# DEVELOPMENT OF SCIENTIFIC RECYCLING OF END OF LIFE AUTOMOBILES IN INDIA AND THE ROLE OF RESEARCH AND DEVELOPMENT

NS Mohan Ram
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Indian National Academy of Engineering
November, 2015

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We would like to thank the many experts in India and abroad who freely shared information with us on this complex issue. It is not possible for us to thank them individually by name.

We take full responsibility for any factual errors which might have inadvertently crept in this report, despite our best efforts.

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# Executive Summary

This project on "Development of scientific recycling of End of Life Automobiles in India and the role of Research and Development" was commissioned by the office of the Principal Scientific Advisor to Government of India, on the Indian National Academy of Engineering in March 2014. It studies the status of disposal of automobiles which had reached the end of life in India, current numbers, future projections and issues related to disposal. A market study was conducted using an external agency for estimating the numbers of vehicles which would come for scrapping in the future, quantities of rubber and plastics to be recycled and the volumes of shredder residues which would need to be disposed.

This report is organized in six chapters. - (1) Overview of recycling of automobile in India (2) Market study on recycling of end of life automobiles (3) Detailed analysis of issues concerning the disposal of rubber with focus on scrap tires (4) Detailed analysis of issues concerning disposal of plastics from scrapped automobiles (5) Systems for handling auto shredder residue, recovery of useful materials and energy and minimizing requirements for landfills and (6) Summary and recommendations.

Recycling of vehicles which have reached end of useful life or involved in accidents will become a major issue in the near future. ELV recycling, if carried out systematically using appropriate technologies, can confer great benefits to society- saving energy, reducing greenhouse gases and pollution, recovering useful material, conserving natural resources, saving foreign exchange and creating employment. By 2020, potential benefits are estimated as

1. Energy saving- Annually 4.5 MW/Hrs. due to recycling of Aluminum and 2.95 MW/hrs. due to Steel recycling, increasing at a compounded rate of 10% annually.
2. GHG reduction- 3.1 million tons by 2015, increasing at compounded rate of 10% annually
3. Material Recovery- 2.1 million tons of Steel scrap and 0.225 million tons of Aluminum, increasing at a compounded rate f 10% annually.
4. Forex saving due to reduction of imports – 0.8 billion dollars, increasing at a rate 0f 10 % annually.

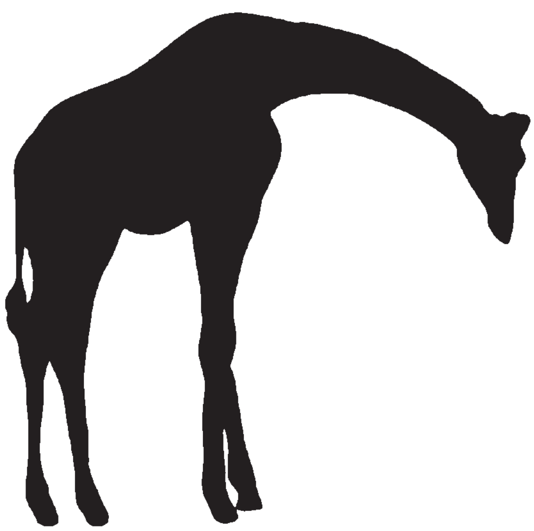
5. Plastics to the tune of 126,700 tons and rubber of 32,500 tons can be effectively recycled, increasing at the rate of 10 % annually.

Huge volumes of Auto Shredder Residues (ASR) will be generated after the vehicle bodies are shredded and would require effective disposal. The extent of ASR likely to be generated with proper recycling in 2020 is 2.8 million Cubic meters increasing to 6 million cubic meters by 2030. We need to start work on adapting systems for recovery of materials and energy from residues, minimizing the amount going to refills to less than 5 % by the weight of vehicles.

This report makes generic recommendations for creation of a viable and vibrant automotive recycling industry. It recommends setting up centers of excellence for recycling rubber and plastics effectively from end of life vehicles. After analyzing different approaches to ASR post treatment, it recommends that India adopts mechanical separation systems initially and suggests setting up a pilot plant at Nagpur initially to understand the process.

The findings of this study will be useful for policy-making Ministries and Departments of Government of India and State Governments including Ministry of Road Transport, Ministry of Heavy Industries, Ministry of Environment and Forests, Ministry of Steel and Mines, Central and State Pollution Control Boards. It is the first comprehensive study of recycling of end of life automobiles at a national level.

It is hoped that these recommendations will facilitate effective policy making for handling the important issue of handling the huge volumes of vehicles which will come in for scrapping in the future.



CHAPTER - 1

# Introduction & Overview

# Introduction & Overview

India faces a major challenge of achieving a goal of equitable economic growth of over 8% in GDP annually, in an environment friendly and sustainable manner.

To provide employment for a growing young population, the share of manufacturing in the economy has to be increased rapidly from the present level of 14 % of GDP to at least 25% of GDP. This has to be managed concurrently with reduction of greenhouse gas emissions.

The automobile industry can help to make this difficult goal a reality. It is already a major contributor to the nation's GNP at over 5 % and is growing at a compounded annual rate of over 10 %.( 1)

India currently ranks sixth in car production in the world and second, behind China only, in two wheelers. (2) The industry directly and indirectly employs over three million people.

Government of India recognized the high growth potential of the industry. The Department of Heavy industry released India's Automotive Industry Mission Plan3 (2006-16) in January 2007 postulating a five-fold growth in production of vehicles over a period of ten years from 2006-2016. The industry is reasonably on track to reach the goals visualized in the Mission. Total production of vehicles during 2014-15 reached 23.37 million, with two wheelers contributing the maximum at 18.49 million, followed by passenger cars [3.22 million], three wheelers [0.95 million] and commercial vehicles [0.70 million].(3) The total is expected to reach 30 million by 2020. Consequently, the population of vehicles on our roads is expected to cross the 200 million mark at around the same time. The outline of the next Automotive Mission Plan 2016-2026(4) postulates a threefold increase over the decade at a CAGR of over12%.

An organized, systematic and modern end-of-life vehicle recycling industry is an essential and necessary adjunct to the booming automobile manufacturing industry. As vehicle population increases, the numbers of vehicles due for scrapping too will rise. The numbers are expected to reach near nine million by 2020.

Currently, scrapping of automobiles is being handled by small-scale units in the unorganized sector. They use low-tech methods and techniques resulting in low recoveries apart from leading to gross air and groundwater pollution. Moreover, they have neither the capacity nor the technical capability to handle anticipated volumes.

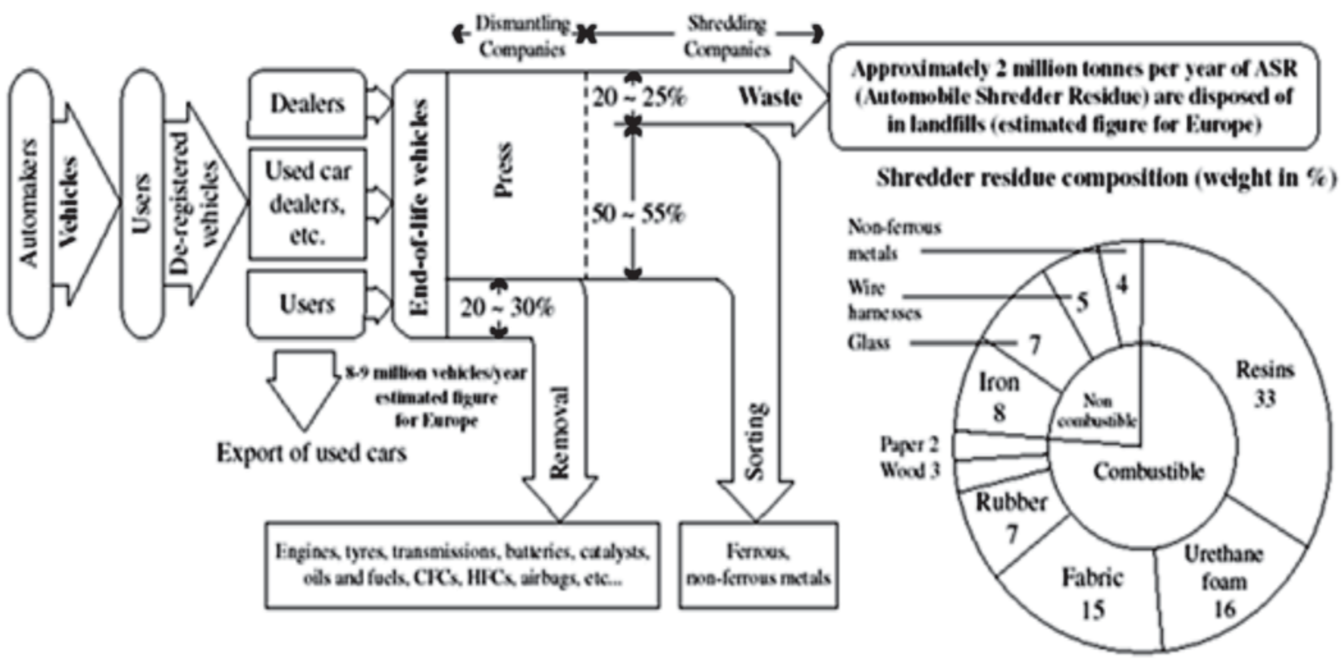
The Indian National Academy of Engineering (INAE) foresaw the problem ten years earlier and organized a seminar on the subject at Bhabha Atomic Research Centre in Mumbai in 2007, with the support of Dr. R. Chidambaram, Principal Scientific Advisor to Government of India.(5) The recommendations of the high level seminar led to the issue of recycling of automobiles finding a special mention in Prime Minister's National Action Plan on climate change 2008 (NAPCC)(6) the Government of India's policy document on India's response to Kyoto protocol on global warming.

Automotive recycling is being regulated in the European Union since 2003. To begin with, it stipulated recycling and energy recovery of 85% by weight. (7) The limit has been now raised to 95%, from January this year. (8) Japan has similar regulations in force.

India too has formulated rules (9) concerning design of vehicles to facilitate recycling of wastes from end-of-life vehicles [ELVs] and another set of rules relating to operation of recycling units. They will be promulgated shortly.

A model dismantling unit (RDU- Recycling Demonstration Unit) (10) has been set up by the Ministry of Heavy Industry at the Global Automotive Research Centre (GARC) at Oragadam near Chennai by Department of Heavy industry, with active assistance from the automotive industry.

The flowchart (11) below enumerates the steps in the process of scrapping a car- dismantling, shredding, auto shredder treatment and disposal of residues in the developed world.



## Benefits and Savings due to recycling of automobiles

Savings in greenhouse gases due to recycling per kilogram of different materials are estimated as:

| | |
|---|---|
| Steel | 0.8 Kg |
| Aluminum | 9.9 Kg |
| Plastics | 2.5 Kg |
| Rubber | 2.0 Kg |
| Copper | 1.8 Kg |

On this basis recycling a typical Indian ELV car, can prevent the emission of as much as 1,600 KGs (1.6 Tons) of greenhouse gases for society. The savings from a motorcycle will be about 200 KGs, a three wheeler 500 KGs, light commercial vehicles 3 tons and larger commercial vehicles like buses, and trucks 8 tons/vehicle.

Using these approximate figures, the savings in GHG for the current year may be estimated at 3.1 million tons considering the production and population statistics of vehicles in the country. These gains can be assumed to increase at a compounded annual rate of about 10 % in the coming years.

## Savings in scrap metals.

There would not only be benefits in terms of avoidance of greenhouse gas emission. There would also be a lot of savings in scrap metals. The potential for savings in steel scrap is estimated at 1.25 million tons for the current year [2015) and 2.1 million tons by 2020.

India presently imports about 6 million tons of auto shredded scrap steel from abroad to fill the demand-supply gap for steel in the country and this is expected to go up steeply in the years to come.

If the country can achieve even 75 per cent recovery of steel from auto scrap generated domestically, there can be a foreign exchange saving to the tune of $500 million at current levels. These savings will increase annually at a CAGR of 10%.

## Energy Savings.

There are significant savings in energy usage. For instance, recovery of one KG of Aluminum by recycling would mean a saving of 14 KWh of power. If we recover the estimated potential of 2.25 lakh tons of Aluminum from end of life vehicles, the saving in energy would be a huge 4.5 Million MWh.

Likewise, recycling of steel can generates substantial savings. Production of one ton of steel requires around 5.6 MWh of energy. Recycling of the metal scrap from automobiles can save 25% energy compared to production from ore- i.e. 1.4 MWh per ton. An energy saving of 2.95 MWh is estimated due to recycling of steel from ELVs in 2020.

## Environmental impact

The production of one ton of iron requires 1.4-1.6 tons of ore or other iron bearing material; 0.5 to 0.65 tons of coke; 0.25 tons of limestone or dolomite; and 1.8 to 2 tons of air. Byproducts consist of 0.2 to 0.4

tons of slag, and 2.5 to 3.5 tons of blast furnace gas containing up to 100 pounds (lb.) of dust. Compared to recycling, primary production of steel takes a heavy toll on the environment.

## Other materials

This is not all. An efficient mechanism for recycling of the end of life automobiles would also lead to recovery of considerable quantities of several other important materials such as copper, noble metals, plastics and rubber.

## The study

The current study titled "Development of scientific recycling of End of Life Automobiles in India and the role of Research and Development' is an exercise to ensure that the best of strategies are deployed for dealing with the end of life vehicles. The office of the Principal Scientific Advisor to Government of India has commissioned the task to the Indian National Academy of Engineers.

Captain Mohan Ram, a fellow of INAE, is the Principal Investigator of the study. He is an expert on the subject with an experience of over ten years and has presented many papers on the status of automotive recycling in India in international forums. ([12, 13]) He also currently chairs a sub-group on recycling formed by the Society of Indian Automotive Manufacturers (SIAM). There are two other co-investigators -- Dr. Basudam Adhikari and Mr. S. Sugumar. Dr. Adhikari is from the Materials Science Centre at the Indian Institute of Technology, Kharagpur. Dr. Adhikari is a renowned material scientist who has done research on recovery of rubber from used tires. Mr. Sugumar is a specialist on plastics. He is Deputy Director Central Institute of Plastic Engineering and Technology [CIPET], Guindy, Chennai.

The study focuses on three areas, for which effective technologies are still not available: recovery of useful materials from the extensive range of plastics used in automobiles; recovery of material and energy from large amount of rubber (especially tires) that are used in automobiles and research needed to reduce the extent of residues which need to be disposed of in landfills.

It is expected that in the initial stages about 20-25% by weight of scrapped vehicles will remain as shredder residues. It is essential that this is brought down as much as possible over time, since land is a scarce and precious resource in India: It will be impossible to earmark land for disposal of auto scrap residues in the future. The third and final part of the report deals with research needed in this direction.

The study has been carried out over in three phases over a period of eighteen months. Phase I was devoted to collection of data required to estimate the magnitude of the issues. The current system operated by the informal sector employs unhygienic practices, pollutes the environment and uses very low tech methods ([14]). Among other things, data had to be collected to understand aspects such as the level of automobile production, population, ELV generation, extent of material recoveries, and ASR generation, over the next twenty years. A similar study had been conducted in 2006 for SIAM by ICRA[(15).]

Phase II was focused on understanding the various issues relating to recycling of rubber and plastics from ELVs and R & D efforts on material/energy recoveries from used tires and plastics under Indian conditions.

Phase III dealt with the recovery of useful materials and energy, from ASR and minimizing residues which need to be dumped in landfills.

Recycling of ELVs is a complex issue involving many stakeholders- Central and State Governments, pollution control boards, vehicle owners, RTOs, scrapping units, recyclers, dismantlers, shredder operators, spares trade and downstream operators.

This study has made recommendations which if implemented would bring about a significant improvement in the situation and help India to face the problem of huge influx of ELVs in the near future. It takes into account all aspects including the role of the different stakeholders.

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CHAPTER - 2

# Market Study of Automotive Recycling Potential in India Carried out for INAE Project by Ms. Feedback Consultants(Private) Limited.

# Market Study of Automotive Recycling Potential in India
# Carried out for INAE Project by
# Ms. Feedback Consultants(Private) Limited.

## 1. Introduction

The automobile industry is one of the fastest growing industries in India. As India's annual sales of vehicles soar, the number of vehicles to be scrapped on reaching the end of useful life and warranting proper automobile recycling facilities will also increase exponentially.

Currently, India is in the process of finalizing regulations on recyclability and disposal of End-of-Life Vehicles (ELVs). India lacks a specialized scrap car collection, treatment, dismantling and recovery infrastructure. Scrapping is currently carried out in the informal sector and in poorly equipped units, resulting in unhygienic practices and low yields. Over 70% of an automobile by weight consists of metals like steel, aluminum, copper, lead, etc. which are relatively easily recovered. With appropriate technologies, substantial quantity of rubber and plastics can also be recycled.

The Society of Indian Automotive Manufacturers (SIAM) has established a group to deal with the issue of recycling of End-of-Life Vehicles. A demonstration center set up at GARC Oragdum, Chennai by the Ministry of Heavy Industry with active help from SIAM, aims to develop methods for recycling ELVs appropriate to India, using maximum manual labor, including systems for recycling two wheelers, and to help train and upgrade units in the informal sector. There are plans to start similar centers in other parts of the country as well.

The Indian National Academy of Engineering (INAE) the premier professional association of eminent engineers of different disciplines conducted a seminar in 2007 on the issue of automobile and electronics recycling. Taking into account the rapid increase in vehicle population, the deliberations stressed the issues involved with the prevalent practices and the urgent need for India to bring in regulations, build infrastructure and adopt scientific methods of automobile recycling. The Principal Scientific Advisor to the Government of India had entrusted a project to the experts of INAE, led by Principal Investigator Capt. Mohan Ram, Fellow of INAE to analyze automobile recycling practices in India and make recommendations on areas where research needed to be undertaken. The Principal Investigator was keen on an independent third party assessment of the sector, practices followed and the likely future scenario of recycling, with special reference to the extent of residue likely to require disposal in landfills.

The Principal Investigator entrusted the study to M/s. Feedback Consulting Services Pvt. Ltd. to assess and understand the current practices of automobile dismantling, recovery of material and disposal practices. The study was also meant to assess the number of ELVs by 2020 and 2030.

## 1.1 Key objectives of the engagement

The objectives of the engagement were to understand in depth the current systems for collection and handling of end of life automobiles, dismantling & recycling processes in vogue, disposal of output from scrapped vehicles, extent of recovery of useful materials and waste handling in the current process.

The survey was to be carried out at two major auto recycling centers – Mayapuri in Delhi and Shivajinagar in Bangalore. The learnings from these two centers were to be extrapolated to get an understanding of the All India picture.

Deliverables from the engagement

1. Estimates of the number of people directly and indirectly employed in the automobile scrapping business in the two centers and extrapolation of the figures to the whole of India.
2. Estimates of numbers of two wheelers, three wheelers, passenger vehicles (cars & other four wheelers) and commercial vehicles, which are likely to come up for scrapping in the year 2020 and for the next ten years nationally with numbers across major vehicle population clusters: NCR- Vadodara- Ahmedabad belt, Mumbai-Pune-Nashik belt and Bangalore- Chennai belt, based on industry past production figures and average life of vehicles before being scrapped.
3. Understanding how waste generated from the process and which is not saleable, is currently being disposed of. What is the volume of the waste material, its general composition, how and where it is being disposed of.
4. Estimates of extent of material to be disposed of nationally and landfill area required in 2020 and for ten years thereafter.

This report was meant to provide an insight into the current system of End-of-Life Vehicle (ELV) disposal in India; assess the impact of important developments in this area and understand the chain of automobile recycling from sourcing to recycling. In addition, it was to highlight the issues and limitations in the current system.

## 1.2 Methodology and approach

The primary survey was conducted in two key locations - Mayapuri in Delhi and Shivajinagar in Bangalore. Discussions were held with members across the entire value chain of ELV disposal to understand the process by which vehicles are brought into these scrap yards, the stakeholders involved and the dismantling & scrapping process.

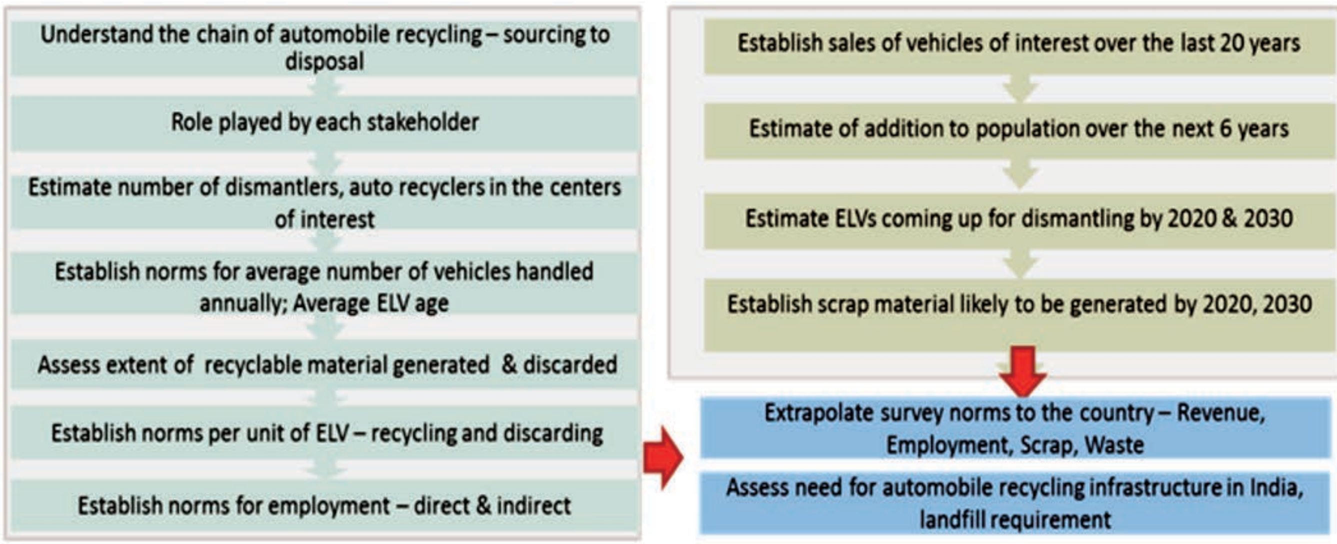
The engagement involved an assessment of the disposal of passenger vehicles (cars & other four wheelers), two wheelers, three wheelers and commercial vehicles. The focus was on understanding spare parts recovery from ELVs, scrap material disposal process, revenue generated, costs incurred, waste generated and its disposal.

