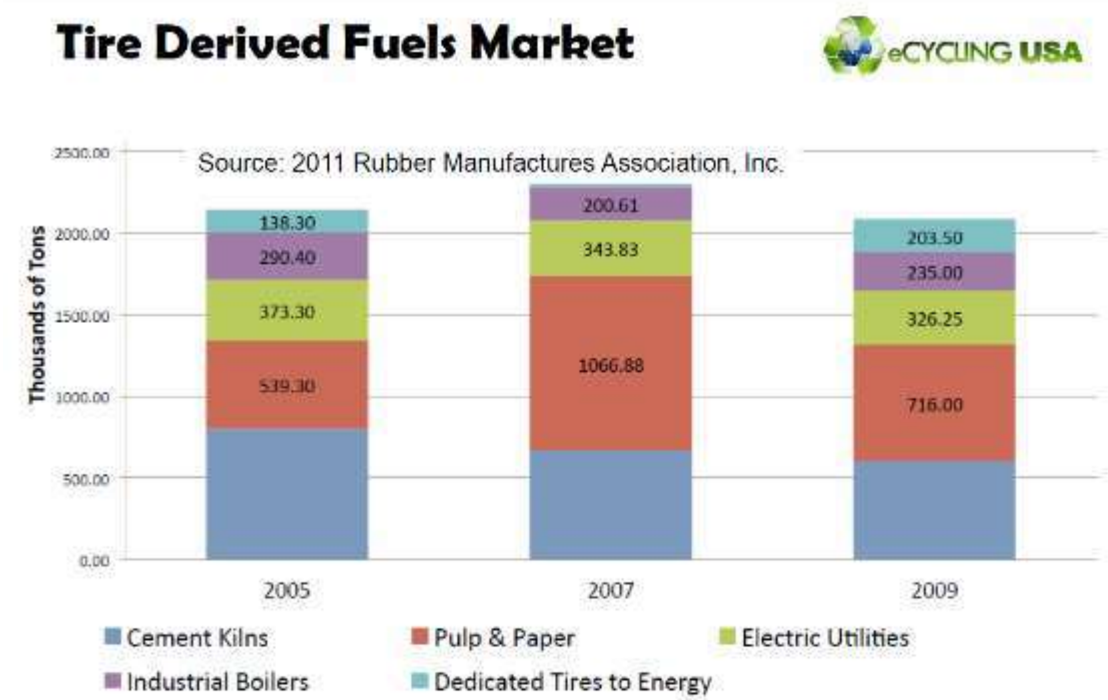


Figure 5.20: Tyre Derived Fuel Makes up over 40% of the Waste Tyre Market in the US

5.5.1.1 Cement industry

Waste tyres have been used as a supplementary energy source in cement kilns in Japan and Europe since the 1970s. There are a number of different kilns used in cement manufacturing and, over the years, technology has been successfully developed to enable the incineration of whole and shredded tyres in all types of cement kilns. **The use of waste tyres in cement kilns offers a constructive and inexpensive way of reducing stockpiles.** For example, waste tyre stockpiles on the border of Mexico and the USA are currently being removed for use in cement kilns. In the USA, cement manufacturers charge less to accept waste tyres than other processing facilities or landfill disposal sites, making this an attractive option for the disposal of tyres both to businesses and members of the public.

Cement manufacturing is an energy intensive process and although manufacturers are constantly seeking to innovate to reduce energy consumption, fuel remains the biggest single cost in cement production. Every cement kiln has the potential to use between 500,000 and 1.5 million tyres per year. In 2007, cement kilns in the USA consumed an average of 1 million tyres each. **Waste tyres cannot be used as the sole source of fuel for cement kilns; generally they will be able to replace 10 - 25% of the total fuel used in a kiln.** However, some facilities in Europe are configured to be able to cope with substantially higher proportions of TDF, up to 80 per cent. **The percentage of TDF that can be utilized in the fuel mix depends on many variables including raw materials, product chemistry, combustion conditions in the process (including air availability and sulfur build up) and the supply of waste tyres.** In a competitive marketplace, TDF offers energy cost savings over fossil fuels that can provide a useful economic advantage.

5.5.1.2 Process description

Cement manufacturing companies can use both whole tyres and TDF shreds to supplement their primary fuel for firing cement kilns depending on the process used and the specifications of the kilns. TDF shreds can be purchased from a separate tyre processing plant or processed on site. **The processing equipment required to produce TDF is typically high-shear, low-torque shredders.** This technology is the same as, or very similar to, that used to produce crumb and ground rubber and tyre derived aggregate. To produce TDF[198]-size shreds and chips, **whole tyres are reduced to nominal 5 cm (2 inch) pieces using one shredder or a series of shredders. To feed whole tyres or TDF into kilns metering systems have been developed to ensure a continuous, uniform supply.**

Whole tyre feeding systems can be as simple as manual operations that utilise a cable or hook conveyor to raise tyres to the kiln floor, using manual labour to weigh and insert tyres into a simple airlock that feeds into preheater or precalciner kilns. These systems require limited capital investment, but need more labour. They can be useful during trial operations to define technical and environmental performance. Alternatively, automated systems requiring significant capital investment can be used to minimise labour requirements. These systems use trailer tippers to dump tyres onto "singulators" that separate, convey, weigh, and insert tyres into the kiln with minimal labour required[199]. **TDF feed systems for dropping shreds into preheater-precalciner kilns generally involve less sophisticated handling systems. These can be as simple as a skid-mounted metering bin with transfer conveyors, weighing equipment, and an airlock. Systems for blowing TDF into the firing end of long wet or dry kilns can be low cost utilising a simple metering bin, conveyor, TDF injection piping, and blower**[200].

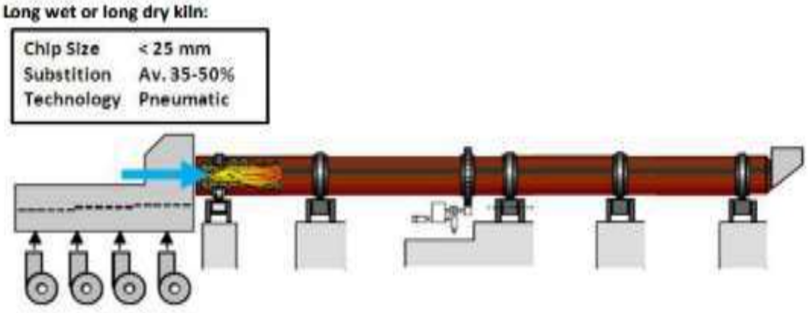
When TDF is utilized in cement kilns metal removal is not required due to the very high processing temperatures. The metal wire contained in the TDF is captured as a raw material or ingredient in the cement making process. **The steel portion of the tyre (each passenger car tyre, for example, contains over 1kg of high-grade steel) becomes a component of the cement product, replacing some or all of the iron required by the cement manufacturing process.**

A sample of shredder and kiln process is shown in **Figure 5.21**.

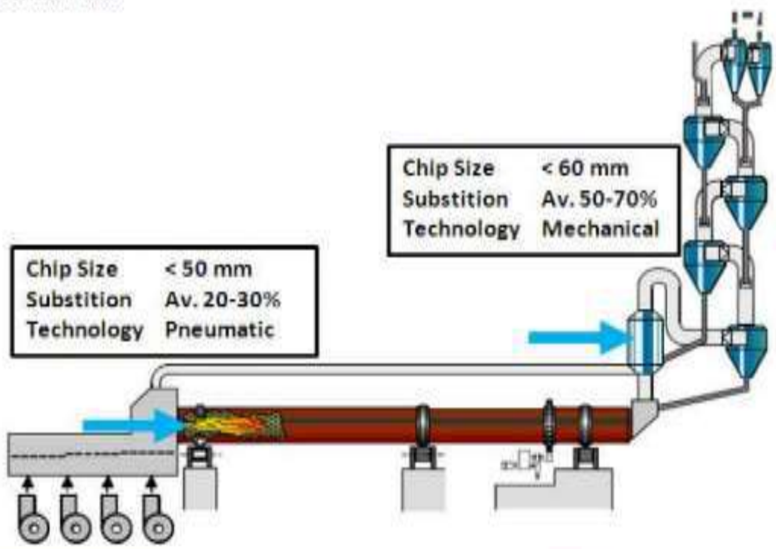
[198] *Scrap Tyre News, Tyre Derived Fuel (TDF) – Overview http://www.scraptyrenews.com/tdf.php, accessed Aug 22, 2013.*
[199] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*
[200] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*

Depending on the kiln system, the following rules of thumb apply with regards to chip size and potential for substitution:

Long wet or long dry kiln:



Precalciner kiln:



CM Single Speed Tire Shredder – Processes passenger car and SUV tires into a 50 mm clean cut chip at a rate of 8-9 tons per hour.

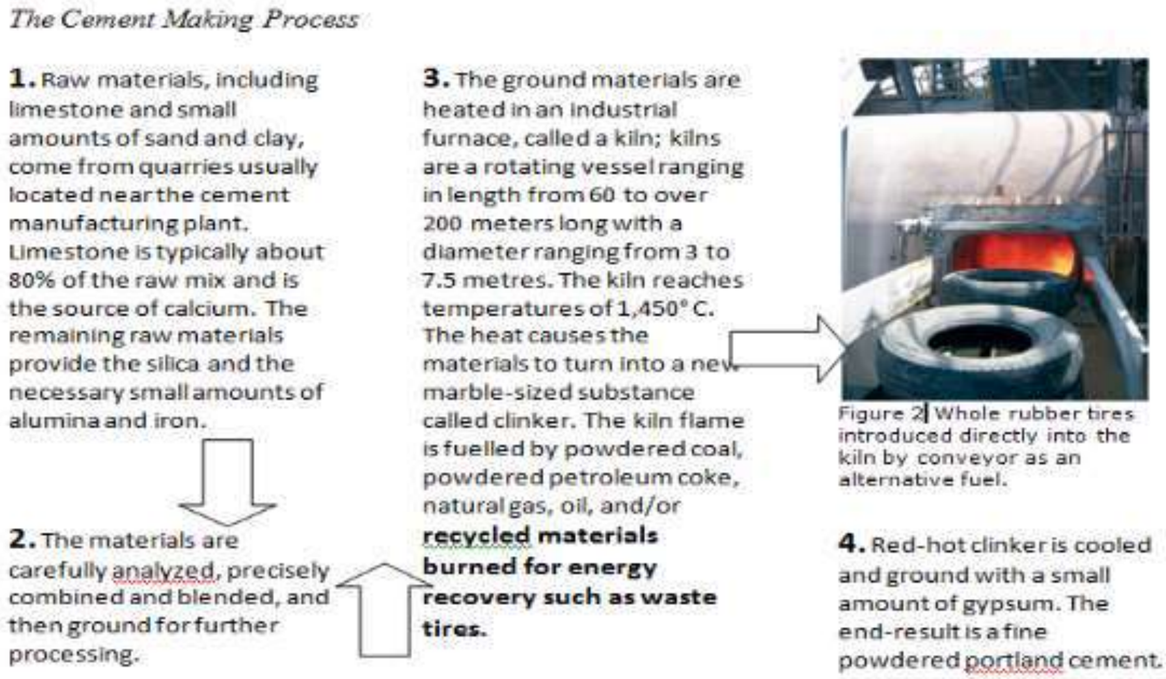


Figure 5.21: Sample Shredder and Kiln Process[201], [202]

5.5.1.3 Products and applications

TDF is an alternative fuel.

5.5.1.4 Environmental and health impacts

The US EPA undertook an ultimate analysis comparing coal and tyres, which looked at their elemental composition. Consequently, it reported that tyres offer some environmental advantages and some disadvantages. Data compiled by the Greenhouse Gas Protocol[203] and reported by the US EPA suggests that the greenhouse gas emissions rate associated with the combustion of waste tyres is approximately 0.09 metric tons of carbon dioxide equivalents ($MTCO_2E$) per million Btu (MMBtu) of waste tyres combusted (GHG Protocol, 2005). By comparison, based on emissions and energy data compiled by EPA, the GHG emissions rates for coal, natural gas, distillate oil, and residual oil are approximately 0.094 $MTCO_2E$ per MMBtu, 0.053 $MTCO_2E$ per MMBtu, 0.073 $MTCO_2E$ per MMBtu, and 0.079, $MTCO_2E$ per MMBtu, respectively[204]. TDF also has higher hydrogen content than coal. When hydrogen combines with oxygen during combustion, it releases energy and forms water (H_2O) with no greenhouse gas, so energy released from hydrogen combustion also decreases the formation of greenhouse gas compared with carbon. TDFs lower nitrogen content can marginally decrease emissions of nitrogen oxide compounds called NOx[205].

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[201] *Tyre Derived Fuel – The Basics to Successfully Co-Process Tyre Chips* *http://cmtyrerecyclingequipment.com/Public/16844/TDF%20Final.pdf, accessed, Aug 22, 2013.*
[202] *Portland Cement Association191*
[203] *The Greenhouse Gas Protocol http://www.ghgprotocol.org/about-ghgp*
[204] *United States Environmental Protection Agency (EPA). 2008b, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006: Annex 2 Methodology and Data for Estimating CO2 Emissions from Fossil Fuel Combustion.*
[205] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*

Tyres have lower sulfur content than coal, which could mean potentially lower emissions of sulfur oxide gas compounds.

Burning waste tyres, however, also raises some concerns as tyres include up to 17 heavy metals (e.g., lead, chromium, cadmium, and mercury) in addition to natural rubber, synthetic rubber, carbon black, extender oils, steel wire, other petrochemicals and chlorine. Synthetic rubber often contains the organic chemicals styrene and butadiene. Styrene, a benzene derivative, and butadiene are suspected human carcinogens. A coal and tyre chlorine content comparison showed that tyres may contain as much as 2 to 5 times as much chlorine as coal. The coal averaged a chlorine weight of 0.04% and tyres showed a weight range of 0.07% to 0.2%. Most of these toxic materials are in low percentages and remain in the burnt wastes or bound inside the cement. According to a 2003 European Commission report, the typical composition of TDF contains Sulfur <1.8%, Chlorine 0.07, Mercury <2mg/kg, Cadmium and thallium <79mg/kg, Antimony, arsenic, chromium, cobalt copper, lead, manganese, nickel, tin and vanadium <640mg/kg, which all fall below EU control limits of <2%,<0.2%, <10mg/kg, <80mg/kg, <1200mg/kg, respectively[206].

The US EPA also reported in 2010 that several cement plants in the southwestern United States have undergone extensive testing. Emission results for California Portland Cement Company showed some pollutants decreased with use of tyres, while others increased. For example, total particulates increased less than 10 percent, while non-methane hydrocarbons decreased about 18 percent. Recognized carcinogens such as benzene and toluene decreased. Total dioxins and furans (PCDD/PCDF materials) increased very little in quantity. Most Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) declined with tyre usage while hydrochloric and hydrofluoric acids increased. Hexavalent chromium, barium, cadmium, lead, and nickel emissions declined while zinc and mercury increased. The emission testing results showed minor changes with a relatively balanced net impact. California Portland engaged a consultant to conduct a comparative health risk assessment[207].

The safe use of TDF is dependent on processing plants utilizing flue gas cleaning systems. Non-condensable gases can be filtered (using a demister filter) and are passed through a wet scrubbing system to remove acid components by NaOH (4%) injection[208]. Common air pollution control equipment such as electrostatic precipitators and bag houses effectively control zinc oxide emissions from TDF combustion[209].

A 2008 study commissioned by the US Portland Cement Association of emission tests from 31 cement plants firing TDF found there were no statistically significant differences in the emission data sets for sulfur dioxide, nitrogen oxides, total hydrocarbons, carbon monoxide, and metals between kilns combusting TDF and non-TDF firing kilns. Separate studies conducted by US government agencies and engineering consulting firms have also indicated that TDF combustion either reduces or does not significantly affect emissions of various contaminants from cement kilns. In a 2007 study, the United States Department of Energy estimated that the combustion of TDF

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[206] *Recycling of Scrap Tyres, Ahmet Turer, Middle East Technical University, Civil Engineering Dept. Turkey. www.intechopen.com accessed Aug 22, 2013.*
[207] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*
[208] *Recycling of Scrap Tyres, Ahmet Turer, Middle East Technical University, Civil Engineering Dept.Turkey. www.intechopen.com accessed Aug 22, 2013.*
[209] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*

produces less carbon dioxide (CO_2) per unit of energy than coal. This confirmed that when TDF replaces coal in a Portland cement kiln, less CO_2 will be produced[210].

5.5.1.5 Investment and operating costs

The primary financial considerations in substituting a meaningful proportion of conventional fuels with TDF in cement kilns are the relative price of TDF vs coal (or other fuel used) and the upfront cost of implementing the technology required to load whole tyres on shredded tyres into the kilns. As discussed, tyres can be shredded on site or purchased shredded. **The current costs of a shredding system (2013) quoted by the US-based shredding equipment multinational, SSI, for the production of 5cm chips suitable for use as TDF started at US $500,000, with the majority of systems priced between US $650,000 and US $1,000,000[211].** A 2006 study commissioned by the Manitoba provincial government, Canada, stated: "For waste tyre fuel system, implementation the primary on-site improvement includes a tyre feeding system and on-site space for tyre-storage. It is very difficult to provide an exact cost of implementation for this project as every company must have custom built system. **The cost depends on variety of factors such as design and complexity of the feeding system and type of kiln or boiler".** The report quoted an expected investment of US $200,000 up to US $500,000. **Much cheaper Chinese built systems or second hand equipment can be found using internet searches, but various industry reports suggest saving made on the purchase price of lower quality equipment is quickly eroded as the wear and tear on blades and motors is high and maintenance costs for shredders can be substantial.**

The savings achieved by using TDF in cement production are two-fold. Firstly, TDF is generally cheaper than coal. For example, global exchange listing for TDF in August 2013 offered waste tyre shreds in a variety of sizes from US$ 5.00 per ton (small, one off supply) to $53.00 per ton (large scale, ongoing, uniform supply)[212]. Over the same time period, global coal prices included Australian thermal coal $82.78 per ton[213], South African coal $72.64 per ton[214] and US coal (high Btu) from $63.00 to $68.50[215]. Although some markets have access to subsidised coal, such as India, coal supply is under stress. Secondly, TDF has higher calorific value than that of coal.

Another important financial consideration is the cost of transporting either whole tyres or tyre shreds to cement kilns. While it may be cheaper to feed whole tyres into kilns, whole tyres are bulky and much more costly to transport than tyre shreds. Generally, cement kilns are located in areas with high population densities, providing local access to waste tyres and relatively short transport distances. However, **the cost and logistical viability of transport must be taken into account when calculating the set up and ongoing costs of using TDF.**

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[210] *Scrap Tyre News, Tyre Derived Fuel (TDF) – Overview http://www.scraptyrenews.com/tdf.php, accessed Aug 22, 2013.*
[211] SSI Applications: Tyre Shredding, SSI Shredding Systems http://www.ssiworld.com/applications/applications3-en.htm, accessed Aug 24, 2013.
[212] Global Recycling Network http://www.grn.com/cgi-bin/exview.cgi?w=60&sc=1310&st=LA, accessed Aug 24, 2013.
[213] *Coal, Australian thermal coal Monthly Price - US Dollars per Metric Ton http://www.indexmundi.com/commodities/?commodity=coal-australian, accessed Aug 24, 2013.*
[214] *Coal, South African export price Monthly Price - US Dollars per Metric Ton http://www.indexmundi.com/commodities/?commodity=coal-south-african,accessed Aug 24, 2013.*
[215] *US Energy Information Administration, Coal News and Markets http://www.eia.gov/coal/news_markets/, Aug 24, 2013.*

5.5.1.6 Institutional and regulatory requirements

Institutional and regulatory requirements vary at different local, provincial, state and national levels. Tyres are not classified as a toxic or dangerous waste by the US EPA. However, the use of TDF in cement production could be expected to be impacted by local or relevant state of national regulations and laws covering aspects such as:

- Industrial land use regulation
- Environmental management plans
- Onsite fire management
- Onsite workers safety
- Transport and storage of whole tyres and tyre shreds
- Import permits for TDF (if required)
- Minimum kiln temperatures to ensure complete combustion
- Defined percentages of TDF as a substitute fuel
- Emissions limits and regulations relating to installation of air pollution equipment
- Regular testing/inspections of emissions and air pollution equipment

For example, guideline for the use of TDF in cement industry in Pakistan, issued by the Pakistan Environmental Protection Agency (PEPA) in September 2011, list regulated areas as: import of TDF, quality of TDF, transport and storage of TDF, determination of the percentage of TDF to be utilized (subject to third party testing and PEPA approval), operating temperature of kiln, installation and maintenance of approved pollution control devices, regular emissions testing against legal limits, regular monitoring and reporting of TDF volumes imported and utilised and volume of coal displaced, plus community consultation[216].

5.5.1.7 Pros and cons with respect to developing countries

TDF is generally considered a cost effective substitute for coal, or other fuels, in cement production and is likely to be an attractive option for developing countries, provided pollution controls are adequate and the capital costs of addition technology required can be met. A recent Thai assessment of options for the disposal of waste tyres concluded: "TDF can be used as an additive to coal with little or no effect on emissions. However, it is important to note that proper operating procedures must be followed in order for energy production to be an environmentally viable use for waste tyres. If tyres are incinerated using poor operating procedures, the environmental damage can be extensive, comparable to open burning"[217].

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[216] *Pakistan Environmental Protection Agency (PEPA), Guideline for the use of TDF in cement industry in Pakistan http://www.innovative-fuel.com/wp-content/uploads/2012/01/TDF-Guidelines-_Final_-13-10-111.pdf*
[217] *Developing a Sustainable Waste Tyre Management Strategy for Thailand, National Science and Technology Development Agency (Mar 2013)*

Case study: Alternative Fuels in Indian Cement Industry

A 2007 paper on the use of alternative fuels in the Indian cement industry found TDF was a feasible option for widespread adoption by the industry but that the age of many kilns may be a barrier. It found that old wet process kilns of first generation incinerators posed technical challenges for the co-combustion of coal and TDF requiring careful attention to ensure optimum operation conditions for enhanced combustion and well maintained pollution control devices such as baghouses and ESPs. It concluded that TDF could help in reducing energy costs and providing a competitive edge for a cement producer while helping in waste disposal. However, regulatory barriers were also problematic at that time. The report cited a lack of agreed standards and "delays on part of State Pollution Control Boards and the Central Pollution Control Board in giving interested plants environment clearance', as well as the prohibitive cost of such clearances.

Significant push factors, however, are emerging that will continue to make TDF an attractive option. Coal stress is an increasingly important challenge for India's growing economy. India has the world's fifth-largest reserves of coal, however coal imports are increasing and imports met 18% of the country's demand in 2012, according to a recent report by HSBC. Indian coal is subsidised so local supplies are much cheaper than international import, but as imports grow, the total cost of coal for India will increase. As India has only 1% of the world's supply of natural gas it is unable to switch domestic power generation to gas, meaning pressure on coal supplies will persist, pushing costs up.

5.5.1.8 Pulp & paper industry

Tyre derived fuel has been successfully used to by the pulp and paper industry since the 1980s. The pulp and paper industry utilizes boilers in production, to provide the stream and power necessary for manufacturing paper. Generally, the stoker-fired boilers use coal and waste wood as fuel. The wood is combusted on moving grates, which also transport residual ash from the boiler. TDF is used to supplement the wood waste. The heating value of the wood waste fuel ranges from about 7,900 to 9,000 Btu/lb. on a dry basis. **TDF's has higher heat value of 15,000 Btu/lb. facilitates uniform boiler combustion, and helps overcome some of the operating problems caused by fuels with low heat content, variable heat content and high moisture content.** The consistent Btu value and low moisture content of TDF and its low cost in comparison to other supplemental fuels make TDF an attractive fuel in the pulp and paper industry. Pulp and paper mills continue to increase their use of TDF to help decrease fuel costs and improve both emissions and combustion efficiency.

In 2007, paper mills in the USA used approximately 1.07 million tonnes of ground rubber in TDF, representing the use of about 70 million waste tyres[218]. Though there is some fluctuation in usage, the increasing cost of fossil fuels has led to resurgence in the use of TDF in the paper industry, particularly with new mills in the south-western USA.

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[218] *US rubber manufactures association 2007 p.44*
http://www.rma.org/scrap_tyres/EPA%20Scrap%20Tyre%20Handbook%20on%20Recycling%20%20Management%20publication.pdf

5.5.1.9 Process description

Pulp and paper mills can burn TDF without major equipment modifications. **To be used in paper manufacturing, tyres must be processed into uniform chips that are less than 5 centimeters by 5 centimeters in size.** The bead wire is generally removed magnetically during shredding to avoid the metal fouling grates and ash handlings systems. The high volatile carbon content of TDF helps enhances the combustion of the wood on the grate and improves fuel efficiency. Within the combustion process, TDF can be integrated into the wood mixture prior to combustion through simple, inexpensive metering systems or introduced to the feed wood conveyor belt separately.

5.5.2 Products and applications

TDF is an alternative fuel.

5.5.2.1 Environmental and health impacts

Despite the widespread use of TDF at pulp and paper facilities across the United States and Canada over many years there is little specific information available about its public health and environmental effects. Most environmental studies have investigated emissions resulting from the co-combustion of TDF with coal and other fuels, primarily in cement production. A 2010 submission by the Environmental Policy Unit of Memorial University of Newfoundland, in response to an application by a large local mill to trial TDF (shown in **Figure 5.22**) stated: **"Research suggests that TDF emissions vary with technology employed at the facility, particularly combustion and stack emissions control technology. Very few peer-reviewed papers exist regarding pulp and paper mill technology and TDF usage."** The submission raised a number of concerns; many related the lack of reliable data about potential pollutants. Some trends noted included instances of rising dioxin and furan emissions, highly variable dioxin and furan emissions in grate ash and fly ash, increased levels of both zinc and iron in grate and fly ash necessitating sophisticated ash disposal methods, and the potential for sulfur introduced through TDF to adversely affect boiler plugging and increase boiler corrosion problems. It quoted the 1997 Reisman[219] study that suggests that TDF can be safely used in "properly designed solid-fuel combustors with good combustion control and add-on particulate controls, such as electrostatic precipitators or fabric filters". Consequently, the parent company, the major North American paper, cardboard and timber producer, Kruger Industrial, withdrew the application for the TDF trial[220].

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[219] *Reisman, J.I. 1997. Air emissions from scrap tyre combustion. Report prepared for U.S. Environmental Protection Agency, EPA Contract No. 68-D30035.*
[220] *Corner Brook Pulp and Paper Withdraws Tyre Derived Fuel (TDF) Co Firing Trial Project http://iw.kruger.com/imports/pdf/en/communiques/2011/20110121_CBPPL_TDF_E3F.pdf, accessed Aug 24, 2013*

Figure 5.22: The Kruger Industrial Mill - Corner Brook Pulp and Paper, Newfoundland[221]

The US EPA report of 2010 states[222]**: "The environmental impact associated with use of TDF in this application depends on characteristics of the displaced fossil fuel and system environmental control equipment". The two common factors determining environmental acceptability are sulfur oxides (SOx) and particulate (zinc oxide) emissions.**

SOx emissions may decrease if TDF displaces coal or oil with higher sulfur content. Alternatively, SOx can be controlled by the scrubbers present in some air filter systems, especially if the scrubbers operate at a neutral or basic pH. Particulate emissions (including Zinc) can be controlled by electrostatic precipitators (ESPs) or baghouses. In general, many environmentally acceptable applications occur when TDF displaces coal in systems with baghouses or ESPs.

One comprehensive batch of tests were carried out at the International Paper facility in Bucksport, Maine one of the largest US users of TDF that is capable of consuming up to 3.5 tons of TDF per hour (14.5 percent by heat input) to produce almost 225,000 kilograms 500,000 pounds) of steam per hour. A baseline test was conducted using the normal mixture of gas, bark, coal, and sludge. TDF was then substituted for coal at levels representing 6.3%, 10.3%, and 14.5% of heat input. At the maximum TDF level, NOx, SOx, and total hydrocarbon emissions remained virtually unchanged while particulate matter increased 6%. Among the metals, beryllium and chromium decreased, lead remained below detection limits, and cadmium increased. Zinc increased significantly percentagewise, but total quantities remained environmentally acceptable. Overall particulate emissions remained well within acceptable limits. However, the US EPA reported: "Only a small percentage of paper manufacturing and industrial facilities in the United States have the required combination of system design, permitting conditions, and fuel usage conducive to appropriate TDF usage."[223]

5.5.2.2 Investment and operating costs

The introduction of TDF into pulp and paper mills does not require major technical modifications. However, as whole tyres cannot be used a source of appropriately sized tyre chips must be located and supply secured. Generally, rising energy costs, improved reliability in the TDF processing industry and more consistent product quality of TDF shreds and chips are driving on-going growth in both the number of mills consuming TDF and in the amount of TDF consumed per mill in many

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[221] *Kruger Industrial http://www.cbppl.com/default.htm*
[222] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*
[223] *Scrap Tyres: Handbook on Recycling Applications and Management for the US and Mexico, EPA, Dec 2010.*

markets. TDF directly replaces a proportion of conventional fuel and so delivers direct savings as well as improves the efficiency of combustion. As TDF is a relatively low cost product with high heat content it allows mills to burn lower grade biomass such as bark and sawdust piles which typically have a higher moisture content and may be otherwise unable to be utilised in the fuel mix. In its submission, Memorial University calculated that the replacement of 10-25% (5,000 - 12,500 barrels) of Bunker C oil in the Newfoundland pulp and paper will (which uses 50,000 barrels per year) would result in savings of $500,000 to 1,000,000 in the first year alone, though savings would vary according to oil prices.

5.5.2.3 Institutional and regulatory requirements

Pulp and paper mills could expect to face similar regulatory requirements as those relating to the use of TDF in cement production. However, emissions are likely to be subjected to more intense scrutiny as are pollution control technologies fitted to mills. As with all regulations, local, provincial, state and national level requirements vary according to the appropriate jurisdiction.

5.5.2.4 Pros and cons with respect to developing countries

TDF is an economically viable substitute fuel for pulp and paper industries provided pollution controls can be achieved. In developing countries with well-developed waste recycling industries already utilising waste tyres for the recovery of materials, TDF may be less attractive than in high income economies burdened with large waste tyre stockpiles.

5.5.3 Technologies for conversion to conventional type fuel

Waste tyres can also be converted into fuels (solid, liquid or gaseous fuels) which can then be used as conventional fuels. Usually, this is carried out through a thermo-chemical process. Typically, 20-35% of the energy content of a tyre will be converted into combustible gas, which is used to fuel the pyrolysis process. The efficiency of conversion of tyres into conventional type fuel depends on its composition and reactivity. Some 35-50% of the tyre is transformed into oil, with the quality ranging from saleable fuel oil to lower-value oil blend stock. The remaining product is a solid referred to as char and contains a mixture of carbon black, titanium dioxide, zinc and steel. The two commonly used processes are pyrolysis and gasification.

5.5.3.1 Process description

Pyrolysis is the common name used for decomposing organic material at elevated temperatures in the absence of oxygen. Oxygen needs to be absent otherwise organic material may burn. Typically the process takes place under pressure at operating temperatures above 430 °C (800 °F). The word originates from the Greek, based on “pyro” and “lysis” meaning “fire” and “separating”, respectively. **The pyrolysis of waste tyres can generate gas, oil and char products, with the quality and quantity of the products dependent on a number of variables in the process.** Various steps in the process are given below.

Step 1: Before the materials are entered into the pyrolysis process, they must be treated. This involves shredding the tyres. The size of the pieces/particles and the moisture contains can affect the quality of the oil, gas and char produced.

Step 2: The shredded tyres are funneled into the pyrolysis reactor. This reactor contains an airlock to keep oxygen and unwanted air out of the process. The reactor sits within a combustor, which indirectly heats the tyre particles to produce gas.

Step 3: The gas is then funneled into a cyclone separator for char collection. This separator spins the char out of the gas and collects it. The purified gas then continues on, and is quenched by cold water. This causes the oil to condense and collect at the bottom of the condensing chamber. Gas which does not condense is funneled out of the chamber and back into the combustor, where it is re-used to heat the material in the pyrolysis reactor. The oil drops down into an oil collection chamber, where it is stored for transport[224].

Pyrolysis was developed more than 60 years ago, as a means of transforming coal into gas for street lamps. In the last 25 years, this process has been applied to waste tyres and in 1983, there were 31 pyrolysis projects operating in the USA[225]. Within pyrolysis, there are many different means of reacting the waste tyre particulates. Fluidized beds, travelling grate chambers, rotary kilns, retorts, molten salt, hot oil baths, plasma arc units and microwave chambers can all be used as reactors. The wide range of different reactors available is a reflection of the research and development of pyrolysis technology, which has been advanced with the aim of optimizing production and the quality of the products. **However, commercial-scale pyrolysis is still not common.**

Gasification is a variation of pyrolysis that involves allowing some air into the reactor to facilitate partial combustion. By introducing oxygen, the gas, oil and char is driven into a low-heat value gas that contains carbon monoxide and low-weight hydrocarbons. The gas is then burned to produce steam or power – this may be achieved using a number of different methods and systems. Many of these systems are not economically viable or practical at a commercial scale of production. The gas also contains a number of chemical and particulate contaminates. The main advantage of this variation of pyrolysis is overcoming the issue of char marketability, by removing much of the carbon by converting it to carbon monoxide.