The stakeholders included brokers, agents, buyers of ELVs & accident vehicles, dismantlers, spare part dealers & shop owners and scrap dealers. Discussions with the stakeholders covered the following aspects:

| **StakeholdersI** | **Information sought** |
|---|---|
| Brokers, Insurance agents | Types of vehicles brought in for dismantling; Source; Regions from where sourced; Age of vehicles; Number of vehicles brought in annually; Selling prices of vehicles |
| Buyers | Purchase price of vehicles; Source of vehicles; Age of vehicles; Current process of dismantling; Labor deployed for all processes; Spares recovered from vehicles; Scrap handled; Spares and scrap disposal; Scrap discarded; Costs involved; Regulations |
| Dismantlers | Time taken to dismantle vehicles; Processes, Tools & Equipment used; Spares recovered; Scrap selling practices; Waste handling |
| Spares shop owners | Fast moving spares; Customer profile; Shelf life of spares; Selling price of spares |
| Scrap dealers | Type of scrap collected; Typical volumes handled in a day;<br>Process of recycling/ disposing scrap; Prices paid for various scrap material |
| Government, Non-Government oanizaions, ollutino Conrol Boards; Indnusutry experts | Regulations governing ELV disposal; Need for automobile recycling regulations in the country; Need for and extent of landfills |

The engagement focused on understanding practices, building norms and extrapolating to the universe primarily for passenger vehicles, two wheelers, three wheelers and commercial vehicles.

### 1.3 The framework




Essentially, norms for age of ELVs (for all vehicles type of interest), number of vehicles dismantled in a year, parts salvaged, usable scrap and unusable scrap were built from the two centers of interest and extrapolated to estimate the all India figures. All projections were based on ELVs. Accident vehicles were not considered as it varied across cities and years, thereby making it difficult to predict. Domestic sale of vehicles alone was considered, exports not taken into consideration.

In addition to primary research in these two markets, secondary sources, relevant publications from SIAM and ACMA were also examined to assess the population and sale of vehicles over the past twenty years. This data, along with the survey norms of ELV age, was used to estimate the number of ELVs by the year 2020 and 2030. Other secondary sources were also accessed to understand ELV dismantling practices in Europe, America and other countries. Sources referred are set out in Annexure 9.1.

## 2. Vehicle Sales in India

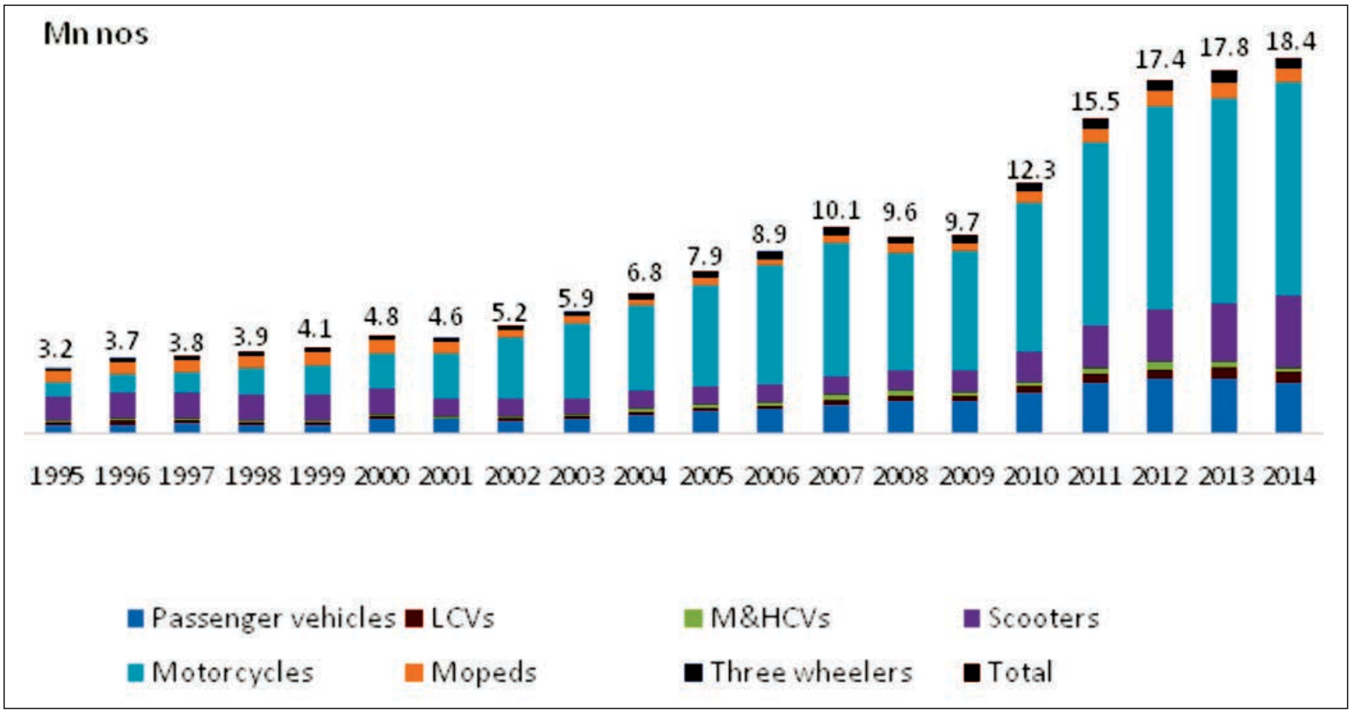
The automobile industry in India accounts for close to 6% of the National GDP and 22% of the Manufacturing GDP. It is one of India's manufacturing success stories. 100% FDI is allowed in the automobile sector, under the automatic route. The cumulative FDI to date (April 2000 – August 2014) was at US$ 10,119.68 million (mn) as per the Department of Industrial Policy and Promotion (DIPP).

Major investments have been planned in this sector by many global as well as Indian vehicle manufacturers – Ashok Leyland, Honda Motors, Yamaha and Hero Cycles to name a few.

### 2.1 Sales of vehicles of interest till 2014

The vehicles of interest in this engagement are passenger vehicles (cars & other four wheelers), two wheelers, three wheelers and commercial vehicles. Domestic sales of all the vehicles of interest from 1995 to 2014 were obtained from secondary sources such as SIAM.

India, whose current vehicle population is an estimated 200 mn, has added over 174 mn vehicles over the last twenty years in the vehicle categories of interest, with 128 mn (73%) having been added in the last 10 years.



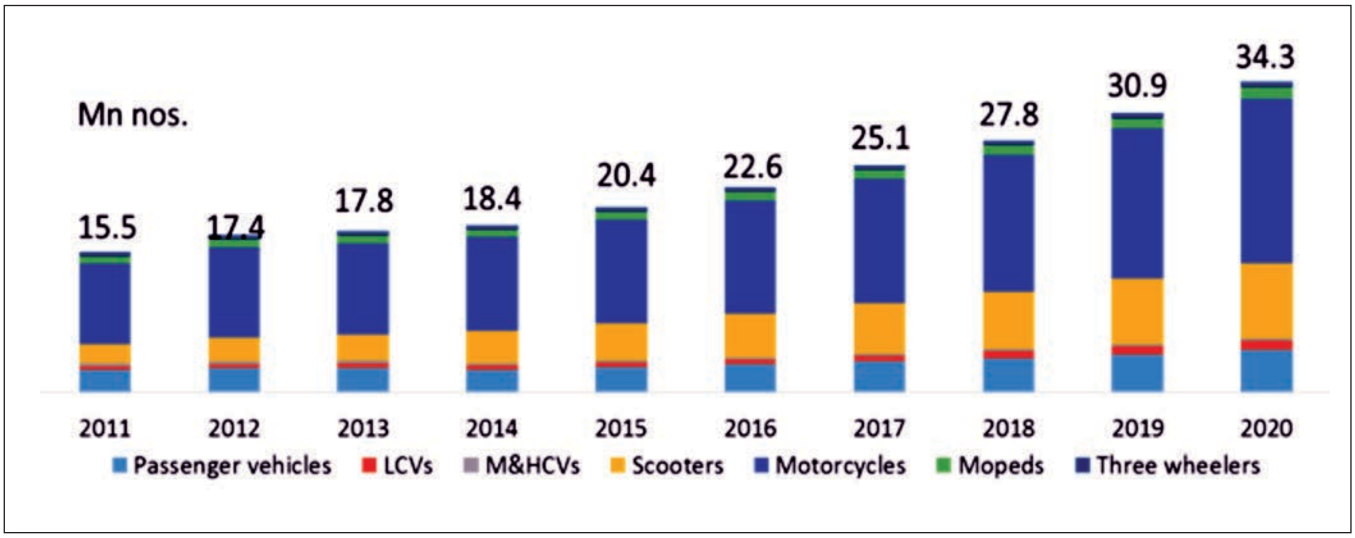

## 2.2 Sales projections till 2020

The four wheeler segment has been growing at a very fast pace, fuelled by customer pull as well as supplier push. On the one hand, a growing middle class, demographic change, higher disposable incomes, higher aspirations of consumers and easy financing are creating a huge demand for four wheelers. On the other hand, manufacturers are aggressively aiding this process through frequent introduction of new models, low cost cars (to displace the higher end two wheelers), innovative financing models, buy back options, etc.

India is primarily a two wheeler nation. More than 75% of the vehicles on the road are two wheelers, with four wheelers still remaining beyond the reach of a vast majority of Indians. Poor public transport infrastructure, low/ affordably priced two wheelers, higher mileage levels without sacrificing power and easy maneuverability have helped drive the sales of two wheelers – popular both in urban and rural markets.

Three wheelers comprise both passenger and transport vehicles. Passenger carriers constitute 80% of the three wheeler market and have witnessed a rising demand thanks to their being a cheap and convenient public conveyance. New permits and a rise in CNG filling infrastructure have further buoyed the demand for three wheelers.

Given this background, vehicle sales are expected to touch 350 mn by 2020, as per Feedback's estimates:




## 3. ELV Dismantling Practices

Currently in India, the management and disposal of ELVs are essentially in the domain of the informal and unregulated sector, unlike several other countries that are in a fairly advanced stage of automobile recycling. Interactions with the formal sector are non-existent.

Internationally, 85-95% of the vehicle is recovered and vehicle designs are also well suited for easy dismantling and disposal. Europe and Japan have in fact mandated 95% of vehicle recovery from January 1, 2015. Automobile recycling is used extensively to help reduce waste, aid in the reuse of components and recycling of raw materials. End-of-Life Vehicles (ELVs) contain many materials and parts that can be refurbished and reused.

A wide range of materials, from valuable metals to low grade used oils can be retrieved from an end-of-life vehicle. According to industry sources, recycling a normal saloon car can help conserve 2,500 kilograms of iron ore and 1,400 kilograms of coal; reduce the release of 1,000 kilograms of carbon dioxide, and save more than 1 mega-watt of energy. In the case of a motorcycle, the corresponding gains are approximately one-eighth of the gains of a car. The accrued energy savings are essentially due to melting of scrap, rather than smelting ores. Recycling one kilogram of aluminum saves 14 kilo watts of electrical energy, compared to producing virgin metal from bauxite.

### 3.1 ELV dismantling

ELV dismantling is undertaken in small scrap yards located within the city limits of all major cities. Historically, these scrap yards mushroomed in the outskirts of large cities. However, as the city limits expanded over time, the scrap yards have remained in the same locations and integrated into the city's densely populated areas. Consequently, they are constrained by lack of space with limited or no scope to expand their operations.

Both ELVs and accident vehicles are dismantled in these scrap yards. There was also a mention of stolen vehicles and spares finding their way to these scrap yards, especially in the case of two wheelers.

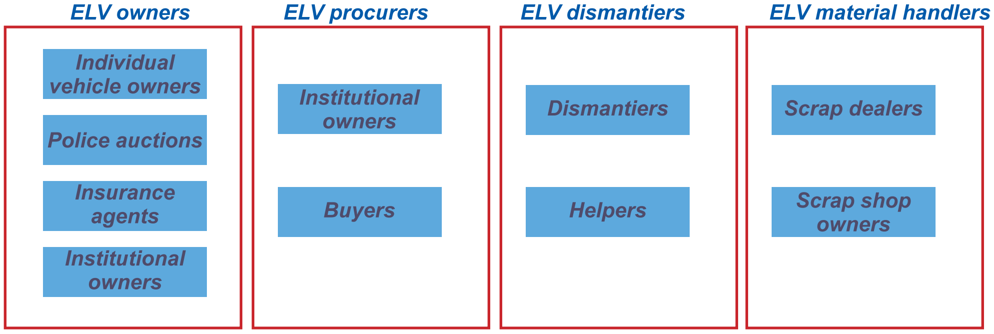
Mayapuri, in West Delhi is India's largest recycling hub, which as per our estimates and industry sources, accounts for nearly 20% of the vehicles dismantled across the country. Over 55,000 passenger vehicles, 20,000 three wheelers and 40,000 two wheelers are dismantled here annually. Commercial vehicles are dismantled in Matiala and Nangli villages (in around 100 warehouses) and the reusable spares are brought to Mayapuri and sold in spares outlets located in the area.

Similarly, Stephen's Square, popularly known as Shivajinagar gujri in Bangalore, is one of the oldest scrap yards in the country. Spread over a radius of 2-3 km, this area also houses over 400-550 shops retailing used auto spares recovered from the dismantled vehicles. Whilst passenger vehicles (cars & other four wheelers) and two wheelers are dismantled here, government commercial vehicles are dismantled in scrap yards belonging to the road transport undertakings. For instance, KSRTC has scrap yards at Kengeri, Hassan, Hubli and Gulbarga. Private commercial vehicles and three wheelers are dismantled in areas located outside the city.

While in most cases, locally registered vehicles alone are brought in for dismantling to the city's scrap yard, in Mayapuri alone, vehicles from Delhi as well as Punjab & Haryana are brought in for dismantling. Details of Mayapuri and Shivajinagar have been set out in Annexure 9.2.

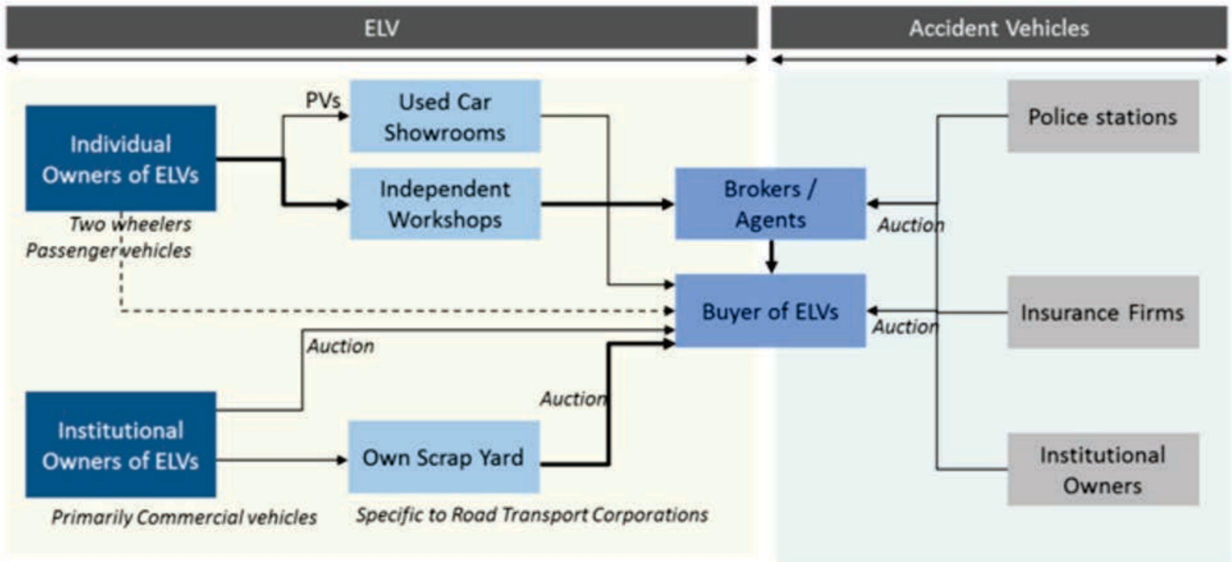
## 3.2 Stakeholders involved

The ecosystem of these scrap yards is fairly well established with distinct channels for vehicle sourcing (brokers and agents) and dismantling (buyers responsible for dismantling the vehicles). The buyer employs dismantlers and helpers to dismantle the vehicles. Adjacent to these scrap yards, flourish used spares outlets that deal with the spares of various vehicle categories. These outlets cater to local mechanics as well as upcountry mechanics.



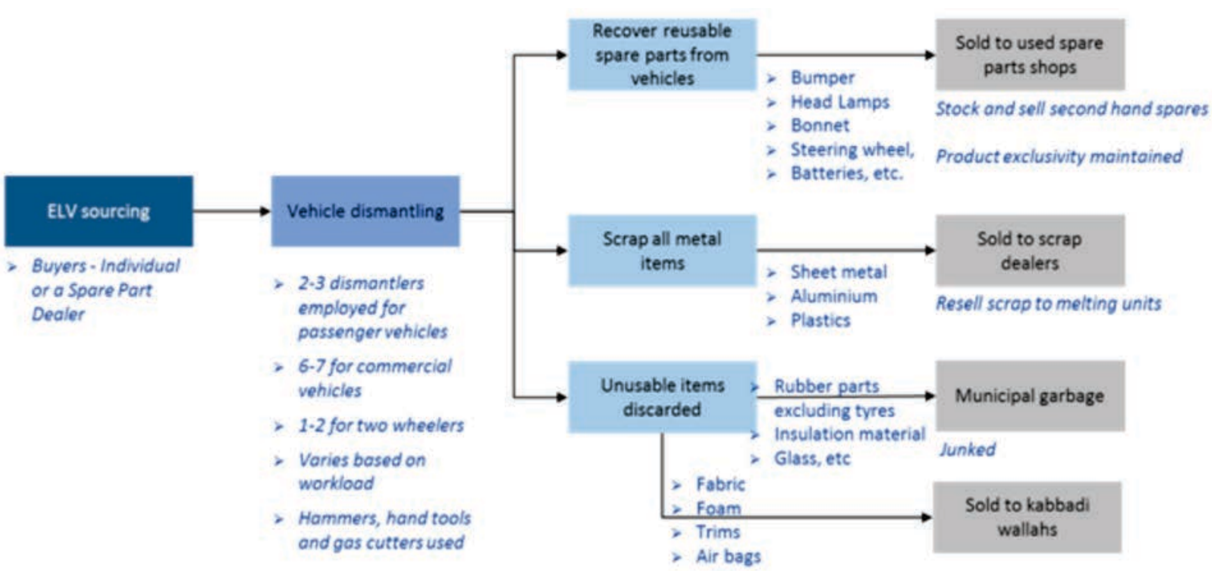
## 3.3 Vehicle sourcing

ELVs as well as accident vehicles are brought to the yard by dealers, brokers or agents. Individual owners rarely involve themselves directly in the sale of their vehicles; they generally operate through brokers or agents. In the case of accident vehicles, police auction the vehicles to brokers / agents in lots of 40-50. Similarly, government / institutional customers auction the vehicles they wish to scrap. Government run transport organisations operate their own scrap yards where usable parts are recovered before auctioning the vehicle for disposal.




## 3.4 Dismantling process

The dismantling process followed across centers is similar with the scale alone varying from city to city. The reusable parts are recovered from the vehicle, refurbished wherever necessary and sold through spare parts outlets located in the vicinity. The metal body, plastic and rubber are sold to scrap dealers and 'kabbadi wallahs' (Small time scrap sellers) by weight.

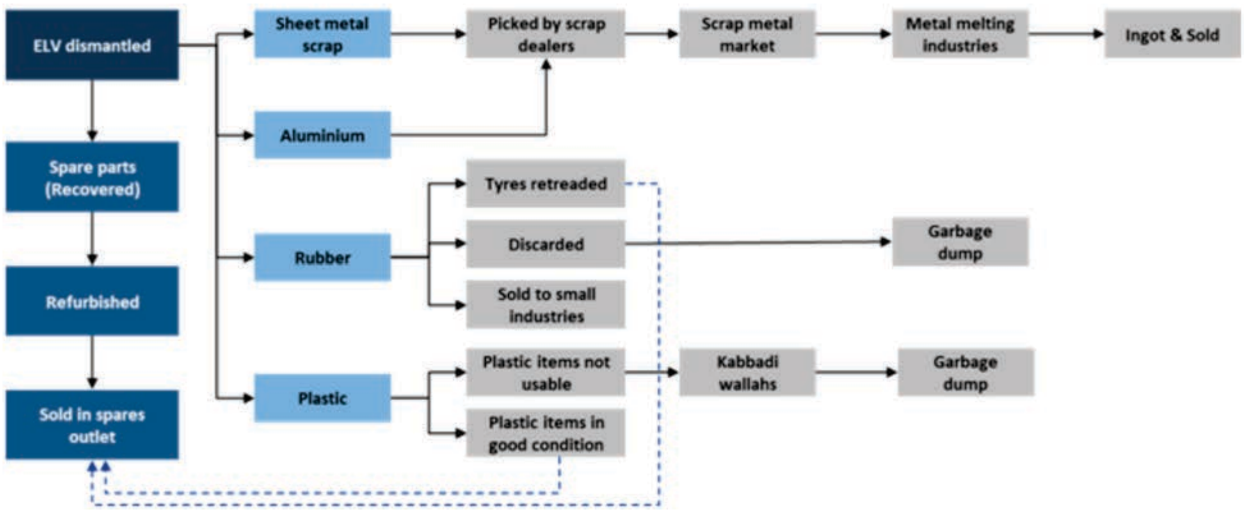


Rudimentary hand tools are used to dismantle the vehicles. It was noticed that in the Shivajinagar area, hand held devices and gas cutters were extensively used, whereas in Mayapuri, gas cutters were not in use due to a ban.

It typically takes 2-3 people, 2.5-3 hours to completely dismantle a car. 1-2 dismantlers are sufficient to dismantle two wheelers, while in the case of commercial vehicles, 6-7 dismantlers take a whole day to dismantle the entire vehicle. Commercial vehicle owners/ agents/ buyers deregister the vehicle before it is dismantled.

### 3.5 Recovery of usable spare parts

Focus is on maximising the recovery of reusable parts from the vehicle, either selling them 'as is' or refurbishing them and selling through second hand spares outlets.




Nearly 50-60% of the spares are recovered in passenger vehicles and over 75% in two wheelers. All these parts are routed to automobile dealers/ spare parts dealers with a presence in the general vicinity. Some of these spares get sold immediately to mechanics and end users, while some languish in the spare parts outlet for years. Recovery is generally higher in accident vehicles, however dispute resolution which is time consuming, often results in deterioration of parts. In commercial vehicles, recovery of spares is estimated to be in the range of 50-60%.

Parts typically recovered from vehicles dismantled:

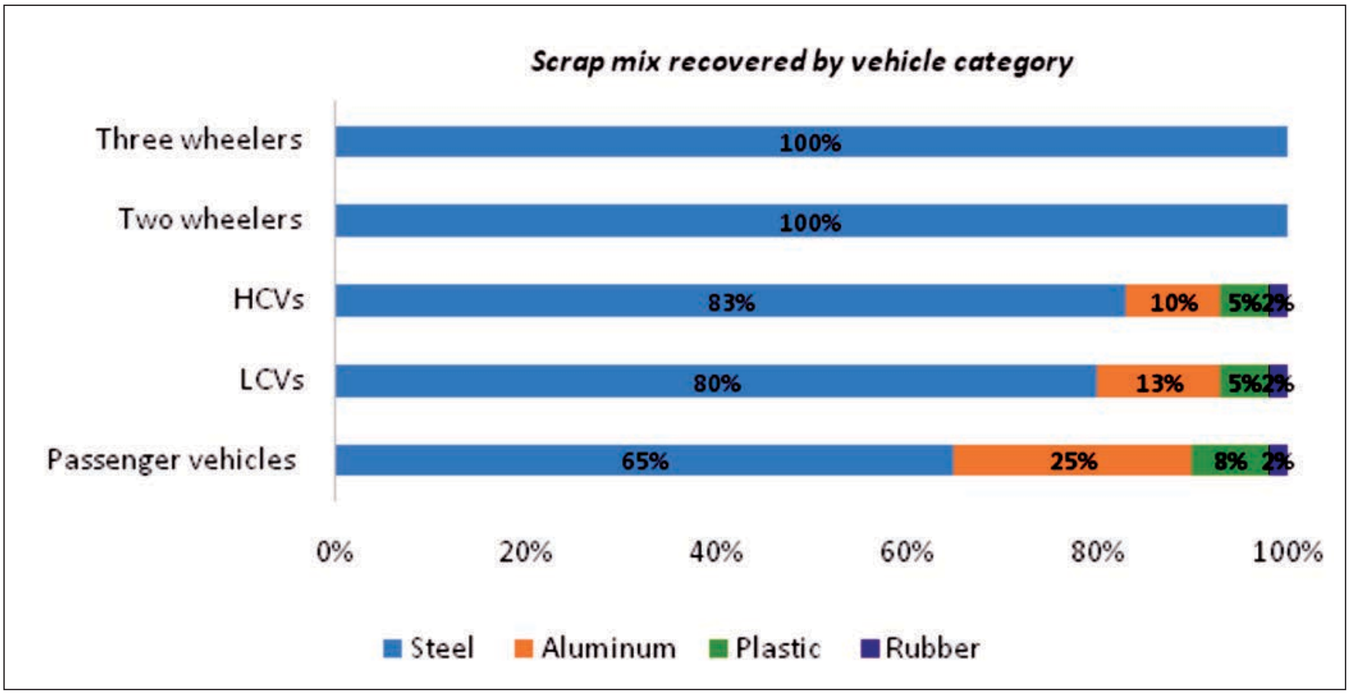
| Passenger vehicles | Two wheelers | Three wheelers | Commercial vehicles |
|---|---|---|---|
| • **Engine related assemblies, engine block, housing, bearings, fuel carburetor, fuel injectors** | • Body (plastic items)<br>• Mudguard<br>• Handles<br>• Fuel tanks<br>• Indicators<br>• Head lights | • Mudguard<br>• Handles<br>• Mirrors<br>• Head light<br>• Indicators | • Engine<br>• Housing<br>• Spring plates<br>• Wheel discs<br>• Axle |

| Passenger vehicles | Two wheelers | Three wheelers | Commercial vehicles |
|---|---|---|---|
| • **Front & rear suspension**<br>• **Radiators**<br>• **Condensers**<br>• **Headlamps & electrical items**<br>• **Bumpers**<br>• **Bonnets**<br>• **Tail lights**<br>• **Steering wheels**<br>• **Fog lamps**<br>• **Horns**<br>• **Emblems**<br>• **Tires- for retreading**<br>• **Seating- front & rear**<br>• **Catalytic converters**<br>• **Batteries**<br>• **Others- Door handles, doors, interior handles, electronic goods in working condition** | • Silencers<br>• Rim wheels<br>• Shock absorbers<br>• Engine bores | | |

### 3.6 Scrap handled

Approximate tonnage of scrap recovered by various vehicle categories:

- Indica : 700 kgs
- Ambassador : 800 kgs
- Two wheelers: 40-80 kgs
- Three wheeler: 300 kgs
- Tata 407: 2 tons
- HCV : 6 tons




The scrap mix recovered by vehicle category (rubber excludes tires): Scrap sales

All metal items are scrapped and sold by weight to scrap dealers. Plastic items are also sold to the scrap dealers who in turn sell it to recycling units. However, according to industry sources, close to 20% of the plastic scrap is eventually discarded in garbage dumps.

Oils and lubricants are recovered and sold to dealers who purify them and sell to local furnaces as fuel.

The process used to recover the scrap is so archaic that while they are able to recover substantial amount of scrap, the quality of material recovered is often suspect. Further, they are unable to recover expensive material such as palladium.

## Scrap discarded

Rubber items other than tyres are discarded and picked up by the municipal garbage trucks. Wherever possible, tires are re-treaded and sold. Unusable tires are discarded along with the other waste. It was observed both in Shivajinagar and Mayapuri that the municipal garbage trucks carry these for disposal. In some cases, rubber is bought by local breweries & small industries and used as fuel. Glass is another material which is discarded as waste. Fabrics, Foam, Trims are either discarded or sold to local 'kabbadi wallahs'.

## 4. 2014 scenario: ELVs, Vehicles dismantled and Scrap handled

### 4.1 ELVs

The primary survey conducted in the two markets placed the age of ELVs coming up for dismantling in the following broad bands:

- Cars: 15-25 years

- Two wheelers: 10-20 years
- Three wheelers: 15 years
- Commercial vehicles: 10–15 years

From the age bands of ELVs coming up for dismantling, we were able to identify a modal age, which was used to develop our estimates. ***ELV numbers in 2014 are estimated at approximately 5 mn vehicles at an all India level*.**

| Vehicle category | ELV age (years) | Year of vehicle sale | ELVs as of 2014 (Nos) |
|---|---|---|---|
| **Passenger vehicles** | 18 | 1996 | 436,330 |
| **Commercial vehicles** | | | 218,070 |
| **LCVs** | 12 | 2002 | 56,675 |
| **M & HCVs** | 10 | 2004 | 161,395 |
| **Two wheelers** | | | 4,203,725 |
| **Scooters** | 12 | 2002 | 908,270 |
| **Bikes** | 12 | 2002 | 2,887,195 |
| **Mopeds** | 12 | 2002 | 408,260 |
| **Three wheelers** | 15 | 1999 | 189,080 |
| Total number of vehicles | | | **5,047,205** |

### 4.2 ELVs dismantled

***While over 5 mn vehicles achieved ELV status at an all India level, the number of vehicles actually dismantled in 2014 is just a fraction of that number, at 418,000 numbers.***

| Vehicle category | ELVs (Nos) | Vehicles actually dismantled (Nos) | % - vehicles dismantled / ELVs |
|---|---|---|---|
| Passenger vehicles | 436,330 | 65,450 | 15% |
| Commercial vehicles | 218,070 | 65,420 | |
| LCVs | 56,675 | 17,000 | 30% |
| M & HCVs | 161,395 | 48,420 | 30% |
| Two wheelers | 4,203,725 | 126,110 | |

| Vehicle category | ELVs (Nos) | Vehicles actually dismantled (Nos) | % - vehicles dismantled / ELVs |
|---|---|---|---|
| Scooters | 908,270 | 27,250 | 3% |
| Bikes | 2,887,195 | 86,610 | 3% |
| Mopeds | 408,260 | 12,250 | |
| Three wheelers | 189,080 | 160,720 | 85% |
| | **5,047,205** | **417,700 ~ 418,000** | 8% |

The All India estimates were extrapolated from the norms obtained from Mayapuri and Shivajinagar:

- Shivajinagar - close to 200-250 cars and 400-500 two wheelers were dismantled in a month. ELVs in Bangalore – 140,000
- Mayapuri handled close to 4,000 - 5,000 cars, 3,000 – 3,500 two wheelers, 2,000 three wheelers and 2,000 commercial vehicles a month; ELV estimates 250,000 (Delhi, Haryana, Punjab)

### 4.3 Scrap handled

Scrap yards in the country handled 415, 000 tons of scrap from dismantling of 418,000 ELVs in 2014. This comprised 348,000 tons of Steel, 44,700 tons of Aluminum, 18,000 tons of Plastics and 4,200 tons of Rubber. This excludes scrap resulting from accident vehicles

Among the various vehicle categories, commercial vehicles are the largest contributors to scrap.

| Total scrap handled in 2014 (Tons) | | | | |
|---|---|---|---|---|
| | **Steel** | **Aluminum** | **Plastic** | **Rubber** |
| Passenger vehicles | 29,500 | 11,450 | 4,200 | 900 |
| Commercial vehicles | | | | |
| LCVs | 27,000 | 4,250 | 1,700 | 900 |
| M & HCVs | 237,000 | 290,00 | 12,100 | 2,400 |
| | | | | |
| Two wheelers | 6,300 | | | |
| Three wheelers | 48,200 | | | |
| **Total** | **348,000** | **44,700** | **18,000** | **4,200** |

Steel, Aluminum and Plastic are sold to scrap dealers commercially. The rates for all these scrap material are fairly well established and fall within similar price bands across the country.

Rubber and part of the plastic (20% of the plastics sold to scrap dealers) find their way to garbage dumps. In 2014, 4,200 tons of rubber and 3,600 tons of plastic were discarded.

Considering the average density of all scrap material discarded in dumps at 0.5 kg/ cubic meter, the landfill requirement would be 0.82 mn cubic meters.

***348,000 tons of Steel, 44,700 tons of Aluminum, 18,000 tons of plastics was sold as scrap in 2014. 4,200 tons of rubber and 3,600 tons of plastics got discarded in open garbage dumps.***

## 5. 2014 Scenario: Revenue from Spares and Scrap

Close to 418,000 vehicles were estimated to have been dismantled in various cities and towns in the year 2014. This chapter focusses on the revenue generated from this process.

Vehicle dismantling provided two distinct revenue streams:

- Sale of spare parts
- Sale of recovered scrap material

### 5.1 Revenue from spare parts sale

Spare parts retrieved from the dismantled vehicles are routed to spare parts dealers located in the same locality. While the dealers stock all parts, not all of them find ready markets. Some of the spares gather dust on the dealer's shelves for months before they get sold.

While no clear pattern in the time frame of spare sales emerged, based on discussions with dealers & other experts, it was felt to be prudent to assume 50% sales (of the total spares recovered) in the case of four wheelers and 75% (of the total spares recovered) in the case of two & three wheelers. Approximate revenue from sale of spares of different vehicle categories:

**Rs.**

| | Passenger vehicles | LCVs | M&HCVs | Scooters | Motorcycles | Mopeds | Three wheelers |
|---|---|---|---|---|---|---|---|
| Proceeds through sale of parts | 6,000 8,000 | 45,000 50,000 | 50,000 60,000 | 2,500 3,500 | 3,000 4,500 | 500 800 | 2,000 3,000 |

In case of government owned commercial vehicles, especially buses, a complete assessment of the condition of the commercial vehicle is undertaken by the maintenance department of the road transport undertaking, based on which, the value of scrap and spares is determined. Once the details are received, the purchase committee arranges for an e-auction with a minimum estimated price for each part. Before bidding for the scrap, buyers also physically inspect and assess the condition of the commercial vehicles. If the estimated value of the commercial vehicle is not recovered through e-auction then the auctioning is terminated and the vehicle is re-auctioned after 2-3 months. Typically, post auction, the commercial vehicle is dismantled in the transport company's depots by the buyer and the recovered scrap & spares transported as transport costs to tow the entire vehicle tends to be high.

Some examples of revenue generated through the sale of recovered and refurbished spares are set out in Annexure 9.3.

***Using the norms of spares revenue obtained from our survey, it is estimated that the total revenue from spares sales, generated from dismantling 418,000 vehicles is approximately Rs. 400 crores in 2014.***

### 5.2 Revenue from scrap sales

The entire scrap is sold by weight. Key scrap items sold include Steel, Aluminum, Plastic, Oils and Engine & Oil filters. Based on the current dismantling levels of ELVs, estimated sale of scrap:

- Nearly 348,000 tons of steel
- 44,700 tons of Aluminum
- 18,000 tons of plastic; of which close to 20% are subsequently trashed and find their way to garbage dumps

Prevailing rates for scrap:

| Scrapped material | Approximate selling prices in Rs. |
|---|---|
| Steel | 20- 22 / kg |
| Aluminum | 80-110 / kg |
| Plastic | 18/ kg |
| Oil | 5 -6/ litre |
| Engine and oil filters | 2/ kg |

Scrap earnings estimated by vehicle category:

Rs.

| | Passenger vehicles | LCVs | M & HCVs | Two Wheelers | Three wheelers |
|---|---|---|---|---|---|
| Proceeds through scrap sales | 24,000-32,000 | 60,000–65,000 | 150,000–170,000 | 800-1,000 | 6,000 |

***Revenue generated from scrap sales is estimated at Rs 1,100 crores at an all India level from dismantling of ELVs in 2014.***

## 5.3 Total revenue generated

The total revenue generated from the sale of spares & scrap from ELVs in 2014 is estimated at **Rs. 1,500 crores.** Downstream revenue generation through resale of scrap, recycled plastics and lubricants has not been reckoned.

**Rs. Crore**

| | Spares revenue | Scrap revenue | Total Revenue |
|---|---|---|---|
| Passenger vehicles | 32 | 163 | 195 |
| Commercial vehicles | 320 | 825 | 1,145 |
| LCV | 90 | 95 | 185 |
| M & HCV | 230 | 730 | 960 |
| Two wheelers | 40 | 15 | 55 |
| Three wheelers | 8 | 97 | 105 |
| **Total revenue** | **400** | **1,100** | **1,500** |

## 5.4 Typical earnings from each vehicle category

This section attempts to provide earnings (net) from different vehicle categories. The costs incurred include purchase price of the vehicle and dismantling costs such as payments to dismantlers, helpers, municipality trucks, etc.

Net earnings vary across product categories - motorcycles and cars appear to fetch better returns. A few examples are set out below:

**Rs.**

| | Indica | Ambassador | LCV | HCV | Motorcycles | Scooters | Mopeds | Three wheelers |
|---|---|---|---|---|---|---|---|---|
| **Total Revenue** | **31,500** | **37,250** | **112,000** | **200,000** | **5,000** | **3,500** | **1,300** | **8,070** |
| Spares | 7,500 | 6,250 | 50,000 | 50,000 | 4,000 | 2,500 | 700 | 2,070 |
| Scrap | 24,000 | 31,000 | 62,000 | 150,000 | 1,000 | 1,000 | 600 | 6,000 |
| **Total Expenses** | | | | | | | | |
| Purchase price | 15,000 | 15,000 | 85,000 | 150,000 | 1,200 | 1,200 | 800 | 6,000 |
| Direct & indirect costs incurred | 3,650 | 3,300 | 6,000 | 10,000 | 300 | 300 | 150 | 500 |
| **Gross Earnings per vehicle** | ***12,850*** | ***18,950*** | ***21,000*** | ***40,000*** | ***3,500*** | ***2,000*** | ***350*** | ***1,570*** |

## 6. Future Scenario

India is adding close to 18 mn vehicles to the vehicle population annually and by 2020, India will have a population of nearly 350 mn registered vehicles in the categories of interest.

### 6.1 ELVs by 2020 - 2030

It is estimated that 8.7 mn vehicles will reach their end of life by 2020 and 26.6 mn by 2030 based on the current estimate of lifespan of vehicles.

This figure could increase with more stringent regulations coming into place with respect to fuel and emission standards. Cities across the world are ordering older vehicles off the roads or restricting private car use to tackle growing air pollution. Closer home, The National Green Tribunal has banned all vehicles older than 15 years from the streets of the capital, New Delhi, in a bid to clean up the air. This ruling hits a significant number of vehicles on Delhi roads. These vehicles could potentially move up-country. However as the laws get more stringent and implementation stricter, we will see vehicles going off the roads faster than the current set of vehicles.

### 6.2 ELVs likely to be dismantled by 2020 - 2030

**ELVs dismantled (current norms)**

**It is estimated that 718,000 vehicles will be dismantled by 2020, going up to 1.8 mn by 2030**. This is based on the current percentage of vehicles actually coming up for dismantling.

**Mn Nos.**

| Year | Passenger vehicles | Total Commercial vehicles | LCVs | M & HCVs | Total Two wheelers | Scooters | Bikes | Mopeds | Three wheelers | Total vehicles |
|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 0.10 | 0.14 | 0.06 | 0.07 | 0.22 | 0.03 | 0.17 | 0.01 | 0.26 | **0.72** |
| 2021 | 0.11 | 0.16 | 0.06 | 0.10 | 0.22 | 0.03 | 0.17 | 0.01 | 0.45 | **0.93** |
| 2022 | 0.14 | 0.19 | 0.09 | 0.10 | 0.28 | 0.04 | 0.22 | 0.02 | 0.44 | **1.04** |
| 2023 | 0.16 | 0.19 | 0.11 | 0.08 | 0.35 | 0.06 | 0.27 | 0.02 | 0.46 | **1.16** |
| 2024 | 0.17 | 0.20 | 0.14 | 0.06 | 0.40 | 0.08 | 0.30 | 0.02 | 0.41 | **1.18** |
| 2025 | 0.21 | 0.22 | 0.16 | 0.06 | 0.41 | 0.09 | 0.30 | 0.02 | 0.37 | **1.21** |
| 2026 | 0.23 | 0.19 | 0.13 | 0.06 | 0.44 | 0.11 | 0.31 | 0.02 | 0.45 | **1.32** |
| 2027 | 0.23 | 0.21 | 0.15 | 0.06 | 0.49 | 0.12 | 0.34 | 0.02 | 0.48 | **1.42** |
| 2028 | 0.29 | 0.24 | 0.17 | 0.07 | 0.55 | 0.14 | 0.38 | 0.03 | 0.50 | **1.58** |
| 2029 | 0.38 | 0.27 | 0.20 | 0.07 | 0.61 | 0.16 | 0.41 | 0.03 | 0.53 | **1.78** |
| 2030 | 0.39 | 0.30 | 0.23 | 0.07 | 0.67 | 0.19 | 0.45 | 0.03 | 0.43 | **1.80** |
| **Total** | 2.41 | 2.31 | 1.51 | 0.81 | 4.65 | 1.07 | 3.35 | 0.24 | 4.78 | **14.15** |

Currently, as mentioned earlier, only 8% of ELVs appear to come up for dismantling. The rest either ply short distances or move up-country and finally get dismantled in local garages / mechanic shops. Considering that these mechanics have no skill sets to dismantle the vehicles, the spares and scrap retrieved are not optimal, resulting in significant loss of revenue. More importantly, the unused material is discarded or burnt with no consideration to the environment. Some of the materials so discarded, such as air bags, tires, glass, seat covers, etc. are quite harmful to both the environment and the workers handling the material.

However, this percentage (8%) is likely to go up with enforcement of regulations, better sourcing facilities, more organized dismantling processes, skilling of workers and better realizations on recovered material.

<u>ELVs dismantled (all ELVs)</u>

***If all ELVs were to be dismantled, the number of vehicles coming up for dismantling would be 8.7 mn in 2020 and 26.6 mn in 2030.***

**Mn Nos.**

| | Passenger vehicles | LCVs | M & HCVs | Scooters | Bikes | Mopeds | Three wheelers | Total Vehicles |
|---|---|---|---|---|---|---|---|---|
| **2020** | 0.68 | 0.22 | 0.24 | 1.05 | 5.77 | 0.41 | 0.31 | **8.68** |
| **2030** | 2.63 | 0.78 | 0.23 | 6.31 | 15.15 | 1.02 | 0.51 | **26.63** |

### 6.3 Scrap handled

***The scrap handled will be of the order of 0.7 mn tons by 2020 and 1.3 mn tons by 2030 going by the current norms of dismantling age.***

| Tonnage of scrap (Tons) | | |
|---|---|---|
| | **2020** | **2030** |
| **Steel** | 598,700 | 1,050,500 |
| **Aluminum** | 78,000 | 168,500 |
| **Plastic** | 31,500 | 66,000 |
| **Rubber** | 8,800 | 19,000 |
| Total | **717,000** | **1,304,000** |

However, if all ELVs were to be dismantled, the potential scrap handled would reach **2.8 mn tons in 2020 (8.7 mn vehicles) and 6 mn tons by 2030 (26.6 mn vehicles).**

| Tonnage of scrap (Tons) | | |
|---|---|---|
| | **2020** | **2030** |
| **Steel** | 598,700 | 1,050,500 |
| **Aluminum** | 78,000 | 168,500 |
| **Plastic** | 31,500 | 66,000 |
| **Rubber** | 8,800 | 19,000 |
| Total | **717,000** | **1,304,000** |

However, if all ELVs were to be dismantled, the potential scrap handled would reach **2.8 mn tons in 2020 (8.7 mn vehicles) and 6 mn tons by 2030 (26.6 mn vehicles).**

| Tonnage of scrap (Tons) | | |
|---|---|---|
| | **2020** | **2030** |
| Steel | 2309,600 | 4837,340 |
| Aluminum | 319,100 | 792,380 |
| Plastic | 126,700 | 306,090 |
| Rubber | 32,500 | 87,250 |
| **Total scrap** | **2,787,900** | **6,023,060** |

## 6.4 Landfill requirement

Rubber and nearly 20% of the plastic from automobile recycling is discarded in open garbage dumps in India. In addition, foam, trims, wood and seat covers are also thrown away albeit indirectly through 'kabbadi wallahs'. Such unchecked dumping of waste poses a major threat to the environment. In addition, it puts a strain on our already overflowing landfills.