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[224] *The biofuels education projects funded by the National Science Foundation and the U.S. Department of Agriculture (http://www.youtube.com/watch?v=Ut3I7OIPFR8)*
[225] *A U.S. Department of Energy publication, "Scrap Tyres: A Resource and Technology Evaluation of Tyre Pyrolysis and Other Selected Alternate Technologies"*

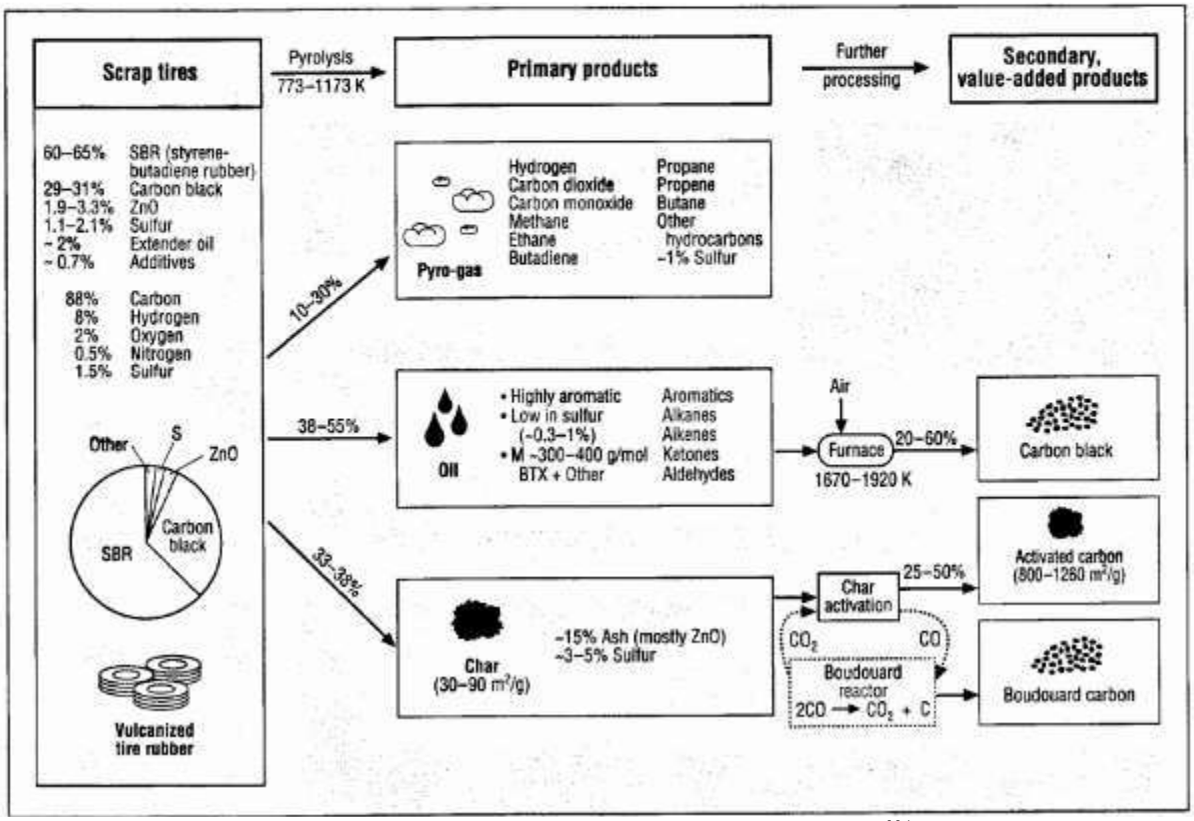

Figure 5.23: Products from Pyrolysis Process[226]

5.5.3.2 Products and applications

The pyrolysis reprocessing of waste tyres yields substantial quantities of oils and char, which can undergo further processing to secondary, value-added products. Char upgrading results in producing high-surface-area activated carbon and Boudouard carbon. Ash-free oils are turned into high-quality carbon black, or the oils can be separated into valuable chemical feed stocks by distillation. The products produced by pyrolysis processing is introduced in Figure 5.23.

5.5.3.3 Environmental and health impacts

There are some inorganic materials in tyres that are not destroyed or decomposed in the thermal process, and so remain in one of more of the products of pyrolysis. Materials such as sulfur and zinc are still present after pyrolysis. Further, partially decomposed hydrocarbons may not be removed through the condensation or combustion processes. As a result, pyrolysis processes must have air pollution control systems installed to prevent these hydrocarbons being released into the environment. Despite claims from pyrolysis promoters that the process produces no emissions, the combustion of the gas produced in pyrolysis to fuel the reactor creates emissions, and as such, pyrolysis systems may be subject to clean air standards/regulations. The char produced, if not marketable, must be disposed of as hazardous waste – another potential impact on the environment.

[226] *http://www.energy-without-carbon.org/sites/default/files/tyre%20pyrolysis.PNG*

These practical realities need to be appreciated and taken into account when looking at the capital and operating costs for pyrolysis systems.

There is also risk of explosion when operating in an oxygen-limited, high- temperature environment. Fire or explosion can occur if air accidentally enters the pyrolysis system. Accidents such as these in the past have led to the severe damage or destruction of pyrolysis operations, including the complete destruction of an operation in Texas.

Pyrolysis: Case Study of India

There are two types of technology being used in India for generation of Tyre Pyrolysis Oil (TPO) viz. Batch Process and Continuous Process. Environmental and safety concerns in these plants arise due to fire hazards, emission of fine carbon particles and odor nuisance and need for flaring of excess pyro gas.

Process Description

(i) Batch Process

Most of the tyre pyrolysis units in the country are batch processes producing primarily oils for use as fuel oil in industrial furnaces. The pyro-gas generated from pyrolysis process is used as fuel in the pyrolysis process. In these plants the full tyres are fed to the pyrolyser manually and at the end of the process the steel wire and carbon are taken out manually. After removing the steel, the labour is sent into the reactor having carbon to feed it with tyres. This leads to lot of carbon spillage, exposure of workers to fine carbon particles and working in the unconducive environment in the pyrolyser. In some of the plants some explosions also have been reported due to frequent opening of the reactors in the hot conditions. The flare system is also not properly designed. Since the system is not completely closed, the odor problem is prevalent throughout the plant. These are some of the major shortcomings of such plants.

(ii) Continuous Process

In this technology the tyres are mechanically cut to about 20mm by 20mm size. This causes the embedded steel to be liberated. This liberated steel is then separated using a magnet. Steel free rubber is then fed into a closed reactor. This reactor processes the tyres and never needs to be opened. The oil phase is collected in tanks after condensing and the carbon phase is conveyed via closed conveyors into a Hopper. In this system the entire system is a closed circuit. The reactors run continuously and are never opened to remove steel or carbon from the system causing no carbon pollution or discharge in the air. This system is generally known as the continuous pyrolysis technology.

Standard Operating Procedure (SOP) for environmentally sound and safe operations of technology:

(A) Batch process:

i. The feed to the pyrolysis reactor should be devoid of steel. This means that crumb rubber only should be fed to the reactor. Further the feeding arrangement of the rubber crumb to the reactor should be mechanized.
ii. The initial heating of the reactor should be done by liquid fuel or gas. The flue gas should be released to the environment through a chimney of at least 30 metres height.
iii. After initial heating, during the pyrolysis process, the pyro gas generated within the plant should be used as a fuel.
iv. Excess pyro gas if any should be flared through properly designed flaring system of adequate capacity considering the emergency situation in which the entire gas may have to be flared. The flaring should be done at a minimum height of 30 metres.
v. Adequate instrumentation for measurement and control of temperature and pressure along with safety interlocks in case of increase of temperature or pressure to cut off heating of the reactor should be provided. Automatic control systems such as Programmed Logic Control (PLC) shall be adopted. It should be ensured that the reactor is under positive pressure all the time.
vi. In order to control fugitive emissions from the reactor during operation, proper sealing should be ensured.
vii. The collection of the oil from the condensers should be in closed vessel and storage also should be in closed tanks with suitable vents. There should be no manual handling of oil. Transfer of oil should be through pumps.
viii. At the end of the pyrolysis process the reactor has to be cooled before the removal of carbon. During this process, the reactor should be purged with nitrogen.
ix. The removal of carbon should be started after the reactor's temperature has come down to below 50oC.
x. The removal of carbon should be through a mechanized system and it should be ensured that no spillage takes place during the collection of the carbon in the bags.
xi. Adequate number of sensors along with alarm system should be provided at suitable locations throughout the plant to detect any leakage of flammable vapors from the system.
xii. Adequate fire-fighting system like sprinklers and fire hydrant with necessary pumping system and water storage should be provided.
xiii. The plot size should be adequate for storage of crumb or cut tyres, oil and carbon black in addition to the pyrolysis plant and accessories as well as enough space for movement of fire tender in case of any emergency. A minimum indicative size of small plant is about 3000 square metres.
xiv. The plant shall possess clearance certificates issued by concerned departments.
xv. The carbon black and the oil obtained from the process should be supplied only to actual users/processors.
xvi. The waste water generated in the process from condensers or any scrubbers should be properly treated in an Effluent Treatment Plant and the sludge generated should be sent to Treatment Storage Disposal Facilitiy (TSDF).
xvii. Oil containing water condensate should be treated in suitable ETP. Oily sludge/residues should be disposed through TSDF.

(B) Continuous Process:

The continuous plants operating in the country do not suffer from most of the environmental and safety problems encountered in the existing batch plants. However, even for the continuous pyrolysis plants the following facilities have to be ensured:

i. The feed to the reactor is in the form of crumbs, it should be ensured that during handling/ transfer of the crumbs there should be suitable system for suction and collection of fugitive fibres.
ii. The feeding system should be provided with air-lock arrangements so that no air enters the reactor during feeding.
iii. The initial heating of the reactor should be done by liquid fuel or gas. The flue gas should be released to the environment through a chimney of at least 30 metres height.
iv. After initial heating, during the pyrolysis process, the pyro gas generated within the plant should be used as a fuel.
v. Excess pyro gas if any should be flared through properly designed flaring system of adequate capacity considering the emergency situation in which the entire gas may have to be flared. The flaring should be done at a minimum height of 30 metre.
vi. Adequate instrumentation for measurement and control of temperature and pressure along with safety interlocks in case of increase of temperature or pressure to cut off heating of the reactor should be provided. Automatic control systems such as Programmed Logic Control (PLC) shall be adopted. It should be ensured that the reactor is under positive pressure all the time.
vii. In order to control fugitive emissions from the reactor during operation, proper sealing should be ensured.
viii. The collection of the oil from the condensers should be in closed vessel and storage also should be in closed tanks with suitable vents. There should be no manual handling of oil. Transfer of oil should be through pumps.
ix. The removal of carbon should be through a mechanized system and it should be ensured that no spillage takes place during the collection of the carbon in the bags. Moreover an air-lock should be provided to ensure no entry of air into the reactor.
x. Adequate number of sensors along with alarm system should be provided at suitable locations throughout the plant to detect any leakage of flammable vapors from the system.
xi. Adequate fire-fighting system like sprinklers and fire hydrant with necessary pumping system and water storage should be provided.
xii. The plot size should be adequate for storage of crumb or cut tyres, oil and carbon black in addition to the pyrolysis plant and accessories as well as enough space for movement of fire tender in case of any emergency. A minimum indicative size of small plant is about 3000 square metres.
xiii. The plant shall possess clearance certificates issued by concerned departments.
xiv. The carbon black and the oil obtained from the process should be supplied only to actual users/processors.
xv. The waste water generated in the process from condensers or any scrubbers should be properly treated in an effluent treatment plant and the sludge generated should be sent to TSDF.
xvi. xvi. Oil containing water condensate should be treated in suitable ETP. Oily sludge/residues should be disposed through TSDF.

5.5.3.4 Investment and operating costs

Across the world, there has been extensive investment in pyrolysis by major companies (more than USD$350 million), as well as pilot projects developed by smaller companies or entrepreneurs. **One example was a project developed by Foster-Wheeler in the UK, called Tyrolysis, which went on to fail both economically and technically after expenditures exceeding USD$30 million.** There are a number of issues with operating pyrolysis on a large scale. These are described below.

Operating problems
The pyrolysis process involves using complex equipment at high temperatures. This combination of factors generally demands high levels of maintenance for the pyrolysis process. This has contributed to the failure of pyrolysis projects in the past as maintenance expenses, and the cost of downtime to conduct inspections and repairs, is often underestimated in the total project costs.

Availability and processing of materials
The quantity of tyres needed in order to make pyrolysis processing economically viable can exceed what is available within a reasonable delivery area. This process is best utilised in areas with a high concentration of tyres in a small area, to minimise the costs associated with transport and collection. Additionally, the costs associated with shredding and preparing the tyres for introduction into the process is often underestimated.

Product Quality
It is difficult to create a pyrolysis system which is able to optimize both the quality and the yields of the three product streams that pyrolysis generates – oil, gas and char. This is because conditions that favour the improved production of one product can often impact negatively on another. Char has also historically only been suitable for low-value applications, because of the complex mixture of carbon black and other constituents it contains.

Economics
There are many different operating factors that impact on the economic feasibility of pyrolysis. These include system reliability, capital and labour costs, process, tyre preparation expenses, environmental control requirements and product revenue. **In the past, operations have not been economically sustainable because they have not been able to produce high-value markets for the char generated. Studies show that the economic viability of this type of processing is almost entyrely dependent on being able to sell the carbon black content of the char back at a relatively high price.** Unless this is possible, pyrolysis becomes a capital-intensive process for the conversion of solid fuel into low-grade liquid fuel. However, Harmonic Energy Inc, a London-based integrated tyre recycler, uses a process which enables whole tyres to be introduced, and claims a significant reduction in operating costs[227]. This technology, however, has not been commercially proven.

5.5.3.5 Institutional and regulatory requirements

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[227] *Harmonic Energy, A process unique to harmonic-whole tyre carbonization http://harmonicenergyinc.com/tyre-technologies-pyrolysis-retreading/tyre-carbonisation, accessed June 29, 2013.*

In the countries where waste tyre pyrolysis is operating on a commercial scale, there's institutional and regulatory requirements for pyrolysis process. **For example, in China, according to the Utilization of Waste Tyre Industry Access Conditions issued by the National Development and Reform Commission[228], there is requirements on technology, pollutant emissions and the energy consumption. Enterprises using vacuum pyrolysis technology must be equipped with oil separation device, carbon black processing apparatus and environmental emission control devices, and make the production process continuous and automatic.** The emissions must follow the "Integrated emission standard of air pollutants"[229] and "Emission standards for odor pollutants"[230]. The pyrolysis processing integrated energy consumption should below 300 kWh / ton.

5.5.3.6 Pros and cons with respect to developing countries

Pyrolysis is a high cost process which has achieved little success despite significant investment over decades and is unlikely to offer developing countries any advantages in dealing with waste tyres.

5.5.4 Technologies for recycling waste tyres in steel production

The use of waste tyres as a source of carbon in electric arc furnace steelmaking is emerging as a cost effective and environmentally friendly opportunity for recycling waste tyres. In the electric arc furnace, the carbon contained in tyres partially replaces coal/coke used in the steelmaking process. An Australian innovation known as Polymer Injection Technology has been successfully commercialized in Australia and overseas, and in Europe waste tyres have been approved for use in steelmaking through electric arc furnace route.

5.5.4.1 Process description

a. Polymer injection technology

Polymer Injection Technology, or PIT, is a patented technology developed by the University of New South Wales (UNSW) in collaboration with Arrium Ltd (formerly OneSteel). **The processes leverages the high temperatures steelmakers work with, but unlike the incineration of waste tyres to release energy, PIT utilises high temperatures to trigger useful chemical reactions to literally re-form waste materials into resources for steel production. Figure 5.24** shows that injecting granulated tyre waste directly into an electric arc furnace at Arrium's (formerly OneSteel) Sydney mill.

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[228] National Development and Reform Commission(China), Utilization of Waste Tyre Industry Access Conditions http://www.jsdpc.gov.cn/ggfw/bmfw/zcfg/zcwj/201209/t20120928_280644.html
[229] Ministry of Environmental Protection(China), Integrated emission standard of air pollutants http://english.mep.gov.cn/standards_reports/standards/Air_Environment/Emission_standard1/200710/t20071024_111824.htm
[230] Ministry of Environmental Protection(China), Emission standards for odor pollutants http://english.mep.gov.cn/standards_reports/standards/Air_Environment/Emission_standard1/200710/t20071024_111822.htm

Figure 5.24: Polymer Injection Technology[231]

Green steel was developed following the discovery at UNSW that transformations to the molecular structure of carbonaceous materials occur rapidly in extremely reactive high-temperature environments (> 1500ºC), and subsequently exposing carbon-rich rubber/plastic (polymer waste) to rapid, high-temperature conditions would result in the production of carbonaceous materials and clean gases[232]. Laboratory experiments at UNSW showed coke/rubber/plastics mixtures could be introduced into the furnace at steelmaking temperatures and produce carbon/slag reactions and extremely efficient slag foaming. As slag foaming is one of the key factors that governs furnace efficiency and therefore determines electricity usage, the resulting "foamier" slag reduced power demand[233].

PIT is the technology that allows a precisely calibrated mix of granulated coke and waste tyres to be introduced directly into the furnace as a carbon injectant to optomise furnace efficiency. The result is a novel recycling solution, which transforms problematic waste, reduces the cost of raw materials (coke) for the steelmaker and improves furnace efficiency – without making fundamental changes to the way steel is manufactured or compromising on the quality of the steel produced.

Industrial trials commenced during 2006 at OneSteel Sydney Steel Mill (SSM) and in 2007 at Laverton Steel Mill, Melbourne. Rubber injection is now a standard practice at both steel plants.

The use of rubber crumbs did not require any particular modification of the furnace infrastructure or operational procedures, other than the introduction of a dedicated storage silo and the polymer injection (PIT) mixing system. A summary of the data for the trial heats clearly shows that the HDPE/rubber blend performs better than coke (**Table 5.7** Summary of

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[231] *OneSteel/Arrium*
[232] *Excellence in Innovation Australia, 2012*
[233] *2013 AIST Howe Memorial Lecture, The Power of Steelmaking – harnessing high temperature reactions to transform waste into raw material resources, Sahajwalla et al. Harnessing, AIST, August, 2013.*

benefits at SSM **Table 5.7**). The use of polymer/coke blends considerably reduces the quantity of injectant required so reduces the amount of raw materials needed.

Table 5.7: Summary of Benefits at SSM

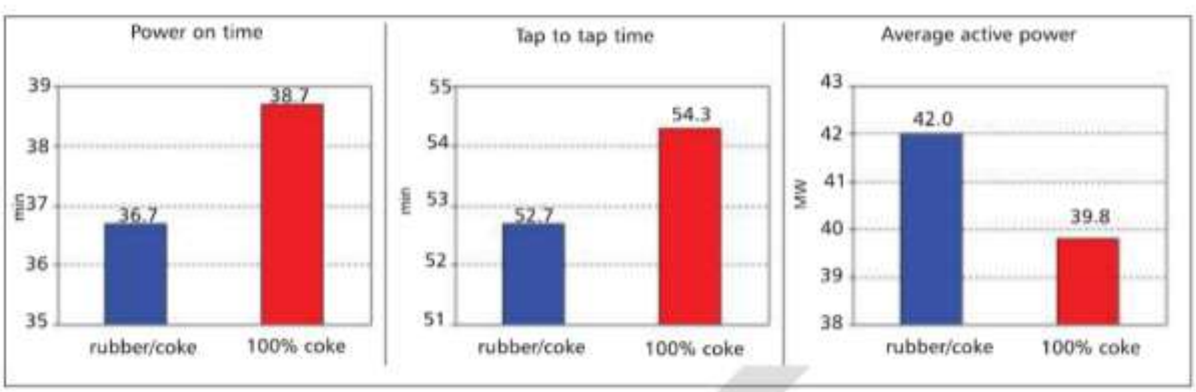
Injected materials	Specific EE (KWh/t)	Carbon (Kg/heat)	FeO (%)
Coke	424	462	27.6
Recycled tyres	412.4	406	26.2
HDPE	406	379	26.1

Other benefits recorded at OneSteel included decreased electrode consumption, decreased lime consumption and improved yield due to a 1.4% reduction of FeO levels in the slag.

5.5.4.2 Environmental and health impacts

Polymer Injection Technology (PIT) reduces the steelmaker's carbon footprint, lowering CO_2 emissions as a result of decreased electricity consumption (generated by coal-fired power stations). The technology also provides the opportunity to differentiate the steel produced on its environmental benefits ('greener steel'). OneSteel has conducted specific campaigns at its SSM to check sulfur pickup in the steel when injecting a rubber/coke blend. No statistical difference in steel sulfur levels was observed when injecting rubber crumbs at OneSteel[234].

Polymer Injection Technology was commissioned at UMC Metals in Thailand in May 2011. The improvement in slag foaming has also resulted in a 12% reduction in the total amount of injectant used per heat as well as a reduction in furnace power on time and an increase in the average active power. Three months after initial commissioning, OneSteel returned to UMC to conduct trials with the aim of increasing the proportion of rubber in the injection blend. These trials proved successful and a higher rubber ratio was made a standard practice, with a further reduction in total injectant per heat of an additional 8%. A comparison was made of heats made using the higher rubber/coke blend, versus heats made with coke only, under controlled conditions. Heats made using the rubber blend showed clear improvements in average active power, reduced power on time and greater productivity, as shown below in **Figure 5.25**[235].



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[234] *A. Fontana, P.O'Kane, D. O'Connell, M. Schroer, Proceedings 2012 SEAISI Conference, Bali, Indonesia.*
[235] *2013 AIST Howe Memorial Lecture, The Power of Steelmaking – harnessing high temperature reactions to transform waste into raw material resources, Sahajwalla et al. Harnessing, AIST, August, 2013.*

Figure 5.25: PIT Implementation in UMC Thailand, Key Performance Indicators

The operational benefits experienced by OneSteel and UMC as a result of implementing Polymer Injection Technology, combined with the environmental benefit of diverting used rubber and plastics from landfill, have shown that the process of harnessing high temperature environments to transform waste as raw materials can be a 'win-win' for both EAF steelmakers and the environment. Steel manufactured using PIT, now ccolloquially known as 'green steel' and has been rated by the Green Building Council of Australia as an 'energy reducing technology", reducing the carbon footprint of a building utilising 'green steel'[236].

The incorporation of PIT into OneSteel's commercial furnaces in Sydney and Melbourne has achieved a 12-16 per cent reduction in coke consumption, generated significant power savings and absorbed large amounts of waste. To date (2013), over 1.6 million tyres have been diverted from landfill into value-added steel products[237].

5.5.4.3 Investment and operating costs

PIT does not require fundamental changes to EAF steel furnaces, but achieves a reduction operating costs due to the reduction in coke usage and reduce power required. However, the process relies on precise calibration of the waste/coke mix so saving may not be achieved without the technology and expertise to manage calibration.

5.5.4.4 Institutional and regulatory requirements

The regulatory measures for air pollution from EAF have been developed by all various countries. For example in United states of America, U.S Environmental protection Agency has standards for the emissions from EAF and effects of hazardous air pollutants, under section 307(b)(1) of the Clean Air Act (CAA).

5.5.4.5 Pros and cons with respect to developing countries

Recycling waste tyres in steelmaking is an environmentally sustainable solution for production of steel compared to using coke, as it reduces consumption of energy and carbon. In developing countries this may be an attractive option, as it supports EAF steelmaking which recycles scrap steel and requires lower levels of energy to produce steel compared to a larger integrated steel plant. By coupling tyre recycling, along with steel reduces resource requirements.

b. Other Processes

The use of waste tyres in electric arc steel production in Europe emerged from 2004 and was approved for industrial applications in France in 2006, based on the conversion of both the carbon

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[236] *Polymer Injection Technology: Environmentally Friendly Steelmaking* *http://www.buildwithstandards.com.au/asset/cms/News/bwsweb_PIT_Oct11.pdf, accessed June 26, 2013.*
[237] *2013 AIST Howe Memorial Lecture, The Power of Steelmaking – harnessing high temperature reactions to transform waste into raw material resources, Sahajwalla et al. Harnessing, AIST, August, 2013.*

and steel within waste tyres into steel[238]. In mid 2012, ArcelorMittal Belval reported utilising used tyres instead of coal in the electric arc furnace (EAF) process at Belval operations site in Luxembourg. The company announced the Belgium Ministry of Environment has granted it authorisation to recycle used tyres in EAF steelmaking until 2024. This process is different to PIT. In the furnace the carbon contained in the tyres, combines with surrounding oxygen and prevents scrap oxidation, while the steel contained in the tyres is recycled in the steel bath. The small amount of zinc contained in the tyres evaporates and is collected by the dust extraction system and treated together with the dust at the furnace. The measurements carried out during the trials at Belval, demonstrated that neither dust, nor gas emissions, are negatively influenced when processing waste tyres in electric arc furnaces. In 2011 ArcelorMittal Belval used the equivalent of 75,000 car tyres in steel making[239].

5.6 Specific Technologies for Recovery of Materials / Energy from Used Tyres

Conventional and state of the art technologies, both are in use for the material/energy recovery from waste tyres. Developed countries tend to use state of the art technologies as it is often warranted by the environmental schemes and protocols [240]. On the contrary developing countries tend to use conventional methodologies as finances are often a constraint and only very few standardized well established sectors adopt current technologies for recovering materials/energy from used tyres. **Therefore, Material and energy recovery technologies and their Budgetary cost estimates are described in following section. Further, examples of operating expenses have also been described.**

5.6.1 Material recovery technologies

In developing countries technologies such as shredding, is the most common method used for the material recovery in tyres. Shredding operations are carried out in various means depending upon the availability such as manpower, technological advancements, outsourcing, etc. In general the waste tyres are cut into suitable shapes for assembly which is then later reassembled or designed into new products such as plastic hangers, rubber mats, accessory parts in chairs, as segments in many furniture designs, etc., The waste tyres are shredded prior to grinding into finer granules termed as crumb rubber. This kind of granules can be produced by ambient or cryogenic processing. This kind of rubber can be applicable widely in the molded and die cut products. Apart from the crumb rubber, tyre chips are also produced during the shredding process. These tyre chips are segregated and then processed. It finds its applications in road beds, core of the earthen embankments, septic tank drainage fields etc. Shredded tyres are used as one of the significant medium in another widely used material recovery process of tyres, which is pyrolysis.

5.6.2 Shredding process of material recovery from used tyres

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[238] *Fazilet Cinaralp, Europe on the right track: Encouraging prospects for end-of-life tyre management, http://www.waste-management-world.com/articles/print/volume-7/issue-7/features/europe-on-the-righttrack-encouraging-prospects-for-end-of-life-tyre-management.html, accessed June 29, 2013*
[239] *ArcelorMittal ,Belval recovers used tyres in steelmaking process, http://www.aliapur.fr/media/files/RetD_new/ArcelorMittal_Belval_recovers_used_tyres_in_steelmaking_process_EN.pdf*
[240] *CRISIL Global Research & Analytics (GR&A), "Tyre Recycling Industry: A Global View".*

Shredding of tyres is considered as a mature technology in developed countries because of its lower production & installations cost in comparison to the other technologies. Primary raw materials such as natural rubber, synthetic rubber, carbon black, fabric and steel wire which were used in tyre manufacturing could be recovered with the help of shredding process which are then later used for making various products. Volume of the waste tyres is significantly reduced through the shredding process thereby reducing the space requirement and shipping costs. Tyre shredders with two shafts and four shafts are shown below in **Figure 5.26** and **Figure 5.27**.

Figure 5.26: Tyre Shredder (Four shafts)

Source: CM Shredder, Product Division

Figure 5.27: Tyre Shredder (Two shafts)

Source: ECO Green Equipment

5.6.3 Budgetary cost estimates for shredders

The cost of individual shredders starts at $100,000 USD, while shredding systems begin at $500,000. In general, the cost of the installation of a complete tyre recycling system will begin at $500,000 USD. Certain industries provide detailed quotes on their tyre recycling systems, depending on a number of factors. **If tyres are already being processed, the quote is based on what equipment is already in use, the type of tyres being processed, the number of tyres to be processed per hour and what tyre derived material can be sold in the markets. If tyres are not being processed, the quote is based on the cost of tyre processing permits, type of tyres to be processed, number of tyres to be processed per hour (the size of the operation) and the**

projected markets for the tyre derived products. Some well developed and established firms specialize in making shredders that require minimal maintenance, in order to reduce the costs of upkeep and service, and to minimize the loss of profit and productivity that is associated with shutting down plants for maintenance. They state on their website that their shredding machines offer the most cost-effective means of shredding tyres because of the longevity of their products, and their processing power. The costs are largely based on the type and volume of rubber that needs to be processed. However, unlike the traditional rubber shredding models, in which the waste rubber is converted into a new product for a range of different uses, this system allows for companies to continue reusing their own rubber in the production of existing products. The use of an outside company eliminates the need for startup costs of establishing a ground rubber production facility.

Generally, the larger the system, the more expensive the installation and equipment will be. Further, there are the concerns regarding the cost of tyres themselves, and how much profit can be made from tyre derived materials. **Company like BCA industries (USA) offers the estimate that approximately US $2 can be made per tyre if the rubber is being sold as crumb rubber, rubber mulch and tyre derived fuels. However, they also point out that, particularly within the USA, tyre disposal fees are the key to profitability and functionality. On average, tyre processors are paid between 0.75-3.00 USD per tyre.**

Currently, approximately 50 percent of recycled tyres are used as TDF. One can make TDF with a single shredder, called a "primary shredder," a vibratory screener and some conveyors.

Primary shredders to handle passenger tyres start at about $130,000 to $150,000. In case of processing the passenger tyres and truck tyres (but not OTR, or off-the-road, tyres), then the estimate can be on spending roughly $300,000 for the primary shredder.

It is to be noted that on an average $200,000 to $250,000 is required to be spent for the vibratory screener and conveyors in the TDF production system. Basically a system like this, laid out in a straight line, would be approximately 80 feet long and about 20 feet wide.

The approximate investment would be $300,000 to $500,000, depending on whether the processing includes passenger tyres only or passenger and truck tyres. The approximate operating costs of the system as described is $12 to $15 per ton, and the end product value could range from $25 to $50 per ton, depending on market, the quality of the TDF, customer demand, etc.

A **secondary shredder** is required to liberate tyre wire (top) from rubber (bottom) when processing tyres. Some markets require a particle size of less than 2 inches by 2 inches and, more importantly, they require the material to be "wire free." To produce a wire-free product, a secondary shredder must be added to the processing line.

Few companies offers a rotary tyre re-shredder, or RTR, that has a single rotating head (called the "rotor") that has knives (or "cutters") mounted on it. The RTR has a hydraulic ram that pushes the pre-shred into the rotor and a PLC program that controls the feed rate of that ram based on the amp load of the main drive motor. The cutters on the rotor pass through a stationary bed knife, cutting the rubber and pulling the wire from the pre-shred.

A **stationary screen** controls the particle size of the material. The smaller the screen, the longer the material stays inside the machine. Screens are offered in various sizes and are interchangeable. The rubber and wire come out of the RTR in the same stream, so the product gets carried away via a drag chain conveyor that is equipped with a self-cleaning, rotary drum magnet. The wire is separated from the rubber at this point. The rubber, now mostly "wire free," is dropped into super sacks. **The approximate investment to add this second shredder is $250,000 to $500,000, while the approximate operating cost for this equipment is $9 to $15 per ton.** The typical size of product ranges from 5/8 inches to 1 inch and it is suitable for a range of markets, including playground cover, landscaping mulch, arena cover, wire-free TDF and an engineering grade replacement for gravel at a value of $150 to $200 per ton, depending on market, material quality, customer demand, etc. The wire derived through this processing step can be valued at $40 to $120 per ton, again depending on market, quality, customer demand, etc.

Granulation: the demand for the final smaller/finer product is always more and the prices could be high too. After the removal of the steel wire through the secondary shredder process, further size reduction is easier. Granulators can take the 3/4-inch-minus material out of the secondary shredder and reduce it down to about 1/4 inch to 1/2 inch, depending on the need. If additional size reduction is required after the granulator, then it is necessary to reduce the material down to at least 1/2 inch to 1/4 inch to prepare the material for the next step. In addition to the further size reduction this step offers, it also aids in removing the loose fabric from the shredded material. (Passenger tyres have about 10 to 15 percent nylon or polyester fabric in them by weight.)
Separating the fabric from the rubber is typically done using an air system, which lifts the loose fabric out of the material stream. Each time the material is downsized, more fabric will be liberated from the rubber, and fabric separation will be required. However, some of the fabric can (and will) stay embedded in the rubber.

The approximate investment for the third processing step is $350,000 to $500,000, while the typical product size is 1/4 inch to 1/2 inch. Suitable end markets include horse arena cover and sports field additive, among others. The typical product value ranges from $200 to $300 per ton, depending on factors such as market, quality and customer demand. However, in countries where there is no legislation prohibiting the dumping of tyres, it is much more difficult to run a profitable operation, as this model is based on processors being paid to collect tyres. Without this additional revenue, the resale value of many tyre derived products may not be enough to process tyres and generate any meaningful profits.

An example of operating expenses for different stages of size reduction & material recovery from used tyres is given in following box.