If we consider the case where all ELVs were to come up for dismantling, large landfills will be required to handle the scrap (2.8 mn tons in 2020 and 6 mn tons in 2030), unless dismantling processes are improved to reduce scrap discarded in garbage dumps through Auto Shredder usage & post ASR treatment

With effective recycling of plastic & rubber, recovery of upto 85% and post treatment of ASR, the landfill requirements can be reduced to 1.4 mn cubic metres in 2020 and 3 mn cubic meters by 2030.

| Scrap discarded and landfill requirement | | |
|---|---|---|
| | **2020** | **2030** |
| Scrap generated in mn tons | 2.8 | 6 |
| **With ASR , 85% of the vehicle recycled, 15% goes to landfills** | | |
| Tonnage that will be disposed of - mn tons | 0.4 | 0.9 |
| Landfill required in mn cubic metre | 1.4 | 3 |

## 6.5 Landfill design

Modern landfills are designed scientifically to protect the environment from contaminants which may be present in the solid waste stream. These facilities are located, designed, operated, and monitored to ensure compliance with federal regulations. They ensure there is no ground waste contamination, nor are there any landfill gases which can pollute the air and prove hazardous. Some of the newer plants use the landfill gases and convert them into energy.

US Environment Protection Agency has set out some basic compliance norms for landfills which could also be looked at.

- **Location restrictions**—ensure that landfills are built in suitable geological areas away from faults, wetlands, flood plains, or other restricted areas.
- **Composite liners requirements**—include a flexible membrane (geo membrane) overlaying two feet of compacted clay soil lining the bottom and sides of the landfill, protect groundwater and the underlying soil from leachate releases
- **Leachate collection and removal systems**—sit on top of the composite liner and removes leachate from the landfill for treatment and disposal.
- **Operating practices**—include compacting and covering the waste frequently with several inches of soil, helps reduce odor; control litter, insects, and rodents; and protect public health.
- **Groundwater monitoring requirements**—demands testing groundwater wells to determine whether waste materials have escaped from the landfill.
- **Closure and post closure care requirements**—include covering landfills and providing long-term care of closed landfills.
- **Corrective action provisions**—control and clean up landfill gas releases and achieve groundwater protection standards.
- **Financial assurance**—provides funding for environmental protection during and after landfill closure
- **Specific materials can be banned** : Some materials may be banned from disposal in

municipal solid waste landfills including common household items such as paints, cleaners/chemicals, motor oil, batteries, and pesticides

## 7. Employment

Employment in this sector spans the entire dismantling chain as well as the sales cycle. Employment can be direct as well as indirect in nature.

Direct employment would typically include Brokers, Agents, Buyers, Dismantlers and Helpers. Shivajinagar has close to 40-50 active buyers and 80 dismantlers while Mayapuri has close to 700 dismantlers. The dismantlers are assisted by helpers who undertake all the sundry, non-technical jobs for the dismantler. They are essentially mechanics who have learnt the skills over the years. They have not undergone any formal education or training for handling the dismantling jobs.

Indirect employment includes scrap dealers, spare show owners, shop helpers, transporters, etc. Most of the scrap dealers employ casual labour who collect and pick up material from various buyers. Auto spare shops are manned by the shop owner himself, who is assisted by 1-2 helpers. In addition, these centers also help generate employment for cleaners, eateries, street hawkers, transporters, etc. Shivajinagar houses close to 2,000 such people and Mayapuri employs around 15,000.

### 7.2 Employment estimates

The primary survey information was used to build norms for the labour deployed for handling the inflow of vehicles. Linkages were built with the number of vehicles that were dismantled to estimate the direct employment.

***It is estimated that around 14,000 – 15,000 people are directly employed in automobile recycling.*** This covers buyers, dismantlers and helpers who assist the dismantlers.

It was difficult to establish the numbers of indirect employment as most of these centers also act as scrap yards for other products such as consumer durables, electronics, etc. However, automotive spare parts form over 70-80% of their sales. Indirect employment covers spare part dealers, shop sales personnel, eatery owners and workers, scrap dealers and waste handlers. ***Industry sources estimate the total indirect employment at around 75,000 – 80,000.***

***The total employment in this activity is estimated at 90,000 to 95,000 in 2014.***

## 8. Concerns Requiring Urgent Attention

Currently, India has neither the infrastructure nor the regulatory mechanism for efficient disposal of these end-of-life vehicles. Some issues requiring urgent attention are articulated below.

### 8.1 Infrastructure to handle the large volumes likely by 2020, 2030

The current infrastructure for vehicle dismantling in the country is woefully inadequate. Most of the scrap yards operating currently started out as small workshops and have grown in a haphazard fashion over the years to accommodate the influx of more vehicles. These workshops were not designed to handle large throughput of vehicles. They are just able to manage the current load of vehicles estimated at 418,000 vehicles.

As mentioned in the earlier chapter, a huge influx of ELVs is expected to come up for dismantling in the future. 2020 will witness the dismantling of around 718,000 ELVs at the least and could reach levels of 8.7 mn if all the ELVs were to get dismantled.

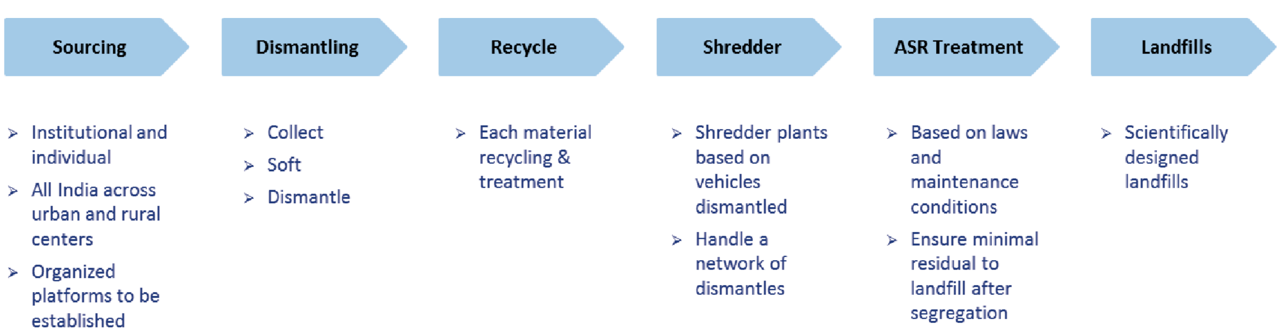
While there could be varying estimates of ELVs expected to be dismantled in 2020 based on the average ELV age reckoned, as per our assessment, the figure is likely to be much higher than 0.72 mn due to reducing lifespan of vehicles with time. One key driver would be improving economic conditions in the country. Increasing affluence could result in banning older vehicles in the interests of environment protection. This is a pattern noted globally. In any case, given the large and ageing population base of vehicles, the magnitude of the problem will be significant and well beyond the capabilities of the current systems.

The current capacity can at best grow to accommodate 600,000–700,000 vehicles by 2020. Capacity expansion beyond that is a very remote possibility for a variety of reasons:

- These scrap yards are located in residential areas, within the city limits. There is no land area available for expansion. Even if they were to acquire the surrounding land, the prices would be astronomical as they are located in prime areas in the city.
- Dismantling practices adopted currently are primitive. It is extremely people intensive and the tools used are rudimentary – hand tools and gas cutters are primarily used. They would be unable to cope with the increased volumes expected, as pure addition of manpower cannot solve the issue. More efficient systems and processes are the need of the hour.

The extent and magnitude of the problem therefore warrants special attention with a paradigm shift in approach.

Further, capacity addition in the scrap yards alone will not be sufficient. The whole value chain will need to be revamped. In most global markets, auto recycler associations work closely with industry to streamline recycling processes.




- **Sourcing**: While there are established practices for ELVs sourcing, they have limited capacity and reach. If a large number of ELVs need to be routed to these scrap yards, systems are required to source them from multiple centers (both rural and urban).
- **Dismantling**: Establish centers in the states with a large population of vehicles. 10 states in India account for 75% of vehicle sales. Within these states, ideally locate these

dismantling centers in the outskirts of cities with higher concentration of vehicles; good connectivity and logistics facility

- **Recycling**: Recycling facilities to help recover high quality metals, oils and other material. Equip these recycling centers with shredders which can crush the scrap material that is generated. As capacities of shredders are high, ELVs from 10-15 dismantlers would need one shredder

  In a typical modern recycling business, inoperative motor vehicles are brought into a facility where the hazardous and recyclable fluids are properly drained. Undamaged parts are then dismantled from the vehicle, cleaned, tested, inventoried, and stored in a warehouse until sold. The remaining vehicle hulk is then prepared for scrapping.

- ***Systems and processes for part identification:*** Currently parts dismantled are sold through spares outlets. However, no records are maintained on the vehicle model, year of manufacture, etc. In global markets, the business is fairly organised, parts are numbered and are easily traceable. This will help legitimise the business further.

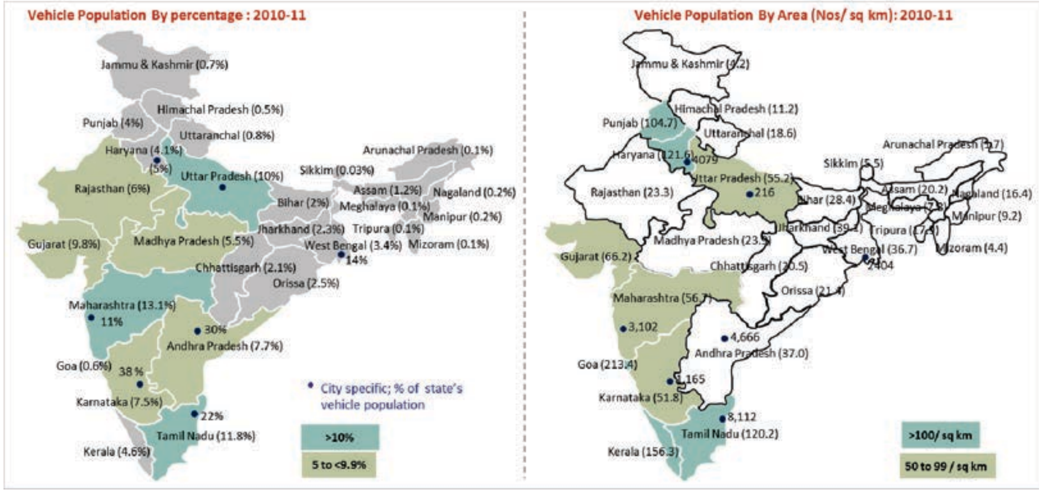
- ***Landfills***: Automobile waste requires special landfills – need to obtain the requisite technology and invest in land and processes

- ***Set up processes for post ASR treatment***: This will considerably reduce the landfill area requirements.

The ten states of Maharashtra, Tamil Nadu, Uttar Pradesh, Gujarat, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, Kerala and Haryana, which account for nearly 75% of the vehicle population of India, would be ideal for the dismantling units suggested.

Looking at land area and density of vehicles, it appears that Delhi (which could service parts of UP, Punjab and Haryana) and Tamil Nadu could be early adopters. Both these cities have a flourishing business already and could lead the way with pilot projects to establish the concept.

The map on the left sets out the vehicle population by states and the map on the right set out the vehicle population by land area. These are indicators of future stress zones for landfills, given that dismantling will be higher and therefore the need for landfills to handle the waste.



## 8.2 Better utilization of scrap handled

The vehicle dismantlers are excessively concerned with saleable parts, components and scrap which fetches them immediate realizations. Important metals like Copper, Palladium, etc. which if recovered and sold would fetch them handsome gains are currently just sold as scrap at fixed rates. The reason for this is, they do not have the infrastructure to recover these elements. Even the aluminum recovered is not of first quality.

Effective use of the scrap generated can help reduce imports of scrap by the automobile sector.

- Segregation processes are required to ensure that different materials are dealt with separately and help recover high quality Aluminum, Palladium and Copper
- Recycling of all material, especially rubber and plastics
- Processes for collection and supply to OEMs

According to the American Iron & Steel Institute, in the US, over 14.5 mn tons of steel was collected from ELVs and placed back in the industrial production stream. ELV re-introduces steel into the production stream, building nearly 13 mn new vehicles and generating 46,000 jobs. 10 mn barrels of oil are preserved each year by using recycled parts instead of manufacturing new parts.

As per industry sources, in India, efficient recycling of a normal sedan could help conserve 2,500 kgs of iron ore, 1400 kgs of coal, reduce the release of 1,000 kgs of carbon dioxide and save more than 1 megawatt of energy.

## 8.3 Prevent environment degradation

By the year 2020, it is expected that 8,800 tons of rubber and 6,300 tons of plastics will be either trashed in garbage dumps or burnt in furnaces/ open grounds, creating a serious health hazard and harmful impact on the environment. In addition to this, plastics, which are purportedly recycled, also get re-routed to garbage dumps and landfills.

Technology enhancement has led to higher usage of plastics and composite materials in vehicles, which the current system is ill equipped to completely recycle. This is slated to increase in the future, burdening the system further.

### Reduce pollution in highly populated areas

The current scrap yards are located in the center of the city, in densely populated areas. Further, they are completely unmindful of the environment, both due to lack of awareness and poor facilities for disposing garbage. They therefore end up pouring/ spilling polluting materials into the ground thereby contaminating the ground water as well as polluting the air.

This is a major health hazard requiring immediate attention, as the impact is felt not only by the employees working in the scrap yards but the residents in the neighboring localities as well. The extent of the problem is only slated to increase with more ELVs coming up for dismantling.

There is an urgent need to relocate these scrap yards outside the city limits. It is also extremely important to provide safe and clean working environment to the employees, equip them with better tools and give them appropriate training.

**Focus on reducing landfill requirements**

There is a crying need to build systems that ensure a very small percentage of this scrap reaches landfills.

- Regulations can further drive recycling up to 85% reducing the waste going to landfill
- Reduction in landfill area can be achieved through ASR treatment

In modern facilities, where auto shredder is used along with segregation of auto residue, less than 5%- around 1-3% of the vehicles by weight is sent to landfills.

**8.4 Introduce requisite regulations with immediate effect**

Given the magnitude of the problem we are likely to face in the future, there is immediate need for regulations to ensure recyclability of at least 85% by 2020. Draft regulations under discussion need to be recognized and enforced. There is need to also set up monitoring mechanisms to drive compliance and acceptance among the various stakeholders.

**8.5 Safe working environment for employees**

Currently vehicles are dismantled on the roadside, scrapped material is dumped within the scrap yards with complete disregard to safety of labor working in that area. Unhygienic processes result in air pollution as well as ground water contamination. This is both due to negligence and lack of awareness of the consequences of dumping hazardous material. The workers work with minimal safety equipment.

- A modern facility will provide better and safer working environment.
- Skill development and appropriate training will enable upgradation of skills and knowledge of workers, ensure better payment for the work done and improve efficiency and productivity of the system.
- Minimal safety norms to be prescribed

**8.6 In summary**

India needs to look at developing an ecosystem that addresses the entire value chain of the business, put in place practices for ensuring safe disposal of vehicles and also specify the basic standards that need to be adhered to.

An unorganized sector that generates revenues of Rs. 1,500 crores from ELV recycling, with a potential to touch over Rs. 2,700 crores by 2020, needs serious attention from the government and industry bodies. Driving initiatives that can bring about consolidation, standardization and respectability to the work being done can result in multi-dimensional benefits to the industry, society and environment.

## 9. Annexure

**Annexure 9.1 : Information sources**

- Society of Indian Automobile Manufacturers (SIAM): Statistical Profile 2000-01
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## Annexure 9.2

### Shivajinagar scrap yard

Shivajinagar gujri, located at Stephen's Square is one of the oldest scrap yards in the country, which has been operational since 1920s. Two wheelers, passenger three wheelers and passenger vehicles (cars) are dismantled here. All types of spares for both cars and two wheelers are available in this market, ranging from nuts and bolts to engine parts, out of production spare parts, etc. This scrap market is spread over a radius of 2 to 3 km, housing close to 400-500 shops in Stephen's square, of which 250-300 shops deal with automotive spare parts. Most of these shops are run by the store owners themselves. It is estimated that close to 2,000-2,200 people are employed here.

### Dismantling process

There are around 80 people who dismantle the vehicle purchased by the spare part dealers / brokers / agents. The vehicles are dismantled on the road side with the help of hand held devices and gas cutters. In Shivajinagar scrap yard, roughly around 200 cars are dismantled and scrapped every month. After removing the parts, the external body or the structure is cut into 3/4 feet size with the help of gas cutters and sold to scrap dealers. All the metal parts and fluids are sold to small scale industries where melting is done.

### Spares selling practices

All types of spares from bonnet of a car to a silencer, shock absorber of bikes are sold across these 250-300 outlets. There are separate shops for two wheeler and four wheeler spare parts. There are shops exclusive for tires, headlamps, hubcaps and electrical items like connectors, wire harness, structures like bonnet, doors, emblems, axles, mufflers and silencers, etc.

There is no fixed price for any of the spare part sold here and it purely depends on the level of bargain and the relationship of the outlet owner with the customer. Old customers and regular buyers are offered very competitive pricing. Spares from stolen vehicles are also available here. Higher prices are demanded for out of production spares and those unavailable in the general market. The outlets here do not directly sell their spares outside the market, but several automotive spare dealers and customers from the state and from different parts of country buy spare parts and take it to be sold as local spare in their respective cities.

## Vehicles dismantled

| | Units | Cars | Scooter | HCV |
|---|---|---|---|---|
| Number of vehicles handled annually | # | 2500- 3000 | 5000- 6000 | 1000-1500 |
| % ELV | | 75% | 20% | 80% |
| % accident | | 25% | 80% | 20% |
| ELV Purchase Price | Rs. | 15000 | 1100 | 150000 |
| Accident Vehicle Purchase Price | Rs. | 50000 | 1100 | |
| Costs incurred for dismantling | Rs. | 3650 | | 10000 |
| Selling price of ELV | Rs. | 25,000-35,000 | 2500 - 3000 | 200,000-220,000 |
| Selling price of an accident vehicle | Rs. | 90,000-100,000 | | 400,000 |

## Mayapuri scrap yard

Mayapuri is one of the oldest and largest scrap yard and vehicle dismantling center located in Delhi. There are close to 2,500-3,000 shops in Mayapuri industrial area, of which 1,200-1,700 shops deal with automotive spare parts. Most of these shops are run by the store owners themselves. It is estimated that close to 14,000-18,000 people are employed here. Nearly 65,000 – 75000 vehicles are dismantled annually at Mayapuri.

## Dismantling process

While in Mayapuri, passenger vehicles and two wheelers are dismantled, all commercial vehicles are dismantled at Matiala and Nangli villages. There are close to 100 warehouses owned by buyers operating in the Mayapuri market in these centers, employing 6000 people. Commercial vehicles, which include trucks and buses are dismantled in these warehouses. Each warehouse has the capacity to hold 6-7 trucks at a time. Both accident and end of life vehicles are brought in for dismantling from Delhi, Haryana, Punjab and Himachal Pradesh. Tractors and Three wheelers are also dismantled here. In Mayapuri, all dismantling is done using hand tools, while in Matiala and Nangli village, gas cutters are used. Dismantlers also have presses which crush the steel.

## Spares recovery practices

Spares from commercial vehicles are brought back to the Mayapuri market while the rest of the scrap is handled out of Matiala and Nangli villages.

From the ELVs and accident vehicles, after all reusable parts are recovered, steel, aluminum and plastic are sold to scrap dealers. Among the various rubber items, tires are fitted with new grips and sold at a price of Rs. 450-500, while the rest are disposed in the municipal garbage system. Glass is another material that is not recycled, but broken and disposed as a waste material. Batteries are sold to battery dealers. Items such as trims, broken plastics and seat covers are sold to kabbadi wallahs at Rs. 2-3 per kg.

| *Mayapuri* | Units | Cars | Motorcycle | Commercial vehicles |
|---|---|---|---|---|
| Number of vehicles handled annually | # | 50000-60000 | 40000-45000 | 25000-30000 |
| ELV Purchase Price | Rs. | 13,000 | 1,200 - 2,000 | 100,000 |
| Accident Vehicle Purchase Price | Rs. | 40,000 | 10,000 | 200,000 |
| Costs incurred for dismantling | Rs. | 3,300 | 300 | 8,000 |
| Selling price of ELV | Rs. | 30,000- 40,000 | 5,000 - 6,000 | 175,000- 185,000 |
| Selling price of an accident vehicle | Rs. | 55,000-75,000 | 15,000-20,000 | 300,000-350,000 |

Source : Primary survey

## Annexure 9.3

### Revenue from recovered and refurbished spares

| Indica car | Rs. |
|---|---|
| Purchase price of a car | **15,000** |
| Selling prices of good quality parts | **15,000** |
| Engine related assemblies, engine block, housing, bearings, fuel pump, carburettor, fuel injectors | 4000 |
| Front & Rear suspension | 1,300 |
| Headlamps & electrical items | 600 |
| Bumper | 1,300 |
| Bonnet | 1,200 |
| Tail light | 400 |
| Steering wheel | 500 |
| Fog lamps | 350 |
| Horn | 150 |

| **Indica car** | **Rs.** |
|---|---|
| Emblems | 200 |
| Tires - for retreading | 500 |
| Seating - front & rear | 2,500 |
| Others - Door handles, doors, interior handles | 2,000 |
| **Assuming 50% are sold** | **7,500** |

| | **Scooter** | **Motorcycle** | **Moped** | **Three wheeler** |
|---|---|---|---|---|
| Purchase price in Rs. | 1200 | 1200 | 800 | 5000 |
| Spares selling prices in Rs. | | | | |
| Body (Plastic items) | 600 | 300 | | |
| Mudguard | 300 | 100 | | 300 |
| Handles | 100 | 500 | 100 | 200 |
| Fuel tank | 500 | 1000 | | 500 |
| Indicators | 150 | 200 | | 500 |
| Head light | 250 | 600 | | 500 |
| Silencer | 650 | 700 | | 950 |
| Rim wheels | 200 | 500 | 200 | |
| Shock absorber | 200 | 500 | 100 | |
| Engine bore | 500 | 500 | 200 | |
| Others | 500 | 500 | 200 | 500 |
| Assuming 70% sold | | | | |
| **Spares revenue** | **2,765** | **3,780** | **560** | **2,415** |

Source: Primary survey

CHAPTER - 3

# Recycling of Automobile Waste Rubber

# Recycling of Automobile Waste Rubber

## 1. Introduction

Automobiles consume huge quantities of rubber year after year. At the end of their service life these products are generally thrown into the garbage bin leading to enormous environmental pollution.

While tires account for 67% of rubber in automobiles, weather strips make up 9%, vibration isolators 8%, hoses 6% and other miscellaneous components 10%. Different rubbers used in making those products are EPDM: 51%, NR: 16%, CR: 11%, SBR: 12%, miscellaneous polymers: 10%. The sum of their weights corresponds, on an average, to about 3% of the total weight of the vehicle.