Plant Equipment Operating Expenses:

Stage 1: Primary Shredder	**Twin Shaft, Slow Speed (Primary Shredder)**
Primary Shredder Input:	18144 kG/Hr (from manufacturer)
Primary Shredder Maintenance Cost:	£0.010725 £ per kG (from manufacturer x2)
Shredder, Classifier & Conveyor (s) Power Need:	135.0 kW kVAr (from manufacturer)
Maximum Planned Throughput:	15422 kG/Hr
Cut Size:	100 mm (from manufacturer)
Stage 2: Secondary Shredder (if needed)	**Single Shaft Rotary (Pre-Grinder)**
Secondary Shredder Input:	10000 kG/Hr ea (from manufacturer)
Secondary Shredder Maintenance Cost:	£0.004950 £ per kG (from manufacturer x2)
Shredder, Classifier & Conveyor (s) Power Need:	200 kW ea kVAr (from manufacturer)
Planned Output:	15422 kG/Hr
Cut Size:	50 mm (from manufacturer)
Stage 3: Primary Granulation /Metal Removal	**Large Granulator / Metal Separator**
Screen Size:	100 mm
Input	4000 kG/Hr ea (from manufacturer)
Primary Granulator/Metal Remover Maintenance Cost:	£0.008712 £ per kG (from manufacturer x2)
Granulator, Classifier & Conveyor (s) Power Need:	221 kW ea kVAr (from manufacturer)
Planned Output:	11875 kG/Hr total
Cut Size:	12.5 mm (from manufacturer)
Stage 4: Secondary Granulation	**Small Granulator**
Screen Size:	20 mm
Input:	3000 kG/Hr ea (from manufacturer)
Secondary Granulator Maintenance Cost:	£0.003872 £ per kG (from manufacturer x2)
Granulator, Classifier & Conveyor (s) Power Need:	147 kW ea kVAr (from manufacturer)
Planned Output:	10331 kG/Hr total
Cut Size:	6 mm (from manufacturer)
Stage 5: Powderisation & Fibre Removal	**Fine Granulator**
Screen Size:	10 mm
Input:	2500 kG/Hr ea (from manufacturer)
Powderiser Maintenance Cost:	£0.001936 £ per kG (from manufacturer x2)
Granulator, Classifier & Conveyor (s) Power Need:	50 kW ea kVAr (from manufacturer)
Planned Output:	10331 kG/Hr
Cut Size:	700 µm (from manufacturer)

Source: Russ Evan, EER Limited, New Business Financial Model Waste Tyre Recycling May 2006, The Waste and Resources Action Programme.
Note: Budgetary cost quotations and estimates are given and specified as and when the client contacts the suppliers, companies or the technology developers.

5.6.4 Waste Tyre Pyrolysis (WTP) for energy recovery from used tyres

Pyrolysis, also termed as thermal distillation or thermolysis, is a thermo-chemical treatment that allows breaking apart chemical bonds by means of thermal decomposition under non- oxidative conditions (inert atmosphere or vacuum) and it is also the first step in any gasification or combustion process. Pyrolysis has been addressed as an attractive thermo-chemical process to tackle the waste tyre disposal problem while allowing energy recovery. Pyrolysis enables the separation of carbon black from tyres and the volatile matter released, both condensable and non-condensable compounds, can be used as a source of energy[241]. There is a growing interest in pyrolysis as a technology to produce valuable products such as oil, char and hydrocarbon gas from waste tyres. The key influence on the material yield, carbon gas and oil composition, is the type of reactor used which in turn determines the temperature and heating rate. The most common reactors used in industrial scale are fixed-bed (batch), screw kiln, rotary kiln, vacuum and fluidized-bed. There are many classifications of types of pyrolysis depending on the operating conditions, such as the heating rate, the volatiles residence time and the temperature. A general simple classification is as slow and fast pyrolysis. Pyrolysis can be also classified on classified on the basis of the environment used such as oxidative pyrolysis, hydro pyrolysis, steam-pyrolysis, catalytic-pyrolysis and vacuum pyrolysis, and also depending on the heater system as the microwave or plasma pyrolysis. Conventionally, fluidized and entrained beds reactors are associated with fast pyrolysis whilst fixed bed reactors (FBR) with slow pyrolysis (a batch or semi-batch process). Other types of reactors such as the AR and the rotating cone (usually used for liquid production since the heating rate is high and the vapour residence time is relative short), may also be categorized for carrying out fast pyrolysis. However, it is worth noting that it is possible to perform fast pyrolysis in FBR adjusting the heating rate and the volatiles residence time[242] for research purposes. **Generally, industries adopt any one or more than one process type discussed above depending upon the client's requirement. . Small scale industries plan and design the entyre process flow subject to their financial affordability.** A scheme represent waste tyre pyrolysis process in **Figure 5.28**. Literature cites example of capital and operating expenditure for pyrolysis and its various applications including different scales. These examples are given in **Table 5.8, Table 5.9 and Table 5.10.**

[241] *Kyari, M., Cunliffe, A., Williams, P.T., 2005. "Characterisation of oils, gases and char in relation to the pyrolysis of different brands of scrap automotive tyres", Energy and Fuels 19, 1165–1173.*
[242] *Paul T. Williams, "Pyrolysis of waste tyres: A review", Waste Management 33 (2013) 1714–1728.*

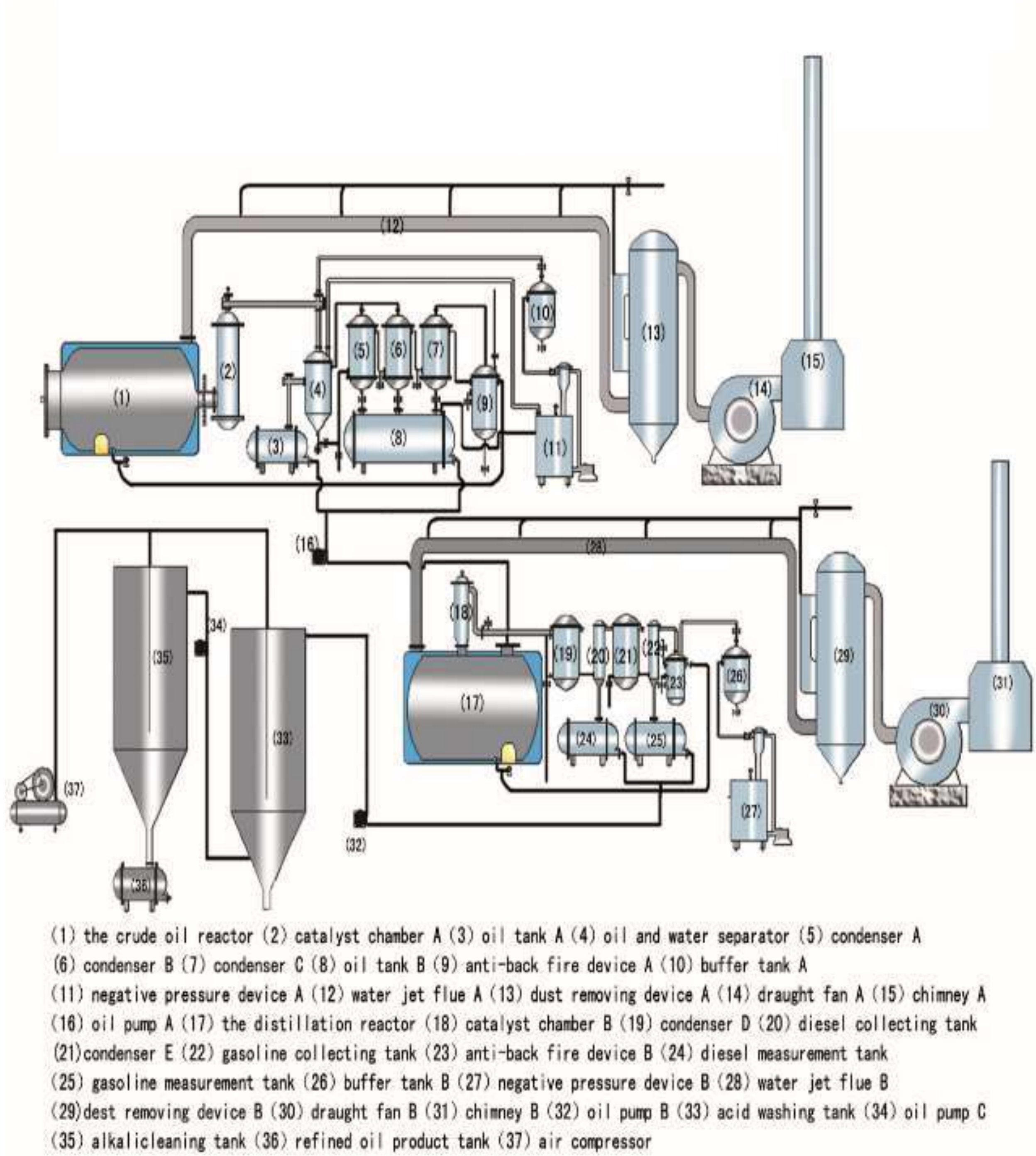

Figure 5.28: Schematic Flow Chart Representation of Waste Tyre Pyrolysis

Source: Huayin Renewable Energy

5.7 Other Specific Technologies Used in Waste Tyres

5.7.1 Retreading

It is considered to be one of the safe and efficient modes of treating the worn tyres to induce a new life in an environmentally friendly manner. The process involves the replacement of worn out treads with new treads, in a way that the tyre can be reused for its designated purposes. However, not every tyre can go through the retreading process. The tyres whose frame, carcass, are damaged cannot be retreaded. In general there are two techniques for retreading: Hot retreading or cold retreading. **Figure 5.29** shows one of the retreading methods.

Figure 5.29: One of the Retreading Methods (Ringtread Building) [provides improved endurance and performance]

Source: Marangoni

Hot retreading of a tyre uses vulcanisation in a mould at a temperature of around 150°C. The sidewall facing the tyre & the tread is normally made up of non-vulcanised rubber compounds. The shape of the tread can be adjusted based upon the requirements by using different moulds in the heating press.

Hot retreading is more economical as it costs only 45-60% of the price of a comparable new tyre. **Retreading in particular plays a crucial role in aircraft tyres mainly because the tyres are exposed to extreme stresses. The tyres in aircrafts have to withstand huge strain at speeds of over 250 km/h, and must undergo retreading after about 150 take-off and landing manoeuvres. The testing procedures involved in aircraft tyres are very stringent and safety comes as the foremost priority. The retreading in aircraft tyres can take place up to twelve times. Cold retreading involving vulcanization without the presence of mould and operates at temperatures between 95 °C and 110 °C. A pre-vulcanized tread liner is pasted on the worn out tyre through a non-vulcanized bonding gum layer. Figure 5.30** shows one of the tyre vulcanizing methods. Autoclave is utilized to create the bonding between the carcass, bonding gum and the new tread[243]. The cold rereading process requires less investment and lower maintenance costs. But the mileage is lower than that of tyres retreaded by hot retreading process.

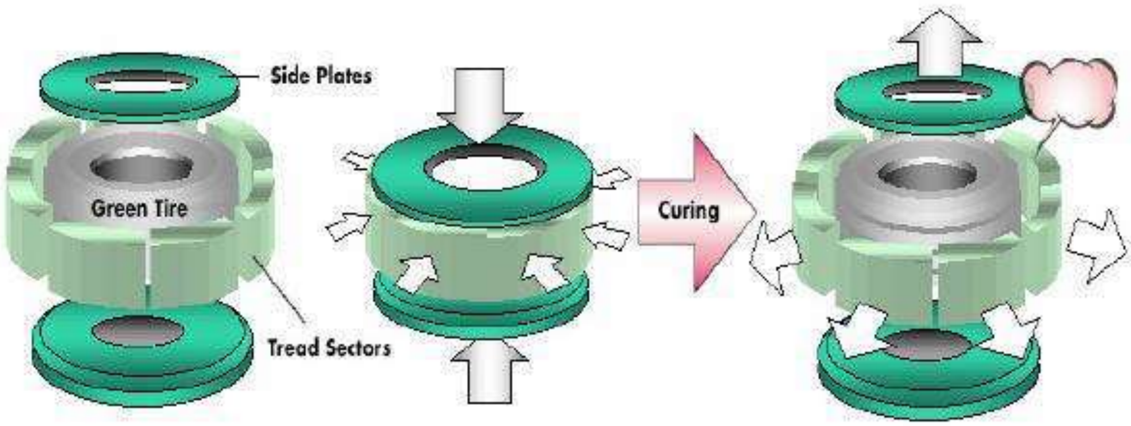

Figure 5.30: One of the Tyre Vulcanizing Methods (Curing process)

Source: tyrenews4u

5.7.2 Cement Kilns (incineration):

Cement production is an energy intensive process. Although coal, petroleum coke, and other fossil fuels have been traditionally used in cement kilns, many cement companies are turning to energyrich alternative sources such as waste tyres (**Figure 5.31**). Many cement plants across the globe meet a substantial portion (20% to 70%) of their energy requirements using alternative fuels. Cement klins are particularly suitable for using tyres as a fuel because rotary kilns (**Figure 5.32**) have very favorable technical conditions for burning used tyres without damage to the final product[244], and without adverse environmental impacts.

[243] *H.Vrakking (1953) BV Netherlands, Aircraft tyres/Industrial tyres/Truck tyres/Boat fenders*

[244] *Solution Note. "Cement Rotary Kilns temperature reading", Honeywell, Automation & Control Solutions, Process Solutions, USA, 2005.*

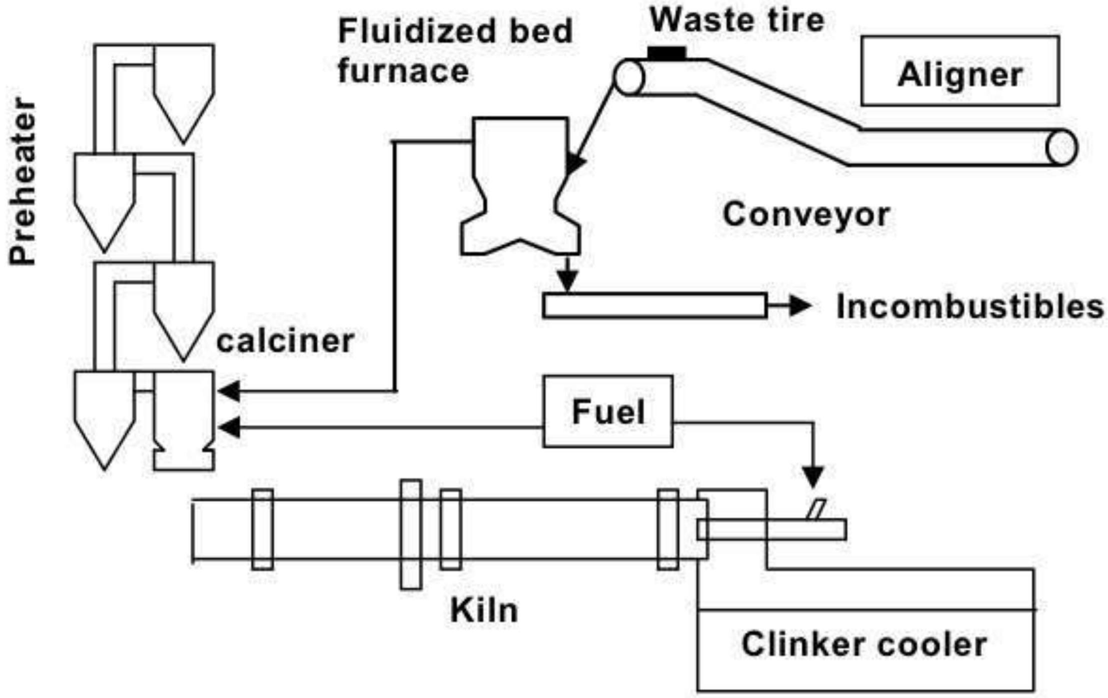

Figure 5.31: Flow Chart Demonstrating Cement Kilns Using Waste Tyres

Source: IETD-Industrial Efficiency Technology Database

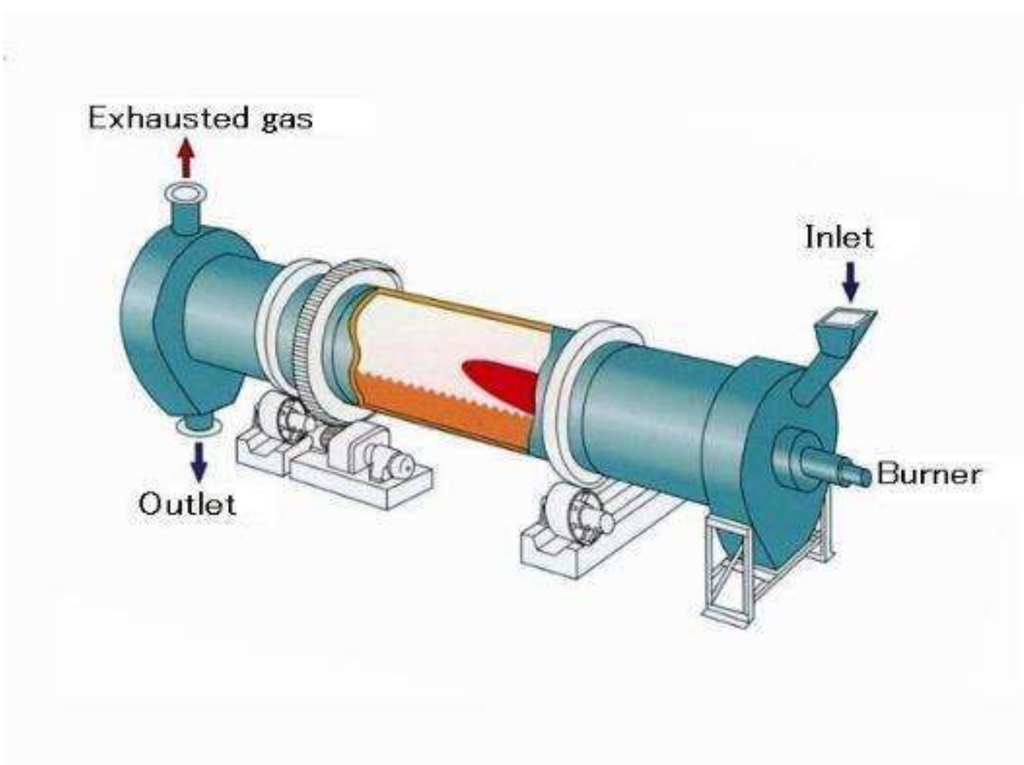

Figure 5.32: 3D Representation of Rotary Kiln

Source: MS-Machinery

5.8 Development of Criteria for Selection of Technology

One of the fundamental criteria for selection of technology, in a country's context its approach to waste hierarchy i.e. how it is referenced in policy and legislative framework. For example, in Australia, re-use through retreading of tyres is consistent with the objectives of its product stewardship scheme as it extends the life of tyres and delays their entry into the waste stream. There are no requirements imposed by the above mentioned scheme in relation to the retreading of tyres. Recycling and energy recovery (apart from direct incineration without effective energy recovery and unsustainable burning for energy recovery) are included in the definition of environmentally sound use. Disposal through dumping, landfill, direct incineration or burning are excluded in the definition of environmentally sound use.

Figure 5.33: Waste Hierarchy

Source: National Waste Report 2010, Environment Protection and Heritage Council and the Department of Environment, Water, Heritage and the Arts, 2010, p.21

Further, life cycle analysis can be used to assess the environmental impacts at each stage. Mapping of life cycle of tyre versus the above waste hierarchy is shown in **Figure 5.34**. Environmental impacts related to each of the stages of the tyre life cycle are given in **Table 5.8, Table 5.9** & **Table 5.10**.

Figure 5.34: The Life Cycle of a Tyre versus Waste Hierarchy

Source: A National Approach to Waste Tyres Prepared for Environment Australia by Atech Group, June 2001

Table 5.8: The Potential Environmental Impacts of Materials used in Tyres and Other Rubber Products

Material	Source	Application	Potential impacts
Natural rubber	Natural rubber is predominantly obtained from the sap of the *Hevea* ***brasiliensi*** **tree.**	**The proportion of natural rubber to total rubber has been declining steadily over the past several decades and currently makes up about 30% to 40% of the total rubber used.**	Loss of habitat in tropical forests - there are approximately 9.5 million ha of rubber plantation. Impacts of agricultural practices on local environments. Impacts from transportation to markets. **Impacts from processing including odour.**
Synthetic rubber	All of the synthetic rubbers are made from petrochemicals.	This makes up approximately 60 to 70% of the total rubber used.	Resource depletion of petroleum. Energy consumption, emissions and waste during manufacture.
Steel cord and beading including the coating materials and activators, copper/tin/zinc/ **chromium**	The steel is premium grade and is only manufactured in a limited number of plants around the world due to the high quality requirements.	Steel is used to provide rigidity and strength to the tyres. In a passenger tyre steel cord makes up about 15% by weight.	Impacts during production and transportation. Leaching of metals during disposal. Issues with difficulty in recycling.
Other reinforcing Fabrics	Predominantly sourced from petrochemicals.	Used for structural strength and rigidity. Makes up about 5% of a radial tyre.	Impacts during production and transport.
Carbon black	Generally sourced from petroleum stock.	Imparts durability and wear resistance and resistance to degradation. Makes up about 28% of a passenger tyre. The % is higher in the rubber that make up the wearing surfaces.	Impacts during roduction and transport.
Zinc oxide		Zinc is added to provide resistance to UV degradation, control vulcanisation and enhance blending. Zinc oxide makes up about 1.2% of a passenger tyre.	Impacts during manufacture and disposal. Impacts due to leach/ emission from waste tyres.
Sulphur (including compounds)	Sulphur is used to vulcanise the rubber.	Makes up about 1% of a passenger tyre.	Impacts during production. Impacts during combustion for energy recovery.
Other additives and solvents9: age resistors, processing aids, accelerators, vulcanising agents, softeners and fillers	The other additives are used in the various rubber compounds to modify handling manufacturing and end-product properties.	The additives make up about 8% by weight of a passenger tyre.	Impact associated with manufacture and transportation. Emissions during manufacture. Impacts associated with use and disposal of the solvents. Emissions from tyres in use, during recycling and in final disposal.
Recycled rubber	Recovered from used tyres or other rubber products.	Used in some rubber compounds in the manufacture of 'new' rubber products and retread materials.	Impacts from energy use in production.

Source: A National Approach to Waste Tyres Prepared for Environment Australia by Atech Group, June 2001

Table 5.9: Environmental Impacts from Retreading

Energy and material use	As retreading extends the life of a tyre and utilises much of the original materials and structure, the net result is a decrease in materials and energy used in comparison with new tyres.
Air emissions	The primary areas of concern appear to be VOCs (volatile organic compounds) from solvents, bonding agents and rubber compounds. Odour may also be an issue in some areas.
Solid wastes	Some waste is produced from retreading facilities due to reject tyres, rubber, retreads and compounding material. The rubber removed from used tyres before retreading is generally sold as rubber crumb, so does not constitute a waste

Source: A National Approach to Waste Tyres Prepared for Environment Australia by Atech Group, June 2001

Table 5.10: Summary of the potential impacts at each stage of the life cycle of a tyre or other rubber product

Life stage	Processes included	Impacts
Raw material	Natural rubber production Synthetic rubber production Steel and fabric production Production of various other additives incorporated in tyres Transportation	Resource depletion Agriculture (for natural rubber) Energy use Greenhouse and other emissions Solid and liquid wastes
Manufacture	Production of the basic components (sheet extrusions, etc) from which the products are made 'Building' of the tyre or other rubber product Vulcanising and finishing	Energy use Greenhouse and other emissions Solid and liquid wastes
Use	Use of the product for its design application	Tyres have a significant impact on the operation energy of vehicles resulting in energy use and emissions, dust from wear and tear
Recycling/ Reuse	Shredding Crumbing Energy/material recovery Whole split or punched tyres	Energy use Greenhouse and other emissions Solid and liquid wastes
Disposal	Disposal to land Uncontrolled stockpiling Disposal in landfill	Leachate to receiving environment Fires Free flow of landfill gas and leached compounds Mosquitoes and other vermin Visual impact Erosion
Transportation	Transport of raw materials Transport of new tyres Transport of used tyres to disposal or retreading Transport of waste tyres	Energy use, greenhouse and other emissions Noise

Source: A National Approach to Waste Tyres Prepared for Environment Australia by Atech Group, June 2001

An example of economic analysis of size reduction & material recovery is given in section 5.6.3 while for pyrolysis plant using different routes is given section 5.6.3 and in **Table 5.11, Table 5.12** & **Table 5.13**.

Table 5.11: Summary of Production Cost for Three Different Scale Solid Tyre Waste Pyrolysis Plants (US$)

Plant Capacity	**144 tons/day**	**36 tons/day**	**3.6 tons/day**
Base equipment cost	1.5×10^6	1×10^6	0.20×10^6
Fixed capital investment (FCI)	5.69×10^6	2.27×10^6	0.45×10^6
Total capital required	6.54×10^6	2.62×10^6	0.52×10^6
Annualized capital cost/Capital charges	768123	307249	61455
Fixed operating cost:			
Salary for employee	190304	110176	17528
Maintenance + overheads + taxes and insurance + other fixed operating costs	398125	159250	31850
Variable operating cost:			
Feedstock	901440	225360	22536
Electricity	450720	135216	22536
General overheads	114182	66105	10516

Plant Capacity	144 tons/day	36 tons/day	3.6 tons/day
Total operating cost	2054771	696107	104966
Total production cost of pyrolysis oil	2822894	1003356	166421
Unit production cost of pyrolysis oil (US$/ton)	136	193	321

Source: C. Hackett, T. Durbin, C. Bufalino, D Gemmill and J. Pence, University of California Riverside, Technology Evaluation and Economic Analysis of Waste Tyre Pyrolysis, Gasification, and Liquefaction, March 2006, Integrated Waste Management Board, California

Table 5.12: Capital and Operating and Maintenance Cost Estimates From Varous Sources, Normalized and Corrected for 2004

Feed Material	Gasifier Type	Feed Rate Plant (thousands of tonnes/yr)	Size Plant (kW thermal)	Capital Costs ($/tpa	Size Plant (kWe)	Capital Costs ($/kWe)	Conversion Efficiency, Percent (HHV)	O&M Annual Cost. Percent Capital	Total Ops. Cost. $/ton
Tyres	IGCC	0.233	289996	732.0	74500	2290.9	25.7	2.5	18.3
Tyres	IGCC	0.239	154.048	650.2	47000	1713.5	30.5	2.5	48.0
Tyres	Min	0.072	89552	620.8	30000	1853.0	33.5	2.5	19.3
Tyres	Max	0.072	89552	828.1	30000	2472.1	33.5	2.5	19.3
Tyres	Small scale	0.030	24069	750	8063	2238.8	33.5	2.5	15.0
Tyres	Small scale	0.030	24069	720.0	8063	2149.3	33.5	2.5	14.4
Tyres	Medium	0.100	80230	690.0	26877	2059.7	33.5	2.5	13.8

Source: C. Hackett, T. Durbin, C. Bufalino, D Gemmill and J. Pence, University of California Riverside, Technology Evaluation and Economic Analysis of Waste Tyre Pyrolysis, Gasification, and Liquefaction, March 2006, Integrated Waste Management Board, California

Table 5.13: Estimated Capital and Operating Costs for PGL Conversion Plants

Conversion Process	Capital Costs $/tpa	Capital Costs $/KWt	Conversion Efficiency (percent)	Annual Operating Costs (% capital)
Gasification with electrical power and process heat co-generation.	687	637	34.6% IGCC EPGS	7.5%
Gasification Alone. No air separation.	237	220	86% HP SPR+HGR	2.5%
Synthetic fuel process with heat recovery.	225	209	24.5% SMR+FTR with TMS	5.5%
Electric power with process heat co-generation.	450	417	26.2% steam turbine EPGS	6.5%
Gasification with synthetic fuel, electricity and process heat.	687	637	48% FT-SD 16% EPGS 2% heat and TMS	7.5%
Pyrolysis alone. No EPGS or heat recovery.	150	139		3.5%
Pyrolysis with EPGS and heat recovery.	600	556	26% EPGS 32% heat and TMS	6.5%
Liquefaction with no heat	137	127		2.5%

Conversion Process	Capital Costs $/tpa	Capital Costs $/KWt	Conversion Efficiency (percent)	Annual Operating Costs (% capital)
recovery.				
Liquefaction with heat recovery.	257	238	32% heat and TMS	4.5%

Source: C. Hackett, T. Durbin, C. Bufalino, D Gemmill and J. Pence, University of California Riverside, Technology Evaluation and Economic Analysis of Waste Tyre Pyrolysis, Gasification, and Liquefaction, March 2006, Integrated Waste Management Board, California

Nomenclature:

IGCC	integrated gasifier and combined (Brayton and Rankine) cycle power conversion 556
EPGS	electric power generating system.
HP SPR+HGR	high pressure steam pyrolysis and hydrogasification.
SMR+FTS	steam methane reformer and Fischer-Tropsch fuel synthesis reactor.

An example of a business model for material recovery facility for used tyres can been studied from Brunei Darussalam. This plant has been established in the Tutong District. This is a public-private-partnership (PPP) initiative, which involved the engagement of a local company whereby the company was given the freedom to propose and introduce technology for the purpose of material recovery, and so long as the technology was compliant to the emissions and discharge limits, within the capabilities and capacities of the company, and also within the realms of regional or the local market and expertise, and the technology was practical and implementable. Under this initiative, the company uses pyrolysis technique, processing used tyres to produce other valuable products such as fuel oil, carbon black and steel wires.

Above analysis indicates that, selection of technology in a country's context is to achieve environmentally sound management of hazardous/ toxic substances in End-of-Life (EoL) tyres, recovery of valuable materials, creation of economically viable and environmentally sustainable businesses inclusive of social considerations under local operations. **Table 5.14** describes economic, environmental & social attributes and indicators, which can be used by countries to arrive at decision for establishing end of life tyre management system.

Table 5.14: Criteria for selection of technology

Attributes	Indicators
Economic attributes	
Net costs (low Vs high)	Costs for transport, processing and labour vs. revenues
Capital costs (low Vs high)	Investment costs for additional plants and technologies used in a scenario
Increased potential for local economic growth (low Vs high)	Additional industries and services involved by implementing a scenario
Environmental attributes	
Use of electricity (low Vs high)	Savings of electricity but also energy in general by implementing a scenario
Fuel use for transport (low Vs high)	Fuel used by shipping and road transport
Use of freshwater (low Vs high)	Freshwater consumption of a recycling scenario
Emissions (low Vs high)	Caused vs. prevented emissions according to the savings of raw materials calculated
Material recovery rates (low Vs high)	Range and yields of material contained in the waste, which can be recovered and used as secondary raw material.
Social attributes	
Creation of jobs for the previously unemployed (Number)	Working hours for low-skilled and semi-skilled workers generated
Creation of highly skilled jobs (Number)	Working hours for highly skilled workers generated
Creation of jobs outside the target	Working hours generated outside the target country

Attributes	Indicators
country (Number)	
Health and safety impacts (Number)	Impacts of a scenario on health and safety of the employees engaged in a scenario

Companies practicing shredding process in developed countries are given in **Annexure 5.1**; List of Tyre Recycling Companies in Developing Country are given in **Annexure 5.2** and WTP technology suppliers from developed countries is given in **Annexure 5.3**.

5.9 Guidance Notes

Objective: The major objective of guidance notes is to assist technical personnel/tyre waste implementation agencies/ other stakeholders to identify technology options for tyre waste treatment. Further, the assessment of technology options will lead to design and development of technical specifications for tyre waste management system. The guiding principles for guidance procedure are given below.

- Initial considerations: investigate the supply of waste tyres in your area. Are there enough tyres to ensure supply and to offset investment costs?
- Market analysis: What tyre derived products can be produced from your rubber crumb and what prices can you achieve?
- Transport: Do you have access to suitable, cost effective transport to get waste tyres to the processing plant and to deliver your product?
- Land Use planning: Do you have a site suitable for large scale equipment (approx 2 hectares), tyre stockpiles, vehicles and administrative offices and is this land zoned for such use?
- Capital investment and ongoing costs: Calculate purchase prices of processing equipment, plus ongoing maintenance costs[245].

Guidance Procedure: Guidance procedure includes completion of following nine steps as given below

Step 1: Determine the supply of waste tyres as per guidance procedure given at the end of chapter 3.

Step 2: Carry out the market analysis of the items which can be recovered from the supply of the waste tyres for the next twenty years or more. This market analysis should be for domestic or international markets.

Step 3: Carry out technology option analysis based on generic & specific technology options.

Step 4: Determine collection and transportation system and the tentative location of the facility.

Step 5: Determine area of collection point/ storage facility considering tentative location of the facility. The area of collection point/ storage facility is fixed as per following guiding steps:

1. Calculate the Tyre Waste capture rate for the geographical area served in a given time frame (week/ month/ year).

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[245] *From Considerations for Starting a Scrap Tyre Company, A Blueprint for Planning a Business Strategy, published by the RMA, accessed Aug 7, 2013.*

2. Calculate volume of each of the tyre waste item based on tonnage captured in a given time frame.

Step 6: Determine number of Collection Points/ Storage Facilities their locations. These are fixed as per following guiding steps.

a. Collection target defines the number of collection points
b. Calculate the tyre captured as per geographical description.
c. Calculate each of the tyre waste capture rate per year in a particular area
d. Calculate the number of collection/storage points required to achieve the target rate
e. Determine the final number of collection points after studying the study area/ land use/ geography after deciding the location.
f. Calculate the Tyre Waste haulage capacity
g. Calculate the number of trucks/ trailers of different capacities required to transport the tyre waste.
h. Optimize the route and frequency of collection based on accessibility of the collection site.

Step 7: Determine layout and equipment specifications for Tyre Waste treatment facility. Different guiding steps to fix up layout and specifications for machinery/ equipment for second level tyre waste treatment facility are given below:

1. Determine the capacity of the treatment facility per day or per annum as per outputs of step 2 & step 3.
2. Determine stages of treatment of tyre waste based on level of size reduction of Tyre Waste item.
3. Determine process based on Tyre Waste treatment capacity per day and level of size reduction and other specifications. This will help to fix up the size shredder/ other size reduction machines.
4. The output of shredder/ other size reduction machines will assist to fix up the magnetic separation machines/ equipment.
5. The output from all the equipment will help to assist in defining specifications of conveying system eg. Speed of conveying system (feed rate as per required capacity of equipment).
6. Determine the consumption of the output from MRT for energy recovery (if required). Fix up specifications for technology option for energy recovery (if required).
7. After defining process elements invite technical quotations from equipment suppliers and identify the area required to establish the process.
8. Determine area for storing tyre waste inventory. This inventory is fixed based on transportation frequency of collected tyre waste items.
9. Determine storage area for finished products (if applicable).
10. Determine total area of tyre waste treatment facility by adding all the three areas mentioned in items 6, 7 & 8.
11. The facility should have balance, weatherproof covering, impermeable surface, spillage collection facility and equipment for treatment of water (if required).
12. Follow the building laws & environmental laws in fixing up the area of the facility.

Step 8: Identify and determine hazardous and non recyclable Tyre Waste fractions disposal options. Different guiding steps for this purpose are given below.

1. Identify the hazardous waste landfill sites closest to Tyre Waste treatment facility.
2. Identify the hazardous waste incineration facility closest to Tyre Waste treatment facility.

3. Check whether the identified facilities have capacities for disposal of Tyre Waste fractions or need up-gradation.

Step 9: General guidelines for Tyre Waste treatment facilities.

1. Prepare Environmental Impact Assessment report along with detailed project report of the Tyre Waste treatment facility.
2. Regular re-evaluation of environment, health and safety (EH&S) objectives and monitoring of progress toward achievement of these objectives is conducted and documented at all facilities.
3. Facilities take sufficient measures to safeguard occupational and environmental health and safety. Such measures may be indicated by local, state, national and international regulations, agreements, principles and standards, as well as by industry standards and guidelines. Such measures for all facilities include:

    - EH&S training of personnel.
    - An up-to-date, written hazardous materials identification and management plan.
    - Where materials are shredded or heated, appropriate measures to protect workers, the general public and the environment from hazardous dusts and emissions. Such measures include adaptations in equipment design or operational practices, air flow controls, personal protective devices for workers, pollution control equipment or a combination of these measures.
    - An up-to-date, written plan for reporting and responding to exceptional pollutant releases, including emergencies such as accidents, spills, fires, and explosions.
    - • Completion of an EH&S audit, preferably by a recognized independent auditor, on an annual basis. However, for small businesses, greater flexibility may be needed, and an audit every three years may be appropriate.

4. Facilities have a regularly-implemented and documented monitoring and recordkeeping programme that tracks key process parameters, compliance with relevant safety procedures, effluents and emissions, and incoming, stored and outgoing materials and wastes.

CHAPTER 6: TYRE WASTE MANAGEMENT MODELS

6.0 Introduction

As large quantities of waste tyres are produced worldwide annually, waste tyre management is becoming a priority in waste management. Waste tyre management differs from country to country. There is no consistent approach adopted by all countries and for many, mainly developing countries, no account can be found for the management of waste tyres at all. The different management practices discussed in this chapter could be references to countries who are considering to establish a waste tyre management system or improve the existing waste tyre management system. In order to make strategies that suit the local condition most properly, decision makers need to consider the local market, legislative framework etc. Based on the understanding of technologies of recovery of materials and energy from waste tyres and the local conditions, the waste tyres management system can be developed in an environmentally sound manner.

6.1 Management Practice of Waste Tyres

Although waste tyres management differs from country to country, there is still some consensus and common practice among different countries. The following sections describe stakeholder's responsibilities, existing waste tyre management models, & framework for effective waste tyre management system.

6.2 Stakeholders' Responsibilities

The major management practice of waste tyres is generally considered to be the shared responsibility of the tyre industry and government while the end user responsibility supports the identified major responsibility. The responsibilities of each sector involved are described below.

6.2.1 Tyre industry responsibility

In many developed countries the tyre manufacturers are considered to be responsible for the recovery and recycling or disposal of waste tyres, and this has been monitored according to the number of units sold within the country under industry stewardship programmes[246], [247]. Not-for-profit bodies administer these systems. Most often a separate fee is charged at the time of original sale, which increases public awareness of the program and funds the activities. In some regions, tyre manufacturers have promoted waste tyres as a resource and consequently have proactively pursued producer-responsibility systems. The objectives for the tyre industry to engage in management of waste tyres are:

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[246] *Estimates based on data from Rubber Manufacturers Association (RMA), 2005.*
[247] *Ministry of Economy, Trade and Industry (METI), Japan, 2003.*

- To ensure the industry fulfils its social and environmental responsibilities
- To ensure waste tyres are recognized as a potentially valuable secondary resource, in a global context of increasing resource scarcity and raw material costs
- To proactively manage threats to the industry of non-action (cost and image threats)
- To promote the goal of 100% recovery rate, to treat waste tyres generated annually and to treat existing stockpiles

6.2.2 Government responsibility

Governments have taken a direct role in clean-up programs. In the USA, many states have active programs to clean up existing stockpiles and eliminate the creation of new ones. Government administered bodies responsible for waste tyres have been established in some parts of Canada[248] where are not covered by stewardship systems. Industry and other stakeholders are frequently involved in governing the system as administered by the government. Specific taxes are levied on tyre sales, or taxpayer-funded systems operate using general tax revenue. Croatia, Denmark, Latvia and the Slovak Republic also have tax-funded systems. Each country has its own methodology to calculate and manage waste tyres.

6.2.3 End User Responsibility

End user responsibility is to support both tyre industry & the government in building an effective waste tyre management system. This includes development of regulations, collection, transportation, treatment & disposal and overall smooth functioning of management system.

6.3 Existing Waste Tyre Management Models

The World Business Council for Sustainable Development (WBCSD) carries out research on the existing models throughout the world. Although different global regions and countries have adopted different types of waste tyre management systems, nevertheless, three different existing options are identified: Producer Responsibility Model, Free Market Model and Tax Model[249]. Many countries have adopted a hybrid of these approaches. A comparison of the 3 models as per WBCSD is given in **Table 6.1**.

Table 6.1: Existing WT Management Models Comparison

Model Features / Model	Producer Responsibility Model (PRO)	Free Market Model	Tax Model
Disposal fee and how the fee is collected (flow of the fee)	Consumer pays fee at tyre purchase: all fees transferred to joint organization	Consumer pays fee at tyre purchase: fee is then transferred along management chain	Consumer pays fee at tyre purchase: fees transferred to government
Disposal route	Recycling / recovery. Some governments may require minimum material & of recycling or retreading	Recycling / recovery without targets	Recycling / recovery, eventually with targets managed by government

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[248] *ARRB Transport Research for Department of Environment and Heritage, Economics of Tyre Recycling, June 2004.*
[249] *End-of-Life Tyres, A framework for effective management systems Appendix, World Business Council for Sustainable Development (WBCSD)*

Model Features / Model	Producer Responsibility Model (PRO)	Free Market Model	Tax Model
Tyre manufacturers' responsibility	…until final disposal documentation is received by appointed recycler	… in some cases must report ELT recovery trends to government	… to grant that the tax is transferred from consumer to government
Government enforcement	Legal framework around PR model, identifying relevant responsibilities	Same as for any non-hazardous waste	Governments' and producers / importers' responsibilities established by law
Responsibility for illegal dumping	Person performing the illegal dumping	Person performing the illegal dumping	Person performing the illegal dumping
Responsibility for historical stockpiles	Tyre industry not responsible, but often voluntary oversees disposal to maintain good relationship and credibility with authorities	Government responsibility if the directly responsible person is not identified	Government responsibility

6.3.1 Brief Snapshot of the Models

In developed countries, like the USA and Japan, the large tyre companies are the driving force behind the management of waste tyres. In the free market approach, a large number of players are involved in working in compliance with overall directives from the government regulatory authorities. The overall system is composed of four components, as described below.

1) Collection of waste tyres

The tyre, when it can no longer be used for its intended purpose, is designated as waste tyre, and is transferred/sold/bought by an authorized agent for beneficial use (i.e., not for landfill or dumping). Tyre users dispose of waste tyres at authorized collection point, which may be a tyre dealer or a designated collection point. Fees/receipts to the collection point are based on market value or cost of waste tyre processing. The waste tyre owner is required to pay a disposal fee while purchasing the new tyre. Legislation involved in the collection of waste tyres ensures that the waste tyres can only be disposed off through authorized/certified tyre disposal routes or with authorized/certified collectors or dealers. It emphasizes that it is illegal to landfill or dispose off waste tyres in any form and finally states that storage of waste tyres at collection point should be regulated[250].

2) Transportation of waste tyres

Waste tyres are transported from the collection point and sorted according to standards to ensure the safe handling of the product. The companies are paid by the dealer/collection point to transport waste tyres to the sorter. Regulated storage and sorting facilities are needed. Waste tyres may be further transported for retreading or regrooving. Legislation should govern the operation of transporters, sorters and storage facilities, and require them to be authorized / certified[251].

3) Processing of waste tyres

Processing companies shred and/or grind tyres, i.e., they process waste tyres for alternative energy for use by recovery companies, or they process waste tyres to produce secondary raw material for

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[250] *ARRB Transport Research for Department of Environment and Heritage, Economics of Tyre Recycling, June 2004.*
[251] *Herbert, B. for the Australian Broadcasting Corporation, The World Today – Australian tyres prompt health Concerns, October 2009.*

use by recycling companies. Processing companies are either paid by or charged by (increasingly) the collector or third party, depending on local market conditions and legislation. The companies overseeing this stage are generally small or belong to an industrial group. Authorization for processing companies to operate includes regulations related to environmental performance, storage, fire safety, financial soundness and sustainability, etc. Chapter 3 explains the processing of waste tyres in detail and also lists various companies involved[252].

4) Recovery of materials and/or energy
The introduction of standards for waste tyre-derived products is the key for their recognition as alternative energy sources or secondary raw materials. Energy recovery is usually carried out by energy generation companies or industries like cement industry or steel industry which can make use of waste tyres as a source of energy. Recycling companies use secondary raw materials derived from processed waste tyres (e.g., ground or powdered rubber) for making products like asphalt, turf, thermoplastics, etc. Waste tyres (whole or shredded) are either paid for or charged for (increasingly) by the recovery or recycling companies, depending on local market conditions and legislation. Legislation should recognize waste tyre-derived products as alternative energy sources or secondary raw materials with respect to criteria identified by that country's/region's regulation[253],[254].

Producer's responsibility model is based on the concept of tyre producers being made responsible for its entyre life cycle. This model is based on the principles of extended producer's responsibility (EPR) where the system manager is the non for profit organization / industry association and (PRO) is responsible for meeting the targets & enforcement as per government regulations. Consumers pay fee at the time of purchase, which is transferred to PRO, which in turn is responsible to finance the entyre collection, transportation & recycling & disposal infrastructure.

Tax based model is based on the system management where the fee by the consumer at the time of purchase is transferred to the government & the entyre management system gets financed by the government.

6.4 Framework for Effective Waste Tyre Management Systems[255]

A Framework for Effective Management Systems" was developed by WBCSD in June 2010, which aimed to provide the industry with valuable information based on some of its experiences in waste tyre management from around the globe. It is hoped that it will support local management who were considering the establishment of a waste tyres management system or in societies where existing systems need to be improved. Anyone implementing a waste tyre management system must do so clearly understanding the local market, legislative framework, culture, etc. One of the primary requirement in developing the waste tyre management system is the legislation

Legislation of waste tyre will develop to respond to perceived needs. The tyre industry must participate in the design of public policies regarding WTs, and share its knowledge on WT

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252 *Herbert, B. for the Australian Broadcasting Corporation, The World Today – Australian tyres prompt health Concerns, October 2009.*
253 *Department of the Environment, Water, Heritage and the Arts, Australian Government, Consultation Regulatory Impact Statement for End-of-life Tyres Management, April 2008.*
254 *Department of the Environment, Water, Heritage and the Arts, Australian Government, Consultation Regulatory Impact Statement for End-of-life Tyres Management, April 2008.*
255 *End-of-Life Tyres: A Framework for Effective Management Systems, World Business Council for Sustainable Development Tyre Industry Project, June 2010*

management experiences from around the world. Stakeholders must be properly informed of all issues surrounding the WT management, and prepared to guide each other to effective and sustainable management systems, whatever the political and cultural context. Though regulation differ from country to country, all legislation that relates to successful WT management systems has the same key components As given in **Table 6.2**.

Table 6.2: Essential Components of WT Management Systems

Legislative Topic	Desired Content of Legislation
To promote a WT management program, legislation must clarify the responsibilities and obligations of all stakeholders	
WT Status	State that WTs are non-hazardous waste.
Responsibilities	The responsibilities of each stakeholder must be clear and agreed by all throughout the design and implementation of an WT management system.
Disposal of WTs	Ban illegal dumping/fly-tipping or uncontrolled landfilling.
Cost transparency	Separate line item on new tyre invoice showing tyre disposal Fee.
Transport of WT	All transporters must obtain a permit or license (permit includes background check against criminal activities, posting performance bond used to clean up any unlawfully dumped ELTs).
Storage	Comply with specific environmental and safety guidelines (e.g., length of time of storage, volume and configuration of storage).
WT-derived product Status	State that WT-derived products are secondary raw materials or alternative energy (criteria to be defined).
WT-derived product use	Promote use of WT-derived products in public contracts.
Reporting e.g., manifest System	A reliable reporting system has to be set up to secure a sound flow from the dealer to the recovery or recycling company. Every time the WT changes hands, requirements for reporting (transparent system, volume/weight, regular reporting, auditing procedure) must be met.
Enforcement	Set the right enforcement procedures to make sure the legislation is respected.

Source*: ETRMA

based on the legislation, a framework for effective waste tyres (WT) management systems can be designed by using the four steps as shown in **Figure 6.1**.

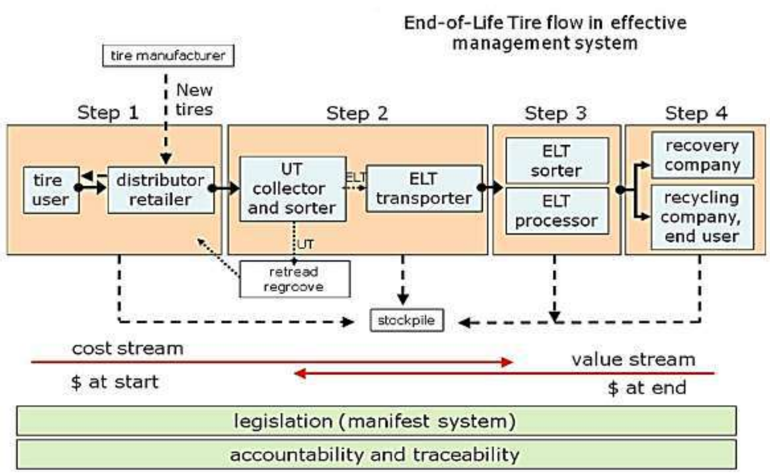

Figure 6.1: Model of an End-of-Life (ELT) Flow in an Effective Management System

Regardless of the type of system in place, ELT management systems must accomplish the following functions on a sustainable basis by following four steps as shown in **Figure 6.2** to **Figure 6.5** at the different stages of ELT management. These four steps are described below.

Step 1: Manage waste-tyre disposal
Step 2: Collect and sort UTs, and transport ELTs to ELT sorter/processor
Step 3: Sort and process ELTs
Step 4: Recover or recycle ELTs

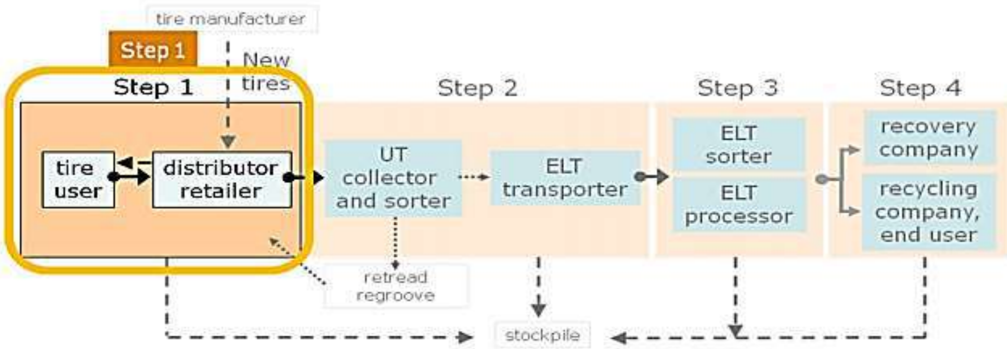

Figure 6.2: Step 1: Manage Waste-Tyre Disposal

Tyre user disposes of used tyre (UT) at authorized collection point, who may be a tyre dealer or a designated collection point. During the start of the system, payment is required so as to fund the process. In both cases, the UT owner is charged a disposal fee, which appears as a line item on their new tyre invoice. Fees/receipts to the collection point are based on the current market value or cost of ELT processing. The collection point is responsible for appropriate handling.

The UT, when no longer useful for its intended purpose, is designated as an ELT, and transferred/sold/bought by an authorized agent for beneficial use (i.e., not for landfill or dumping). Legislation should ensure that:

- ELT can only be disposed of through authorized/certified tyre disposal routes or with Authorized/certified collectors or dealers.
- It is illegal to landfill or monofill UTs in any form (including ELTs).
- Any storage of UTs and ELTs at collection point is regulated.

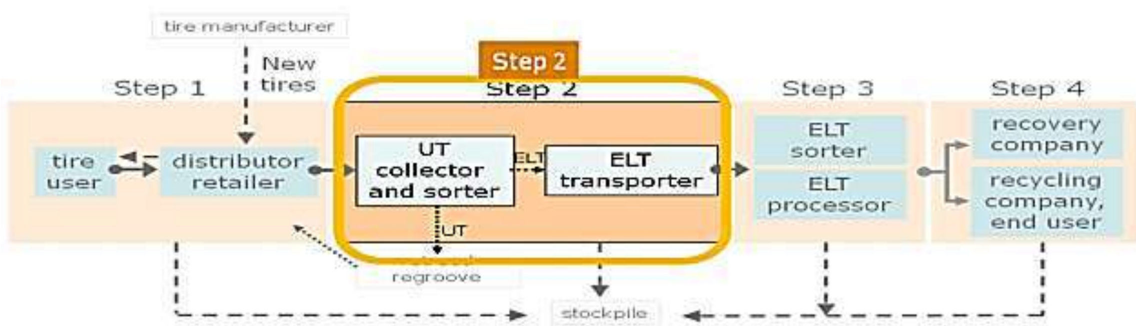

Figure 6.3: Step 2: Collect and Sort UTs, and Transport ELTs to ELT Sorter/Processor

UTs are transported from the collection point and sorted into UTs or ELTs. The companies are paid by the dealer/collection point to transport ELTs to the ELT sorter, processor or third party (storage/sorting facility). UTs are transported for retread or regroove or any other designated processes depending on the condition of UT.

Legislation should govern the operation of transporters, sorters and storage facilities, and require them to be authorized / certified. Land-filling or monofilling UTs in any form (including ELTs) should also be made illegal and further strict code of law should be imposed.

UTs/ELTs are sorted for processing. Processing companies shred and/or grind tyres, i.e., they process UTs/ELTs for alternative energy for use by recovery companies, or they process UTs as a secondary raw material for use by recycling companies. Processing companies are either paid by or charged by (increasingly) the collector or third party, depending on local market conditions and legislation. The companies overseeing this stage are generally small or belong to an industrial group.

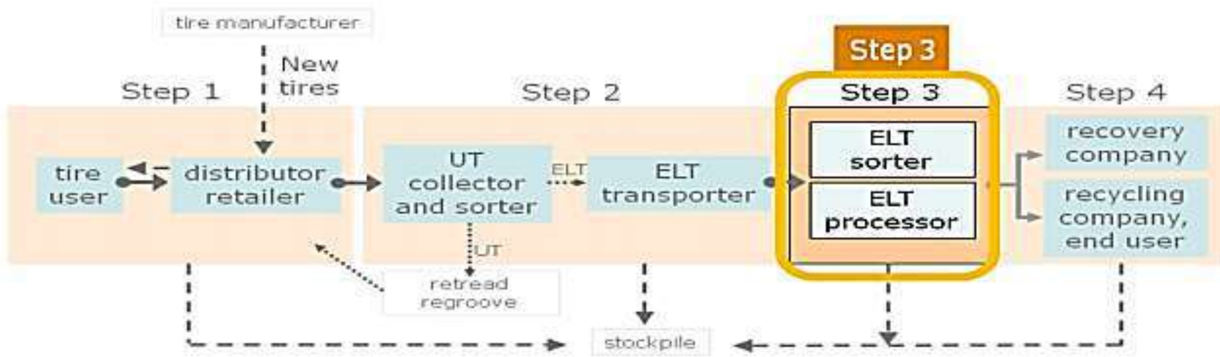

Figure 6.4: Step 3: Sort and Process ELTs

Legislation should ensure that land-filling and mono-filling are regarded as the least favored options. Authorization for processing companies to operate should be based on strict regulations related to storage, fire safety, financial soundness and sustainability, etc.

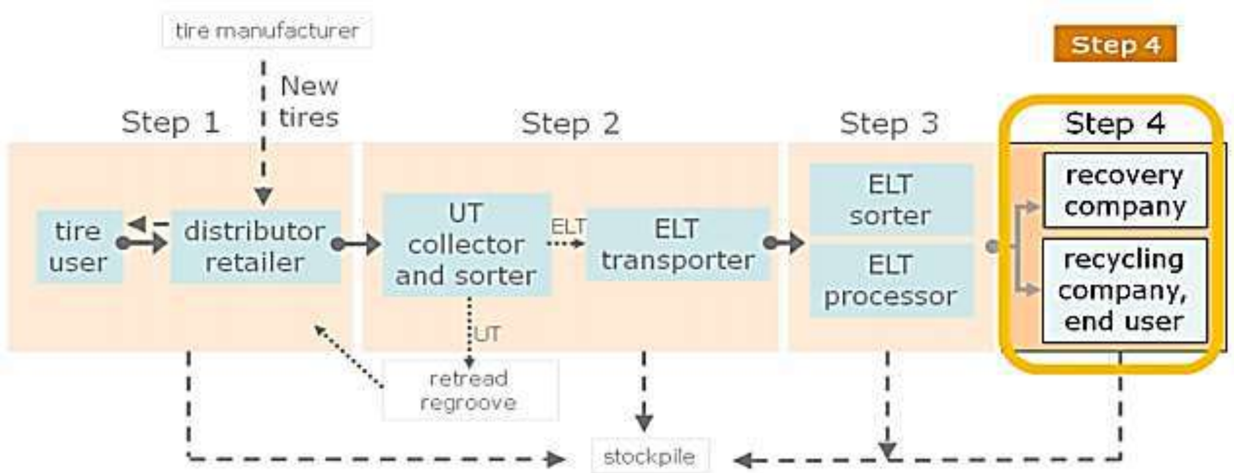

Figure 6.5: Step 4: Recover or Recycle ELTs

Energy generation companies: cement kiln or other energy use. This use is based on calorific properties and must respect local environmental regulations. They generally belong to an industrial group. Recycling companies: material use, for example, asphalt, turf, steel plants, thermoplastics, or other products derived from processed WTs (e.g., ground or powdered rubber) used as secondary raw materials. These are generally small companies that can belong to industrial groups.

The introduction of standards for ELT-derived products is a key for their recognition as alternative energy sources or secondary raw materials and for their payment as such. Legislation must recognize this and address the need to avoid land-filling and mono-filling.

It is beneficial if processing, recovery and recycling companies participate in R&D projects to develop new applications for WT-derived products. Where possible this should be conducted in association with the tyre industry, laboratories, universities and administration.

6.5 Accountability Throughout the Whole System

In principle, throughout all steps, each sector must operate in a way that ensures a reliable and transparent supply chain, with appropriate traceability systems in place. At every stage of the process, from the time the WTs are collected to its final end market, a manifest system must be in place to document the tyre's disposal route (including tyre characterization (type of tyre, etc.), date collected and left by tonnes or units, details of end recipient, etc.). UT/ELTs are effectively managed on the basis of weight, which should be stipulated by law. When the traceability system is based on item weight, and when this is thoroughly implemented at every step of UT/ELT management, the deviation of ELTs from the authorized management system into illegal landfilling or dumping is prevented. This is basically a paper trail to ensure that all regulations are followed and the tyre is treated appropriately at every stage of WT management. The data obtained through the assessment should be shared with the third party vendors. At the stages of ELT transportation, sorting and end market use, periodical verification is necessary to ensure adequate safety and environmental standards are met in areas: Audit scores; Record keeping; Financial standing (i.e., solvency); Financial security (insurance and bonding) and Legislative Requirements for Effective WT Management

6.6 Guidance Notes

The major objective of the guidance notes is to assist the target audience to plan & develop the tyre waste management system by following the steps described below.

Step 1: Identify different stakeholders as per steps 5, 6, & 7 of guidance notes given in chapter 2 e.g. producers, importers, exporters, distributors/retailers, collection points, dismantlers, recyclers and disposal.

Step 2: Carry out review of existing tyre waste policies, laws and regulations (e.g. EPR policies and other national policies and items within the regulatory framework). Identify gaps with respect to existing environmental regulations and recommend tentative content, including the extent and coverage of tyre waste policy, laws and items within the regulatory framework.

Step 3: Assign physical responsibility for the collection, treatment, recovery, recycling and disposal of tyre waste from consumers.

Step 4: Assign financial responsibility (e.g. individual or collective financial responsibility for "new" and "historical" waste) to the stakeholders addressed by the legislation or regulation.

Step 5: Map the proposed tyre waste regulations, including the associated responsibilities of stakeholders.

Step 6: Carry out a gap analysis with respect to the outputs of step 5.

Step 7: Organize workshops of major stakeholders like line ministries and government agencies (e.g. those with responsibilities industry association, environment, forests, finance, economy and commerce), industry associations, retailers' associations, municipalities, formal and informal recyclers, transporters, operators of incinerators and hazardous waste management facilities, and NGOs and CSOs to arrive at an acceptable tyre waste policy, laws, and regulations as well as institutional mechanisms.

Step 8: Fix the target of the tyre waste inventory to be collected and transported within each geographic area. This can be accomplished by using the outputs from the guidance procedures given in chapter 3.

Step 9: Assess the waste collection and transport infrastructure required to meet the target to be achieved.

Step 10: Assess the price sensitivity of procuring and collecting waste tyre with respect to the distance to the collection centre and the quantity to be collected under a "business a usual" scenario. This can also be correlated to the capacity of the recycling facility in terms of the numbers of trucks required per day from the catchment area to feed the recycling facility.

Step 11: Carry out a pilot study in order to assess consumer behavior and address collection and transport requirements.

Step 12: Assess tyre waste collection and transport infrastructure requirements based on the outputs of steps 10 and 11.

Step 13: Carry out a cost-benefit analysis of the infrastructure under a "business as usual" scenario and assess the viability gap for waste item. This will form the basis for developing econometric tools such as an end-of-life (EOL) tax or advanced recycling fee (ARF).

Step 14: Identify the responsibilities and their allocation under regulatory requirements as an outcome of following steps 1 to 14.

Step 15: Identify the model(s) that may be applicable in a given country. Identify the economic instrument that could be used, such as a tax, a fee or a combination of both.

Step 16: Develop an economic instrument, such as a product fee based on the salvage value cost, technical cost and administrative cost.

Step 17: Calculate the technical costs consisting of collection and transport costs & dismantling/recycling and disposal costs.

Step 18: Estimate the administrative costs based on similar activities already underway in a country with similar circumstances.

Step 19: Organize a workshop with different stakeholders, including producers, recyclers, collectors, logistics providers, government agencies, and municipalities in order to discuss the outputs of steps 8 to 18 and arrive at consensus on the economic instrument to be introduced, such as a fee, a tax or a combination of the two. Identify the fund flow and arrive at consensus in identifying the fund manager.

Step 20: Develop monitoring and auditing requirements for each category of stakeholder along the material flow chain. Auditing may include product audits, financial and accounting audits and collection and transport audits.

CHAPTER 7: CASE STUDIES OF WASTE TYRE MANAGEMENT BY COUNTRY / REGION

7.0 Introduction

In this section, some waste tyres (WT) case studies describing management practices in different countries (developed & developing) have been discussed, which could be as reference for countries planning to develop their own waste tyre management strategies. Further, these case studies also show case outputs expected from chapter 2 to chapter 6.

7.1 Case Studies: Developed Countries (WT Management in Australia, WT Management in Canada, WT Management in European Union, WT Management in Hong Kong, WT Management in Japan and WT Management in United States of America

7.1.1 Waste Tyre management in Australia

Waste tyre management in Australia has been described in terms of waste tyre inventory assessment and strategy / plan and the management system.

Australian methodology for assessing the quantity of WT

In Australia, there have been numerous reports commissioned by both the State and Federal Governments, investigating various aspects of the waste tyre industry. In 2012, the Council of Australian Governments Standing Council on Environment and Water (SCEW) commissioned Hyder Consulting to carry out a study into the domestic and international fate of waste tyres. The final report found that approximately 48.5 million tyres Equivalent Passenger Units (EPU) entered the waste stream in 2009-10 (compared to 41.8 million in 2007-08). Tyres were classified into three categories; Passenger, Truck, and Off-The-Road (OTR) tyres. The percentage that these categories of tyres contributed to the overall end-of-life tyres in Australia (EPU) after the secondary usage is as follows:

- Passenger: 20,596,893 (42.5%)
- Truck: 14,673,882 (30.27%)
- OTR: 13,197,603 (27.23%)

- An EPU is a standardised measure for the quantity of waste tyres.
- One EPU contains as much rubber and other materials as a 'typical' passenger tyre.

They can be further subdivided by state as given in **Table 7.1**.

Table 7.1: EPUs Generated Per Jurisdiction (Hyder 2012)

State/Territory	Total EPU	Percentage
ACT	403,147	0.83%
NSW	12,620,986	26.04%
NT	673,660	1.39%
QLD	11,006,907	22.71%

State/Territory	Total EPU	Percentage
SA	3,598,172	7.42%
TAS	1,242,732	2.56%
VIC	10,514,094	21.69%
WA	8,408,678	17.35%
Total	**48,468,376**	**100.00%**

Table 7.2: Final Domestic Destination for EPU's 2009-10 (Hyder 2012)

Domestic destination	Total EPUs	Percentage
Recycling	4,928,500	10.2%
Energy recovery	250,000	0.5%
Civil engineering	2,793,000	5.8%
Licensed landfill	1,611,192	3.3%
Unknown	30,344,169	62.6%
Total*	**39,926,862**	**82.4%**

Note: *The remaining 17.6% of tyres are accounted for in export statistics

A key limitation to this data is that not all OTR (Off-the-Road) vehicles are required to be registered. To overcome this, the default lifespan of OTR tries was set to 12 months. **Table 7.2** provides a summary of the final destination of end-of-life tyres within Australia. It should be noted that the final destination of more than 60% of end-of-life tyres is unknown[256].

The outcome of inventory assessment and establishment of the waste trade value chain, a management strategy / plan and EPR based Tyre Stewardship Australia (TSA) model was evolved.

Tyre stewardship Australia (TSA) and used tyre assessment

The Australian Government's Tyre Implementation Working Group (IWG) has delivered draft guidelines for the voluntary industry-led tyre product stewardship scheme.. Tyre Stewardship Australia (TSA) is a voluntary, industry-led scheme that aims, primarily, to increase the recycling rate of WT[257]. Tyre product stewardship scheme generally acts as an organising committee between parties in the tyre supply chain to share responsibility for the long term management of WT in Australia. The major objectives of the Tyre Product Stewardship Scheme are to: i) Increase the resource recovery and recycling and minimise the environmental, health and safety impacts of WT generated in Australia, ii) Develop Australia's tyre recycling industry and markets for tyre derived products.

As key elements[258] of the strategy, (TSA) include:

- Tailor its activities and investment strategies to ensure increased recycling and resource recovery on a local, regional and national basis, in recognition of the unique geographical and regional challenges in Australia, and
- Work with governments to remove impediments to the establishment of a sustainable domestic tyre recycling industry and markets for tyre derived products.