In industrialized countries, the scrap tyre generation is estimated at an average of one passenger car tire equivalent (PCTE, 20 lbs. or 9 kg) per capita and per year.

The problem with tires and other rubber products starts with the very nature of their manufacture. Basically the rubber products are made by vulcanization of rubbers by sulphur along with some other auxiliary chemical compounds. Consequently the generated waste materials are solid cross-linked rubbers, which are insoluble and infusible thermoset materials.

As a result, recycling of waste rubber product is quite troublesome in contrast to the recycle of thermoplastics. Even though there exists some commercial practices for the recovery of the rubber hydrocarbon by different reclaiming processes but these involve huge energy consumption and highly expensive.

## 2. Environmental problems associated with disposal of Illegal scrap tire

A major issue faced globally is uncontrolled and illegal disposal of scrap tires. In United States, for instance, about 2 to 3 billion scrap tires are estimated to be stockpiled in illegal or abandoned piles, which represent a cumulative scrap tire generation over about ten years. It may be safe to assume illegal or semi-legal scrap tire piles of the same order of magnitude for European Union (EU) member states too.

Fire is one of the severe hazards associated with the uncontrolled outdoor accumulation and disposal of tires. In the event of a fire in a large pile, it is almost impossible to extinguish it. There have been instances when large tire piles have burnt for several months on end with the acrid fumes spreading over vast areas.

**Figure 1: Tire fire in Stanislaus Co. California (September 1999)**

Fire fighters face a hard time extinguishing such fires with conventional means due to intense heat and smoke generation. Not only that. The problem of air and soil pollutions becomes all the more worse if the fire is extinguished with foam or water. As a result, the scrap tire fire is often allowed to continue in a more or less controlled manner until the entire pile is exhausted.

Even if the large tire piles do not catch fire, they cause a serious problem for human health and the environment since the disease carrying mosquitoes find an ideal breeding site in the countless little puddles as it rains. In areas of large tire piles with warmer climates mosquito-borne diseases like encephalitis and dengue feverhave been reported.

Most industrialized countries have imposed legal guidelines on accumulation and disposal of scrap tires and other rubber products derived from vehicles. The main purpose of these regulations is almost the same: to maintain environmentally safe disposal mechanisms, to limit the amount of the products that could be stored at any given location, and to encourage their recycling. Specific clauses may, however, differ from country to country.

There can be many ways of dealing with waste rubber of automobiles including recycling and reuse of the reclaimed rubber mass as raw material for new rubber products.

Over the years, governments, industry, research institutions and other stakeholders have been working to find out cost effective solutions. An overview of the different efforts, which have been made till date on research and development is presented in the following sections and paragraphs.

While sometimes the grants and subsidies become instrumental for the implementation of a recycling project, it lies ultimately on the ingenuity of business community to come up with economically sound and market driven solutions.

Some of the key factors for a long term economic success in this field are:

- Sound and serious marketing of the recycled products
- Judicious selection of the appropriate recycling technology
- Innovative and useful product development from recycled rubber
- Support of the local and national governments for recycling activities

Disposal and recovery data for scrap tires are given below for the European countries

**Table 1: Scrap tire statistics for Europe in 2006 (Published by the European Tyre and Rubber Manufacturers Association)**

| Scrap tire generation in 1,000 t/a | | Trade with used tires | | | Recovery and disposal | | |
|---|---|---|---|---|---|---|---|
| | | Sale | Export | Re-tread | Material | Energy | Landfill* |
| Austria | 55 | - | - | 4 | 16 | 35 | - |
| Belgium and Lux. | 82 | - | 2 | 3 | 28 | 35 | 14 |
| Bulgaria | 10 | - | - | - | - | - | 10 |
| Croatia | 15 | - | - | - | - | - | 15 |
| Cyprus | 5 | - | - | - | - | - | 5 |
| Czech Republic | 80 | - | - | 12 | - | - | 68 |
| Denmark | 45 | 1 | - | 5 | 38 | 1 | - |
| Estonia | 11 | - | - | 2 | 2 | - | 7 |
| Finland | 45 | - | - | 10 | 35 | - | - |
| France | 398 | 20 | 20 | 55 | 157 | 106 | 40 |
| Germany | 585 | 15 | 38 | 60 | 124 | 310 | 38 |
| Greece | 48 | 1 | - | 2 | 5 | 8 | 32 |
| Hungary | 46 | - | - | 5 | 18 | 16 | 7 |
| Ireland | 40 | 1 | 1 | 1 | 3 | - | 34 |
| Italy | 380 | 30 | 50 | 50 | 83 | 148 | 19 |
| Latvia | 9 | - | - | 2 | - | - | 7 |
| Lithuania | 9 | - | - | 2 | - | - | 7 |
| Malta | 1 | - | - | - | - | - | 1 |
| Netherlands (car tires only) | 47 | - | 13 | - | 13 | 21 | - |

| Scrap tire generation in 1,000 t/a | | Trade with used tires | | | Recovery and disposal | | |
|---|---|---|---|---|---|---|---|
| | | Sale | Export | Re-tread | Material | Energy | Landfill* |
| Norway | 47 | - | 1 | 7 | 23 | 16 | - |
| Poland | 146 | 1 | 1 | 21 | 10 | 56 | 57 |
| Portugal | 92 | 1 | 15 | 16 | 26 | 34 | - |
| Romania | 50 | - | - | 5 | 10 | 10 | 25 |
| Slovakia | 20 | - | - | - | 5 | 2 | 13 |
| Slovenia | 23 | - | - | 4 | - | - | 19 |
| Spain | 305 | 10 | 20 | 37 | 42 | 52 | 144 |
| Sweden | 90 | 1 | 7 | 16 | 32 | 34 | - |
| Switzerland | 54 | 1 | 13 | 7 | - | 25 | 8 |
| U.K. | 475 | 32 | 34 | 55 | 212 | 72 | 70 |
| Total | 3,213 | 114 | 215 | 381 | 882 | 981 | 640 |

Source: European Tyre and Rubber Manufacturers Association 2006. Summary **by Kurt**

**Reschner**

*** This figure also includes unknown means or disposal.**

There is a report of 281 million scrap tire generation in the United States in 2001.1 About 78% of total tire waste was consumed by scrap tire market. During 1990 to 2000 about 300 million scrap tires were located as stockpile at different places of United States.2The stockpile not only causes environmental problems but also causes health hazards by creating breeding sites for mosquitoes, rodents, etc.[3]

Since tires are made of high quality rubbers, waste tires can be considered as a large potential source of raw material for the rubber industry. But the major problem associated with such reclaimed raw material is the high cost of recovery due to stringent regulations for environmental protection and high labor input into reclaim production .[4]

The main objective of this chapter is to make an up-to-date account on the existing methods of recycling of rubbers from used tires through grinding, reclaiming and devulcanization, followed by exploring the possibility of recycled rubber utilization as new products.

The recycling process converts the waste scrap tire from a hard and tough mass to a soft, flexible and sticky mass by simultaneous application of heat and mechanical shear in presence of a chemical reclaiming agent. In scientific sense this process is known as rubber devulcanization, which causes the breakup of the chemical network along with the breakup of the macromolecular chains .[5]

## 3. Incineration, energy recovery and thermal recycling as a solution

Several agencies across the world take recourse to incineration, energy recovery and thermal recycling as strategies for dealing with scrap tires. Although the strategies sound impressive, use of a material for its originally intended purpose is more preferable from both environmental and economic standpoints. This becomes apparent when one considers the energy that is used to produce a tire vis-a-vis the energy gained by burning a scrap tire.

**Table 2: Specific energy values related to tire rubber (kWh/kg).**

| | |
|---|---|
| Energy consumed to manufacture a tire | 32.0 |
| Energy consumed to produce tire rubber compound | 25.0 |
| Thermal energy released during incineration of scrap tires | 9.0 |
| Energy consumed in the grinding of scrap tires into crumb rubber (0.5 to 1.5 mm) | 1.2 |

*Sources: W. Dierks: Incorporating the Use of Recycled Rubber, Robert Snyder: Scrap Tire Disposal and Reuse, compilation by Kurt Reschner.*

It can be seen from the above table **[Table 2]** that production of tires consume three to four times as much energy compared to the energy recovered from thermal recycling of tires. Clearly, the use of recycled tire rubber for its originally intended (or related) purpose makes far more sense than incineration, both environmentally and economically.

The following Table 3 shows the various scrap tire disposal and recycling strategies, ranked by environmental preference.

**Table 3: Scrap tire disposal and recycling strategies**

| Rank | Application/processing method | Examples |
|---|---|---|
| 1 | Use of productfor its originally intended purpose for as long as possible. | Design of rubber compound and tire geometry for maximum durability. Keeping tire inflated properly at all times to ensure maximum service life. Reuse partly worn tires. Re-grooving or re-treading tire casings. |
| 2 | Use of materialfor its originally intended purpose. | Grinding scrap tires into crumb rubber, separating steel and fibre. Selling rubber as raw material. |
| 3 | Use of whole scrap tires for energy recovery. | Burning whole scrap tires as fuel supplement in cement kilns. |
| 4 | Use of mechanically processed tires for energy recovery. | Tire chips added to coal as fuel supplement in power plants, paper mills, cement kilns, etc. |
| 5 | Altering the chemical structure of scrap tires and use of products for energy recovery. | Pyrolysis, supercritical extraction. |
| 6 | Storage for possible recovery at a later time. | Mono-filling. |
| 7 | Disposal without any current or future use. | Landfilling. |

On the face of it, it would seem that the list of applications shown is probably based on the recommendation of some environmentalists with little relevance in the real world. But, actually, the vibrant international trade with partly worn tires and retreadable tire casings shows that market participants worldwide have very similar priorities as the environmentalists.

Market forces have a clear verdict on the next two options as well: recycled tire rubber (crumb rubber) sells for 200 – 400 US$ per ton, whereas tire derived fuel (TDF) fetches only one tenth of that price.

**Table 4: Management picture (%) of waste generated from discarded rubber products in different countries.**

| Ways | USA | UK | Germany | France | Italy | Belgium | Netherlands | Japan | Sweden |
|---|---|---|---|---|---|---|---|---|---|
| Landfill | 58 | 23 | 9 | 45 | 40 | 10 | - | 12 | 5 |
| Retreading | 19 | 31 | 18 | 20 | 22 | 20 | 60 | 24 | 12 |
| Energy | 11 | 27 | 45 | 15 | 23 | 30 | 28 | 39 | 64 |
| Export | 5 | 3 | 16 | 4 | 3 | 25 | - | 6 | 7 |
| Recycling | 7 | 16 | 12 | 16 | 12 | 15 | 12 | 19 | 12 |

## 4. Direct uses of waste rubber products

Among other things, waste rubber are used directly also.

### 4.1 Landfill

Landfill has been one of the classical ways of disposal of discarded rubber products. But due to the growing shortage of landfill sites and the environmental problems associated with this process, it is no longer considered a feasible option.

The scrap rubber products discarded in landfills tend to float on top as well as confine dirty water causing mosquito breeding and foul smell. There is also the issue of leaching of low molecular weight additives, such as, stabilizers, flame retardants, colorants and plasticizers contained in rubber products into the environment. These small molecular weight additives may kill advantageous bacteria of soil.

### 4.2 Automobile scrap rubber as fuel source

In some places, waste rubber is also converted into organic fuel. Scrap rubber products including tires contain more than 90% organic materials comprising a heat value of ca. 32.6 mJ /kg (ca. 14,000 Btu/lb), which is more than on par with that for coal: 18.6–27.9 mJ/kg (ca. 8000–12,000 Btu/lb). [7] Therefore, recovery of liquid hydrocarbons from scrap rubber products, which can be a better proposition than landfilling, is followed as a suitable method of recycling.

Conversion of waste rubber to organic fuel is normally done by pyrolysis technique. Basically during pyrolysis thermal decomposition of rubbers occur in absence of air and oxygen to produce oils and gases for reuse by petrochemical industries. Carbon black as solid by-product residue after pyrolysis can be used as fillers. Autoclaves and fluidized beds are normally used for carrying out pyrolysis of scrap tires.

However, pyrolysis produces toxic waste and is not cost effective due to the low price of crude oil. Also there is not much of a market for the oil and carbon black that is produced. As a result, pyrolysis is being done only on a limited scale.

### 4.3 Scrap rubber as fuel supplement

Scrap tires also serves as a fuel supplement for coal or gas in kilns for producing Portland cement, lime, and steel. This saves 25% coal consumption in cement industries. Electricity too is generated by burning scrap tires. The Oxford Energy Company produces electricity by incineration of scrap tires and generates 14.4 mW of electricity. [8]

Basically this is a pyrolytic process (in absence of oxygen) where random breakdown of chemical bonds of vulcanized rubber occurs to generate low molecular weight hydrocarbon molecules. About 25-50 weight % of the rubber pyrolysed is recovered as a distillate having approxmately 42 MJ/kg calorific value, which is higher than that of burning tyres (37.5 MJ/kg) and even higher than that of coal (29 MJ/kg).

But a major shortcoming with this process is that it not only leads to air pollution but also results in very low energy recovery. For, to produce one pound synthetic tire rubber around 60,000 BTU energy is consumed [9], but energy recovered by burning one pound rubber is a meagre 13,000 to 16,000 BTU.

Shredded tire chips have been burnt in boilers, but problems with regards to the grinding of the tire and size of the chips have been a major drawback.

An environmental friendly process that is said to be free of hazardous emissions was patented for recycling waste tires to generate fuels or valuable chemical feed stocks in a closed oxidation process. 10 The process involves breakdown of vulcanized rubber molecules by selective oxidation of C–C, C–S and S–S crosslink bonds using water as a solvent at or near its supercritical condition.

Adkins11 also invented a method of processing used tires for the recovery of oil, steel, vinyl chloride and carbon. The process describes the addition of a shredded automobile tire to a batch of isocyanide, polyurethane latex and soybean oil followed by heating the mixture at 371 0C for 10 min to obtain the products.

## 5. Reclamation of good rubber from scrap rubber

Considering the limitations of landfilling and pyrolysis processes, recovering the rubber from scrap rubber would be the most desirable approach to solve the disposal problem especially since rubber is a valuable resource.

Reclaiming process of rubber from used automobile tires and tubes, hoses, conveyor belts etc. involves the conversion of a three dimensionally interlinked, insoluble and infusible strong thermoset rubber to a two dimensional, soft, plastic, tackier, low modulus, processable and vulcanizable thermoplastic rubber simulating many of the properties of virgin rubber.

Adopting such recovery process can save some precious petroleum resources also, apart from solving the disposal issues. Many such attempts are found in patent literatures for reclaiming of scrap rubber products. The first steps in the process of reclaiming of scrap rubber is reducing the size of the rubber products and shredding them into thin pieces.

The main purposes of size reduction of rubbers in scrap tires are:

- To separate and remove steel and fibre from rubber
- To convert the rubber fraction into a sellable particle size

Processing of scrap tires into granular/crumb rubber can be one of the useful disposal options if a market is available for recycled rubber. Since tires contain tough and durable rubber materials, required for a long service life and a safe ride, size reduction of scrap tires is very difficult and technology is expensive.

Presently, due to the commonplace use of steel belted radial tire, grinding of scrap tires into crumb rubber free of steel and fibre requires fairly complex machinery.

A typical estimate of product yields from scrap tires is shown in the following **Table 5**.

**Table 5: Yield (%) of different products from scrap tires after size reduction and separation.**

| Product yield from | Truck tires | EM tires | Car tires |
|---|---|---|---|
| Crumb rubber | 70 | 78 | 70 |
| Steel | 27 | 15 | 15 |
| Fibre and scrap | 3 | 7 | 15 |

The main purpose of shredding scrap tires is to reduce the volume to about one fourth to cut down on space requirement, transportation cost and for easier handling with standard equipment like front end loaders.

Generally most of the processors first shred the scrap tires into chips of around two inch size using rotary shear shredders with two counter rotating shafts. The machines are run at low RPM (~20 to 40) and high torque, which can handle all sorts of tires, including truck and farm equipment tires.

Since de-beading can reduce wear and tear on the shredder and the consecutive size reduction machines, some processors remove the steel beads from truck tires by a debeader prior to shredding.

A truck tire contains steel beads amounting to around 10 – 15 % of the weight of a truck tire in the form of one inch thick circular steel cables, which are responsible for 70% of the wear and tear in the shredder as well as in the consecutive grinding machines.

Reliable tire shredding machines are manufactured by a number of reputed companies throughout North America and Western Europe. Most of these shredders having a capacity of two to six tons/hr are powered by electric motors (approx. 200 – 300 HP) depending on the input material and the size of the chips produced.

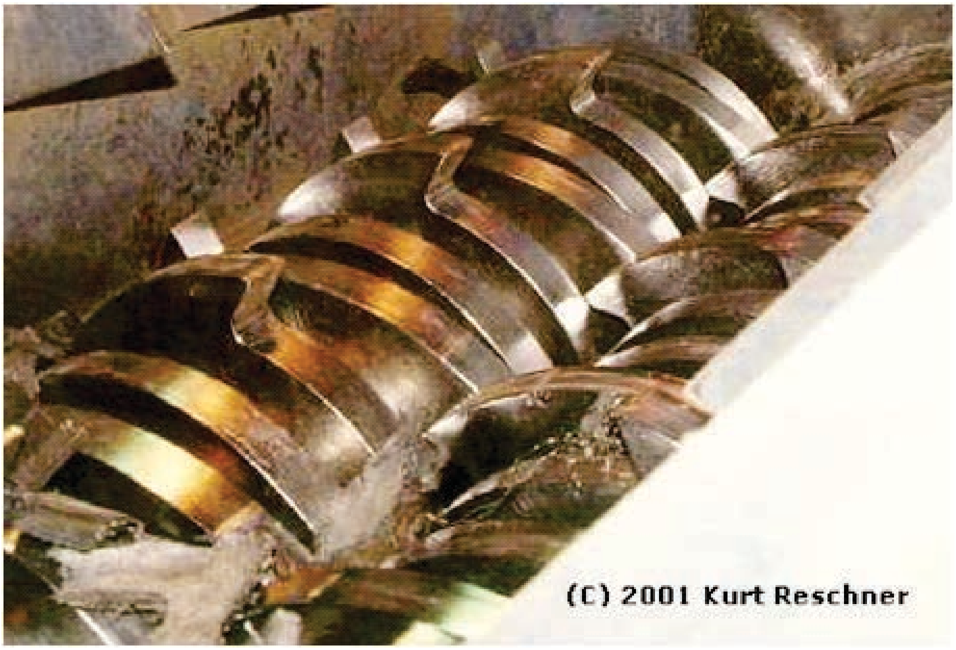



**Figure 3: Inside cutting chamber of shredder for scrap tire**

In reclaiming technology, disintegration of the waste rubber product is essential to convert it into crumb or particle form. Methods which are in vogue for size reduction of waste tires are: ambient grinding, cryogenic grinding, and wet-ambient grinding using guillotine, cracker mill, high-impact hammer mill, and rotary shear shredder.[12]

Waste/scrap rubber is ground to 5x5 $cm^2$ or 2.5x2.5 $cm^2$ chips followed by passing through a magnetic separator and a cyclone separator to remove steel and nylon/polyester fibre fragments. Necessary further size reduction is possible by grinding in ambient or cryogenic conditions. [4]

The principle of the reclaiming process is known as de-vulcanization. During this process, cleavage of intermolecular chemical network bonds, viz., carbon-sulphur and/or sulphur-sulphur bonds as well as cleavage of carbon chain occur. [5]

In different reclaiming processes 13, 18 the feedstock is ground rubber scrap. Warner13, Adhikariet al.14 and Isayev15 have presented reviews on relevant rubber reclaiming literature.

Other reported literatures5, 16, 17 are also available for tire rubber recycling and waste rubber utilization. These are re-treading, reclaiming, grinding, pulverization, microwave and ultrasonic processes, pyrolysis, and incineration.

There are two broad classes of reclaiming processes: physical reclaiming and chemical reclaiming. Warner13 has reviewed the developments on reclaiming using chemical and physical processes.

The common reclaiming processes are pan process, digester process (either wet or dry), and mechanical or reclaimator processes. Different types of physical reclaiming processes are: (i) mechanical [19]; (ii) thermo-mechanical [20]; (iii) cryo-mechanical [21]; (iv) microwave [22,23] and (v) ultrasonic [24,25].

### 5.1 Mechanical reclaiming process

Mechanical reclaiming is carried out at high temperatures by milling in a two-roll open mill, which drastically decreases the molecular weight of rubber by mechanical shearing. Most of the mechanical reclaiming processes are continuous in nature. In mechanical reclaiming process [26, 27], fine crumb rubber (typically 30 mesh) is mixed with various reclaiming oils and subjected to high temperature with severe mechanical shearing in a modified extruder.

Fabric-free fine scrap rubber is mixed with reclaiming chemicals prior to feeding into an extruder for devulcanization at about 200°C for about five to ten minutes. The temperature of the extruder is maintained by partial electrical heating and friction of the crumb rubber with the extruder barrel and the screw. The extruded product is devulcanized rubber in a dry form ready for refining.

The mechanical reclaiming of crumb rubber is also done by mixing/milling in an open two-roll mill at high temperatures resulting a drastic breakdown of molecular weight due to mechanical shearing at high temperatures (>200°C).

A physical reclaiming process of vulcanized rubber and refining of the reclaimed rubber is patented by Maxwell [28] In this process vulcanized rubber particles were reclaimed by applying mechanical shear between a smooth stator and a cylindrical rotor in which the rubber was frictionally propelled by the rotor action. Sometimes the shear action used to be assisted by mixing a suitable amount of previously reclaimed rubber or vulcanized rubber or supplemental heating.

In another process, De and co-workers [29] have reported the mechanical reclaiming of vulcanized NR sheets by milling at about 80°C on a two roll laboratory mill. The rubber formed a band on the roll during reclaiming operation. After adequate milling the process provided reclaim rubber ready to be used as a blend with virgin rubber.

### 5.2 Thermal reclaiming processes

The thermal reclaiming processes deal with the exposure of scrap rubber to heating at high temperature with necessary reclaiming agents/chemicals to plasticize the cross-linked rubber of the scrap materials. There are several types of thermal reclaiming processes. Outlines of these processes are described in the following sections.

#### 5.2.1 Digester process

Digester process is a two stage process and in the first stage the textile fibre in the ground scrap rubber is removed by digestion with acid, alkali or neutral agents (e.g., zinc chloride) along with water, plasticizing oils and reclaiming agents. The fabric dissolves and the rubber softens. The textile content may be reduced to less than five per cent.