The scope of this strategy is to develop an approach for waste tyre management across the State including:

- Encouraging the development of a self-sustainable waste tyre recycling industry;

[256] *Gunter M. The Environmental Suitability of Shredded Scrap Tyre Chips in a Saturated Environment. University of Wisconsin as cited in The Environmental Impact of EcoFlex Paving Systems, EcoFlex, Australia.*
[257] *Hyder Consulting for the National Environment Protection Council, Study into end-of-life tyres, 23 March 2009.*
[258] *Net Balance for the Department of Environment, Water, Heritage and the Arts, Final Report Product Stewardship Common Data Requirements, October 2010.*

- Optimizing the recovery and resource value from waste tyres throughout the state;
- Minimizing the problems associated with waste tyre disposal; and
- Compatibility with the implementation of a national scheme for waste tyres.

More specifically the strategy aims to identify appropriate waste tyre management options that can be sustainably implemented in Western Australia, mechanisms for their introduction and to recommend an action plan. The Action Plan also assigns responsibilities for each action to one or more stakeholder. Issues related to extending the life of the tyre, addressing ongoing tyre wear-and tear and use of recycled rubber in the manufacture of new tyres are best addressed by the tyre industry itself at a national level.

The key objectives of the strategy will be achieved through the following steps.

Step 1: a series of commitments requiring tyre importers, retailers, collectors, transporters, recyclers, governments, fleet operators and other consumers to play an active part in ensuring WT are designated to their respective applications and ELT are disposed in a way which is environmentally friendly and sustainable.
Step 2: enterprise to enterprise agreements or contractual arrangements between individual businesses and organisations, which give effect to the industry wide long range withstanding commitments.
Step 3: a tyre stewardship fund used to support the activities of the scheme and for investment in research and development for new technologies and market development.
Step 4: a company called Tyre Stewardship Australia, funded by tyre manufacturers and importers, which will be responsible for administering the scheme and for working to remove impediments to the development of a sustainable domestic tyre recycling industry.

Finally, this strategy is designed to identify achievable actions by following above steps within the foreseeable future. It aims to provide leadership in encouraging the development of a self-sustainable local tyre recycling industry and to set the groundwork for the introduction of the National Tyres Product Stewardship Scheme.

7.1.2 Waste Tyre Management in Canada

Like many other countries in the world, Canada has had to find alternatives to landfills for waste tyre disposal. In the late 1980's and early 1990's, Canada disposed of their tyres by simply burning them. However, after 13 million waste tyres burned uncontrollably in Ontario, Canada, they had to find alternative ways to deal with their disposal (Farrell, 2000). Most provinces in Canada decided to levy a tax on new tyres in order to fund recycling programs. These programs are run privately under what are called stewardship programs, with each province having its own program. These stewardship boards are responsible for tax collection, as well as distributing incentives to the tyre tax recyclers. Rubber is the most popular by-product of recycled tyres. Therefore, most recycling processing firms concentrate on obtaining rubber from the tyres and turning them into crumbed rubber. Crumbed rubber is then used by different industries to make such products as rubber mats, mud flaps for trucks, automotive and industrial parts, sports fields/turfs, and rubberized pavements and roads.

Different regions in Canada have slightly different stewardship programs, which are discussed below:

New Brunswick is the eighth largest province or territory in Canada, with a population of approximately 800,000 people. It is also one of three Maritime Provinces in Canada. New Brunswick, much like the other provinces and territories in Canada, had a problematic waste tyre disposal problem and sought to fix it by implementing a waste tax levy and a stewardship board to ensure that the taxes from the levy are used to recycle waste tyres. The New Brunswick Department of Environment created the New Brunswick Stewardship (**Table 7.3**)board in October 1996.

The board's primary goal is to divert waste tyres from waste disposal facilities and ensure that they are recycled through collecting levies from retailers and by providing financial assistance (for transporting the tyres and processing them) to waste tyre recyclers. Every year the board collected approximately 15 million tons of waste tyres (cumulative in every following year) and collected approximately $3 million CAD (Canadian Dollars) from levies and fees. The breakdown of the levies and fees are as follows: tyres up to 17" in diameter require an additional fee of $3CAD, and tyres up to 24.5" require a fee of $9CAD.

The board receives the levies through remittances from tyre retailers once a month. Retailers are offered the option of having the Board pick up their waste tyre instead of paying a hauling fee or landfill tip. The board has also designed a 'tyre round up program', where residents can drop off their old tyres at designated locations around the province. After the waste tyres are collected, they are then processed and used as raw material for products like livestock mattresses for dairy operations, synthetic roofing shingles, and re-treaded tyres.

Table 7.3: New Brunswick Stewardship

The New Brunswick Stewardship Board is composed of five members;	
Government Appointee	1
Member New car Dealership	1
Atlantic Tyre Dealers Association	1
Tyre Dealer	1
Trucking Company Member	1

Manitoba is the fifth largest province in Canada with a population of approximately 1.2 million people and is located in western Canada. Like New Brunswick, Manitoba also created a Stewardship program to deal with their waste tyre problem (**Table 7.4**).In 1992, the government of Manitoba, under the Waste Reduction and Prevention Act (WRAP Act), created a tyre levy on new tyres that were sold in Manitoba.

Initially the department of Finance collected the levies, but the government established the Manitoba Tyre Stewardship Board on April 1, 1995, and they assumed the collection of the levy (Farrell, 2000). The Stewardship board is directly responsible for licensing all tyre and motor vehicle dealers in order to collect the levies from them (The Manitoba Tyre Stewardship Board, 2007). The money collected by the board is used to pay for the collection, transportation, storage, processing and disposal of ST.

Unlike most other provinces, Manitoba has only levied a tax on the purchase of passenger vehicles and lightweight trucks. The levy comprised of a $2.80 CAD fee on all tyres purchased and $0.20 CAD Provincial sales tax (The Manitoba Tyre Stewardship Board, 2007). In 2005, the Manitoba Tyre Stewardship board collected approximately $3 million CAD from fees and levies (Discussion Paper: The Stewardship Program, Energy Science and Technology, 7th January 2006). The board supports several contractors that recycle tyres; these contractors recycle waste tyres and create products such as blasting mats, tyre-derived fuel and cattle mats for trailers.

Table 7.4: Manitoba Stewardship

The Manitoba Stewardship Board is composed of five members;	
Lieutenant Governor Council Appointee	2
Manitoba Motor League	1
Western Canadian Tyre Dealers Association	1
Rubber Association of Canada	1

British Columbia is located on the west coast of Canada and is the third largest province with an estimated 4.4 million people. In 1991 British Columbia became the first province to pass a comprehensive waste tyre management law, under the mandate of this law, the Financial Incentives for Recycling Scrap Tyres (FIRST) program was introduced in June 1991. FIRST is a government program that provides financial incentives for the transportation and recycling of waste tyres. In order to fund the FIRST program, a tax was levied on all tyres that were newly bought. The Tyre Stewardship of British Columbia (TSBC)* replaced the FIRST program on January 1, 2007, after 16 years of operation (Moore M., 2007). The TSBC (**Table 7.5**) is a non-profit organization, whose goal is to manage the waste tyre recycling program on behalf of the tyre retailers in the province. The TSBC funded its program with the tax that was used by the FIRST program. At this point, the tax is $4.00 CAD for all passenger and light truck tyres. The funds obtained from the tax are used to finance transportation incentives, as well as providing financial support for the research and development of new methods to recycle waste tyres.

Table 7.5: TSBC Board

The TSBC board is composed of seven members;	
Western Canada Tyre Dealers	3
Retail Council of Canada	1
Rubber Association of Canada	2
New Car Dealers Association *(Tyre Stewardship Board B.C,)*	1

7.1.3 Waste Tyre Management in European Union

The European Union countries account for over 50% of waste tyres. The companies organize collection and recovery, participate in research and development activities for new recovery routes, liaise with local authorities and promote the introduction of product standards. In addition, the European Tyre & Rubber Manufacturers Association (ETRMA) has established 'The Waste Tyres Group' to promote waste tyres as a resource and to propose regulations and directives for their proper management. **Table 7.6** given below developed by ETRMA is a dynamic typical reference to calculate the quantity of ELT piled up in a nation and the amount of material & energy recovered from the scrap/piled up tyres. ETRMA covers the 27 EU states as the members plus the addition of Norway & Switzerland. ETRMA has a standardised regulatory principle and governance over the tyre management of the member states.

EU member states of ETRMA disclose the entyre tyre cycle from its manufacturing till recycling through the state statistical reports. Each state has a number of association and councils to govern the tyre production and management of waste tyres. ETRMA collectively generates and maintains the statistics of the number of tyres produced within the member states, record for number of tyres in use, generation of waste tyres, regulations to manage WT to its member states, record generation for the materials & energy recovered from waste tyres, percentage of conversion of tyres manufactured to recycle and application of the recycled materials. It acts as a window to acquire knowledge and awareness about the current standards in tyre regulations in EU. It also provides information to other developed and developing nations on the proactive measures of developing a sustainable tyre industry without affecting the society and the environment.

> Several other countries like Japan, Korea, Brazil and Australia adopt methodology similar to the EU. In Japan, "The Fundamental Law for Establishing a Sound Material-Cycle Society", the Japan Automobile Tyre Manufacturers Association Inc. (JATMA) promotes the 3Rs - "Reduce, Reuse and Recycle" to coordinate the collection and recovery of used tyres, and to encourage further research and development. JATMA has also implemented a program for the removal of legacy stockpile sites. In Korea manufacturers and importers pay a deposit fee that is refunded if they collect the used tyres. Brazil requires importers to demonstrate the disposal of 20% more tyres per annum than they import. Stewardship systems also exist in South Africa and about half of the Canadian provinces. Nigeria and Turkey have also begun stewardship systems and Russia is also considering proposals.

Table 7.6: Quantity of ELT Stockpiled in Europe Nations and the Amount of Material & Energy Recovered from the Scrap/Stockpiled Tyres (EU)

National Figures	A	B	C	D	ELT (E) E=A-(B+C+D)	Material Recovery (UT)			Energy (UT)	J	K (B+C+D +H+I)	L
						F	G	H H=F+G	I			
Austria (est.)	63	0	0	3	60	0	24	24	36	0	63	100%
Belgium	87	0	8	5	74	1	59	60	14	0	87	100%
Bulgaria(est.)	25	0	0	3	22	0	8	8	5	9	16	64%
Croatia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cyprus (est.)	4	0	0	0	4	0	0	0	0	4	0	0%
Czech Rep. (est.)	63	0	0	2	61	0	10	10	32	19	44	70%
Denmark	44	0	1	0	43	0	43	43	0	0	44	100%
Estonia (est.)	10	0	0	0	10	0	6	6	3	1	9	90%
Finland	53	0	0	1	52	46	4	50	2	0	53	100%
France	416	45	0	48	323	50	115	165	158	0	416	100%
Germany	670	10	92	85	483	0	220	220	263	0	670	100%
Greece	44	0	2	2	40	0	23	23	11	6	38	86%
Hungary	43	0	0	0	43	4	18	22	21	0	43	100%
Ireland	28	3	1	2	22	6	14	20	0	2	26	93%
Italy	433	27	21	34	351	0	70	70	180	100	332	77%
Latvia (est.)	10	0	0	0	10	0	5	5	4	1	9	90%
Lithuania (est.)	11	0	0	0	11	0	5	5	4	2	9	82%
Luxembourg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Malta (est.)	1	0	1	0	0	0	0	0	0	0	1	100%
Netherlands	65	0	16	2	47	0	37	37	10	0	65	100%
Poland	190	5	0	20	165	0	55	55	110	0	190	100%
Portugal	90	1	0	17	72	0	47	47	25	0	90	100%
Romania	57	0	0	0	57	0	14	14	43	0	57	100%
Slovak Rep. (est.)	25	0	0	1	24	0	23	23	1	0	25	100%
Slovenia (est.)	11	0	0	0	11	0	6	6	5	0	11	100%
Spain	283	10	24	35	214	14	92	106	108	0	283	100%
Sweden	73	0	1	0	72	13	16	29	43	0	73	100%
UK	369	27	24	32	286	17	149	166	113	7	362	98%
Total EU	**3,168**	**127**	**188**	**292**	**2,557**	**156**	**1,063**	**1,214**	**1,199**	**151**	**3,016**	**90%**
Non EU Countries												
Norway	45	0	0	0	43	16	19	35	8	0	45	100%
Switzerland	53	3	5	5	45	0	13	13	32	0	53	100%
Turkey	246	N/A		N/A	246	0	49	49	43	103	92	75%
Total Non EU	**344**	**3**	**5**	**5**	**334**	**16**	**81**	**97**	**83**	**103**	**190**	**92%**

*Legend: [**A** - Used/Scrap Tyres (UT); **B** – Reuse; **C** – Export; Retreading; **E** – ELT; **F** – Civil Engineering, Public Works & backfilling; **G** – Recycling; **H** – Total Material Recovery; **J** – Landfill/Unknown; **K** – Total UT (used Tyres) Recovery; **L** – UT treated;]*

Numbers represent quantity in tons x 1,000.

7.1.4 Waste Tyre Management in Hong Kong

Waste tyres are classified as special waste in Hong Kong, which means they need special treatment. Based on the local situation of waste management, the waste tyre management in Hong Kong has three major issues:

- Identify the scale of the problem
- Establish a local processing system
- Research on innovative disposal methods

(1) Identify the scale of the problem

The methods used to identify the magnitude of the problem of waste tyres in Hong Kong were-archival research, such as government websites, and interviews with professors and government officials.

- The Hong Kong Polytechnic University and University of Science and Technology libraries contained reports and papers on waste tyres, which were used to collect data on methods used in Hong Kong. The volume of tyre waste produced in comparison to municipal waste in Hong Kong was also determined (**Figure 7.1**).
- By observing the traffic on some of Hong Kong's major roads, in Sham Shui Po, the types of vehicles which were the most heavily used, were determined. Though this could not be done in a controlled manner leading to representative data, they observed enough traffic to gain an insight into the general composition of traffic. They observed three major roads, on different days and different times of the day, for half an hour each, recording the number of each type of vehicle observed.

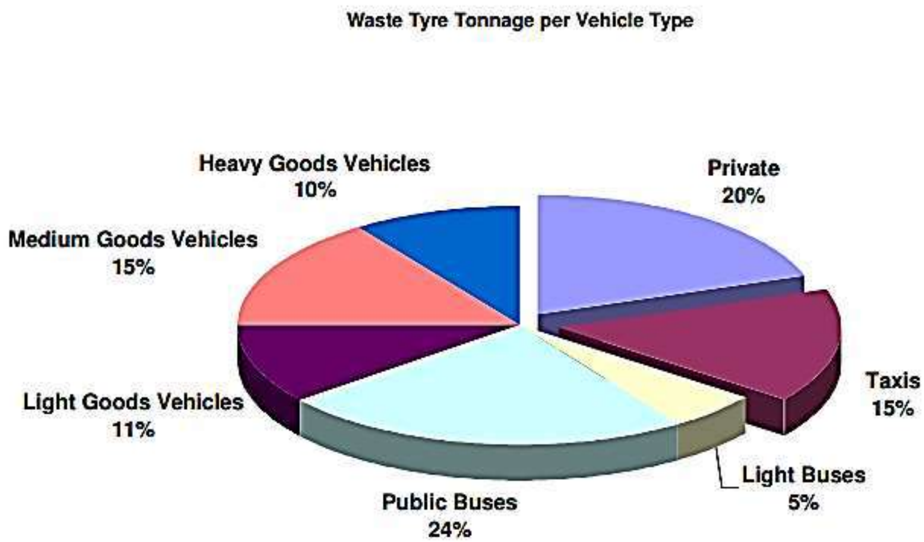

Figure 7.1: Approximate Annual Tonnage of Scrap Tyres Produced per Vehicle Type in Hong Kong

(2) Establish a local processing system

A large portion of Hong Kong's challenges with recycling and waste management is due to the overload of waste tyres being thrown away and not recycled. Hong Kong's government and the Environmental Protection Department (EPD) are working with various recycling companies (**Table 7.7**) to prevent these tyres from being brought to the landfills as waste and recycled instead.

According to the document "Monitoring of Solid Waste in Hong Kong", the quantity of waste tyres processed has varied from 7,000 tonnes/ year in 2000 to 12,000 tonnes/ year in 2012. The quantity includes reuse, refurbishment and recycling of tyres. Compared to other wastes which are exported for recycling, all the tyres are locally recycled.

Table 7.7: Part of Recycling Company Directory from the Website of EDP

Collection Point	District	Contact	Contact Details	Recycler/ Collector
Asia	Tuen Mun	Ms.	Phone: 24556690	Collector

Collection Point	District	Contact	Contact Details	Recycler/ Collector
Environment Protection (International) Recycle Company		Lam	Email: recycleic@yahoo.com.hk	
B. T Auto-Mobile Waste Material Treatment Co.	North	Mr. Wong	Phone: 26599734/91255552 Email: btautomobile@yahoo.com.hk	Collector
Baguio Waste Management & Recycling Limited	Sham Shui Po	Mr. Yu	Phone: 25413388 Email: waste@baguio.com.hk	Both
Grease Tech Limited	Kwun Tong	Ms. Po	Phone: 37499301 Email: info@greasetech.com	Collector
Huan Ke (Hk) Green Tech Limited	Tuen Mun	Mr. Ng	Phone: 91955559 Email: cq102000@163.com	Both
Lucky Wind Motors And Scrap Centre	Tuen Mun	Mr. Choy	Phone: 24791065 Email: lwnandsc 9666@yahoo.com.hk	Collector

Some local companies are also making contributions to waste tyres management in Hong Kong. The Kowloon Motor Bus (KMB) has achieved the target of zero disposal of bus tyres. Over 60% of the 31,000 bus tyres that are in use on 3,900 KMB buses are retreaded tyres. The life of a new bus tyre, which can typically be for seven months, can be extended up to two years through retreading. Each year KMB retreads around 30,000 waste tyres.

A project for recycling waste bus tyres has also been implemented. A contractor has been collecting all waste tyres to shred them into rubber chips for recycling into a variety of rubber products. This enables KMB to achieve the target of "zero disposal". In addition, more than 200 tons of tyre chips, by-products of the retreading process, are also collected by the contractor each year for recycling into a variety of products. These measures help reduce the solid waste disposal problem and lengthen the lifespan of landfills.

(3) Research on innovative disposal methods

The main disposal method of waste tyres is landfills after shredding or cutting. According to EDP's annual monitoring report, in the year 2012, 5 tons of waste tyres were being processed in landfills every day in Hong Kong. Some examples of other innovative disposal methods which have been adopted by Hong Kong are given below.

One example is the Sai Tso Wan Recreation Ground in Hong Kong. The sub grade of the playground's pavement is laid by rubber soil, which is a new lightweight and porous construction material produced from rubber chips derived from waste rubber tyres and cementitious materials. Safety mats used in the children's play area and jogging track of this facility are made from rubber chips derived from waste tyres.

Other innovations include the research in the asphalt rubber led by the Hong Kong Polytechnic University. Another research by Hong Kong University of Science and Technology aims to convert waste tyres into activated carbon and pyrolysis oil. If the results of these researches are replicable and scalable, they would be put into practice according to the Hong Kong government's environmental report.

Future Strategies

Hong Kong plans to bring waste tyres under part of the Producer Responsibility Scheme (PRS) program. It's a policy stating that producers and users of products should be held responsible for the products they produce and consume. According to the government, "Producer Responsibility schemes (PRSs) place the obligation for managing certain products on the producers, distributors, or sellers of the products. E-waste (waste electrical and electronic equipment) is already part of PRS program. Hong Kong's government plans to bring waste tyres as part of the PRS program in the year 2016 to 2018.

Hong Kong produces an abundance of tyre waste[259] every year. Considering its limited acreage and densely population, the waste tyre management practice of Hong Kong could be of interest to other countries.

7.1.5 Waste Tyre Management in Japan

Japan produces approximately 100 million waste tyres per annum and has been one of the world's leading recyclers for many years. This is partly driven by space restrictions. With intense land use patterns and the scarcity of land commanding extremely high prices, there is little scope for large landfill sites. As such, the rates of used tyre recycling in Japan (85-90%) are higher than in any other developed country. Japan also exports a significant number of waste tyres and aims to reach a recycling rate of 100% in the future. Due to these exports, their recycling industry is not as developed as that of the United States, as the majority of tyres are not processed in country. Japan's recycling structure is similar to that of most developed countries, with waste tyres coming from two main sources: (1) tyre replacement (where consumers replace the old with the new), and (2) end-of-life vehicles, where they are disposed of as a part of the whole vehicle. Consumers generally dispose of tyres through retailers, car dealers, service stations and mechanical repair shops – typical tyre dealers. End-of-life vehicle tyres are disposed of by scrap metal companies and passed on to collectors and processors[260].

The majority of Japan's waste tyres are utilized for tyre derived fuels (TDF), and many of the remaining tyres are exported. Within TDF, in the cement industry, they are mainly used in kilns for heat utilization purposes during the production of cement. This application has fallen in recent years due to the use of other waste as fuel, and regulatory pressures on Japan to reduce its greenhouse gas emissions under the Kyoto protocol. Another use of end-of-life tyres in Japan is in reclaimed and powdered rubber. The main markets for these materials are molded products, new tyres and as a rubber additive. An example of an application is the rubber additive developed by Bridgestone from crushed tyres that can be used in pavements[261].

Finally, Japan exports a significant number of its end-of-life tyres. This number has been increasing as the domestic market has shrunk. In 2000, 9% of Japan's total waste tyres were exported; however, this number rose again quickly in 2003 with 23% of waste tyres exported[262]. Japan does not have specific laws regarding the recycling of tyres, unlike many other developed countries, and they have been treated as part of solid waste recycling. Like stewardship programs in Australia and the USA, Japan has a cooperative program between tyre manufacturers, the government and other industry players to facilitate their recycling[263]. Though Japan has one of the highest rates of tyre recycling, their end-market is not nearly as diverse as in other countries. This may hinder their ability to cope with waste tyres in the future, depending on the continued viability of TDF.

7.1.6 Waste Tyre Management in United States of America[264]

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[259] *WBCSD (2008). Managing End-of-Life Tyres - Full Report. World Business Council for Sustainable Development, ISBN 978 3 940388 31 5.*
[260] IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai
[261] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*

[263] *IREVNA (2003). Tyre Recycling Industry: a Global View. CRISIL Global Research & Analytics, Mumbai*
[264] *U.S Environmental Protection Agency http://www.epa.gov/epawaste/conserve/materials/tyres/index.htm*

USA has the largest waste tyre recycling industry in the world, with end-markets further developed than in any other country[265]. Annually millions of waste tyres are generated in United States of America. The US Environmental Protection Agency has put scrap tyres as a "common waste & material". Waste tyres are managed primarily at the state level in the USA. Each state employs different legislations and governance to maintain and manage the waste tyre flow. In 2003, markets for scrap tyres were consuming 233 million, about 80.4%, of the annually generated 290 million scrap tyres. Percentage of waste tyre and end usage is given below.

- 130 million (44.7%) are used as fuel
- 56 million (19.4%) are recycled or used in civil engineering projects
- 18 million (7.8%) are converted into ground rubber and recycled into products
- 12 million (4.3%) are converted into ground rubber and used in rubber-modified asphalt
- 9 million (3.1%) are exported
- 6.5 million (2.0 %) are recycled into cut/stamped/punched products
- 3 million (1.7%) are used in agricultural and miscellaneous uses

About 27 million scrap tyres (9.3%) are estimated to be disposed of in landfills or monofills[266].

7.1.6.1 Markets and uses for scrap tyres

Scrap tyres are used in a number of productive and environmentally safe applications. From 1990 through 2003, the percentage of scrap tyres generated going to market increased from 24.5% to 80.4%[267]. In 2009, the percentage has reached 89.3%. **Figure 7.2** and **Figure 7.3** indicate the tyre waste market trends.

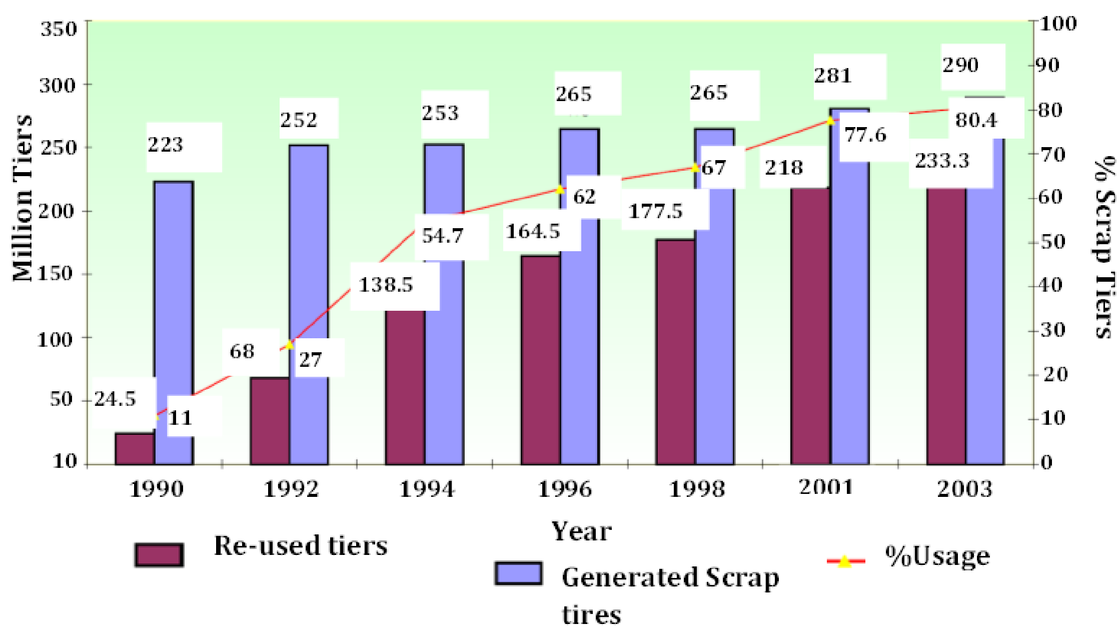

Figure 7.2: Scrap Tyres Market from 1990 to 2003 in the USA

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[265] *OECD (2007). Improving recycling markets. Organisation for Economic and Cooperative Development, Paris*
[266] *Rubber Manufacturers Association, 2004.*
[267] *RMA (2004). US Scrap Tyre Markets 2003. Rubber Manufacturer's Association, USA*

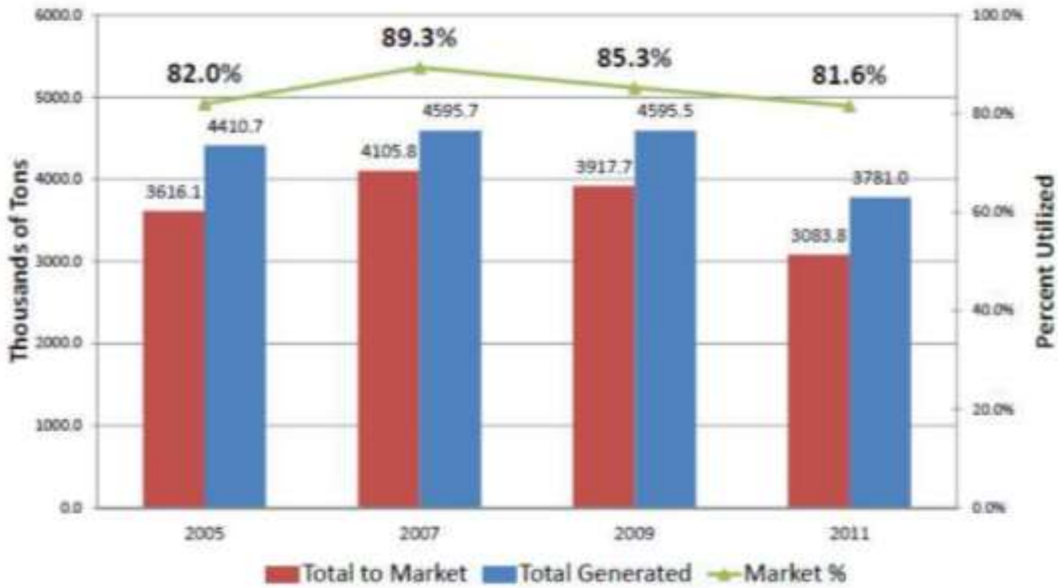

Figure 7.3: U.S. Scrap Tyre Management Trends 2005 - 2011

The three largest scrap tyre markets are:

- Tyre-derived fuel

In 2003, 130 million scrap tyres were used as fuel (about 45% of all generated) — up from 25.9 million (10.7% of all generated) in 1991. **Table 7.8** describes different sectors of industries using tyre derived fuel.

Table 7.8: Scrap Tyre Fuel Use by Industry[268]

Of the 130 million scrap tyres used as fuel per year:	
Cement industry	41%
Pulp and paper mills	20%
Electric utilities	18%
Industrial/institutional boilers	13%
Dedicated tyre-to-energy facilities	8%

- Civil engineering applications

The civil engineering market encompasses a wide range of uses for scrap tyres as given in **Table 7.9** and **Figure 7.4**. In almost all applications, scrap tyre material replaces some other material currently used in construction.

Table 7.9: Civil Engineering Applications[269]

Sub grade Fill and Embankments
Backfill for Wall and Bridge Abutments
Sub grade Insulation for Roads
Landfills

[268] *Rubber Manufacturers Association, 2004*
[269] *U.S.Scrap Tyre Management Summary 2005-2009, October 2011, Civil Engineering Markets p.9 Rubber Manufacturers Association.*

Septic System Drain Fields
Other Uses

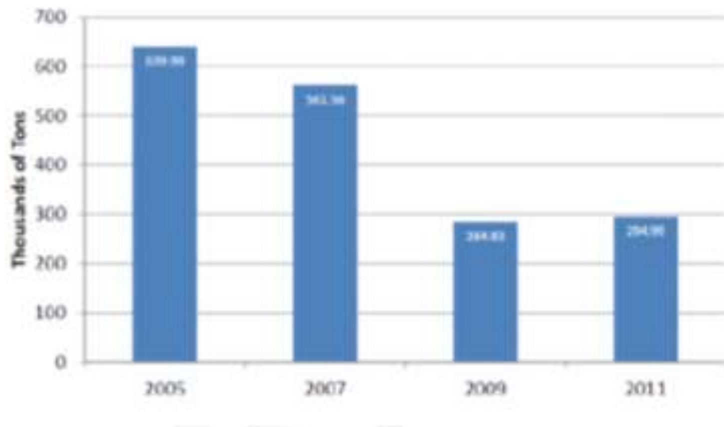

Figure 7.4: U.S. Civil Engineering Markets 2005 - 2011[270]

- Ground rubber applications/rubberized asphalt

The market for ground rubber, also referred to as size-reduced rubber or crumb rubber, has been growing over the past several years. **Figure 7.5** shows the ground rubber usage market in 2014 in USA. In the ground rubber market there are two classes of particle sizes: "ground" rubber (10 mesh and smaller) and "coarse" rubber (larger than 10 mesh, with a maximum size of one-half inch).

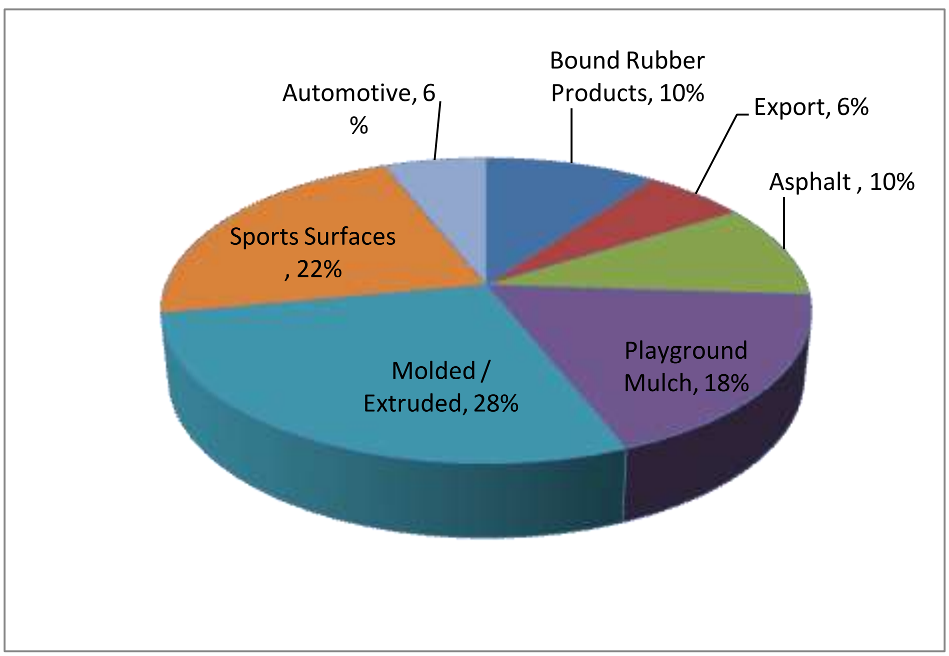

Figure 7.5: U.S. Ground Rubber Markets 2011[271]

[270] *U.S. Scrap Tyre Management Summary 2005 - 2011, Rubber Manufacturers Association*

(Percentage of total pounds of ground rubber consumed in market)

Other applications include:

- Whole Tyres and Cut, Stamped, and Punched Products

Scrap tyres may be recycled by cutting, punching, or stamping them into various rubber products after removal of the steel bead. Products include floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, and washers. Whole tyres may be recycled or reused as highway crash barriers, for boat bumpers at marine docks, and for a variety of agricultural purposes.