In a typical process, the ground waste rubber is loaded into a digester with the chemicals and the additives. The digester is basically a cylindrical jacketed pressure vessel fitted with a horizontal agitator. Steam is passed through both interior and the jacket so as to ensure a uniform temperature throughout the mass.

The contents of the digester are heated at 190°C for three or more hours with continuous agitation. At the end of this period the digester is blown down and the contents are fed into extruders for straining, and refining.

Before feeding into the extruder the plasticity as well as the specific gravity of the reclaimed mass can be adjusted, if necessary, by the addition of plasticiser, carbon black, or fillers in a ribbon blender. This batch process may be suitable to produce whole tyre and butyl reclaims.

### 5.2.2 Pan process

The pan process is a simple but classical process in which the fibre free (separated by mechanical cyclone) scrap rubber is mixed with reclaiming chemicals and placed on pans in an autoclave and heated with steam at 15 bar and a temperature of 180°C for four to 12 hours.

The reclaiming chemicals which are normally used are aromatic thiols, disulphides and aromatic oils, which allow faster reclaiming at lower temperatures resulting in products with superior mechanical properties. The reclaiming operation is followed by straining and refining in the conventional manner. Scrap rubber products made from NR, SBR, IIR, CR, and NBR can be reclaimed by this method.

### 5.2.3 High pressure steam process

The reclaiming in high-pressure steam process is carried out in a short period. In this process the, coarse ground rubber scrap , which is free of fibre, is mixed with necessary reclaiming agents and reclaimed in a high pressure autoclave at a temperature ~280°C for one to 10 minutes.

### 5.2.4 Engelke process

In the Engelke process, coarse ground rubber scrap is mixed with plasticizing oil and peptizers and the mixture is heated in an autoclave to very high temperatures (> 250°C) for 15 minutes followed by refining and straining. This process is extremely simple since it does not require fibre removal and large pieces of the rubber products can be subjected to reclaiming operation.

During the reclaiming operation the fibre is completely carbonised in situ throughout the mass. If necessary, the cracked mass can be premixed with plasticising oils and peptizers. The reclaimed rubber is strained and refined in the usual manner.

## 5.3 Thermo-mechanical reclaiming process

Thermo-mechanical reclaiming of rubber involves simultaneous breaking of C-C bonds and S-S cross link network bonds by both thermal as well as mechanical shear energy. As a result both soluble branched rubber molecules and a part of rubber gel (insoluble) are formed making the product soft.

This process involves the thermo-mechanical degradation of the vulcanized rubber network previously swollen in a suitable solvent followed by milling to a fine powder (~20 mm diameter). The rubber powder thus obtained after re-vulcanization with curing ingredients showed slightly inferior properties to those of the original vulcanizates.

Some of the modern rubber recycling processes uses thermo-mechanical techniques. Reclaiming agents and oils are also frequently used over and above the thermal and mechanical breakdown. Some of the common recycling chemicals used are disulphides, thiols, amines and unsaturated compounds in quantities of around 1 wt %.

Softeners, if used, may lower the thermal degradation resistance of the rubber by weakening the interaction between filler and rubber chains already present. In a fast thermo-mechanical recycling process [30] high-speed mixing (at 500 rpm) of rubber was carried out when the temperature rose to 200°C. The reclaimed rubber is reported to be obtained by this process in 15–20 minutes.

## 5.4 Mechano-chemical reclaiming process

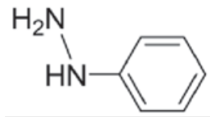
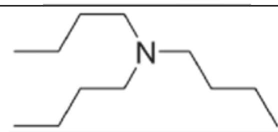
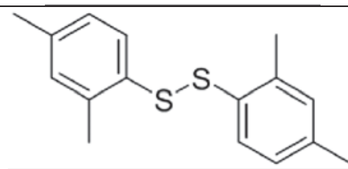
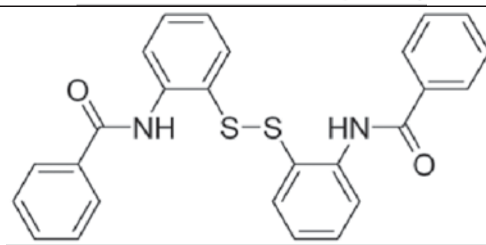
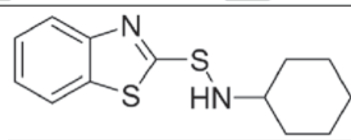
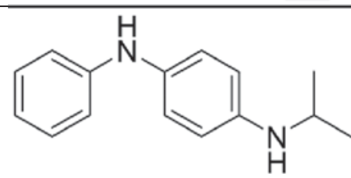
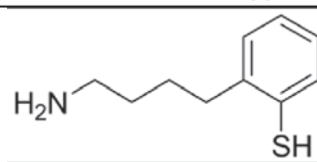
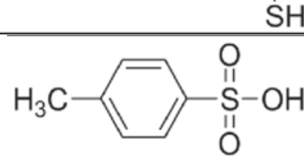
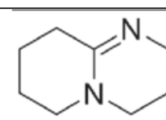
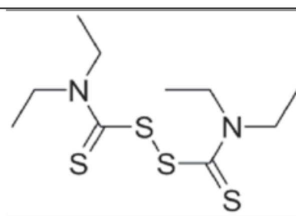
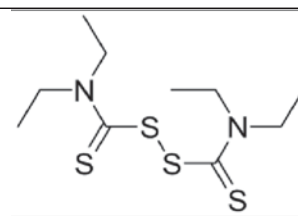
Mechano-chemical reclaiming is done by subjecting scrap rubber powder to both mechanical force and chemical action. The process is carried out at room temperature by applying a mechanical shear force in presence of a reclaiming chemical and initiator, which accelerate the plasticization of the rubber mass. Major input to the breakdown of the vulcanized rubber network is given by the reclaiming chemicals along with reclaiming oil and process oil. Chemical agents along with accelerator/catalyst are included in Table 6.

Peroxide-methyl halide combination acts as a powerful radical initiator in a redox system. Phenyl hydrazine-ferrous chloride and tributylamine-cuprous chloride combinations form complexes which are easily degraded by oxygen with the formation of oxidative initiators. Thus these systems are capable of degrading diene-based rubbers in presence of oxygen at room temperature.

Dioxyldisulphide and 2, 2'-dibenzamido diphenyl disulphide act as peptizing agents. N-cyclohexylbenzothiazole-2-sulfenamide (CBS), which is a common accelerator for vulcanization of rubber and N-isopropyl-N'-phenyl-p-phenylene diamine is a potential rubber antioxidant.

Thiophenol and n-butylamine, toluene sulfonic acid and 1, 8-diazabicyclo [5.4.0] undec-7-ene (material 9) combinations as well as tetraethylthiuramdisulphide (ultra-fast rubber accelerators) and triphenyl phosphine combinations increase the plasticity of reclaim rubber.

**Table 6: Reclaiming agents used in mechano-chemical methods [30].**

| Chemical name | Reclaiming accelerator | Reclaiming catalyst |
|---|---|---|
| Peroxide-methyl halides | R–O–O–R | $Me_nX_m$ |
| Phenyl hydrazine-ferrous chloride (PH-$FeCl_2$) |  | $FeCl_24H_2O$ |
| Tributylamine-cuprous chloride (TBA-CuCl) |  | $Cu_2Cl_2$ |
| Dixylyldisulphide |  | |
| 2,2'-Dibenzamidodiphenyldisulfide |  | |
| N-cyclohexylbenzothiazole-2-sulfenamide (CBS) |  | |
| N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD) |  | |
| Thiophenol-n-butylamine (TP-BA) |  | n-$BuNH_2$ |
| Toluene sulfonic acid[-1,8-diazabicyclo 5,4,0]undec-7-ene (TS-DBU) |  |  |
| Tetraethyl thiuramdisuphide-triphenyl phosphine (TETD-TPP) |  |  |

### 5.5 Trelleborg cold reclaiming (TCR) process

In the TCR process, cryogenically ground rubber powder is mixed with small quantities of reclaiming agents followed by a short treatment in a powder mixer at room temperature or at a slightly higher temperature in presence of phenyl hydrazine-methyl halide or diphenyl guanidine combination to react with the cross-linked rubber powder. [30]

### 5.6. De-Link process of reclaiming

A new technology, termed as "Delink" process for the de-vulcanization of sulphur-vulcanized tire scrap rubber by "Delink" material, is reported [31]. Being a proprietary material the composition of the "Delink" is not known but it may be considered as a composition of reclaiming agent. In this process, 100 parts of 40-mesh or finer crumb was mixed with 2 to 6 parts of Delink reactant in an open two-roll mixing mill.

Rudi Kohler [31] reported a new technology termed as "Delink" process for the devulcanization of sulphur cured scrap rubber products using this proprietary material. In this process 100 parts of 40 mesh or finer crumb was mixed with 2–6 parts of Delink[31] reactant in a two roll open mixing mill. It was claimed [31] that the tensile properties, tear resistance etc. of the developed devulcanized rubber were very similar to those for the virgin materials.

**Table 7: Mechanical properties of reclaimed rubber [14, 32]**

| Sample | Mooney viscosity | Tan δ at maximum torque | 300% Modulus (MPa) | Tensile strength (MPa) | Elongation at break (%) | Tear resistance (MPa) | Compression set (%) |
|---|---|---|---|---|---|---|---|
| NR | 61.9 | 0.056 | 13.56 | 29.14 | 543 | 3.49 | 19.5 |
| NR-D | 72.3 | 0.062 | 14.68 | 27.44 | 489 | 2.51 | 22.0 |
| SBR | 96.6 | 0.091 | 20.88 | 26.48 | 358 | 1.60 | 15.0 |
| SBRD | 109.2 | 0.097 | 19.95 | 24.44 | 345 | 1.53 | 13.6 |

NR: Vulcanizate made from virgin natural rubber, NR-D: natural rubber with 30% devulcanized rubber added to the blend, SBR: vulcanizate of virgin SBR, SBR-D: SBR with 30% devulcanized SBR added to the blend.

It is evident from the data in Table 7 that Mooney viscosity, tan δ and 300% modulus are high for blend of 30% devulcanized rubber with virgin rubber for NR and SBR, whereas tensile strength, elongation at break and tear resistance are low. But it may be said that the tensile properties, tear resistance etc. were very similar to those for the virgin rubbers.

### 5.7 Cryo-mechanical reclaiming process

Cryo-mechanical reclaiming is basically a process of size reduction at cryogenic temperature (below -70 0C, the glass transition temperature of rubber) where the rubber becomes brittle like glass. So mechanical breakdown at this temperature helps production of finer rubber particles.

In cryogenic grinding ~30-100 mesh rubber particles are obtained by cooling scrap rubber below their glass transition temperature and then pulverising them in a hammer mill. But this process lacks cost effectiveness due to the use of the highly expensive liquid nitrogen for the cooling process.26

This suggests mechanical size reduction by chopping and grinding at ambient condition in high-powered rubber mill at close nip. Since this process generates heat during grinding, such excess heat degrades rubber and even leads to combustion if not cooled properly.

Mechanical and thermo-mechanical recycling processes only comminute the vulcanizates but do not devulcanize by breaking S-S crosslink bonds. Using a twin-screw extruder, which provides compressive shear on rubber, solid-state shear extrusion pulverization of waste rubber can be done 33 to produce fluffy rubber particles in the reclaimed product. The same process may also be adopted for pulverization of rubbers in a single screw extruder to obtain particles of size ranging from 40 to 1700 µm. 34, 35

In the cryo-mechanical process 21, 36 scrap rubber is ground in a ball mill after cooling in liquid nitrogen to form a fine powder. The particle size of the cryo-ground rubber varies from 30 to 100 mesh for most products. The particle size can be controlled by the extent of cooling in liquid nitrogen and by the mesh size of screens.

The cost of cryo-ground rubber increases with decreasing particle size. It is reported that the use of 5–10 phrcryo-ground rubber in passenger and truck tire compounds shows some economic advantage 37. With the 10% use of cryogenically ground rubber the economic benefit becomes double as shown in Table 8. The advantages of cryogenic grinding process are: the equipment cost is less; operating costs are lower, increased productivity, and better product flow characteristics than those of ambient ground rubber.

**Table 8: Cost savings per tire by the use of cryogenically ground rubber.**

| Usage (%) | Cost savings in USD | |
|---|---|---|
| | In passenger tires | In truck tires |
| 5 | 0.0980 | 0.5424 |
| 10 | 0.1861 | 1.0310 |

## 5.8 Cryogenic tire recycling

In cryogenic tire recycling the whole tires or tire chips are cooled down to a temperature (below –80 $^0$C, i.e., below the glass transition temperature of rubber) at which the rubber becomes brittle like glass to reduce the size by crushing and breaking. People claim that cryogenic tire recycling requires less energy and machinery compared to size reduction at ambient temperature. Also, the steel and fibre separation is much easier in the cryogenic process leading to a cleaner end product. But the cost of liquid nitrogen ($LN_2$) is a major drawback.

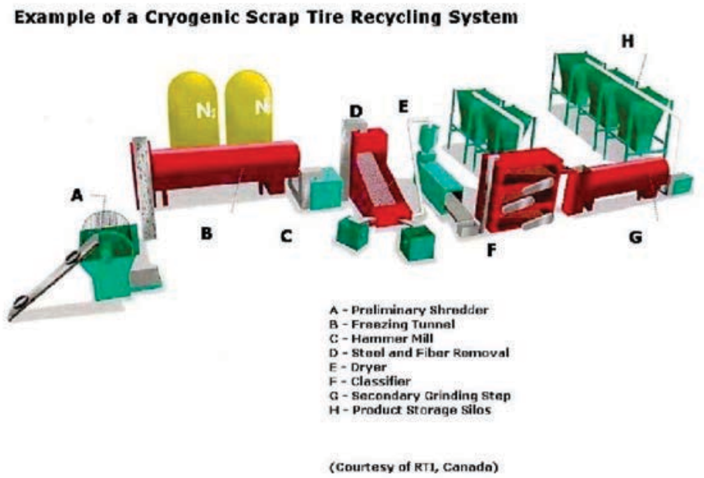



**Figure 4: Schematic of a cryogenic scrap tire processing plant**

In a cryogenic process (Figure 4) the preliminary treatment of scrap tires, i.e., de-beading, pre-shredding, etc. is similar to those in ambient grinding plants. In cryogenic grinding the 2" (50 mm) tire chips are cooled to below –120°C in a continuous freezing tunnel (B) and then dropped into a high RPM hammer mill (C), where the chips are shattered into a wide range of particle sizes with simultaneous removal of  and steel. Due to operation at very low temperature in the hammer mill the material requires to be dried (E) before classification into different, well defined particle sizes (F). Cryogenic processing of scrap tire may provide clean and fine mesh rubber powder.

## 5.9 Other processes for grinding rubber

### 5.9.1 Ambient (dry and solution/wet) grinding processes

The first step in the manufacture of reclaim rubber is grinding of the scrap rubber products to be reclaimed 38. Grinding increases the surface area of the rubber particle which helps to get uniform product by increasing the rate of chemical reaction in reclaiming. In dry ambient grinding,vulcanized rubber pieces are placed in a serrated grinder for preparation of ground rubber of particle sizes from 10 to 30 mesh. Ambient ground rubber is largely used in tires and mechanical goods. Wet or solution grindingof rubber is done in a liquid medium, usually water, between two closely spaced grinding wheels. The advantage of the fine particle wet ground rubber is that it allows good processing producing relatively smooth extrudates and calendered sheets.

In the digester process 4, 13, 39, a steam vessel equipped with a paddle agitator is used for continuous stirring of the crumb rubber. In the wet process the crumb rubber is mixed with caustic and water, while steam is used in the dry process. Sometimes various reclaiming oils are used in the vessel.

### 5.9.2. Ambient scrap tire processing

Figure 5 shows the layout of a typical ambient scrap tire recycling plant without using any cooling system to make the rubber brittle for necessary size reduction.

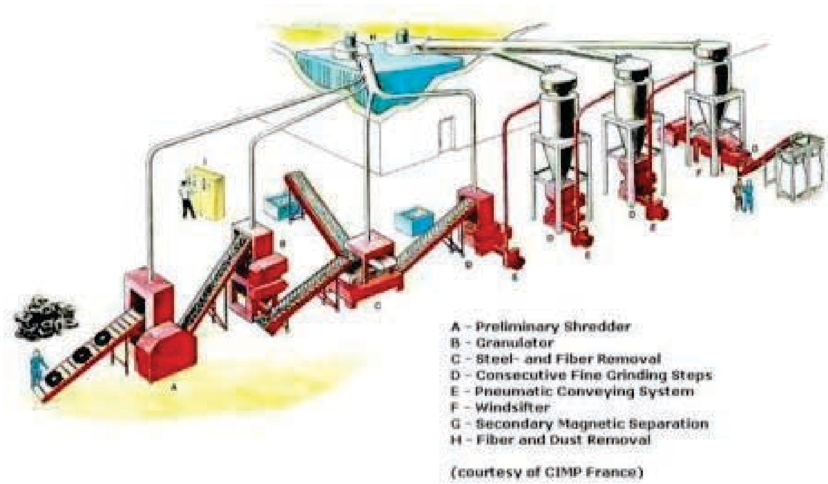



**Figure 5: Schematic of an ambient scrap tire processing plant**

A: Preliminary shredder, B: Granulator, C: Steel and fibre removal, D: Consecutive fine grinding steps, E: Pneumatic conveying system, F: Windsifter, G: Secondary magnetic separation, H: Fibre and dust removal

The tires are first broken down to chips of 2" (50 mm) in size in the preliminary shredder (A). The tire chips are then reduced to a size smaller than 3/8" (10 mm) in a granulator (B), while removing most of the steel and fibre from the rubber granules. The materials from the granulator enter into a combination of shaking screens and wind sifters (C) for removing the fibre fraction and magnetic removal of steel.

For obtaining finer mesh materials (~ 10 to 30 meshes) most of the ambient grinding plants use a number of consecutive grinding steps (D). For obtaining a bulk rubber output of relatively coarse material (down to approximately 20 mesh) ambient grinding can be safely and economically operated. The following machines are commonly used for fine grinding in ambient plants.

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

## 5.10. Comparison between ambient and cryogenic technology

Some comparative features of ambient and cryogenic grinding of scrap tires are shown in Table 9.

**Table 9: Comparative parameters of ambient and cryogenic grinding of scrap tires**

| Parameter | Ambient process | Cryogenic process |
|---|---|---|
| Operating temperature | **Ambientto max. 120 °C** | Lower than - 80° C |
| Underlying principle of size reduction | Cutting, tearing, shearing | Breaks cryogenically hardened brittle rubber pieces |
| Texture and morphology of the product | Spongy and rough particles with high specific surface | Even andsmooth particles with low specific surface |
| Particle size distribution (PSD) | Achieves relatively narrow PSD with only limited reduction per grinding step | Achieves wide PSD (10 mm to 0.2 mm) in just one processing step |
| Maintenance cost | Higher | Lower |
| Electricity consumption | Higher | Lower |
| $LN_2$ consumption | None | 0.5 – 1.0 kg $LN_2$ per kg tire input |

### 5.11 Microwave recycling

Microwave has also been used for recycling rubber. Since microwave exposure can uniformly heat a material it was exploited to break the sulphur crosslink bonds. But, it is essential that the waste rubber products was polar enough to accept microwave energy. This method can be economical particularly for the reuse of elastomeric waste.

It is claimed in a patent [40] that the devulcanized rubber is not degraded when the material is being recycled using microwave, which, otherwise, normally takes place in the usual commercial processes. In this process they also claimed that sulphur vulcanized elastomer containing polar groups is suitable for microwave devulcanization.

In another patent, Tyler et al. [41] claimed that their microwave devulcanization process provided for a method of pollution controlled reclaiming of sulphur vulcanized elastomer containing polar groups. The microwave reclaiming process generates heat to raise the temperature beyond 260$^0$C to yield a rubber mass which can be extruded at a temperature of 90–125$^0$C for use as a compounding stock.

Another process was patented [42] on reclaiming waste rubbers by microwave radiation. This patent describes the impregnation of waste rubber with an essential oil followed by heat treating the impregnated material under reduced pressure with microwave radiation. They also recommended the waste rubber material to be polar for the microwave energy to generate necessary heat to devulcanize.

According to the patent, microwave frequency between 915 and 2450 MHz and energy between 41 and 177 WH per pound is sufficient to sever all crosslink bonds but is insufficient to cause polymer chain degradation. The tensile properties of devulcanized rubber and virgin rubber-devulcanized rubber blend are almost comparable.

In other works [22,23] microwave technique was used with a controlled dose of microwave energy sufficient to cleave carbon–carbon bonds.

Thus, using microwave technique, rubber waste can be reclaimed to a material capable of being re-compounded and re-vulcanized having physical properties essentially equivalent to the original vulcanizate.

Another technology on devulcanization of waste rubber was developed based on microwave treatment [43]. If microwave devulcanization is done in a batch process it requires expensive equipment. Reclaim rubber obtained after microwave treatment was revulcanized to useful products. Some physical properties of the reclaimed rubber obtained by microwave devulcanization are shown in Table 10.

**Table 10: Physical properties of rubber devulcanized by microwave technique[14].**

| Physical properties | EPDM | | | | IIR | | | EPDM hose | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % Devulcanized EPDM | | | | Control | Blend of 50% virgin, devulcanized rubber | Devulcanized IIR | % Devulcanized EPDM | | |
| | 0 | 18 | 26 | 100 | | | | 0 | 10 | 25 |
| Tensile strength, psi | 1600 | 1340 | 1230 | 1430 | 1520 | 1210 | 1300 | 1190 | 1080 | 1057 |
| Elongation at break, % | 300 | 375 | 290 | 175 | 835 | 670 | 400 | 300 | 250 | 375 |
| Hardness, Shore A | 67 | 70 | 71 | 66 | 55 | 72 | 71 | 65 | 66 | 68 |

## 5.12. Ultrasound recycling

Some have also applied ultrasonic energy for devulcanizing waste rubber to overcome the various drawbacks of conventional reclaiming technology.

The first work on the treatment of rubber with ultrasonic energy was reported in the form of a patent by Pelofsky[44]. The process as described was treating solid rubber articles, such as tires kept immersed in a liquid, with a source of ultrasonic energy (about 20 kHz and at a power intensity of greater than 100 W ) whereby the bulk rubber effectively disintegrated upon contact and dissolved into liquid.

Later, in a patent on vulcanization of rubber by ultrasonic waves Mangaraj[45] indicated a possibility of rubber degradation and devulcanization by ultrasonic energy.

After one year, Okuda and Hatano[46] patented rubber devulcanization by applying ultrasonic energy and claimed rupturing of carbon-sulphur bonds and sulphur-sulphur bonds, but not carbon-carbon bonds by applying 50 kHz ultrasonic waves for 20 min. As per their report the properties of the revulcanized rubber was found to be similar to those of fresh rubber vulcanizates.

A continuous chemical/solvent free process was developed using high power ultrasound to recycle used tires and other waste rubbers. The process was also found to be suitable for waste rubbers containing peroxide cured cross link bonds.

Later, Isayev and co-workers[47] also patented their developments followed by reporting the phenomenon of devulcanization by ultrasound energy in a number of publications[24, 25]. A paper was published on the ultrasound devulcanization of sulphur vulcanized SBR and vulcanization of ultrasonically devulcanized SBR elastomers [48].

They characterized the degree of devulcanization by the measurement of crosslink density and gel fraction of the devulcanized rubber. Devulcanized rubbers consist of uncross-linked fraction (known as sol meaning soluble) and cross-linked fraction (known as gel meaning insoluble).

But, compared to the vulcanized finished rubber product the gel fraction in devulcanized rubber is soft due to lower crosslink density and the sol fraction acts like a plasticizer making the material soft and sticky. The ultrasound devulcanization reactor developed for the purpose consists of a 1.5 in rubber extruder with L/D = 11 with a co-axial cone shaped ultrasonic die attachment.

The extruder barrel contains three temperature-controlled zones with electrical heating and water cooling arrangement. The reactor is equipped with a 3 kW ultrasonic power supply, an acoustic converter, a 1:1 booster and a 3 in cone-tipped horn, which vibrates longitudinally at a 20 kHz frequency and 5–10 mm amplitude.

Isayev and co-workers [24] carried out the devulcanization of SBR vulcanizate using the above ultrasonic reactor at different temperatures 121, 149 and 176$^{0}$C. They studied the extent of devulcanization by measuring the percentage and crosslink density of the gel fraction. With the license from the University of Akron for the ultrasonic devulcanization technology, NFM Co. of Massillon, Ohio, has built a prototype ultrasonic devulcanization reactor for recycling of tire and rubber products [49].

## 5.13 Reclaiming of rubbers by chemical reclaiming processes

Many rubber reclaiming technologies are based on chemical reclaiming agents. In fact, majority of them are. In general such chemical reclaiming agents are organic disulphides or mercaptans, which are simultaneously used during mechanical milling at elevated temperatures.

### 5.13.1 Reclaiming by organic disulphides and mercaptans

A large number of chemical reclaiming agents, viz. diphenyl disulphide, dibenzyldisulphide, diamyldisulphide, bis(alkoxy aryl) disulphides, butyl mercaptan and thiophenols, xylene thiols and other mercaptans, phenol sulphides and disulphides were developed and patented for natural and synthetic rubbers.

Cook and co-workers [50] used alkylphenolsulphides as reclaiming agents for SBR products. Some *N*,*N*-dialkyl aryl amine sulphides were patented as highly active reclaiming agents for vulcanized SBR in both neutral and alkaline reclaiming processes.

Knorr [51] reported the action of diaryldisulphide on the natural and synthetic rubber scraps of technical goods. The finely ground fabric free scrap of such technical goods was heated in saturated steam at a very high temperature (150–180$^0$C) in presence of reclaim oil and Aktiplast 6 (containing disulphides). Some data on physical properties are shown in Table 11 reflecting very poor mechanical properties of the reclaimed rubber obtained by this process.

**Table 11: Physical properties of reclaimed rubber products [51].**

| Type of reclaim | Hardness, Shore A | Resilience, % | Tensile strength, MPa | Elongation at break, % |
|---|---|---|---|---|
| Mechanical waste NR/SBR (1:1) | 61 | 22 | 6.5 | 270 |
| Mechanical waste NBR | 63 | 5 | 6.8 | 220 |
| Mechanical waste CR | 64 | 12 | 4.6 | 230 |
| Truck tires 80 -100% NR | 58 | 35 | 4.4 | 200 |
| Passenger car tires 80 -100 SBR | 60 | 22 | 7.4 | 200 |

The efficiency of different organic disulphide reclaiming agents for NR and EPDM vulcanizates are reported in the literature. [52]

Schnecko reviewed rubber recycling and reported the use of some chemical probes, which selectively cleave carbon-sulphur and sulphur-sulphur bonds but do not cleave carbon-carbon bonds, for reclaiming of cross-linked rubber. [53]

Chemical reclaiming process de-vulcanizes a vulcanized rubber network by chemical agents that break C-S or S-S intermolecular bonds. This process is reported to be slow and needs removal of solvents if used during reclaiming.

Anderson patented the reclaiming of sulphur vulcanized rubber in presence of an oil, water vapour and a mixture of diphenyl disulphide, dicresyldisulphide and dixylyldisulphide at elevated temperature (175-195$^0$C) and pressure (230-260 psi) for 1-4 hrs.[54]

In another attempt, reclaiming of a rubber scrap to a rubber like product was done by mixing rubber scrap with sulphur, antioxidant and anti-ozonants at 250–450$^0$F temperature and 1000-3000 psi pressure for 1-10 min. The process was particularly focused for making roofing products. [55]

In a chemical method involving 2-butanol as a devulcanizing agent under high temperature and pressure the molecular weight of the rubber is claimed to be retained.

But due to slow process and requiring 2-butanol removal this technique may be expensive. [56]

Similarly, inorganic compounds were used as devulcanizing agents for desulfurization of vulcanized rubber crumbs (10 to 30 mesh) in a solvent such as toluene, naphtha, benzene, cyclohexane, etc., in presence of sodium, which cleaves mono-, di-, and polysulphidic cross-links of the swollen and suspended vulcanized rubber crumb at around 300$^0$C in the absence of oxygen.

But, a major drawback of this process is the use of metallic sodium and organic solvent which not only cause pollution but could also make it uneconomical.

### 5.13.2 Reclaiming of rubbers by the use of a renewable resource material

In the above-mentioned chemical reclaiming processes, a large number of chemical reclaiming agents have been used for treatment of scrap ground rubber crumbs or powders at elevated temperatures and pressures. But no report is found on reclaiming of scrap rubber at around ambient temperatures.

Also, handling of all such disulphides and thiols are not desirable because of their foul smell and probable health hazards. Apart from these, except in the case of ultrasound devulcanization method, the extent of reclaiming had neither been evaluated nor reported.

While such reclaiming was thought to occur probably by scission of carbon–sulphur and sulphur-sulphur crosslink bonds but the prospect of carbon–carbon bond scission during reclaiming was not investigated.

It is not out of place to believe that in reclaiming processes polymer chain breaks due to mechanical shearing, chemical action, thermal scission, or by ultrasound energy at high temperatures. The chain scission of vulcanized scrap rubber during reclaiming is, therefore, supposed to increase plasticity as well as the sol (soluble) fraction.

The sol fraction as well as the molecular weight of the sol fraction of reclaim rubber is expected to contribute to a great extent to the properties of the reclaim rubber. But except in ultrasound process nowhere the molecular weight of sol is reported.

In the prevailing state of the art in the reclaiming technology of waste rubbers, Adhikari and co-workers [57] reported a simple process for reclaiming of vulcanized rubbers with an eco-friendly vegetable product which is a renewable resource material (RRM). The major constituent of the material is diallyldisulphide. Other constituents are different disulphides, monosulphides, polysulphides and thiol compounds. [58]

The RRM was prepared by crushing the vegetable product into an aqueous paste followed by squeezing through cheesecloth to obtain a liquid mass. The water in the liquid mass was removed by desiccation over anhydrous calcium chloride. The remaining liquid having organic matter was used as such for reclaiming of natural rubber vulcanizate. This vegetable product extract contained 40% organic matter.

The rubber reclaiming activity of RRM was carried out with vulcanized natural rubber, styrene butadiene rubber and natural rubber–polybutadiene rubber blend systems and the results of such reclaiming experiments were compared with the reclaiming activity of synthetic diallyldisulphide.

The formulation of a standard representative natural rubber compound required for the reclaiming study after vulcanization is shown in Table 12. The composition of the reclaiming agent containing RRM/DADS and spindle oil is shown in Table 13. This reclaiming agent composition was used for the reclaiming of the vulcanized natural rubber compound the formulation of which is shown in Table 12.

**Table 12: Compound formulation for recycling study**

| Ingredients | Parts by weight |
|---|---|
| Natural Rubber (RSSI) | 100 |
| Zinc oxide | 5 |
| Stearic acid | 2 |
| CBS | 1 |
| Sulphur | 1.7 5 |
| N330 Carbon black (HAF) | 40 |

**Table 13: Composition of Reclaiming Agents per 100 g Vulcanized NR at Different Milling Temperatures**

| Ingredients | Composition at Milling Temperature (gram) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 60 °C | | | | 40 °C | | | |
| RRM [a] | 10 | 20 | --- | --- | 10 | 20 | --- | --- |
| DADS | --- | --- | 2 | 4 | --- | --- | 2 | 4 |
| Spindle oil (Process oil) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

[a] Containing 40% organic matter.

The reclaiming was done by milling the aged vulcanized ground rubber in a two roll mixing mill with simultaneous addition of the RRM and spindle oil or diallyldisulphide (DADS) and spindle oil separately at 40 and 60$^{o}$C for 15 and 35 min durations. The extent of reclaiming was evaluated by the measurement of sol content, molecular weight of sol and Mooney viscosity of the reclaim rubber.

The results of sol content in the reclaimed mass of the vulcanized NR obtained after milling at abovementioned two different temperatures for different milling periods are shown in Figures 6 and 7. The changes in the molecular weights of the corresponding sol fractions with the progressive milling times are shown in Figure 8. The Figures 6-8 compare the effects of RRM as reclaiming agent with those of a synthetic reclaiming agent DADS in identical conditions. [The synthetic DADS was chosen since the active reclaiming constituent present in RRM was also DADS].

The plots in Figures 6-8 justify the reclaiming action of RRM when compared with that of synthetic DADS. Both the sol fraction and the molecular weight of the sol increased with the increase in milling temperature as well as milling time during reclaiming.

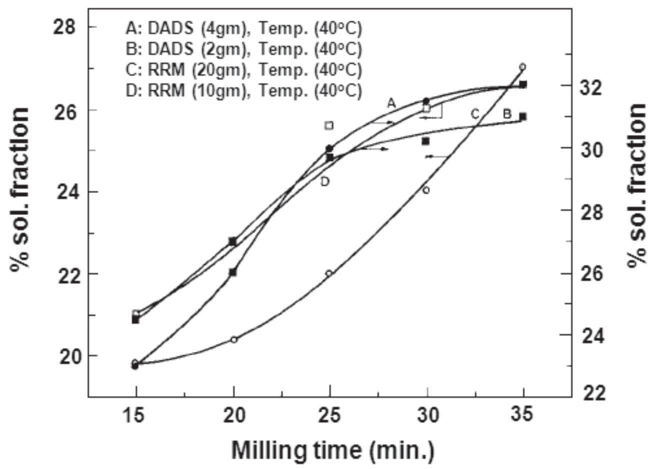



**Figure 6: Effect of RRM and DADS on percent NR sol fraction at 40°C.**

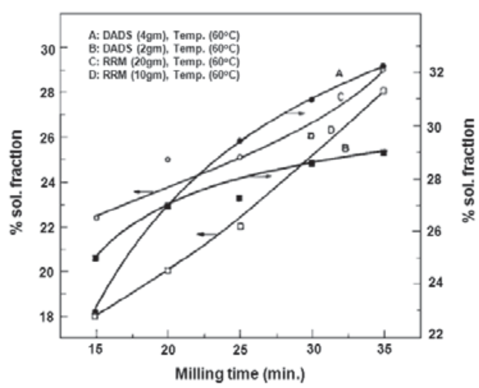



**Figure 7: Effect of RRM and DADS on percent NR sol fraction at 60oC.**

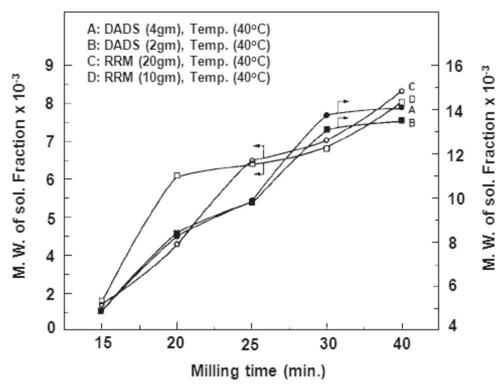



**Figure 8: Effect of RRM and DADS on molecular weight of NR sol fraction at 40oC**

Tensile properties of the revulcanized NR reclaim, NR reclaim-virgin NR blend were also evaluated and the results are shown in Table 14.

It can be seen that for obvious reasons NR reclaim either obtained by reclaiming with RRM or DADS, the tensile strength values are quite low. But when 40% of such reclaim rubber was blended with 60% virgin (fresh) NR, the vulcanized blend retained 19% tensile strength of that of the fresh NR vulcanizate. This shows the usefulness of the reclaim rubber obtained by milling with RRM.

**Table 14: Tensile properties of revulcanized NR reclaim and NR reclaim-virgin NR blend.**

| Nature of the vulcanizate | Tensile strength (MPa) | Elongation at break (%) | Shore A hardness | Swelling value (Q) | Weight loss after eq. swelling (%) |
|---|---|---|---|---|---|
| Vulcanized NR | 22.88 | 500 | 66 | 2.99 | 1.79 |
| Revulcanized NR reclaim by RRM | 4.34 | 283 | 34 | 5.52 | 2.98 |
| % Retention | 19.00 | 57.0 | 51.5 | 184.0 | --- |
| Revulcanized NR reclaim by DADS | 3.52 | 300 | 33 | 6.60 | 3.31 |
| % Retention | 15.40 | 60 | 50 | 220.7 | --- |
| Reclaim NR, fresh NR blend[a] (RRNR = 40:60) | 19.13 | 450 | 75 | 2.5 | 3.57 |
| %Retention | 83.60 | 90 | 114 | 84 | --- |

[a]*Formulation (phr): RR: 40; NR (RSSI): 60; ZnO: 5; stearic acid: 2; CBS: 1; sulphur: 1.75; carbon black: 32; vulcanized at 150$^{O}$C for 5.75 min.*

The results of this investigation on reclaiming of vulcanized NR with RRM reveals a definite influence of reclaiming agent and milling conditions on the molecular weight of the sol, sol content, and viscosity of the reclaim rubber.

Achievement of higher sol fraction as well as higher molecular weight of the sol after reclaiming will definitely increase the quality of reclaim rubber. Such better reclaiming effect will be available by increasing the reclaiming temperature to about 80 0C, milling time and milling at higher shear force using an internal mixer instead of two roll open mill.

The effects of RRM/DADS as reclaiming agents on the Mooney viscosity of the NR reclaim, SBR reclaim and NR/polybutadiene (PBR) reclaim were compared with the inherent viscosity and molecular weight of respective sol contents. The results of these experiments are summarized in Table 15.

As shown in Table 15, 15 min milling with RRM or DADS produced lowest sol content, lowest molecular weight of sol and highest Mooney viscosity of the reclaim rubber whereas 35 min milling provided the highest sol content with the highest molecular weight and the lowest Mooney viscosity.

Either 10 g of RRM or 2 g DADS was sufficient to obtain reasonable amount of sol with highest molecular weight as well as lowest Mooney viscosity of the reclaim rubber obtained after 35 min milling at 600C. It is to be noted that higher the sol content with higher molecular weight and lower gel content better will be the quality of reclaim rubber.

So, irrespective of the process of reclaiming, either mechanical or thermal, desirable reclaim parameters are maximum sol fraction, high enough molecular weight of the sol for improved properties of reclaim.

The reason for increase in sol content with progressive milling lies on the action of DADS either added externally or present as the major constituent of RRM. The DADS present in RRM breaks into free radicals with the temperature rises due to mechanical shearing. Such free radicals combine with the fragmented polymer chain radicals and thereby prevent the recombination of these polymer radicals, which explains the increase of sol fraction with increase in milling time.

**Table 15: Effects of reclaiming agents on sol content, molecular weight of sol and Mooney viscosity of reclaim rubber**

| | NR (mill ing time) | | SBR (milling time) | | NR/PBR (milling time) | |
|---|---|---|---|---|---|---|
| | 15 min | 35 min | 15 min | 35 min | 15 min | 35 min |
| Percent sol | | | | | | |
| RRM | 18.0 | 28.0 | 19.0 | 32.0 | 17.0 | 28.5 |
| DADS | 25.0 | 29.0 | 21.0 | 35.0 | 22.0 | 29.0 |
| Molecular weight x $10^{-4}$ | | | | | | |
| RRM | 0.50 | 1.05 | 0.55 | 1.13 | --- | --- |
| DADS | 0.38 | 0.98 | 0.46 | 1.02 | --- | --- |
| Mooney viscosity ML (1+4) 100 $^{o}C$ | | | | | | |
| RRM | 97.9 | 61.5 | 170.8 | 120.2 | >200 | 63.7 |
| DADS | 54.1 | 26.2 | 156.8 | 70.6 | 120.5 | 45.5 |
| Inherent viscosity (dl/g) | | | | | | |
| RRM | --- | --- | --- | --- | 0.13 | 0.21 |
| DADS | --- | --- | --- | --- | 0.12 | 0.24 |

### 5.13.3 Mechanical properties of virgin rubber-reclaimed rubber blend

It is well known that irrespective of the method used for reclaiming, the performance quality of the recovered rubber product is inferior to that of the fresh rubber product. However, blending a certain proportion of reclaim rubber with fresh rubber provides suitably useful properties of the blend.

In view of this suitability of the reclaim rubber obtained by the reclaiming action of RRM on NR vulcanizate was evaluated by blending with fresh rubbers like NR, SBR and NR/BR blends. Some formulations of such rubber compounds with fresh NR only are shown in Table 16.

These formulations were made by varying the content of fresh NR as well as NR reclaim obtained by the actions of RRM or DADS. Amounts of other ingredients were kept same except that of carbon black.

Varied amounts of carbon black were taken in order to see the influence of carbon black on the mechanical properties of the final vulcanizate containing NR reclaim and fresh rubber since the NR reclaim inherited the full amount of carbon black mixed initially.

**Table 16: Mix formulations of rubber compounds.**

| Ingredients, phr | Formulation code[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | $B_1$ | C | $C_1$ | D | $D_1$ | E | $E_1$ |
| Natural rubber (NR) (RSS1) | 100 | 75 | 75 | 60 | 60 | 50 | 50 | 40 | 40 |
| Reclaim rubber (RR) (RRM as reclaim ing agent) | --- | 25 | --- | 40 | --- | 50 | --- | 60 | --- |
| Reclaim rubber (RR) (DADS as reclaiming agent) | --- | --- | 25 | --- | 40 | --- | 50 | --- | 60 |
| Zinc oxide | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Stearic acid | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| CBS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Sulphur | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 |
| Carbon black (N330) | 40 | 35 | 35 | 32 | 32 | 30 | 30 | 28 | 28 |

[a]*Formulations B, C, D and E contain RRM reclaim and $B_1$, $C_1$, $D_1$ and $E_1$ contain DADS reclaim, A is control formulation. The rubber compounds were cured at 150°C for respective optimum cure times.*

Tensile properties, Mooney viscosity and swelling value of NR/RR blend formulation of Table 16 are shown in Table 17. It is evident from Table 17 that with the increase in the proportion of reclaim rubber 100% and 200% moduli increased but tensile strength and elongation at break decreased.

The reason for higher 100 and 200% moduli might be due to increase in crosslink density of rubber vulcanizates which is also supported by swelling value data. The reason for lower tensile strength of the vulcanizates might be due to the presence of cross-linked gel in the vulcanized matrix originated from the reclaim rubber gel which is difficult to disperse in the fresh rubber matrix.

Such gel in the rubber matrix remains as weak sites for stress concentration resulting in a lower tensile stress. From Table 17 it is also apparent that the tensile strength value is higher for DADS reclaim rubber containing vulcanizate than RRM reclaim containing vulcanizate. Similar trend of mechanical properties was also observed when SBR reclaim and NR-PBR reclaim were incorporated in fresh SBR and fresh NR-PBR blend, respectively.

**Table 17: Effect of varied proportion of reclaim rubber on vulcanizate properties of different NR/RR blends.**

| Vulcanizate properties | Formulation code [a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | $B_1$ | C | $C_1$ | D | $D_1$ | E | $E_1$ |
| 100% Modulus (MPa) | 1.7 | 2.2 | 2.1 | 2.2 | 2.4 | 2.4 | 2.9 | 2.8 | 3.3 |
| 200% Modulus (MPa) | 4.9 | 5.7 | 6.2 | 7.8 | 6.5 | 7.6 | 8.3 | 9.1 | 8.3 |
| Tensile strength (MPa) | 22.9 | 21.4 | 21.6 | 19.1 | 18.1 | 18.5 | 14.5 | 17.7 | 12.7 |
| Elongation at break (%) | 500 | 500 | 500 | 450 | 400 | 400 | 400 | 400 | 350 |
| Hardness, Shore A | 66.0 | 68.3 | 67.7 | 75.0 | 70.3 | 77.6 | 74.5 | 79.7 | 74.8 |
| Mooney viscosity ML (1+4) 100 °C | 31.3 | 30.4 | 32.5 | 44.3 | 40.8 | 45.9 | 45.2 | 52.7 | 50.9 |
| Swelling value (θ) | 3.0 | 2.7 | 2.9 | 2.5 | 2.7 | 2.3 | 2.3 | 2.1 | 2.2 |

[a]*Formulations B, C, D and E contain RRM reclaim and $B_1$, $C_1$, $D_1$ and $E_1$ contain DADS reclaim, A is control formulation.*

Since reclaim rubber itself is a degraded product, ageing characteristics of rubber vulcanizates containing reclaim rubber (RR) should be given proper attention. For this reason the reclaim rubber obtained by the action of RRM was evaluated for its aging behaviour.

Therefore, accelerated aging experiment of such a blend of RRM reclaim rubber and fresh rubber was carried out up to 24, 48 and 72 hr in a forced circulation air aging oven at 70±2 °C. The results of such aging performances were evaluated by measuring the tensile properties of the vulcanizates before and after aging. The aging results for NR-RR compounds are shown in **Table 18**.

It can be found from the table that 40% inclusion of NR reclaim in fresh NR showed 60% increase in 200% modulus and 17% decrease in tensile strength for RRM reclaim containing compound. The RRM reclaim rubber showed better aging resistance than that of DADS reclaim rubber. The same trend is also found in aging resistance of RR-SBR [57] and RR-NR/PBR [29] compounds. These results indicate that [during] the inclusion of reclaim rubber in making new rubber products the usage of antioxidant may be avoided.