- Reuse-Retreading

Retreading involves removing the outside, or tread, of the tyre and adding a new tread. Retreading saves millions of gallons of oil each year, because it takes only seven gallons of oil to retread a waste tyre compared to 22 gallons to produce a new tyre. Some of the other benefits of retreading include usage of 75% post consumer material and reduced costs (30% to 70%) in comparison to new tyre.

The Rubber Manufacturing Association estimates that in the US, about 16 million scrap tyres were retreaded in 2001. Most are used by the trucking, aircraft, construction, and agriculture industries, and on US government vehicles.

7.1.6.2 Landfill Disposal

Even with all of the reuse and recycling efforts, part of waste tyres still end up in landfills each year. Landfilling scrap tyres can cause problems due to their uneven settlement and tendency to rise to the surface, which can harm landfill covers. To minimize these problems, many states require chipping or grinding of tyres prior to disposal. Sometimes scrap tyres are also incorporated into the landfill itself as part of daily cover, or in a landfill cap.

In recent years, the placement of shredded scrap tyres in monofills—a landfill, or portion of a landfill, that is dedicated to one type of material—has become more common. Monofills may be used when no other reuse / recover markets are available and municipal solid waste landfills do not accept tyres. Monofills are preferable in comparison to above ground storage of tyres in piles, due to fire hazards and human health hazards.

7.1.6.3 State and Local Governments

Scrap tyres, as a solid waste, are regulated primarily by state governments. **Figure 7.6** & **Figure 7.7** shows US State Tyre Program feature and state land disposal regulations. In 1985, Minnesota enacted the first state law for the management of scrap tyres. By now, 48 states have enacted laws that address scrap tyre management. Alaska and Delaware do not have any scrap tyre laws or regulations. While each state has its own program, some common features include:

- Source of funding for the program;
- Licensing or registration requirements for scrap tyre haulers, processors and some end users;

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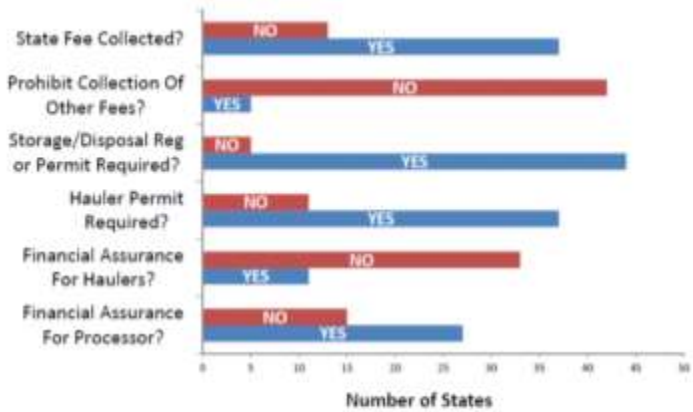
[271] *Ground rubber market distribution data are based on ground rubber consumed in end-use markets, not whole tyres entering these market streams. The data represented in RMA U.S. scrap tyre market summaries refer to the weight of whole tyres diverted to all scrap tyre markets, including ground rubber, whereas this chart refers to the weight of processed ground rubber, with wire, fluff and agglomerated rubber removed that is consumed in ground rubber end-use markets.- U.S. Scrap Tyre Management Summary 2005 - 2011, Rubber Manufacturers Association*

- Manifests for scrap tyre shipments;
- Limitations on who may handle scrap tyres;
- Financial assurance requirements for scrap tyre handlers; and
- Market development activities.

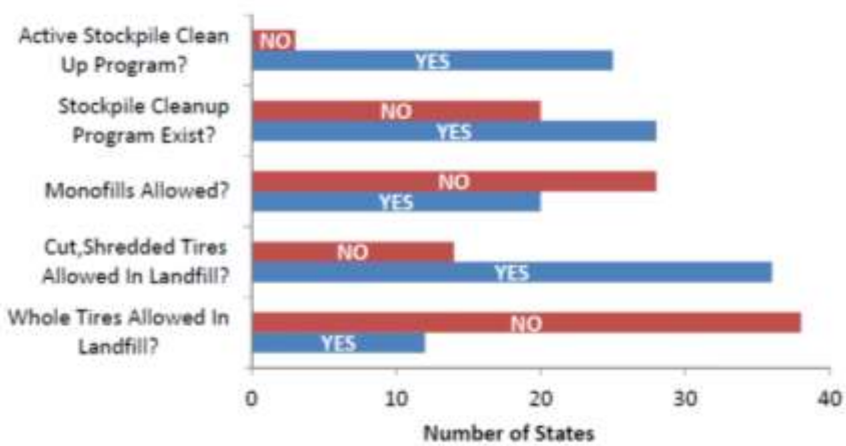
Local municipalities help educate the public about illegal dumping and enforce anti-tyre dumping laws. Local agencies are also usually responsible for tyre pile cleanup. Some local jurisdictions encourage proper disposal by allowing local citizens to drop off limited numbers of tyres at recycling centres, or conduct tyre amnesty days where any local citizen can bring a limited number of tyres to a drop-off site free of charge. State scrap tyre programs may provide financial help to fund such events.

Local municipalities also play big role in procuring products made with scrap tyres including playground/park applications. And in many states, local government agencies are also large users of rubberized asphalt in public paving projects. The Federal government is also a large purchaser of products made with recycled rubber, and has established purchasing guidelines.



* Current as of 2011. Data not available for all 50 states.

Figure 7.6: U.S. State Scrap Tyre Program Features[272]



* Current as of 2011. Data not available for all 50 states.

Figure 7.7: U.S. State Land Disposal Regulations

[272] *U.S. Scrap Tyre Management Summary 2005 - 2009, Rubber Manufacturers Association*

***Tyre Fees[273]**

Many states collect fees to fund scrap tyre management programs or stockpile cleanup. Tyre fees are typically assessed on the sale of new tyres or on vehicle registrations. Fees generally range from $0.50 to $2 per passenger car tyre, and truck tyre fees range from $3 to $5.

Some scrap tyre fees also help local communities establish market programs, create licensing/enforcement systems, and host tyre collection programs/amnesty events. States and municipalities may also use money generated by scrap tyre fees to offer grants or loans to scrap tyre processors and end users of tyre-derived materials. Many states collect fees to fund scrap tyre management programs or stockpile cleanup. Tyre fees are typically assessed on the sale of new tyres or on vehicle registrations. Fees generally range from $0.50 to $2 per passenger car tyre, and truck tyre fees range from $3 to $5.

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7.2 Case Studies: Developing Countries (WT Management in Argentina, WT Management in Brazil, WT Management in South Africa)

7.2.1 Waste Tyre Management in Argentina

Argentina produces a large number of tyres every year. On the basis of the statistical report released by the Tyre Manufactures' Association (Spanish: CÁMARA DE LA INDUSTRIA DEL NEUMÁTICO), in 2009, the production was 11,093,304 tyres, including cars, trucks and other tyres. The apparent consumption (An estimate of the size of a given product's market, based on a simple arithmetic expression: Apparent Consumption = Production + Imports – Exports) in Argentina has varied from 3,837,673 tyres/year in 1990 to 11,447,143 tyres/year in 2008.

With a large number of tyres production, sustainable tyres management throughout their life cycle, and especially at the end of their useful lives, is not only a concern for Argentina alone, but rather one that is shared with its regional neighbors, especially the MERCOSUR[274] member countries. Therefore, Argentina has decided to include waste tyre as a priority item on its administration's agenda.

In May 2013, Resolution No.523/2013 on Sustainable Tyre Management throughout their Useful Life, particularly Waste Tyres, was published in the Argentine Official Gazette. This resolution provides the conceptual framework to further develop a national strategy for sustainable tyre management throughout their life cycles, especially after they have become wastes, during the post-consumption period. Several public and private organizations have made efforts to work out this resolution. It has been agreed upon by major stakeholders associated with it.

- The Argentine Secretariat of Environment and Sustainable Development (SAyDS, as per its Spanish acronym) started to develop a Draft Common Policy Decision on retreaded and waste tyres in 2008. The SAyDS hosted the 1st and 2nd "Seminar on Sustainable Waste Tyre Management" to discuss comprehensively the issue of waste tyre management. Concurrently, they gathered information from various institutions, involving government agencies and private sector institutions. The purpose was

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[273] *U.S. Environmental Protection Agency http://www.epa.gov/epawaste/conserve/materials/tyres/laws.htm*
[274] MERCOSUR*: Spanish:Mercado Común del Sur, an economic and political agreement among Argentina, Brazil, Paraguay, Uruguay, Venezuela and Bolivia as an acceding member)*

to assess and develop logistics and technology proposals to design a national program for the recovery/reuse of tyres as they reach the end of their useful lives, and to promote specific environmental legislation so that they may be sustainably managed. **Table 7.10** sumarized the general guidelines related to waste tyre management in Argentina.

Table 7.10: Waste Tyres Management Governed by the General Environmental Guidelines

Source Reduction	Prevent and minimize the generation of end-of life and waste tyres by adequate design of and innovation in production processes, as well as suitable treatment, value-adding and final disposal systems.
Integrated Life Cycle	Apply the best available techniques (BAT) and the best environmental practices (BEP) throughout the lifecycle of waste tyres (production, use, reuse, recycling, value-adding, treatment and/or final disposal) to prevent and minimize risks.
Proximity	Waste tyres treatment shall be carried out in proper locations, as close to the place of generation as possible
Extended Producer Responsibility	Place the burden of environmental management throughout the whole product lifecycle, including post consumption, on producers.
Prevention	Environmental problems shall be addressed through a priority-based integrated approach, seeking to prevent any potential negative impact on the environment.

The technical assessments conducted by the Undersecretariat of Pollution Prevention and Environmental Surveillance and Control (SsCyFAyPC, as per its Spanish acronym) led to the conclusion that waste tyres should be considered as special universal waste. If the waste tyres are not properly and sustainably managed, they will pose a significant risk of environmental damage or pollution and may affect the health of the population. Stages included in the tyre lifecycle from the design to environmentally sound waste tyre management is given in **Table 7.11**.

Table 7.11: Stages Included in the Tyre Lifecycle from the Design to Environmentally Sound Waste Tyre Management

Tyre lifecycle	Design
	Production and import
	Marketing
	Tyre utilization by users
	Temporary storage before final disposal
	Delivery to qualified retreading centres
	Waste tyre market recall
	Waste tyre transformation for component recovery purposes
	use of recovered components
	Final disposal of tyre materials that may not be reused

- The National Institute of Industrial Technology (INTI) carried out the valuable technical work. Actions undertaken by the INTI-Caucho Committee include initial the assessment and regular technical audit of a project under way at the time to transform end-of-life tyres (Neumáticos Fuera de Uso– NFU) into industrial input for new products following execution of a contract between CEAMSE and a company called REGOMAX. The project has been fully executed, and the company has set up an NFU reuse plant in San Martín, Buenos Aires province. A list of WT management practices approved by the pertinent authorities is shown in **Table 7.12**.

- The INTI-Caucho Centre also participated in the development of draft regulations to create a "comprehensive Waste tyre environmental management System", which includes a list of definitions and recommended uses to ensure waste tyres are sustainably managed.

Table 7.12: List of WT Management Practices Approved by the Pertinent Authorities

Use of whole waste tyres		use of shredded waste tyres	use as energy source
• In artificial jetties and breakwaters. • For erosion control. • For sound barriers. • For collision barriers (race tracks, ports, etc.)	• Sport court / track surfacing. • Playgrounds. • Safety floors. • Sea freight container lining. • Recycled asphalt. • Concrete pavements.	• As alternative fuel source in cement kilns. • As alternative fuel source in power plants. • As alternative fuel sources in industrial processes.	

7.2.2 Waste Tyre Management in Brazil

Brazil has faced a number of challenges concerning the use of tyres in recent years. In 2007, the World Trade Organization's highest court upheld a ruling that Brazil had illegally banned the import of re-treaded vehicle tyres. The decision was based on the fact that Brazil imports used tyres to retread and, as such, it would be unfair to prevent the import of the finished re-treaded product. Like India, Brazil has been concerned about becoming a dumping ground from more developed countries and, in 2003, refused to import used tyres from Europe. Brazil held that Europe was trying to export its pollution, and as tyres can only be re-treaded once, by importing them Brazil would become responsible for the tyre waste problem once they came to the end of their second life[275].

From this case, it is clear that Brazil is dealing with a different used tyre market to those in developed countries, due to the high use of re-treads. There is some formalized infrastructure within Brazil for the collection of used tyres[276]. The Brazilian National Commission of the Environment (CONAMA) determined, in 1999, that tyre manufacturers and importers were responsible for the environmentally friendly collection and management of waste tyres[277]. This regulation has evolved over time, but has in essence maintained that recycling tyres is mandatory by law and is, therefore, the responsibility of the manufacturers[278].

As a result, in 2007 the major tyre manufacturers, Bridgestone, Firestone, Goodyear, Michelin and Pirelli, created Reciclanip which is responsible for the collection, transportation and final destination of tyres. This process is achieved through partnership, mainly through local councils who grant plots of land that meet specific safety and hygiene requirements. These plots are used for the gathering and storing of tyres from repair shops, resellers and citizens. In 2009, Reciclanip had 460 collection points throughout Brazil and collected 250,000 tyres. The end-of-life market still needs to be developed in Brazil, but the legislative framework in place has pushed tyre manufactures to take responsibility for their products. This model will allow for the relatively easy transition into recycling and reuse of tyres as there are already mechanisms in place for their collection[279].

7.2.3 Waste Tyre Management in South Africa

In South Africa, approximately 10 million tyres per year are currently sold. Waste tyres present a challenging disposal problem. Land filling has been the only feasible waste tyre management strategy so far. The South African government, seeking alternative and ecologically friendly waste tyre disposal options, has accepted the Recycling and Economic Development Initiative of South Africa (REDISA plan)(311) in accordance with the National Environmental Management Waste Act, (Act 59)[280], 2008 (Government Gazette, 17April 2012).

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[275] *New York Times, W.T.O. Court Rejects Brazil's Tyre Ban. http://www.nytimes.com/2007/12/04/business/worldbusiness/04fobriefs-WTOCOURTREJE_BRF.html?_r=0 (accessed 6 April 2013)*
[276] *Bressan Mühlbeier, D. (2010). Tyre Recycling becomes riving force in Brazil. http://infosurhoy.com/cocoon/saii/xhtml/en_GB/features/saii/features/society/2010/10/14/feature-02 (accessed 6 April 2013)*
[277] *Bressan Mühlbeier, D. (2010). Tyre Recycling becomes driving force in Brazil. http://infosurhoy.com/cocoon/saii/xhtml/en_GB/features/saii/features/society/2010/10/14/feature-02 (accessed 10 October 2010)*
[278] *Bressan Mühlbeier, D. (2010). Tyre Recycling becomes riving force in Brazil. http://infosurhoy.com/cocoon/saii/xhtml/en_GB/features/saii/features/society/2010/10/14/feature-02 (accessed 6 April 2013)*
[279] *Bressan Mühlbeier, D. (2010). Tyre Recycling becomes riving force in Brazil. http://infosurhoy.com/cocoon/saii/xhtml/en_GB/features/saii/features/society/2010/10/14/feature-02 (accessed 6 April 2013)*
[280] *National Environnemental Management Waste Act,2008 http://govza.gcis.gov.za/sites/www.gov.za/files/35927_gon988_0.pdf*

REDISA[281] is a not for profit organization representing various organizations in the tyre and waste tyre industry. It is industry independent and meets all Government requirements for handling the waste tyre problem in a sustainable manner. The proposed REDISA Plan has come at a time when South Africa needs to reinforce stringent laws on their waste management strategies in particular the waste tyre problem. Before the proposition of the plan, no clear approach was used to tackle the accumulation of waste tyres at landfill sites and illegal stockpiles. The plan also helps with job creation, capacity building, and creation of small businesses and R&D of new and innovative techniques on waste tyre utilization.

According to REDISA, the annual projection of the quantities and types of tyres that are manufactured or imported will be managed through the Integrated Industry Waste Management Plan. Priority will be given to;

- preventing and reducing waste tyre generation through the launching of awareness campaigns regarding the maintenance guidelines and procedures recommended by tyre producers. The aim is to promote the importance of keeping their tyres in good condition and thus extending the lifespan of the WT.
- encouraging investment in the retreading industry and actively promote the use of retreaded tyres.
- training programmes to equip stakeholders with the relevant skills and competencies. Similarly, there will be a need to market the concept of WT recycling and encouraging participation.

A single plan with consolidated funding is not only more effective, but the message is simpler and can easily be communicated.

Any tyre producer, waste tyre processor or stockpile owner having received a Waste Tyre Regulation registration number (from Department of Environmental Affairs) must become a subscriber to the plan for as long as the REDISA Plan is the only Integrated Industry Waste Tyre Management Plan (IIWTM) approved by the minister. All subscribers are expected to sign a deed of adherence acknowledging the existence to the IIWTM and the requirements of the waste tyre. Regulations. In addition, subscribers are required to provide a monthly declaration of their production (including rejects) imports and exports to an external auditor.

7.2.4 Waste Tyre Generation & Material Flow Analysis in Thailand

The following example has been drawn from the research paper "Dealing with emerging waste streams: Used Tyre Assessment in Thailand using Material Flow analysis", Paul Jacob, Prakriti Kashyap, Tasawan Suparat and Chettiyappan Visvanathan, Waste Management & Researcy 1-9, SAGE, 2014.

Thailand manufactured nearly 54.1 million tyres (passenger car, bus, truck and motorcycle tyres) in the year 2012 (BOI, 2012) as shown in Figure 1. Tyre production in Thailand has shown a continuous increase each year complementing the growth in the Thai automotive industry. The Thai automotive industry is one of the leading industries in Thailand, and is the largest in the Association of Southeast Asian Nations (ASEAN) countries – Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei, Burma (Myanmar), Cambodia, Laos and Vietnam – and the 15th largest in the world in 2011 (TAI, 2012). Figure 1 shows that the progressive increase in the size of the tyre market has been caused by increases in domestic production of tyres, domestic consumption and exports. Tyre imports are almost negligible.

There are two types of tyre markets in Thailand, namely original equipment manufacturing (OEM) and replacement equipment manufacturing (REM). OEM comprises automobile manufacturing that buys new

[281] *http://www.redisa.org.za/*

tyres as an addendum to the car body. REM, on the other hand, is the measure of tyres replaced after the original, ensemble vehicle tyres wear out. REM depends on road condition, weather, distance travelled, maintenance level and vehicle driving preferences. Tyre manufacturers sell new tyres to distributors, such as tyre shops, car care shops and garages.

Tyre manufacturing in Thailand is handled by both foreign investor groups and Thai entrepreneurs. Although USA, Japan, China, Korea and the EU dominate global tyre production, Thailand is also a major player in Asia. The total number of new tyres produced increased steadily from 45.9 million in 2008 to 54.1 million in 2012 (OIE, 2013), as shown in **Figure 7.8**. The Thai government's tax rebate policy for first-car buyers in 2012 contributed to an increase in domestic car sales. The 'First car policy' gave a tax refund up to THB 100,000 (~USD 3225) to Thai citizens buying their first car. As a result of this policy, the number of passenger/light truck car registrations in Thailand jumped to 11.4 million cars in 2012, of which more than three million were bought under the first-car policy (DLT, 2012). The addition of these vehicles to Thai roads will add waste tyre generation in the next 2–3 years.

The replacement rate for passenger cars and light trucks was calculated to be 1.6 tyres vehicle-year-1. Consequently, passenger car users need to replace all four tyres every 2.5 years. The tyre replacement rate for passenger cars in Thailand was slightly higher than 1.1 tyre vehicle-year-1 as calculated by Sarkar et al. (2011) in the Dominican Republic. The high replacement rate might be owing to consumer behaviour and prevailing road conditions. Buses and trucks had the highest tyre replacement rate (3.7) among all vehicle types. The replacement rate of buses and trucks was high, possibly owing to heavy loads and long hours spent on the road per day. The replacement rate for motorcycles was 0.8 tyre vehicle-year-1, implying that motorcycle users need to change both tyres every 2.5 years. This group of tyres had a low replacement rate owing to lighter carrier loads and shorter travelling distances. The replacement rates and weights of tyres in each category are presented in **Table 7.13**.

Table 7.13: Tyre Production, Replacement Rates and Tyre Waste Generation in Thailand

Items	**Unit**	**Vehicle category**			**Reference**
Time	**Year**	**Passenger cars + light truck cars**	**Buses + Trucks**	**Motorcycles**	
2008	Million vehicles	8.83	0.9	16.43	(DLT, 2012)
2009	Million vehicles	9.25	0.92	16.71	(DLT, 2012)
2010	Million vehicles	9.88	0.95	17.3	(DLT, 2012)
2011	Million vehicles	10.65	0.99	18.15	(DLT, 2012)
2012	Million vehicles	11.82	1.04	19.15	(DLT, 2012)
Weight of tyres (field observations)	kg tyre-1	14	50	3.4	Field observation
Weight of tyres (literature)	kg tyre-1	5.91–25	10–90	0.8–4.1	(Dufton, 2001; Ferrão et al., 2008)
Average tyre replacement rate (2008–2012)	Rc ± SD	1.6 (±0.002)	3.7 (±0.01)	0.8 (±0.0004)	Current study
Tyre replacement rate (2003–2007) (Literature)	Rc ± SD	1.1 (± 0.3)	12.9 (± 1.4)	1.9 (± 1.1)	(Sarkar et al., 2011)
Weight of replaced tyres	t y-1	0.024	0.172	0.003	Current study
Used tyre generation in 2012	t y-1	283,786	178,162	68,930	Current study

SD: standard deviation

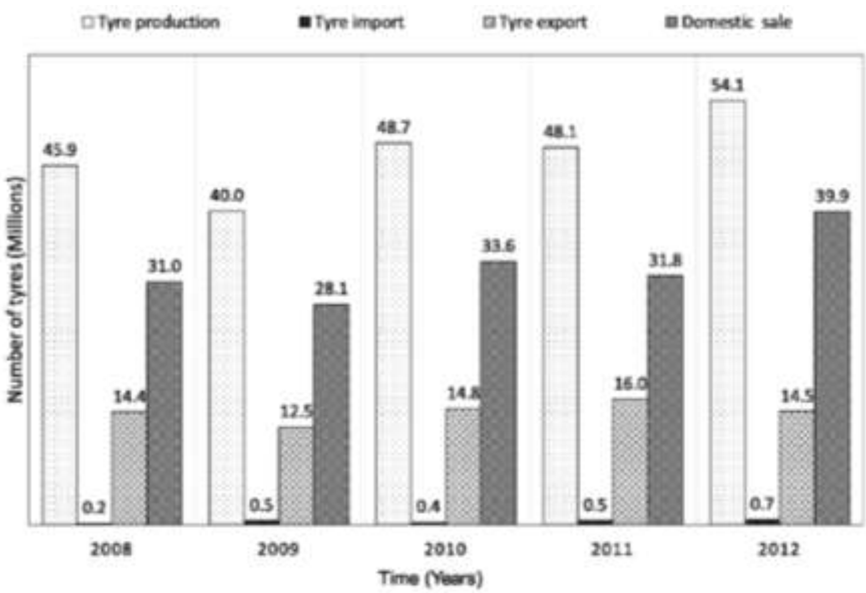

Figure 7.8: Trends in the Tyre Market in Thailand from 2008 to 2012

Source: Used tyre assessment in Thailand using material flow analysis (adapted from OIE. 2013)

Current situation of waste tyre management in Thailand based on the material balance approach

In order to strategize the best options for waste tyre management, it was essential to first quantify the flows and accumulation of stocks tyre within Thailand. Figure 2 presents the flow of tyres through various processes throughout their life cycle. As observed in Figure 2, in 2012, out of 703,099 tonnes of tyres entering the system, 66.80% exited the MFA system boundary and the remaining 33.20% stayed in the system boundary. It can be observed in 2012, the domestic market consumed 3.29% more than the overall production capacity (after exports). This sale (–6098 tonnes) was compensated for by the excess stock of 77,145 tonnes present with the manufacturers from the previous year (Figure 1). This stock in the trading process was calculated based on data made available by OIE (2013).

The overall used tyre generation in 2012 was calculated to be 519,389 tonnes **(Figure 7.9)**. It is worth noting that exported tyres, including both new and retreaded tyres (191,968 tonnes), are excluded from further calculation as they do not contribute to the overall stock in the country. Hence, the calculation of percentage share of waste tyre management (recycling, energy recovery and disposal) is based on the actual waste tyres generated in the country in 2012, i.e. 519,389 tonnes. These used tyres were directed to various formal, informal waste management facilities, open dumps and stockpiling in the open environment.

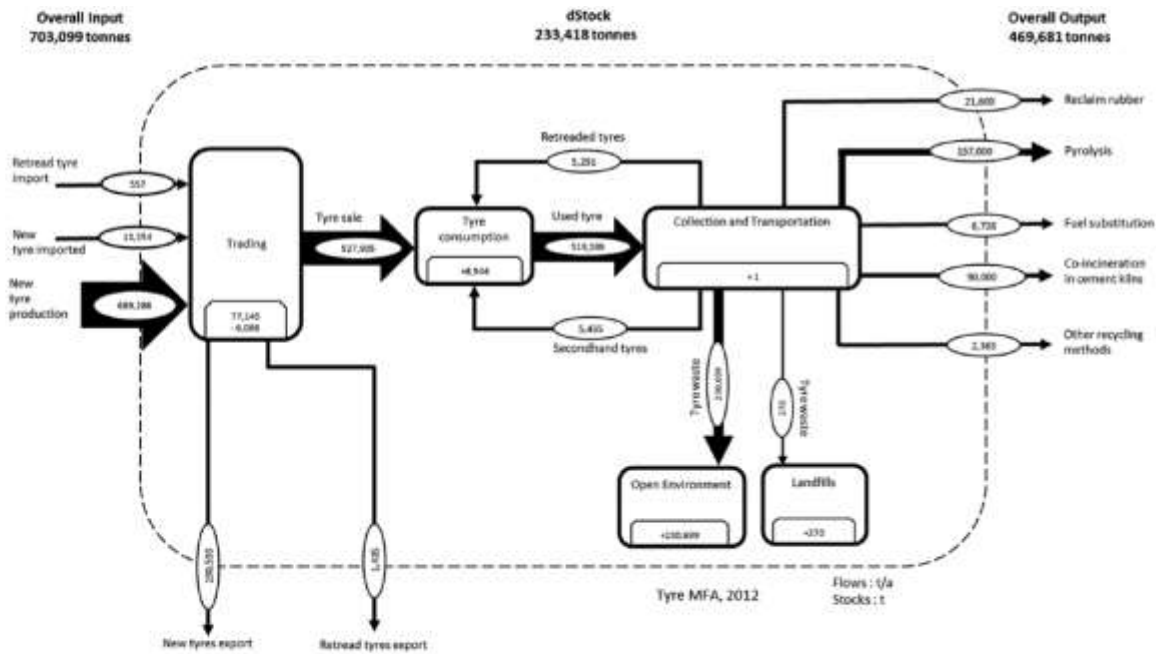

Figure 7.9: MFA of Waste Tyres in Thailand for the Year 2012

7.2.5 Waste Tyre Pyrolysis Technology Demonstration in India

M/s. Divya International, India has successfully demonstrated 46 Tyre Pyrolysis plants across length and breadth of the country. These plants are located at: 5 Ton Plant Running successfully In Tamilnadu at Thoothukudi; 10 Ton Plant running successfully In M.P at Katni; 10 Ton Plant running successfully in Telangana at Kodad & Nalgonda; Two 10 Ton Plants installed and running in Haryana at Yamunanagar: 10 Ton Plant running at Badnawar, Madhya Pradesh; 10 Ton Plant running successfully at Hisar, Haryana; 10 Ton Plant running successfully in Greater Noida, Uttar Pradesh; 10 Ton Plant running successfully in Jaspur, Uttarakhand; 10 Ton Plant running successfully in Coimbatore, Tamilnadu; 10 Ton Plant running successfully in Miyapur, Hyderabad, Telangana; 2 x 10 Ton Plants running successfully in Masaipet, Andhra Pradesh; 5 Ton Plant running successfully in Karnal, Haryana; 10 Ton Plant running successfully in Navapur, Maharashtra; 10 Ton in M.P; 10 Ton Plant running successfully in A.P; 10 Ton Plant running successfully in Assam; 10 Ton Plant running successfully in Abu Road; 10 Ton Plant installing in Assam; 10 Ton Plant installing in Abu Road; 10 TPD Plant Installed in Mathura (U.P); 10 TPD Plant In Patna (Bihar); Installation of pyrolysis plant in Gondia (Nagpur), Maharashtra; in Prakasam, Andhra Pradesh; in Hisar, Haryana; in Bicchiwara, Rajasthan; in Karnal, Haryana; in Wada (Thane), Mumbai, Maharashtra; in Ajmer, Rajasthan; in Theni, Tamil Nadu; in Chennai; in Hassi; in Rohtak, Haryana; in Kolhapur Maharashtra; Pyrolysis plant installed in Bichhiwada, RJ; Pyrolysis plant installed in Bilaspur, CG; 2nd pyrolysis plant installed in Chattisgarh, Durg; in Hisar; Haryana; in Jalgoan, Maharashtra; in Jaipur, Rajasthan; One of the most the awaited & the biggest project two 12-tons Plants parallely in Indore; Pyrolysis plant installed in Sonepat, Haryana; in Gujarat; and Pyrolysis Plant installed in Durg, Chattisgarh

Input Material : Waste Tryes and Plastic Scrap

Output : Fuel Oil, Carbon Black Powder, Scrap Steel & Gas.

Discription of the Outputs:
Fuel Oil (40% TO 45%):-

The main product produce by pyrolysis plant is Tyre oil (industrial fuel oil). This is used in many industries as a fuel. There are 2 types of oil produced from the process, one is normal Tyre oil and other is heavy oil. Heavy oil is about 5% to 7% of Tyre oil. The final percentage of oil is about 40% to 45% depends on Tyre quality.

Carbon Black (30% TO 35%):-
The second product of Tyre pyrolysis plant is carbon black. The quantity of carbon black is about 30% to 35% according to Tyre quality. The carbon black can be used as a chemical strengthener in rubber industries and coloring agent in pigment industries. This carbon black price is very competitive compare to petroleum carbon black, so pyrolytic carbon black is good option instead of petroleum carbon black.

Steel Wire Scrape (10% TO 15%):-
The third product of Tyre pyrolysis plant is steel wire, the quantity of steel wire is about 10% to 15% according to Tyre quality.

Pyrolytic Gases (About 10 %):-
Pyrolytic gases are received during process (about 10% of waste Tyre). The main component of these gases is methane (CH4), these gases are used to heat the reactor and excess gases can be used for other heating application.
Source: http://www.divyaint.com/

7.3 Waste Tyres Management Association & Conferences

Many countries have set up associations giving focus on waste tyres management. For example, the Rubber Manufacturers Association (RMA)[282] in the USA, the European Tyre and Rubber Manufacturers' Association (ETRMA)[283] in European Union and the Japan Automobile Tyre Manufacturers' Association (JATMA)[284] in Japan, and Korean Tyre Manufacturers' Association (KOTMA)[285] in Korea etc.

Meanwhile, there are also some regional waste tyre management organizations. For example, California's Department of Resources Recycling and Recovery (CalRecycle) promotes waste tyre management in California. It will organize Waste Tyre Management Conference regularly. In 2005 the 6th Waste Tyre Management Conference: Paving the Way for the Future was held by CalRecycle in USA. The presenters from California and across the nation provided the most current information on waste tyre issues. They included the latest information on tyre recycling technologies, regulations governing the handling, storage, and disposal of waste tyres, enforcement training for local governments, and issues other states are facing with their waste tyre piles[286].

These WT conferences emphases the following key aspects:

- Developing the method and tools to update tyres data and trends on an annual basis.
- Consistent with the developed method, obtaining data on, and analyzing the trends in the sources and fate of UT to ELT.

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282 *http:// www.rma.org*
283 *http:// www.etrma.org*
284 *http://www.jatma.org.jp.*
285 *http://www.kotma.or.kr/*
286 *California's Department of Resources Recycling and Recovery (CalRecycle) http://www.calrecycle.ca.gov/tyres/events/Conference/2005/*

- Analyzing the domestic market and developing an understanding of the international market for end-of-life tyres and tyre derived products.

The conferences provide attendees with a wealth of industry networking opportunities, as well as information on current market trends and hot topics, which is greatly beneficial to promote the development of waste tyre management.

Annexure - 5.1: Companies Practicing Shredding Process in Developed Countries

a) Granutech Saturn Systems is in Texas, USA (United States of America); have tyre-processing equipment installed worldwide. As they are suppliers of tyre recycling machinery, particularly shredders, they do not operate their machinery once it has been installed. They do, however, provide ongoing servicing. They supply a wide range of shredders that can suit many different operations and also supply custom-built shredders. They also provide shredding systems, where more than one shredder is necessary, such as with the manufacture of ground rubber and tyre derived aggregate.

Full contact of company
201 E Shady Grove Rd
Grand Prairie, TX 75050, USA
Ph: 877 582 7800 I Fax: 972 709 8733
Website: http://www.granutech.com

Special features: Though Granutech Saturn Systems has changed and evolved from a number of different companies, on a whole, they have been processing tyres since 1971. As a result, there are a number of unique designs supplied by Granutech. The Roto-Grind is one such design. Granutech Saturn Systems prides itself in offering comprehensive services in conjunction with significant experience and knowledge in the field of tyre recycling. The average seniority within the company is 13 years, with an average of 22 years' experience in the company per person. They also offer a continued service of their equipment after sale.

Product features and downloads:
http://www.granutech.com/assets/files/New%20Saturn%20Brochure.pdf
http://www.granutech.com/assets/files/Roto-Grind%20Bites%20brochure.pdf
http://www.granutech.com/assets/files/Granutech%20brochure.pdf

b) CM Tyre Recycling is based in Florida, USA and was the first company to develop "turnkey" recycling systems that were specifically designed for the reduction of waste tyres and the generation of useful and valuable tyre derived materials. Since 1982, CM has installed over 215 tyre-recycling systems in 15 countries throughout the world.

Full contact of the company:
CM Tyre Recycling, A Columbus McKinnon brand,
1920 Whitfield Avenue,
Sarasota, Florida - 34243
Ph: (800) 848-1071 Ext. 29
(941) 755-2621 Ext. 29
Fax: (941) 753-2308
Website: http://www.cmtyrerecyclingequipment.com/default.aspx

CM recycling has its main parent company in USA and has its suppliers all around the globe. It is located in , Canada, Puerto Rico, Brazil, Morocco, Spain, Italy, UK, Latvia, Poland, Germany, Sweden, The Netherlands, Belgium, Czech Republic, Taiwan, Japan, South Korea, Pakistan.

Full contact details of the suppliers of CM recycling worldwide:
Europe:
Martin Rots, Sales CM-Europe
Office: +31 544 375 053
Mobile: +31 646 377 955
E-mail: rots1@chello.nl

Asia:
Chris Aum, C&energy Company, Ltd.
Office: +82-31-266-6656
Fax: +82-31-266-6674
E-mail: chris@cnenergy.co.kr
Web: www.Cnenergy.co.kr

Latin America:
Jeff Jensen, Sales Director, Goettsch International, Inc.
Office: +1-513-588-3172
Fax: +1-513-588-3172
E-mail: jeff@goettsch.com
Web: www.goettsch.com

Special features: CM Recycling has developed specific technologies to increase the effectiveness of their tyre shredding systems. One feature of their shredding systems is the use of the "Holman Patent", a shredding knife system that has extremely close knife-to-knife tolerances. CM purchased this patent and incorporated it into their shredders. This technology allows the processors to create high quality tyre chips, with little exposed steel. This, in conjunction with a highly effective screening system, allows for the production of cleanly cut tyre chips of regular and consistent size.

CM has also developed a system of extracting clean steel from tyres, as well as clean rubber. The Liberator™ was developed when the demand for smaller, cleaner ground rubber increased. While other companies strove to find means to create cleaner rubber, CM developed a system to liberate clean steel from tyres. The steel can be sold back to steel mills, creating an extra revenue stream. Further, the extraction and production of clean steel means that the rubber extracted from these tyres is almost completely free of metal. The Liberator™ allows for the production of two different products from one source – used tyres.

Brochure download includes product features:
http://www.cmtyrerecyclingequipment.com/Public/15625/CM2RLiberatorEnglish1.pdf

c) SSI shredding Systems, Inc. is located in Oregon, USA; designs and manufactures industrial shredding systems, waste reducers and transfer station compactors. They have installations in 51 countries around the world, and provide single rotator, two-shaft and four-shaft shredders.

Full contact detail of the company:
SSI shredding Systems, Inc.
9760 SW Freeman Dr.
Wilsonville, OR 97070, USA.

Toll free numbers inside USA: 800-537-4733 I
Toll free numbers outside USA: 1-505-682-3633
Company's website: http://www.ssiworld.com/

SSI shredding Systems has its head office in USA and branches and suppliers worldwide. Countries operating SSI shredding Systems includes UK, Europe, Australia, Japan, Korea, Mexico, Argentina, Taiwan, Indonesia and Israel.

Special feature: SSI Shredding Systems is able to provide bespoke shredding systems all over the world. They also have a number of partner organizations, suppliers and branches, as mentioned above, which ensures that there is assistance available for the use and maintenance of their product in nearly every country worldwide.

Brochures:
Single rotator shredder http://www.ssiworld.com/docs/PD-SR01-Uni-Shear-all%20models.pdf
Dual rotator http://www.ssiworld.com/docs/Dual-Shear_brochure.pdf
Quad shredder http://www.ssiworld.com/docs/PD-Q85-Quad-Shredder.pdf

d) BCA industries are based in the Wisconsin, USA; but their shredders are available worldwide. The majority of their installations have been in the USA. They offer shredding systems and information on the financial aspects of tyre recycling to their clients, and are able to provide individual shredders or whole shredding systems, depending on the needs of the suppliers, client and market demands.

Full contact of the company:
4330 West Green Tree Road
Milwaukee, WI 53223
Ph: 414-353-1002 I Fax: 414-353-1003 I Email: sales@bca-industries.com
Website: http://bca-industries.com/

Special features: BCA Industries offers individual shredders and shredding systems, which can be customized to meet the specific needs of the client. They offer ongoing service and repairs of their equipment, as well as any parts that may be needed. This is an important feature as the maintenance of tyre processing systems is often a significant part of the cost of running these operations. They ship equipment internationally, and offer equipment set-up and training and maintenance and safety reviews. Information and brochure downloads on the different shredders and shredding systems are available here: http://bca-industries.com/shredders/

e) ELDAN Recycling, head office is located at the island of Fyn (Faaborg, Denmark). ELDAN Recycling is a global supplier of recycling equipment for processing of tyres, cables, WEEE, aluminium, refrigerators, MSW, magnesium and various scrap materials. Since 1956, ELDAN has installed more than 830 complete plants and 7,100 single machines all over the worldwide. The company has sales offices in Germany (Düsseldorf), USA (Sanborn, NY), Australia (Gordon NSW) and France (Paris). Suppliers, vendors & sub-vendors and agents are located all over the world.

Full contact detail of the head office:
Head office, Denmark, Finland
Eldan Recycling A/S

Vaerkestervej 4
5600 Faaborg, Denmark
Ph: +45 63 62 25 45 I Fax: +45 63 61 25 40 I Email: info@eldan-recycling.com
Website: http://www.eldan-recycling.com

The worldwide production units, distribution points, sales offices and customer service centers of ELDAN's locations includes Algeria, Morocco, Tunisia, France, South Africa (operates in the name of MMH Recycling Systems (Pty) Ltd.), China (operates in the name of Ferrostaal Commercial (Beijing) Co., Ltd.), India (functions as Ferrostaal India Private Ltd.), Japan (operates in the name of Correns Corporation, Pakistan (suppliers in the name of East-West Commercial Enterprise), Australia (operates in the name of ELDAN-Westrup South Pacific Pty Ltd.), Austria & Germany (operates in the name of ELDAN Recycling A/S), Belgium, Holland & Luxembourg (operates in the name of ELDAN Recycling Benelux), Bosnia & Herzegovina (sales & suppliers unit, in the name of Arcon Overseas Ltd.), Bulgaria (agents in the name of Arcon Bulgaria Ltd.,) Croatia (in the name of Arcon Overseas Ltd.), Czech Republic (functions as the distribution and production unit, serves in the name of Arcon Machinery a.s.), Greece (operates as a production unit in the name of Industria S.A.), Hungary (operates in the name of Arcon Hungary), Ireland (operates in the name of MMH Recycling Systems Ltd.), Italy (operates as a supplier in the name of P.I. Armando Icardi Sas di Maurizio Icardi), Macedonia, Montenegro & Serbia (operates in the name of Arcon Overseas Ltd.), Poland (operates as Rub-Met), Portugal & Spain (Operates as suppliers and vendors in the name of Recycling Equipos S.L), Romania (Functions in the name of Arcon Overseas Ltd.), Slovakia (operates in the name of Arcon Slovakia s.r.o.), Slovenia (In the name of Arcon Overseas Ltd.), Switzerland (operates in the name of Eldan Recycling A/S), Turkey (Operates in the name of Ferrostaal A.S.), United Kingdom (operates in the name of MMH Recycling Systems Ltd.), Middle East (Functions in the name of Ferrostaal GmbH), Canada (operates in the name of Eldan Inc.), Mexico and Central America (operates as a supplier and sales unit in the name of Ferrostaal México, S.A. de C.V.), USA (Functions as Eldan Inc.), Russia and CIS (operates as GP Systems LLC), Argentina (functions are carried out in the name of Ferrostaal Argentina S.A.), etc., Furthermore, ELDANS's locations and their corresponding contact details of the same can be found out at the following link: http://www.eldanrecycling.com/contact/head-office

Special features: ELDAN tyre recycling shredders and systems aim to downsize the tyre enough in order to separate the various materials. Their technique allows for the processing of whole car and truck tyres (including super singles) without the need for prior debeading. Their systems are also able to process larger tyres, such as those used for off-the-road vehicles and earthmovers. The main feature of their systems is that they are able to be easily added to and expanded, allowing customers to invest a small amount at first, with the possibility of expansion later. The use of a modular system allows for a greater number of combinations within the tyre recycling plant, and allows for the generation of different types of ground rubber. As previously mentioned, ELDAN's multi-size plants offer the ability to produce a range of different forms of ground rubber with the simple change of screens.

Brochures & Downloads:
Brochures for the different kinds of shredders and shredding system components are all available at given link: http://www.eldan-recycling.com/content/single-machines

f) Unlimited Resources Corporation (URC) is based in Missouri, USA, but their shredders are available worldwide. The majority of their installations have been in the USA. They are the exclusive worldwide dealer of Raptor Tyre Processing Equipment, which is built and design by IDM, LLC. The Raptor designs are thought to offer innovative design, easy maintenance and high quality construction. URC ships their equipment worldwide, and offers installation and maintenance services.

Full contact of the supplier
1088 County Road 1745,
Cairo, Missouri, United States
Ph: 1800 423 9062 I Local Ph: 1660 295 4204 I Fax: 1660 295 4871 I Email Contacts
Website: http://www.urcrecycle.com/

Special features: URC is the worldwide supplier of Raptor Tyre Processing Equipment. They also offer appraisals of used equipment, offering information based on the replacement value of the equipment, the fair market value, the orderly liquidation value, the auction value and the distressed value. They offer consulting on the type of equipment that would be most suited to each individual operation, and how equipment can best be acquired. They also offer "service after the sale" – URC has a fully equipped rebuild shop that allows for the refurbishment of most equipment. These services are available in Missouri, and the company also has two fully equipped service trucks, which are able to be dispatched within the USA to make on-the-site repairs.

Product information:
Information on tyre shredding machines
http://www.urcrecycle.com/category/tyre-shredders/
Information on tyre recycling equipment
http://www.urcrecycle.com/category/tyre-recycling-equipment/
Information on equipment for crumb rubber
http://www.urcrecycle.com/category/crumb-rubber-equipment/

g) Artech Reduction Technologies located in Ontario, Canada; designs and produces shredding machines. They offer products, which are designed to deliver high production rates, with minimal service, maintenance and downtime. Artech custom designs mobile and stationary shredding plants, offering shredders that can be driven by hydraulic or electric motors, and which are tailored to the specific needs of each client.

Full contact details of the head & sales office:
Artech Head Office
1218 South Service Road
Oakville, Ontario
Canada L6L 5T7
Ph: 905 829 1350
Fax: 905 829 1535
Sales Office (Located in United Kingdom)
Unit 1, Foresters Green
Trafford Park, Manchester
UK M17 1EJ

Ph: 0161 877 1288
Website: http://www.artechreduction.com/

Special features: Unlike many of their competitors, Artech offers mobile shredding machinery. This machinery is ideal for situations where the cost of transporting tyres to a central processing facility is high. These machines allow for a large number of tyres to be processed where they are located.

Shredders information and specifications:
Single shaft shredders
http://www.artechreduction.com/Products/Single-Shaft-Shredders.aspx
Two shaft shredders
http://www.artechreduction.com/Products/Two-Shaft-Shredders.aspx
Four shaft shredders
http://www.artechreduction.com/Products/Four-Shaft-Shredders.aspx

h) Tyres Herco SA with its corporate headquarters in Maroussi, Greece is private; venture capital backed recycling company converting waste commercial-vehicle tyres into rubber granules and fine powder products in a wide range of sizes and grades for marketing commercially. The company has its factory in Patras, Greece which is the 3rd largest port in Greece. It has a capacity of approximately 20,000 tons of tyres a year - about 400,000 individual casings - producing 13,000 tons a year of rubber granules and fine powder products. Tyres Herco's plant in Patras uses Amandus Kahl & Co state of the art technology to produce rubber crumb from used tyres. The rubber from the tyres is transformed into rubber granules and fine powder, which the scrap steel and textile fibres are also recycled and reused.

Full contact details of the head office & factory:
Office Headquarters
Atrina Tower – 17th floor
32 Kifissias Avenue
15125 Maroussi Greece
Ph: 2108174300 I Fax: 210 8174302
Industrial Area of Patras (Factory)
Block 37,
B2 Street,
Patras, Greece 25018
Ph: 2610 647331
Website: www.herco.gr

Tyres Herco operates out of Greece, and currently exports rubber crumbs to 39 countries. Tyres Herco currently exports to; Albania, Australia, Azerbaijan, Belarus, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Egypt, Finland, Germany, Georgia, Germany, Greece, India, Indonesia, Iraq, Israel, Italy, Jordan, Latvia, Lebanon, Malta, Morocco, Nigeria, Norway, Poland, Romania, Russia, Saudi Arabia, South Korea, Sweden, Turkey, U.A.E., U.K., U.S.A., Vietnam.

Special features: Tyres Herco sells rubber granules and powder. Herco is one of four companies that have developed an application called "ACE – Advanced pre-commercialization of Eco Rubber materials". This means that the company supplies rubber powder as part of an Eco-innovation project. The project aims to introduce an innovative hybrid material – a recycled polymer called "Eco-rubber" – made from recycled rubber and plastic. It aims to introduce this product to the European market by adapting and fine-tuning it to meet end user's needs.

Product details and a brochure copy: http://www.herco.gr/content.php?id=2&version=en

i) Lehigh Technologies specializes in transforming waste tyres into micronized rubber powder, and the creation of their MicroDyne™ and PolyDyne™ products. They aim to operate in an environmentally friendly manner through the use of a close loop service in their production of micronized rubber powder.

Full contact detail of the company
Corporate Headquarters
120 Royal Woods Court SW
Tucker, Georgia 30084
Phone: (678) 495-2200n I Fax: (678) 495-2201 I
Website: http://www.lehightechnologies.com/
For additional contact details: http://www.lehightechnologies.com/index.php/contact_us/

Lehigh Technologies is located in Tucker, GA, outside Atlanta, and is backed by Kleiner Perkins Caufield & Byers, Index Ventures, NGP Energy Technology Partners and Leaf Clean Energy Company. This operation uses a closed loop process. They manufacture green micronized rubber.

To learn more about the company's closed loop process click the following link:
http://www.lehightechnologies.com/index.php/products_services/closed_loop/

The other locations where the operations are carried out are Brazil and Spain.

Special features: Lehigh Technologies produces Micronized Rubber Power. Micronized Rubber Powder, or MRP, is 80 mesh (or 180 microns) and smaller (300 mesh or 50 microns) and is virtually metal and fibre free. It is produced using a cryogenic manufacturing process, which takes crumb rubber material and "upcycles" it into micron-scale – this is referred to as "upcyling" because it is able to be used in a greater number of applications and therefore there is value added to it in the process. MRP is 3rd-generation technology; more technically advanced allowing for more sustainable rubber to be available to more industries in higher value applications. These high value applications include high performance tyres, plastics, coatings, and roofing systems.

A brochure copy of the company: http://www.mktcom.net/PDFs/LehighBro.pdf

j) Global Recycling Equipment (GRE) located in Montreal, Canada; has been in operation since 1966, and developed some of the first designs and patents for industrial shredding. They are a worldwide manufacturing company offering industrial tyre shredders, and a number of other industrial shredders. They are based out of Quebec and have installations all over the world.

Full contact detail of the company:
Address of the office headquarters:

318 Portland Ave.
TMR, QC, H3R, Montreal, Canada.
Ph: 815-674-5802 I Skype: 312-376-8127
For global contacts and sales enquiries please click the following link: Overseas contact details with sales enquiry contact list
Website: http://www.globalrecyclingequipment.com/

Since 1966 GRE has been in operation in Montreal, Canada; and has their machinery installed in countries all over the world. The size of these instillations is largely dependent on the size of the operation, and what product is desired, rather than the location. Global Recycling Equipment (GRE) has a global network of shredder suppliers, with international representatives for Europe, South America, Central America, North America, Asia, the Middle East, the Caribbean, Europe and Russia.
The entyre list of GRE's product specifications can be downloaded from the link below:
http://www.globalrecyclingequipment.com/manuals

k) Western Tyre Recyclers located in Tremonton, Utah (USA); converts whole industrial and truck tyres into water tanks, with sizes ranging from 5-13 feet, with a maximum capacity of 2,000 gallons of water. The tanks are very strong and able to resist ice, bulls and other wildlife – making them ideal for use in farms. In order to recycle the off-the-road tyres, they must first be transported to the Western Tyre Recyclers facility in Utah, where they are then processed using custom-built equipment. The water tanks are built by removing one of the sidewalls of a large mining tyre.

Full contact detail of the company:
Western Tyre Recyclers,
l-15 and l-85 in Tremonton
Utah, USA
Ph: (435) 730-1872 I (435) 452-8551
Website: http://www.westerntyrerecyclers.com/

Western Tyre Recyclers in based in Utah, USA and their products are installed throughout the United States. They are the leaders in off road tyre recycling, and in particular provide recycling services for the mining industry.

Special feature: Western Tyre Recycling specializes in the processing of large off-the-road tyres. They are able to process tyres that are significantly larger than typical passenger tyres, and as such, offer a viable alternative for the waste tyres generated in agriculture and the mining industry. Such processing may be suitable for many developing nations.

l) ECO Green Equipment located in North salt lake, Utah (USA); manufactures turnkey tyre recycling systems, with a focus on providing custom designed tyre recycling systems that deliver optimum production for a range of applications, including tyre derived fuel (TDF), wire free chips, rubber mulch and ground rubber.

Full contact of the company
Address of the USA headquarters office:
425 North 400 West, Building 3A

North Salt Lake, Utah 84054 USA
Ph: 001-801-505-6841 I Fax: 1-801-653-0234
Website: http://www.egtyreshredders.com/
Contact details of the European distributor of the company's product:
General Recycling GmbH
Wichtelgasse 19/2,
A-1160 Vienna, Austria.
Ph: +43 (0) 1 9962008-0 I Fax: +43 (0) 1 9962008-9 I Email: info@ecogreenequipment.com
Eco Green Equipment European website: http://general-recycling.eu/index.php/en/

Eco Green Equipment has manufactured and installed recycling systems in countries all over the world, including the USA, Canada, Mexico, South America, South Africa, Iraq, and Asia.

Special feature: ECO Green Equipment builds and installs turnkey recycling plants. They offer two shaft, single shaft, and fine grinding shredding systems that range with purposes ranging from volume reduction (of waste tyres) to TDF (Tyre Derived Fuel) chips, wire-free mulch, crumb rubber, and rubber powder. ECO Green Equipment has been designing and manufacturing equipment for the recycling industry since 2001. They provide custom designed tyre recycling systems that deliver optimum production for a variety of applications such as TDF (Tyre Derived Fuel), Wire-free chips crumb rubber and rubber powder. Each system is tailored to the needs of the business location, market, and customer. The company manages the complete process from system design to installation anywhere in the world, using proven US and European technology and components from suppliers such as Siemens and General Electric.

Product information and specifications can be accessed by clicking the following link:
http://www.egtyreshredders.com/plants/tdf-plants/

m) Hikari World Co., Ltd. Located in Nara, Japan; one of the leading tyres recycling company in the country with over 60 years of expertise in eco-friendly operations. Industry in general collects all types of tyres from trucks, semi-trucks, domestic vehicles like cars, scooters, etc., and recycles them in conventional shredding and thermal recycling processes. Over the years this company ventured in to the latest energy and material recovering technologies such as advanced shredding & retreading process and pyrolysis to extract carbon, oil and steel.

Full contact of the company:
1309, Sugawa-cho,
Gojo, Nara, 637-0014, JAPAN
Ph: +81-747-26-3000 l Fax +81-747-26-3380 l E-mail: general@hikari-world.com
Website: http://www.hikari-world.com/
http://www.j-sra.jp/ (japan tyre association)

Hikari operates in the location mentioned above and it is closely associated with the Japan Shipbuilding Research Association (JSRA) which closely monitors the tyre recycling process.

Special Features: Industry offers several pulverizing equipment which can cut the tyre parts into several fragments than usual tyre recycling firms. The machines designed from these companies are able to cut large tyres from trucks tyres from caterpillar & construction based tyres. Cutting of tyres can start from 8 fragments of crumbs to the maximum of about 32 fragments.

Additional Information about the company, products and its certification: http://www.hikariworld.com/e/company.html

n) Matec Inc. a major tyre recycling company in Japan located in Hokkaido; specializes in dismantling ELV (End of Life Vehicles) automobile tyres though crashing & shredding tyres chips and then subjecting the shredded crumbs through magnetic separator. The final chips from these ELV tyres are used as boiler fuel.

Full contact detail of the company:
3-20, Kita1-chome, Nishi21-jo, Obihiro,
Hokkaido, 080-2461
Ph: 0155-37-5511 l Fax: 0155-38-7185 l
Additional contact source: http://www.matec-inc.co.jp/english/contact/
Website: http://www.matec-inc.co.jp/english/elv/tyre/

Special features: Matec established several branches in the country and works on recycling on developing sustainable products through recycling. The firm has its self-developed and standardized program to control the material flow within the organization. It's effectively organized, which enables a transparent and provides an easy window for the employees and to the clients to monitor the status of the chips generated from the ELV's.

Additional information: http://www.matec-inc.co.jp/english/corp/license.html
List of related companies to Matec: http://www.matec-inc.co.jp/english/r_company/

o) Kokubu Shokal Co., Ltd. (KKB) is another well-established tyre recycling industry located in Kumagaya City, Japan. It deals with all types of tyre scraps starting from cycle, cars, semi-trucks, heavy trucks till aircrafts tyres. The establishment is known for products such as Kokubu Green Farm, Sarah Turf (Artificial Grass) and Rubber chip (EPDM- Ethylene Propylene Diene Monomer) derived from waste tyres.

Full contact of the company:
Kokubu Shokai Co., Ltd
2643-1 Magechi, Kumagaya City,
Saitama Prefecture, 360-0161, Japan
II unit address: 3714-4 Magechi, Natsume, Kumagaya City, Saitama Prefecture,
Ph: 048-537-1733Ph: 81-48-536-1564 l Fax: 81-48-536-7151 Email: hiroshi@kkb-tyre.co.jp; n.manaka@kkb-tyre.co.jp

Tokyo Office Address:
Akarenga Dori Building 6th floor,
3-7-4 Shinbashi, Minato-ku, Tokyo, Japan
Ph: 03-5532-1313
Website: http://www.kkb-tyre.co.jp/eng/which/index.html

Special features: Company specializes in making artificial grasses for football grounds and domestic & commercial gardening. It uses state of the art technology to manufacture floor mats applied on a household and industrial scale. It has a capacity of storing 40,000 pcs (tyres) in Saitama location and another 40,000 pcs in its Iwatuki warehousing location. Its products are exported to USA, Europe, North America, South America, India, China, Russia, Middle East, Australia, Canada, Africa and New Zealand. Apart from the tyre recycling company also treats industrial wastes to energy recovery and material recovery processes. Thermal treatment plants are employed the most in terms of its operational structure. Cutting and crushing (a part of shredding process) of waste tyres, is another established division of the firm other than thermal treatments.

Additional links: the following link provides an estimated figure of the company's recycling outputs: http://www.kkb-tyre.co.jp/eng/shs/

This link will detail out the complete cycle of process involved in tyre recycling designed in KKB: http://www.kkb-tyre.co.jp/eng/recycle/

Lists out the company's history and the major clients involved in the business: http://www.kkb-tyre.co.jp/eng/company/#soshikizu

Annexure - 5.2: List of Tyre Recycling Companies in Developing Country

Selected list of the tyre recycling companies in Canada (Materials Based)

Name	Address	Role in Tyre Recycling
Achievor tyre Inc.	117 Industrial Park Rd Minto E4B 3A6, ON	Resale
International growth associates	765, Exterior rd., unit 111, London, ON, N6E, IL3	Export of used tyres
Int. waste management group	2252 Lawrence Ave. Weston, ON M9P 2A3	Export of used tyres
Jacques Lauzon	2641, Treviso Ct. Mississauga, ON L5N 2T3	Export of used tyres
Multi Shared manufacturing company Inc.	142 Woodside Ave. Ste. 203 Cambridge, ON NIS 4A9	Export of used tyres
Overseas Canadian	5307 Canotek Rd. Suite 202, Ottawa, ON K1J 9M2	Export of used tyres
Crown Tyre Service	2520 Millar Ave. Saskatoon, SK S7K 4K2	Retreads the used tyres
Hopkins Tyre Service Ltd.	125 circle drive east, Saskatoon, SK S7K OT4	Retreads the used tyres
Nor-Sask Tyre Center	3110 Millar Ave. Saskatoon, SK S7K 5Y2	Retreads the used tyres
Western Tyre Retreaders (Regina) Ltd.	687 Adams St. Regina, SK S4N 4W4	Retreads the used tyres
Western Tyre Service	805 Winnipeg St. Regina, SK S4R 1J1	Retreads the used tyres
Budget Steel	2770 Pleasant Street Victoria, BC V8T 4V3	Shredding process, products from shreds
Northwest Rubber Mats	33850 Industrial Ave Abbotsford, BC, Canada V2S 7T9 Website: http://www.northwestrubber.com/	Making mats from the used tyres
Trac Tyre Recovery Corporation	149 Industrial Park Rd Minto, New Brunswick Canada E4B 3A6 Website: http://www.tracc.ca/faq.html	Utilizing Crumbs & Shreds
Western Rubber Products	721A Aldford Ave, Delta, BC V3M 5P5, Canada Website: http://www.western-rubber.com/	Involved in various tyre recycling processes such as retreading, mat manufacturing, plastic accessories for industrial accessories, etc.,
Algoma Tyre Recycling	105 Northland Dr. Unit E, Waterloo, ON, N2V 1Y8	Crumb rubber, grinding of used tyres and shredding
Anyox metals ltd.,	150 York St. Ste. 1814 Toronto, ON M5H 3S5	Chips of the used tyres, tailings and its stabilization
Custom Cryogenic Grinding	105 Thompson Rd. E. Waterford, ON N0E 1Y0	Crumb rubber (Cryogenic)
Domal Industries	1564 Kingston Rd. Scarboro, ON	Crumb rubber, Microwave

Name	Address	Role in Tyre Recycling
	M1N 1S1	Technology
Ferret manufacturing Inc.	1200 Wonderland Rd. S. Bld. 9, Unit 9 London, ON N6L 1A8	Dock bumpers, industrial floor mats.
Ministry of Environment	2 St. Clair Ave. W. 14th Floor Toronto, ON, M4V 1L5	Rubber asphalt Demonstration
Ministry of Environment/Regional Municipality of Haldimand-Norfolk	2 St. Clair Ave. W. 14th Floor Toronto, ON, M4V 1L5	Rubber asphalt Demonstration
National Rubber	394, Symington Ave. Toronto, ON M6N 2W3	Crumb Rubber (Ambient)
New World Enterprise	2 Twelfth St. Grimsby, ON L3M 2V7	Crumb Rubber (Cryogenic)
Ontario Tyre Recycling	60 Colborne St. Welland, ON L3P 3P1	Crumb Rubber (Cryogenic)
Petro-Techna International	3 Robert Speck pkwy Ste. 900 Mississauga, ON L4Z 2G5	Crumb Rubber
Playbound International	21 Albert St. Waterdown, ON L0R 2H0	Crumb Rubber from solid rubber tyres
Recovery Tech. Inc. (Group Venture Inc.)	5925, Airport Rd. Ste. 612 Mississauga, ON L4V 1W1	Crumb Rubber (Cryogenic/ Cryogenic equipment)
Resource Recovery Orangeville	22 Robb Blvd. Orangeville ON L9W 3L2	Crumb rubber from waste Tyres
Roofing Concepts	5280, lakeshore Rd. E. Ste. 507 Burlington, ON L7L 5R1	Crumb Rubber
Stevensville Tyre	3976-A, Bowen Rd. 2 Twelfth St. Grimsby, ON L0S 1S0	Crumb Rubber (Cryogenic)
Thermofriction Waste Recycling (TWR)	2651, John St. Ste. 1 Markham, ON L3R 2W5	Shredding/Crumb (Thermal Screw Press)
T.R.C. Corporation	2409-33 Harbour Sq. Toronto, ON M5J 2G2	Crumb Rubber (Cryogenic)
Triple T Industries	2651, John St. Ste. 1 Markham, ON L3R 2W5	Crumb Rubber/(Noise Barriers)
Viceroy/Trent (Group of Companies)	1655, Dupont St. Toronto, ON M6P 3T1	Crump Rubber (Ambient)
Hortness Enterprises Ltd.	Box 341 Redvers, SK S0C 2H0	Welcome/Domestic Mats
Saskatchewan Rubber Recycling	Sub 24 Saskatoon, SK S7M 0V0	Crumb Rubber (Cryogenic)
Tyre Cycle Products Inc.	607-4th Ave. East Regina, SK S4N 4Z8	Crumb Rubber

Selected list of the tyre recycling companies in Canada (Energy Based)

Name	Address	Role in Tyre Recycling
La'Fair Inc.	1700 Wilson Ave Suite148-149 North York, ON M3L 1B2, Canada	Kiln Fuel from the waste Tyres
Fronda Ltd.	P.O. Box Bridgewater, Nova Scotia B4V 2W8	Microwave processes
Ireton International	2 Keele Street Suite 203 Toronto,	Pyrolysis processes

Name	Address	Role in Tyre Recycling
Waste Recovery Inc.	ON M6P 4C1	
Surety Environmental Inc.	Suite 501, 940 940 – 6th Ave. S.W. Calgary, Alberta T2P 3T1	Incineration process for energy recovery from used tyres
Willis Consulting Group	270 Adelaide St. W. Suite 201 Toronto, ON M5H 1X6	Incineration process for energy recovery from used tyres
Atlantic Synfuels Ltd.	250 Consumers Rd. Ste. 701 Willowdale, ON M2J 4V6	Pyrolysis for energy recovery.
Emery Associates	Purdy Rd, Box 219 Colborne, ON K0K 1SO	Pyrolysis (Microwave Technology)
IBIS products ltd	17 Munham Gate Scarborough, ON M1P 2B3	Pyrolysis
Evergreen Waste Management Inc.	60 Columbia Way Ste. 710 Markham, ON L3R 0C9	Compacting of Tyres
MRP Waste Management	1020 Pond Mills Rd. London, ON N6N 1A2	Baling of tyres

Selected list of the tyre recycling companies in USA (Materials/Energy Based)

Name	Address	Role in Tyre Recycling
Recovery Technologies Group(RTG) Inc.	7000 Boulevard East, Guttenberg, NJ 07093	Ambient and cryogenic crumb rubber; TDF; civil engineering
Lakin General Corp.	2044 N. Dominick St., Chicago, IL 60614 Website: http://www.lakincorp.com/	Reusable tyres; die-cut products; TDF (Tyre Derived Fuel); crumb
GreenMan Technologies Inc.	7 Kimball Lane, Lynnfield, MA 01940	TDF; crumb rubber
Emanuel Tyre Co.	1300 Moreland Ave., Baltimore, MD 21216 Website: http://www.emanueltyre.com/	TDF; horse arena and playground cover material
Florida Tyre Recycling Inc.	9675 Range Line, Port St. Lucie, FL 34987	TDF; drainfield aggregate; playground surface; crumb
TYRES Inc.	617 Washington, Winston-Salem, NC 27107	Crumb rubber for asphalt pavement and for sports surfaces
Integrated Tyre	333 Ganson St., Buffalo, NY 14203	TDF; resalable tyres; engineering applications
Meridian Inc.	1414 Norwich Rd., Plainfield, CT 06374	TDF; used tyres; casings
Midway Tyre Disposal/Recycli Ng	8925 E. Centro Blvd., Fountain, CO 80817	Baled for civil engineering Applications
Mac's Tyre Recyclers	2058 Mississippi 145 Saltillo, MS 38866 United States	Shredded tyre chips for TDF
Champlin Tyre Recycling	P.O. Box 445, Concordia, KS 66901 Website: http://www.champlintyrerecycling.com/	Manufactured products, including outdoor furniture
Waste Recovery West Inc.	372 Florin Rd., Sacramento, CA 95831 Website: http://www.tyredisposalrecycling.com/	TDF; crumb rubber; reusable casings
Golden By-Products Inc.	13000 Newport Rd., Ballico, CA 95303 Website: http://www.goldenscraptyre.com/	2-inch TDF; 3/4-inch ground cover; civil engineering

Name	Address	Role in Tyre Recycling
Entech Inc.	69676 M-103, White Pigeon, MI 49099 Website: http://www.4entech.com/	TDF; septic and landfill drainage material;
Utah Tyre Recyclers	1398 N. Beck St., Salt Lake City, UT 84116	TDF; crumb rubber; alternative daily landfill cover
First State Tyre Recycling	1500 278th lane NE Isanti, MN 55040 Website: http://www.firststatetyre.com/	Civil engineering Applications
BAS Recycling Inc.	14050 Day Street Moreno valley, CA 92553 Website: http://www.basrecycling.com/	Crumb rubber; buffings; custom grinding
Environmental Rubber Recycling	6515 N. Dort Hwy., Flint, MI 48505 Website: http://environmentalrubberrecycling.com/	TDF
Colt Inc.	P.O. Box 1408, Scott, LA 70583 Website: http://coltscraptyre.com/	TDF; civil engineering Applications
Phoenix Industries	300, E. Delhi Ave. North Las Vegas, NV 89032 Website:http://www.phoenixindustries.com/	Shredding (Ambient/Cryogenic); Asphalt Pelleting/; Turnkey Solutions;
TyretoFuel/Birch Energy	Website:http://www.tyretofuel.com/index.html	Shredding/Crushing/Crumbs; Pyrolysis ; Scrap Steel
Libertytyre	Pittsburgh, PA Ph: 412.562.1700 l Email:Corporate@libertytyre.com Website: http://www.libertytyre.com/Home.aspx	Scrap tyre collection; crumb rubber; rubber mulch; asphalt (Shredding mechanical) fuel; aggregates (pyrolysis)
International Environmental Solutions, Inc.	1620 Cypress Gardens Road, Moncks Corner SC 29461 Ph: 843-761-7955 l Fax: 843-761-5920 l Email: Tyre_International@hawkassociates.com Website: http://www.tyreinternational.net	Shredding; Granulation; Pulverizing; Yield products: Tyre Chips, crumbs, asphalt rubber, etc.,
Tyre Recycling Consultants	Waste Tyre Processing Equipment, Leasing and Sales Robert J. Czukor, Senior Sales Consultant, Ph: (800) 557-5692 Fax: (888) 761-4995 l Email: recyclingtyres@aol.com Website: http://www.recyclingtyres.com/	Provides consulting services, financial solutions and leasing across USA for all types of industries involved in tyre recycling.
Global Recycling Network	P.O. Box 58228, Salt Lake City, Utah 84158, USA Ph: (801) 531-0404 l http://www.recyclenet.com/ Website: http://www.grn.com	North Americas global network for recycling solutions.

Selected list of the tyre recycling companies in UK (Materials/Energy Based)

Name	Address	Role in Tyre Recycling
Fraser Evans & Sons Ltd (Tyre Recycling Center)	Worsham Quarry, Burford Rd, Minster LovellOX29 0RU Website: http://www.fraser-evans.co.uk/	Shredding, Compacting, Disposal
Hogarth Tyre shredders	Bodys yard, Heron Hill Lane Culverstone Green, Meopham, Kent, DA13 0QT Website: http://www.hogtyres.co.uk/	Crumb Rubber, Shredding, Tyre Chips
Tyre Recovery Association	Media House, Berewyk Hall Court, White Colne, Essex, CO6 2QB	Organized Recycling

Name	Address	Role in Tyre Recycling
	Website: http://www.tyrerecovery.org.uk/	
Entyre Recycling	14 Church Lane, Lochgelly, Fife, KY5 0XE Website: http://www.entyrerecyclingfife.co.uk/	Shredding of waste Tyres
KayBoat Casings Ltd	30 Burlington Crescent Goole DN14 5EF	Collections & Disposal
SW Tyre & Rubber Recyclers	Unit 3 Station Approach, Hayle, TR7 6JW Website: http://www.swtyrerecyclers.co.uk/	Collections & Disposal
A & C Tyre Collections	Hall Lane Farm Little Warley Hall Lane, Brentwood, Essex, CM13 3EN Website: http://www.tyrecollectionservice.co.uk/	Shredding, Crumb Rubber
Mcgrath Group	Mcgrath House, Hepscott Road, Hackney, London, E9 5HH Website: http://www.mcgrathgroup.co.uk	TDR (Tyre Derived Rubber), Bailing, Bespoke Shredding, Crumb Rubber
DME Tyres Ltd	Unit 1 Ring Road, Burntwood Business Park, Burntwood, Staffordshire, WS7 3JQ Website: http://www.dmetyres.co.uk/	Shredding (Crumb Rubber 30 mm to 50 mm); TDF
Niramax Total Waste solutions	Niramax Group Limited 6 – 8 Tofts Farm West, Tofts Farm Industrial Estate, Hartlepool TS25 2BQ Website: http://www.niramax.co.uk/	TDF; Crumb Rubber
Scrap Tyre Recyclers	Skeffington Mills Uppingham Rd, Skeffington, Leicester, Leicestershire, LE7 9YE Website: http://www.scrap-tyrerecyclers.co.uk/	Baled/Shredded Tyres
Rubber Recycling Solutions Ltd.,	49 Chase Rd, Park Royal, London, London, NW10 6P Website: http://www.rrs-tyres.co.uk/	TDF, Crumb Rubber, Domestic & Commercial Mats
Recycle Tyre Services Ltd.,	W3W Recycling Ltd., Unit 2b, Standon Business Park, Stortford Road, Standon, Hertfordshire, SG11 1PH Website:http://www.recycletyreservices.co.uk/	Worn tyre to crumb rubber, disposal and sales to other vendors

Selected list of the tyre recycling companies in European Union (Materials/Energy Based)

Name	Address	Role in Tyre Recycling
Genan A/S & GmBH (Germany/Denmark)	Genan Business & Development A/S. Jegindovej 16. DK-8800 Viborg Website: http://www.genan.eu	Retreading, Incineration, Landfill
Virgo Environmental Technologies (Germany)	Bliersheimer Str. 80A Logport Office Center 47229 Duisburg, Germany Website: http://virgo-et.com/	Rubber powders; steel; Textile fiber; Rubber Production Plant (from waste tyres)
TOMRA Sorting Solutions (Norway)	Drengsrudhagen 2, 1385 Asker Norway Website:http://www.tomrasorting.com/	Shredding, Retreading
WIL (Austria)	WIL Anglagenbau, Neubaugasse 4/7-9 1070 Wien Austria Website: http://www.wil-ag.com	Rubber Products & Granules
PE International (Germany)	Hauptstrasse 111-113 Leinfelden-Echterdingen 70771 Germany,	Retreading, Crumb Rubber

Name	Address	Role in Tyre Recycling
	Webiste: http://www.peinternational.com/	
BMH technology (Finland/Sweden)	BMH Technology Oy, P.O. Box 32 (Sinkokatu 11) FI-26101 Rauma, Finland (Also has its operations in Sweden) BMH Technology AB; P.O. Box 12 (Kaptensgatan 23), SE-745 21 Enköping, Sweden, Website: http://www.bmh.fi	Shredding (Cryogenic); TDF; TDP; Rubber products; Mats
Banyan Recycling (Germany)	beginenhof 7 44135-Dortmund Germany	Shredding, Crumb Rubber, Butyl Rubber
Recicaucho, S.L. (Spain)	Avenida de los Arces 24 Madrid Madrid Spain 28042	Cryogenic
MTB Recycling (France)	Quartier de la Gare 38460 Trept – France Website: http://www.mtb-recycling.fr	TDF; Textile fiber yields from tyres; rubber granules; steel yield
SDAB (Sweden)	Svensk Däckåtervinning AB, Box 90131, 120 21 Stockholm, Sweden Website: http://www.svdab.se	Disposals, Landfills, Shreds, Recycling Regulations; Kiln Fuel; incineration; Asphalt; Noise Banks;
Department of Environment, Transport, Energy and Communications	Federal Office for the Environment FOEN, 3003 Bern, Switzerland Website: http://www.bafu.admin.ch	Tyre waste controlling; distribution of the scraps tyres to the recyclers;
Lafarge, Building better cities France)	61 rue des Belles Feuilles 75116 Paris – France l Ph: +33 (0)1 44 34 11 11 Website: http://www.lafarge.com	Energy recovery, carbon, oil and steel producing.

Selected list of the tyre recycling companies in other parts of the world (Materials/Energy Based)

Name	Address	Role in Tyre Recycling
Pusung Tyre Recycling Company (South Korea)	1307 Gumpo-ri, Nongong-eup, Dalsung-gun, Daegu 711-850 Ph:(82-53)611-1991 l Fax:(82-53)611-2900 I Email: greentekllc@gmail.com Website:http://busung.net/eng/main/main.Html	Shredding; Rubber products; Construction materials from waste tyres.
Anothen Green Energy (South Korea)	723-28 Young Building, 5th Floor, Yeoksam 2-dong, Gangnam-gu, Seoul, Korea Email: info@anothenwte.co.kr Website:http://anothenwte.com/english/main/main.html http://anothenwte.com/english/customer/cus_04.html (Catalogue download link)	Pyrolysis; Oil, carbon, steel, gas, rubber products; Fuel for boilers.
Green Korea Material Co.,Ltd (South Korea)	194-2, Bonghang-ri, Byeongchon-myeon, Cheonan-si, Chungcheongnam-do 330-862 Korea I Ph: 82-41-5678614 Website: http://gkmkita.en.ec21.com/	Artificial Green Mats for play grounds, domestic floor mats. Industrial mats, Rubber products; etc.,
C & S Industrial Co., Ltd. (South Korea)	Address: 675, Shingil7-dong, Youngdeungpo-ku, Seoul, Korea Ph: 82-2-835-0965 I Fax :82-2-835-0954 Website: http://www.usedlist.com/	Shredding; rubber products. Material recovery (steel & rubber)

Name	Address	Role in Tyre Recycling
S.A. Tyre Recyclers (South Africa)	P.O. Box 1445 Dassenberg Atlantic 7350 Ph: 021 577 1704/021 577 4355 I Fax: 021 577 3964 Website: http://satyrerecyclers.co.za/satyre/	Shredding; sorting; granulation; applications in Athletic tracks, building insulation; playground surfaces; matting surfaces; in marine applications; etc.,
REDISA (Recycling and Economic Development Initiative of South Africa	Ph: 087 35-REUSE (73873) Email: info@redisa.org.za. Technical Assistance: support@redisa.org.za Website: http://www.redisa.org.za/ Downloads: http://www.redisa.org.za/infofacts/	Provides network between the collection sites, recyclers and product manufactures (from waste tyres).
Newco Recycling (South Africa)	Contact details: http://www.newcorecycling.co.za/index.php?option=com_contact&view=category&catid=0&Itemid=41 Website: http://www.newcorecycling.co.za/	Shredding; rubber products; artificial grass manufacturing for sports tracts and play grounds;
SATRP (South Africa)	Email:info@rubbersa.com Fax: 086-503-9880 Website: http://www.rubbersa.com/ Company catalogue: http://www.maxtsolutions.co.za/assets/satrpzfoldleafletfinal.pdf	Buyers from tyre collections centers; shredding processors; distributing to tyre recycled products (rubber products) manufacturers)
Southern Tyre Disposals, (Australia)	6 Meyer Rd Lonsdale SA 5160 Ph:08 8326 8555 I Fax 08 8186 3507 Website: http://southerntyredisposals.com.au/	Collection and disposal of tyres; tyres of all sizes are recycled; small medium, large and heavy.
Tyrecycle (Australia)	Nationwide contact details: http://www.tyrecycle.com.au/contactus Website: http://www.tyrecycle.com.au/	Collection and logistics of waste tyres; sorting; shredding; steel recovery; Granulation; R & D.
C & N RUGGIERO (Australia)	552 Geelong Road Brooklyn Victoria 3012 AUSTRALIA Ph: +61-3-93148833 I Fax: +61-3-93141461 Website: http://www.cnruggiero.com.au/	Shredding; tyre recycling equipment manufacturing and distribution, nationwide; rubber products.
Carbon Recovery (New Zealand)	Contact detail: http://www.carbonrecovery.co.nz/contact/ Website: http://www.carbonrecovery.co.nz/	Pyrolysis; oil derived from tyres, TDF & carbon yields; rubber products
CADsoul (Egypt)	471 A Pyramids gardens - Cairo - Egypt Ph:00201011478797/00201125355442 E-mail : cadsoul@cadsoul.com Website: http://www.cadsoul.com/productsen/tyre%20recycling.htm	Designing and outsourcing of various tyre recycling equipments.

Additional list of tyre recycling companies/equipment manufacturers / retailers from developing countries

Name	Address	Role in Tyre Recycling
Leshan Tyrupro Import & Export Co.,Ltd (China) (In addition the company also provides consulting for the other clients and vendors. Suppliers of tyre Recycling equipments. Acts as intermediate for the buyers and sellers).	NO.5 Nanxin Donglu, Leshan High Tech Development Zone, Leshan, China 614000 Ph +86 833 2275774 (Office) I FAX: +86 833 2599883 I Email: tyrupro@hotmail.com /retreadingtech@hotmail.com Websites: www.tyrupro.com (company website) www.tyrerecycleline.com (for tyre recycling & reclaimed rubber related business) www.retreadingtech.com (for tyre retreading related business)	Shredding; mechanical, manual, physical and chemical processes. Granulations; rubber products, crumb products, asphalt production, mattresses and sponges. Retreading; from regular car to truck and even Giant OTR (Over the Road).
Jiangyin City Mingdong Machinery Manufacture Co.,Ltd (China)	Zhutang ,Jiangyin ,JiangSu China; Attn: General manager Ph : 86-510-86391579 I Mobile：(0086) 13961640163 Fax: 86-510-86381208 I E-mail：kzfzrf@yahoo.com.cn Website: http://www.chunnant.com	Manufacturers & distributors of tyre recycling machineries: shredders, cutters; crushers; milling machines; grinders; etc.,
Tyre Recycling Plant (China)	No.2, Jianshe Road, Qiaonan Development Zone, Tiantai County, Taizhou City, Zhejiang Province, China. Ph: +86-576-83986698 I Mobile: +86-13506760698 I Fax: +86-576-83986603 IEmail:lzjx2008@yahoo.cn/zhengxuede @hotmail.com Website: http://www.tyrerecyclingplant.com/	Manufacturers & distributors of tyre recycling machineries: shredders; cutters; crushers; milling machines; grinders; rubber coarse crushers; fiber separators; linear vibrating screens; automatic bag filters; magnetic separators; automatic control system of tyre recycling plant, etc.,
Xuchang Huarui Machinery Co., Ltd. (China)	Industry Area, Changge, Xuchang City. China Zip code: 461000 Ph: 86-374-2339028 I Mobile: 8613849857531 Fax: 86-374-2339029 I Email：tina@xchrjx.com Website: http://www.xchrjx.com/cpzs_en.aspx?dflid=20120313141001859	Manufacturers & distributors of tyre recycling machineries: Steel wire separator, tyre trip cutter; tyre block cutters; tyre strip cutters; and much more.
Tyrerecycleline (China) Note: One of the major client to Indonesia from China.	Address：No.5 Nanxing Donglu, Leshan High-Tech Zone, China. English Sales & Service Hotline：Ph:+86 13981391202 Mobile：+86 833 2275774	Indonesian client recycles the waste tyres into crumb products and rubber oriented products. Manufacturers & distributors of tyre recycling

Name	Address	Role in Tyre Recycling
	E-mail： tyrupro@hotmail.com Website:http://www.tyrerecycleline.com/info-213.html	machineries: shredders, crushers, separators, etc.,
SSK (Sin Sheng Kuang Electric & Machinery Industrial Co., ltd.) – (Taiwan)	3F, No. 476, Fuhsing N. Rd., Taipei 10476, Taiwan Ph: +886-2-25018600/3 I Fax: +886-2-25030142 Email:d28962@ms31.hinet.net/youhsien@ms31.hinet.net Website: http://www.ssk.com.tw Complete product description http://www.ssk.com.tw/index_en.htm	Manufacturers & distributors of tyre recycling machineries: waste tyre recycling system (shredding, crushing, separators, collection) to produce tyre chips
Chang Woen Machinery Co.,Ltd & Gan Liang (Taiwan)	No.22-22, Chung Shan Road, Sha Lu Town, Taichung Country, Taiwan Ph :886-4-2662-7809 I FAX:886-4-2662-7590 Email: jako.kao@msa.hinet.net Website:http://www.changwoen.com.tw/Tyre-Recycling-Machine.html Japan Branch: Chang Woen Machinery Japan co., ltd. Ph : 0533-65-9212 I FAX : 0533-65-9212 Mail : jako.kao@msa.hinet.net	Expertise in manufacturing the tyre recycling plants across the country and also in distributing the same to partner countries. Designs the system & processes involved in shredding operations of tyre recycling.

Most of the companies in various countries listed out in the sections 3.2.1./3.2.2./3.2.3 and further also include retreading process along with shredding and crushing. A few other retreading companies are given below:

1. TRIB (Tyre Retread & Repair Information Bureau) – USA I
   Website: http://www.retread.org/
   Contact details: https://trib.site-ym.com/?page=ContactUs
2. Retread Tyre Association (USA) I Website: http://www.retreadtyre.org/ I Contact details: http://www.retreadtyre.org/contact-us.htm
3. Purcell Tyre & Rubber Company – USA
   Websitehttp://www.purcelltyre.com/ I Locations & Contact details: http://www.purcelltyre.com/retail/locations.aspx
4. RDH Tyre and Retread Company – USA I Website: http://www.rdhtyre.com/
5. Tyre's home (Gaotang Xinglu-bendak tyre retread co. Ltd. – China
   Website: http://www.ftlmw.com/en/index.asp I contact details: http://www.ftlmw.com/en/contact.asp I product details: http://www.ftlmw.com/en/eq.asp

List of organizations which support used tyre application in cement Kilns:

1. Cement Kiln Recycling Coalition (CKRC) – USA I
   Website: http://www.ckrc.org/member-companies.shtml I
   Contact details: http://www.ckrc.org/contact.shtml
2. Giant Cement Holdings Inc. – USA I Website: http://www.gchi.com/ I Contact Details: http://www.gchi.com/gchi-contact.html
3. Portland Cement Association – USA I

Website: http://www.cement.org/tech/sustain_alt_fuels.asp I contact Details: info@cement.org
Brochure download: http://www.cement.org/Briefingkit/pdf_files/TDFBrochure.pdf

4. Global Anti-Incinerator Alliance (GAIA) – Global
Website: http://www.no-burn.org/article.php?list=type&type=87
http://www.odms.net.au/files/organise/donaldsonfilters/case_studies/cement%20ref2.pdf
http://www.nak-kiln.com/about.htm
http://www.polysiususa.com/minerals/pyroprocessing_systems/rotarykilns/rotary_kilns.html

The following link provides an alphabetical list of other major companies using waste tyres for cement kilns: http://www.ehso.com/cssepa/tsdfcementkilns.php
(Source: EHSO - Environmental Health and Safety Online)

Annexure - 5.3: WTP Technology Suppliers From Developed Countries

a) Klean Industries is specialized in the design, manufacture, and installation of advanced thermal treatment facilities using carbonization, liquefaction, pyrolysis, and gasification technologies to produce clean energy products. Klean Industries' technologies are targeted to convert petroleum based waste streams (such as plastics and tyres) into energy.
Full contact of the company:
Address of the office headquarters;
Klean Industries Inc. C/O
#2500 - 700 West Georgia St,
Vancouver, BC, Canada,
V7Y 1B3
Tel: +1.604.637.9609
Fax: +1.604.637.9609

Address in United Kingdom (UK):
Klean Industries (UK) Ltd. C/O
4 More London Riverside
London, United Kingdom,
London Bridge 4, 132076
SE1 2AU
Company's website: http://www.kleanindustries.com/s/Home.asp
Complete contact detail of the firm

KLEAN Industries widely practices WT pyrolysis and it has its operations in developed countries such as Canada, USA, UK and Japan. The industries operate under the same name in USA whereas it is identified as GreenWorks and NanoCarbon in UK and Japan respectively. Pyrolysis plants, gasification plants, specialized tyre & plastic recycling equipment, waste to energy converting technological gadgets, etc., are the other interests and activities of the company.

Special feature: Unlike many other recycling companies, all of Klean's technologies have are being used in large scale recycling/energy-recovery applications. Klean has cultivated very strong relationships with a network for downstream end product users (groups that need energy). Klean Industries offers several types of pyrolysis systems, including the rotary kiln, rotary hearth unit, and the fluidized bed; some systems provide direct heat, others indirect, and both continuous feed and batch feed variations are available. Both the pyrolysis and the gasification processes turn waste into energy-rich fuels by heating the waste under controlled conditions.

The following link provides the brief information of Klean Industries and the pyrolysis technique practiced by them. http://www.kleanindustries.com/s/Pyrolysis.asp

Brochures downloads:
http://www.kleanindustries.com/s/tyre_plastic_pyrolysis_gasification_brochures.asp

b) Harmonic Energy Inc. is a project development company, operating from London but headquartered in the United States which acquired the rights to integrated recycling tyre technology in March, 2012. It aims to develop the world's first integrated tyre recycling facilities in multiple locations. As a one-stop tyre recycling facility Harmonic Energy Inc. will source used tyres, sort them into those that can be re-manufactured (retreads) for further use and those that are at their end-of-life, will be diverted to a pyrolysis plant for energy recovery. Both remanufacturing and energy recovery processes will be done on site.

Full contact of the supplier

3rd Floor,
207 Regent Street,
London, United Kingdom
W1B 3HH
Sales and Information:
Ph: +44 (0) 207 617 7300 I info@harmonicenergyinc.com
Website: http://harmonicenergyinc.com

Harmonic has acquisition facilities in operation in Europe and North America. These facilities are currently processing tyres, and once permits are approved, these facilities will also remanufacture tyres and utilise the Tyrolysis™ process. Each location will have the capacity to process in excess of 150 tonnes of tyres per day, amounting to 55 000 tonnes annually. Harmonic plans to be the first fully integrated tyre manufacturer and Tyrolysis™ recycling plant operator.

Special features: Harmonic's model integrates tyre manufacturing and waste tyre management, to create an environmentally sound process that uses the least amount of energy and resources. Using the Tyrolysis™ process to heat whole tyres, or shredded waste tyres, thermally decomposing the tyres and degrading them to their original components – Harmonics plans to produce carbon blacks in the forms of char, oil, & gas and steel – without burning or combusting the tyre. The carbon char will be refined into commercial grade carbon black; the recovered oil is high grade and can be further refined to produce limonene, naphthalene and other lighter oils. The fuel oil can also be used for environmentally friendly power generation. Tyrolysis™ is a process that is unique to Harmonic energy, which involves whole tyre carbonization. In this process, the tyres do not need to be shredded before they are processed – and thus reduced processing, operating and maintenance costs. Tyres are transported to the top of a kiln on a conveyor belt, and then dropped into a vertical system that continuously feeds the kiln and is controlled by a computer operating system. This vertical system utilizes a series of alternatively sealed, gravity fed, control valves that transports the tyres through the processing system. According to Harmonic Energy, the Tyrolysis™ process creates zero waste and produces no more emissions that a natural gas boiler.

A Copy of the company's brochure with fact sheets: http://harmonicenergyinc.com/wpcontent/ uploads/Harmonic_Energy_Corporate_Factsheet.pdf

c) PYReco Ltd. is located in Wilton, United Kingdom; PYReco receives at its offices in The cheaper processes are 'batched' or static pots, while the more 'upmarket' methods are 'continuous' 24/7 operations. This firm also has enhanced WT pyrolysis technology to produce PZP (PYReco Zero waste Process) carbon, PZP oil, PZP gas and PZP steel.

Full contact detail of the company:
Wilton Centre
Room H245, Wilton
Redcar, TS10 4RF
Email: info@pyreco.com
Website: http://pyreco.com/

Special features: The company specialises in refining the materials (by products) to a high quality level. There are many lower cost pyrolysis techniques available around the world but unfortunately most of them produce a carbon char product with a significantly lower market value than that delivered by PYReco. The company has one of the largest plant for the tyre pyrolysis and it produces *about 7,500,000 Barrels, or 1,071,428 Tonnes of oil & gas.*

Brochure & product downloads: http://pyreco.com/

d) Splainex Ecosystems ltd. Rijswijk, Netherlands; is one of the European companies that implements pyrolysis process for the energy recovery from used tyres. Similar to the above mentioned UK based industry, Splainex also produces carbon, oil and gas from the used tyres.

Full contact detail of the company:
Steenvoordelaan 360h
Rijswijk, 2284 EH
Netherlands I Ph: (+31) 70 - 394 4415 *I Fax*: (+31) 70 - 394 3365
Website: http://www.splainex.com/ Network blog: www.pyrolysis.biz

Splainex has 3 major areas of interest: waste-to-energy, carbonization and soil remediation. In the field of waste-to-energy used tyres are one of the feedstocks.

e) Metso located in Helsinki, Finland; is an international corporate body with its branches established worldwide. Metso largely works on waste recycling and it facilitates high temperature pyrolysis techniques for the energy recovery from the waste tyres. It has large pyrolysis plants operating globally. It has its headquarters in Helsinki and has 50 establishments worldwide. The other countries where Metso has its operations are Algeria, Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Croatia, Czech republic, Denmark, Estonia, France, Germany, Ghana, Hungary, India, Indonesia, Italy, Japan, Kazakhstan, Kingdom of Bahrain, Korea, Macedonia, Malaysia, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Qatar, Romania, Russia, Singapore, Slovakia, South Africa, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, Ukraine, United Arab Emirates, UK, USA, Uzbekistan, Vietnam, Zambia, Zimbabwe.

Full contact detail of Metso:
Metso Shared Services Oy, Metso IT
Eteläranta 8
FI-00130 Helsinki
Finland
Ph: +358 20 484 100
Fax: +358 20 484 101
Postal address
Metso Corporation,
PO Box 1220,
FI-00101 Helsinki,
Finland
Wesbite: http://www.metso.com/

For further global contact details please clink this link:
http://www.metso.com/corporation/contacts_eng.nsf/WebWID/WTB-041110-2256FCC134?OpenDocument#.Ui5xXb-9JnV

Brochure downloads:
http://www.metso.com/miningandconstruction/mm_pyro.nsf/WebWID/WTB-041108-2256FF5E00/$File/Tyre%20Flyer.pdf
http://www.metso.com/miningandconstruction/MaTobox7.nsf/DocsByID/EE94F5E6DAE080B985256FD4004EBB1F/$File/Thermal_Waste_Processing_Systems.pdf

Further downloads:
http://www.metso.com/recycling/mm_recy.nsf/WebWID/WTB-041123-2256F-70B5A?OpenDocument#.UoLRA3CnqI0

WTP technology suppliers from developing countries

Not only the developed countries are facing the problem of disposal of used tyres even developing and high tyre consuming countries like India, China, Africa and countries in South East Asia region are trying to tackle this issue[287], [288]. Their problem is further exacerbated as these countries often end up as a dumping ground for used tyres. In recent years, in view of the constraints and some typical local features, some indigenous technologies have been developed in these countries[289].

These are described below.

a) Bhagirathi India is located in Gujarat, India; is one of the pyrolysis and tyre recycling plant manufacturer. This industry additionally manufactures mechanical equipment such as drum mix plant and paver finisher plant.

Full contact detail of the company:
Office:
B-5, First Floor, "Shreemad Bhavan",
Opp. Kanta Stri Vikas Gruh,
Off. Dhebar Road,
Rajkot–360002 (Gujarat) India.
Ph.: +91 281 3050722 / 2229956
Mobile: +91 99250 55540

Factory:
Plot No. 7, Balaji Industrial Area,
B/h. Railway Track,
Opp. Hotel Krishna Park,
Gondal Road, Kothariya,
Rajkot (Guj.) India.
Telefax: +91 281 278218E-mail: info@bhagirathindia.com
Website: www.bhagirathindia.com

Product specifications, by products and data:
http://www.bhagirathindia.com/Tyre_Recycling_Plant.html
http://www.bhagirathindia.com/Paver_Finisher_Plant.html

b) Pyrocrat systems LLP, is located in Mumbai, India; A turnkey pyrolysis plant industry & supplier who converts waste plastic & tyres into pyrolysis oil, carbon black & hydrocarbon Gas. The mentioned end products are used as industrial fuels for producing heat, steam or electricity.

Full contact details of Pyrocrat systems LLP:

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[287] *ATMA (1998);' All: Overview of Indian Tyre. Industry, Automotive- Tyre Manufacturers Association, New Delhi, Pg. 9*

[288] *Burger. K, V Haridasan, H·P Smit·and·W·Zant (-1995): The Indian Rubber Economy: History, Analysis and Policy' Perspectives, Manohar, publications', 'New Delhi; pp'-779~784.*

[289] *Mohan Kumar. S, Tharian George. K, "Impact of Economic Reforms on Tyre Industry", Economic and Political Weekly. Vol XXXVI. No 12. March 24, 2001.*

J-103, 1st Floor, Tower No. 7, Railway Station Commercial Complex,
Sector 1A, C.B.D. Belapur,
Navi Mumbai, Maharashtra State,
India. PIN: 400 614.
Ph: +91 22275 99010 | Mobile: +91 99306 55477 I Email: info@pyrolysisplant.com
Website: http://www.pyrolysisplant.com/

Special features: It is one of the established firm in India by operating 22 pyrolysis plants around the country and aimsto set up 150 pyrolysis plants by the year 2015. The byproducts obtained through the WTP are black carbon, oil and gas.

Brochure downloads: Turnkey plant setup description

c) Alben Industries, Gujarat, India; is the manufacturer & supplier of the pyrolysis plant, waste tyre recycling plant and waste tyre pyrolysis plant.

Full contact detail of the company:
Plot No. 525/2, New GIDC,
Gundlav, Valsad - 396035,
Gujarat, India
Ph: 91-2632-236525 I Mobile: +919824142079, +919924050251
Website: http://www.albenindustries.com/
Complete details of the product and its specification can be accessed by clicking the following link: http://www.albenindustries.com/products.html

c) Ocean Tradelink, Rajkot, India; The company supplies waste tyre recycling and pyrolysis products applicable to large scale industries as well as small scale plants ranging from 5 to 10 tonnes capacity.

Full contact detail of Ocean Tradelink:
Ocean Tradelink
310, Sanskar Complex,
Opp- KKV Hall,
150 Ring Road,
Rajkot - 360005, Gujarat, India
Ph: 91-281-2575966/3057110 I Mobile: +91 9574659360 I Fax: 91-281-2577974
E-mail: info@oceantradelink.net
Website: http://www.oceantradelink.net/index.php
Company brochure & product details: http://www.oceantradelink.net/ocean-tradelink-project.pdf

d) Divya international has its head office located in Ahmedabad, India; An ISO certified organisation with dedicated units for manufacturing tyre recycling Plant, tyre pyrolysis plant machines & equipment spare parts. Waste tyre recycling and pyrolysis plants fabricated in this firm vary in size from 5 to 12 tonnes.

Full contact detail of the company:
6, Shivshaktinagar,
NR sola over bridge,
Near Audi Showroom, S.G.Highway,
Sola, Ahmedabad – 386060.
Gujarat, India.
Mobile: +91 9978944111 I +91 9925766111 I E-mail: sales@divyaint.com
Website: www.divyaint.com

Downloads:
Link 1 (Company Brochure) http://divyaint.com/Download.aspx?file=BROCHURE.pdf
http://divyaint.com/downloadproducts.aspx

e) Fab India is located in Vatva, India; Fab India designs and manufactures industrial pyrolysis systems for recycling waste/used tyres. This is an ISO 9001:2000 Company and has introduced a high commercial viability process for recycling plastic scrap and waste tyre into fuel oil, carbon black, steel wire and gas. Industry provides installation and logistics service for scheduling a pyrolysis plant. The recycled products are envisioned to apply for various mechanical, textile, rubber, food and catering industries. The plants manufactured in Fab India are of 5, 7.5 and 10 tonnes capacity. Apart from recycling equipment in relation to tyre pyrolysis, auto feeders for tyre shredding, mechanical crushers, hydraulic cutter and few other material handling devices are also fabricated by this firm.

Full contact detail of the company:
Fab India
Plot No.3/4, Khodityar Estate
Nr.Shakriba Estate, Phase – IV,
Vatva G.I.D.C Ahmedabad.
Ph: +91-79 – 40301472 I Mobile: +91 9725012741 I +91 97250 12744 / 46 I +91 8980014620
Emails: fabindia2@gmail.com , info@fabindia.me
Website: http://www.indiamart.com/fabindia-ahmedabad/
For more technical details and for the product information please click the following links:
http://www.indiamart.com/fabindia-ahmedabad/waste-tyre-recycling-plant.html
http://www.indiamart.com/fabindia-ahmedabad/waste-tyre-recycling-plant.html
http://www.indiamart.com/fabindia-ahmedabad/pyrolysis-10-ton-plant.html#scrap-tyre-recyclingplant-model

f) NEL Eco Energy Co. Ltd.; China's first National High-tech Enterprise specializing in technology, research and equipment manufacture of waste tyre & waste plastic pyrolysis for oil extraction, oil distillation as well as further processing of carbon black .

Full contact detail of the company:
Room 507, Lanshi Business Center,
No 6 North Baotuquan Rd,
Lixia District, Jinan, PRC 250011
Ph: +86-531-8619 6301 I Fax: +86-531-8619 6329 I E-mail: info@niutech-energy.com
Website: http://www.niutech-energy.com/index_en.html

Eco Energy have installed production lines in Mainland China, Taiwan, Germany, Estonian, Thailand, India and Malaysia and have orders for US, Ireland, UK, France etc.

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