**Table 18: Ageing characteristic of different NR/RR blends**

| NR Vulcanizate | Percent retention value after 72 h aging | | |
|---|---|---|---|
| | 200% Modulus | Tensile strength | Elongation at break |
| | 140 | 68 | 70 |
| *RRM reclaim containing vulcanizate* | | | |
| NR/RR: 75/25 | 155 | 101 | 70 |
| NR/RR: 60/40 | 138 | 105 | 78 |
| NR/RR: 50/50 | 138 | 93 | 75 |
| NR/RR: 40/60 | 128 | 100 | 75 |
| *DADS reclaim containing vulcanizate* | | | |
| NR/RR: 75/25 | 136 | 82 | 80 |
| NR/RR: 60/40 | 156 | 91 | 87.5 |
| NR/RR: 50/50 | 128 | 107 | 87.5 |
| NR/RR: 40/60 | 128 | 88 | 63 |

## 5.14. Pyrolysis of waste rubber

Some also go in for recovery of organic materials in the form of oil and gas from waste rubber through the process of thermal pyrolysis. But it is a complex process in respect of environmental pollution and is also capital intensive in a large scale process. Technically pyrolysis involves thermal decomposition of the cross-linked rubber waste in absence of air. Pyrolysis can provide the recovery of materials such as carbon black, metal, oils, and gases for the use of waste material for its energy value.

### 5.14.1. Pyrolysis process

Pyrolysis is the process of heating the scrap/waste rubber under pressure till decomposition. Normally the pyrolysis is carried out following three different processes depending on the temperature range, viz., above 600°C; between 400°C and 600°C and below 300°C. The pyrolysis processes differ from each other in terms of proportion of production of carbon black, oil and gasses. At high temperatures less carbon black but more gas is produced.

### 5.14.2. Products of pyrolysis

As mentioned in the previous section, the products of pyrolysis are mainly metals, oils, carbon black and a wide range of gaseous and liquid hydrocarbon along with varying amounts of residual char.

About 25-50 weight % of pyrolysed rubber can be recovered as a distillate of approximately 42 MJ/kg calorific value, which is higher than that obtained from burning tyres (37.5 MJ/kg) and coal (29 MJ/kg). The distillate is a low sulphur (< 0.5%) fuel of light and heavy fractions.

The solid residue is char, which is 40 to 50 weight% of rubber pyrolysed and has a calorific value of 33 MJ/kg. The char was found to perform as activated carbon in the treatment of industrial wastewater.

After pyrolysis of tire about 5-20% gas is produced with respect to the weight of the scrap rubber treated. The gas is used as a fuel to run the pyrolysis process as well as purification and separation of other fractions. The oil fraction can also be used as fuel, process oil and as raw material for chemical manufacturing.

Here are some videos relating to pyrolysis of tires:

**AK-ER Bioenerji tire pyrolysis system animations**

https://www.youtube.com/watch?v=EthyDDYNH5Q

**Process of pyrolysis**

https://www.youtube.com/watch?v=Ut3I7OIPFR8

**Pyrolysis process**

https://www.youtube.com/watch?v=0seqGaUkQTc

**3D animation of pyrolysis plant**

https://www.youtube.com/watch?v=ZWqCoNkcE0s

**Semi-automated tire pyrolysis machine WXT-8**

https://www.youtube.com/watch?v=PDHfbWkAG2Q

**Waste tire pyrolysis plant flash flow chart processing waste tire to oil**

https://www.youtube.com/watch?v=jp4NAwvrw6U

**Prior tire pyrolysis process overview**

https://www.youtube.com/watch?v=jfYN4vAwg8A

## 5.15. Reclaiming of scrap latex products

Scrap latex products which is rejected as 15% of the products, viz., gloves, condoms, latex threads, etc. contain high quality rubber hydrocarbon, which is lightly cross linked. These rejects create a major disposal problem for the rubber industry. Such waste materials were modified by novel economic processes for generating reclaimed rubber of superior quality and blended with other polymers. At the same time, the local authorities prohibit open burning of this waste due to environmental pollution.

In a method of reclaiming latex products Thomas et al. [59] initially powdered waste condoms in a two roll mill at 80–90 0C to a size of about 40 mesh. By mixing this powdered material with 10 phr naphthenic oil and 1 phrpentachlorothiophenol (PCTP) on a cold mill the resulting compound was heated in an air oven at 140 0C for 30 min. The reclaimed rubber obtained by this process was found to form a smooth band on the mill and contained about 82% of rubber hydrocarbon. But only a small amount of this reclaim was recommended to be used for blending with fresh rubber to avoid adverse effect on the mechanical properties of the product. But use of this reclaim showed a better processing characteristic of a rubber compound.

## 5.16. Reclaiming of rubber by microbial degradation

Microorganisms attack natural rubber in the latex or dry forms. But after vulcanization with sulphur and other chemicals, biological attack is minimized [31]. Spent rubber could be used as substrate for microorganisms provided the structure can be efficiently degraded. Many studies have been made on microbial degradation of rubber materials aiming to either prevent or enhance mineralization. Most studies deal with micro-organisms belonging to the *Actinomycetes*.

A German patent utilized a chemolithiotrope bacterium in aqueous suspension to attack the surfaces of elastomer powder for facilitating the diffusion and bonding of soluble polymer chains after mixing with virgin rubber and vulcanization.[60]

Straube et al. also developed a biotechnical process for the devulcanization of scrap rubber by holding the comminuted scrap rubber in a bacterial suspension of chemolithotropic microorganisms with a supply of air until elemental sulphur or sulphuric acid is separated.[61] Adaptation of microbial enrichment cultures with tire crumb material for several months resulted in enhanced growth of micro-organisms on natural rubber.

## 5.17. Comparison of recent reclaiming processes

**Table 19: Comparative study of recent reclaiming processes [14].**

| **Conditions and properties** | **Ultrasound energy** | **De-Link process** | **Reclaiming by RRM and DADS** |
|---|---|---|---|
| Temperature, $^0C$ | 121, 149 and 176 | Ambient temperature | 40, 60 and near ambient temperature |
| Pressure | Die pressure is substantially reduced as the amplitude of ultrasound is increased | Not required | Not required |
| Additives | Ultrasound energy (20 KHz) and **amplitude (5 -10 µm** | De-Vulc being proprietary in nature | Renewable resource material (RRM) and diallyldisulphide (DADS) |
| Environmental effect | No pollution | ---- | No pollution |
| Instrument used for reclaiming | Ultrasonic reactor | Either two -roll mill or internal mixer | Either two -roll mill or internal mixer |
| Sol content or SBR reclaim | 36% | Not mentioned | For RRM as reclaiming agent 32% and DADS as reclaiming agent 35% |
| Molecular weight of SBR sol | $M_n = 2\text{-}4 \times 10^3$ | Not mentioned | For RRM as reclaiming agent $M_v = 1.13 \times 10^3$ and DADS as reclaiming agent $M_v = 1.02 \times 10^4$ |
| Crosslink density of SBR gel | 0.06 kmol/$m^3$ | Not mentioned | Not determined |
| Mooney viscosity of SBR reclaim, ML (1+4) 100 $^0C$ | Not mentioned | 104 | 120.2 using RRM and 70.6 using DADS |
| Tensile strength of revulcanized sample, MPa | SBR reclaim : 1.5 - 10.5 | SBR reclaim : 6.99 | 4.34 for NR reclaim using RRM<br>3.52 for NR reclaim using DADS |
| Elongation at break of revulcanized sample, % | SBR reclaim : 130 - 250 | SBR reclaim: 311. 5 | For NR reclaim for RRM : 283, for DADS : 300 |
| Tensile strength of virgin NR/RR (70/30) blend, MPa | Not determined | 27.44 | RRM : 21.4<br>DADS : 21.6 |
| Elongation at break of virgin NR/RR (70/30) blend, % | Not determined | 489 | RRM : 500<br>DADS : 500 |
| Mooney viscosity of | Not determined | 72.3 Mooney | For RRM: 30.4 Mooney units, |

### 5.18. Summary of different reclaiming processes

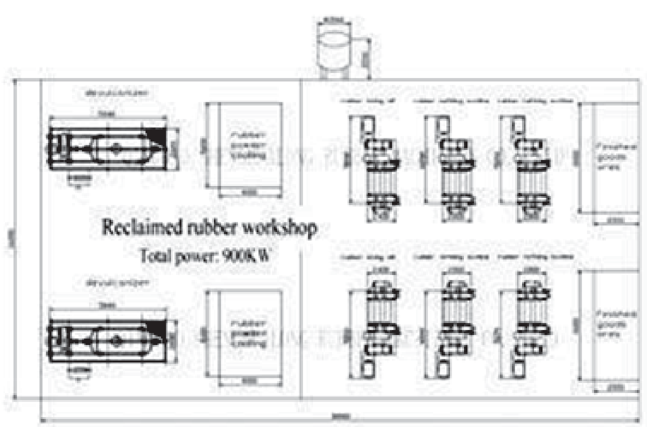
The following **Table 20** lists the most common devulcanization methods.

**Table 20: Summary of different devulcanization processes**

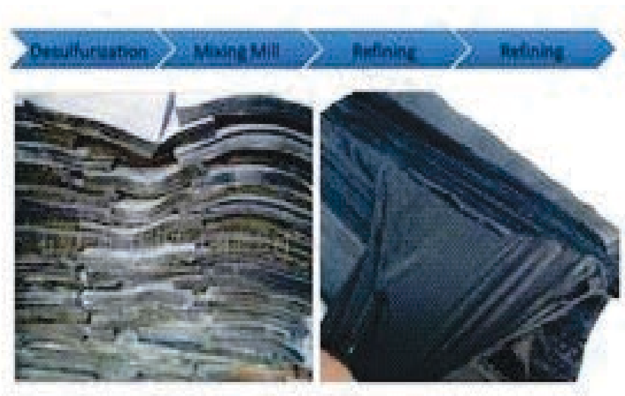
| Devulcanization process | Description |
|---|---|
| Thermal reclaiming process | In this process rubber is exposed to elevated temperatures in absence of oxygen over an extended period of time in order to break the sulphur bonds as well as the polymer backbone due to severe thermal effects. This process was patented by H. L. Hall in 1858, but is rarely used today due to environmental concerns and relatively severe degradation of the material. |
| Mechanical devulcanization process | Vulcanized rubber is exposed to intense mechanical work (with the effect of mastication) in order to selectively break the sulphur bonds in the polymer matrix using two roll mills, high shear mixers and extruders. Mechanical devulcanization method leads to good results and may find economic viability. |
| Devulcanization with ultrasound energy | Technically ultrasound devulcanization is a special form of mechanical devulcanization where ultrasound energy breaks the bonds. |
| Bacterial devulcanization of vulcanized rubber powder | Fine rubber powder is exposed to an aqueous suspension containing bacteria that consume sulphur and sulphur compounds. The different bacteria tried are thiobacillus, rodococcus und sulfolobus. The process seems to be technically viable but its economic viability is questionable due to the complexity of the process. |

### 5.19. Reclaimed rubber production line (Courtesy: Qingdao Shenghualong Rubber Machinery Co., Ltd. China)

**Workshop Floor Plan**



**Technological Process**




**Devulcanizer**

### 5.20 Some video links on waste tire recycling plant/machinery/process

https://www.youtube.com/watch?v=GKvjw9GGEno

https://www.youtube.com/watch?v=vXnQA7sIo3g

https://www.youtube.com/watch?v=ui7IErF2vh4

https://www.youtube.com/watch?v=ux7bVKXetSI

https://www.youtube.com/watch?v=BXbkWBn4tp0

## 6. Application of reclaim/recycled materials from scrap rubber products

Since the vulcanization reaction is not truly reversible, irrespective of the process of recycling/ reclaiming, a scrap/waste rubber undergoes [only] partial devulcanization of crosslink bonds and partial degradation of polymer backbone.

In other words, it may be said that a reclaimed rubber contains a good proportion of low molecular weight polymer which limits its application in high tech application, such as automobile tire. However, it can very well be used in making low profile products.

There are reports of using considerable amounts of NR reclaim for carcasses of bias ply tires for cars. Reclaim is also included in the formulation of compounds for bead wire and sidewalls.

A number of different applications of ground rubber tires (GRT) have been proposed outside the scope of rubber industry [also]. For example, use of GRT as filler in asphalt for road surface treatment, rubberized surface for sport ground. The GRT can be used as fillers [62,63,64] and in plastic compounds. [62]

Advantages of using reclaimed rubber in the manufacture of different products are:

- Easy breakdown and mixing time
- Low power consumption during breakdown and mixing
- Advantages in calendering and extrusion
- Influence on curing and aging
- Influence on tack behaviour
- Cost and energy savings

## 6.1. Uses of crumb rubber

### 6.1.1. Crumb rubber as a filler in virgin rubber compound

An increasing trend of using crumb rubber as filler (5 – 15%) in virgin rubber compound is observed in many tire manufacturing units for making new tires. This is being made possible by suitably adjusting the mixing and processing methods, without any compromise in tire properties, viz., quality, safety or performance characteristics. Substantial cost savings can be achieved by the use of crumb rubber as filler in the compound.

In addition inclusion of some quantity of crumb rubber to the virgin rubber compound offers the following advantages:

- Improved mixing characteristics and form stability of uncured parts
- Improved degassing during vulcanization
- Improved mold release
- Increased productivity due to reduced cure times
- Improved abrasion resistance in some applications

These benefits have prompted some tire manufacturers to use crumb rubber as filler for tread compounds whenever speed and high performance are not crucial.

An enormous growth of commercial application of recycled tire rubber also termed as crumb rubber or ground tire rubber (GRT) is being noticed.

A market summary and application of recycled tire rubber for United States and Canada is given in Table 21.

**Table 21: Markets and applications for recycled tire rubber in North America in 2001**

| Application/ market | Million lbs. | Metric tons |
|---|---|---|
| Rubber modified asphalt (RMA) | 292 | 132,727 |
| Moulded products | 307 | 139,545 |
| Athletic surfaces | 141 | 64,091 |
| Tires/automotive | 112 | 50,909 |
| Devulcanized and surface modified rubber | 36 | 16,364 |
| Plastic/rubber blends | 38 | 17,273 |
| Construction and miscellaneous | 70 | 31,818 |
| **Total** | **996** | **452,727** |

### 6.1.2. Surface activation of crumb rubber

Although there is a practice of using crumb rubber as filler in a virgin rubber compound but due to lack of reactivity the crumb rubber cannot equally contribute to the ultimate properties with those of virgin rubber. This is a major shortcoming of crumb rubber in comparison to virgin rubber.

But, surface activation can increase the adhesiveness of crumb rubber particles within the major virgin rubber matrix. With the increased adhesiveness through surface activation it becomes possible to use a higher loading of crumb rubber without any detrimental effect commonly experienced when untreated material is used.

Use of surface activated crumb rubber may be a good compromise between using crumb rubber as a mere filler versus the scrap rubber material with complete devulcanization. The economic suitability of surface activated crumb rubber, however, may depend on the market price of virgin rubber compound.

### 6.1.3. Moulded products from crumb rubber

Crumb rubber can also be suitably used as a number of compression moulded products after blending with moisture-curing urethane binder. High-volume but low-tech products, such as livestock mats, railroad crossings, removable speed bumps and athletic mats may be produced from crumb rubber and moisture-curing urethane binder by a simple compression melding technique with a significant reduction of processing time and material costs. Of course the manufacturers should design such products in this category having requirement of only moderate tensile strength and abrasion resistance.

### 6.1.4. Wet poured layers of crumb rubber

This is an important and interesting area of application in playgrounds and athletic surfaces where crumb rubber can be utilized as a layer of rubber granules to prevent injuries. In this application normally a moisture-curing urethane is mixed with 4-10 mesh crumb rubber and applied in a similar way as done in other poured pavements. As a general practice many stadiums throughout the world have constructed running tracks consisting of recycled material. These poured layers are usually softer than hot cured, compression moulded rubber mats. In some cases, the top layers of the poured-in-place athletic surfaces are made of UV-resistant, coloured EPDM granules, which is a saturated elastomer.

### 6.1.5. Sprayed layers of crumb rubber

Apart from the use in playgrounds and athletic surfaces a combination of crumb rubber and moisture curing urethane binder can be used for covering by spraying onto surfaces where elasticity, waterproofing, corrosion resistance or vibration and impact dampening properties are desirable. This method may find a wide range of possible applications with a good potential for growth.

### 6.1.6. Use of crumb rubber in soil

Use of crumb rubber in soil significantly reduces soil hardness, soil shear strength, and water content.[65] Ontario, Canada generates about ten million waste tires per year and less than 20% of these tires are recycled, some of which are granulated to produce crumb rubber (a government statistics of 1991). This crumb rubber (~20%) found an innovative application in sports field soil to enhance the physical properties of soils susceptible to the negative effects of compaction. Highly compacted sports fields require constant aeration to maintain a healthy and safe playing surface. Rubber crumb was found to add resiliency to sports turf maintaining recommended total porosity of the soil and reduced surface hardness.

### 6.2. Pyrolyzed products of scrap tires

Sometimes scrap tires are pyrolyzed to convert to fuel oil and gases along with some solid residue. Basically pyrolysis of scrap tire is a process of thermal decomposition of the organic materials in absence of ambient oxygen. The typical products obtainable from scrap tire pyrolysis include the following:

- Hydrocarbon gases (mostly used to fuel the same process)
- Pyrolysis oil (properties are similar to those of heavy fuel oil)
- Carbon black (may be used as pigment or filler for rubber products)
- Scrap steel

Although pyrolysis of scrap tires may be technically viable but running this process may face serious environmental pollution if proper measures are not taken.

### 6.3. Thermoplastic polymer-crumb rubber blend

Thermoplastic-elastomer like materials can be produced from crumb rubber by blending with a suitable thermoplastic polymer as binder at high temperatures. This material can be processed like a thermoplastic compound retaining some of the elasticity of rubber. This is a very cost effective method of producing materials for high volume products such as acoustic insulation in cars, pallets, railroad crossings, highway fencing, etc.

### 6.4. Use in new tires

GRT should be considered as a blend of different rubbers and carbon blacks. GRT is basically a powder material obtained by grinding of scrap/discarded tires. Such GRT particles retain the cross-linked structure of the rubber molecules, whereas devulcanized GRT consists of a mixture of cross-linked and uncrosslinked rubber mass. Therefore, GRT powder can be used as filler in a rubber compound containing virgin rubbers, and being a soft and sticky mass devulcanized GRT can be used in blends with virgin rubbers. There is report of almost identical wear behaviour of tuck tire containing 10 wt% of devu1canized rubber with that of a tire made from new rubber compound.[66]

### 6.5. Rubber/recycled rubber blends

For making pre-packaged pour-in-place surfacing product, recycled tire rubber crumb is found to be used. GRT can be blended with premixed polyurethane to produce a soft, pliable energy-absorbing rubber surface for playground and other recreational surfaces.

The blends of devulcanized NR and virgin NR have shown much improved tensile properties than blends with fully cured ground rubber.[67] On the contrary modulus of blends of devulcanized and virgin NR decreased due to the migration of curatives.

### 6.6. Thermoplastic-recycled rubber blend

One of the solutions of waste disposal problem is the compounding of ground tire rubber (GRT) with thermoplastics thereby reducing the product cost. This technique normally leads to subsequent re-melting and shaping to a wide range of moulded and extruded products.[68] Simultaneously it is to be accepted that the mechanical properties of GRT-thermoplastic composites would be lower than that of the virgin system due to lack of adequate dispersion and adhesion between the two phases.[69]

Compatibilizers have been used to promote adhesion between polyethylene and GRT.[62, 70,71] Effective compatibilizers used to improve the impact properties of PE-GRT composites are epoxydized natural rubber, ethylene-co-acrylic acid copolymer,[62, 70, 71] and ethylene-co-glycidyl methacrylate polymer.[71]

To improve the compatibility with polymer, the GRT particle surface was modified by chemical treatments, e.g., chromic acid etching, thermo oxidation or mechanical means. Use of Maleic anhydride-grafting as well as chlorination of GRT improved physical properties of GRT-EPDM-acrylated high-density polyethylene and GRT-PVC blends.[72]

Surface treatment of GRT with an unsaturated polymer and a curing agent also improved the performances.[73] Composites of silane-treated ground rubber showed better mechanical properties than composite made from untreated cryogenically ground rubber.

The GRT surface was also modified by high-energy treatments, viz., plasma, corona discharge, and electron-beam radiation. [68] The oxidation of GRT surface by plasma and autoclave in presence of oxygen improved the adhesion between GRT and polyamide in the blend. Improvement of mechanical properties of epoxy resin-GRT compound was done by plasma surface treatment.[74]The effects of corona treatment on the impact property of GRT-thermoplastic composites were investigated.[71] However, prolonged high power corona treatment reduced the impact strength of the GRT composites.

### 6.7. Concrete modified by recycled rubber

Another prospective use of recycled rubber is its inclusion in concrete compositions.[75-79] Use of recycled rubber in cement-concrete structure can provide advantages of increased crack, freeze-thaw, and impact resistance, shock wave absorption, decreased heat conductivity and increased resistance to acid rain, but with the decrease of compressive and flexural strength.

Some investigation was done on the influence of the shape of rubber particles on mechanical properties, workability, and chemical stability of rubber-filled cement.[75] It is reported that the rubber in the concrete structure is able to bridge any crack and prevent catastrophic failure of the specimen.

Attempts were made in some studies to improve the weak interface bonding by washing the rubber particles.[78] Several surface modifications of rubber have been proposed [78] to chemically oxidize rubber and introduce polar groups, viz., treatment with sulphuric acid and nitric acid.

Treatment with sulphuric acid improved the adhesion of rubber to concrete. Hydrophilicity of the inherently hydrophobic rubber surface was improved by acid or base treatment.[80]

It is reported that the addition of rubber particles to concrete decreases their compressive and flexural strengths due to pull out of particles.[81] However, treating rubber particles with a silane-coupling agent before mixing can improve the interface leading to increased ductility.[81] These materials can find suitable utility in highway pavement overlays, sidewalks, medians, sound barriers, and other transportation non-structural uses.

## 6.8. Recycled rubber modified asphalt (RMA)

The use of rubber modified asphalt in pavement making dates back to around 1870 when the area around St. Pancreas Station in London was paved with a rubber compound since it helped muffle the sound of the horses' hooves. In addition the pavement became durable and easy to keep clean.

Commercial applications of RMA pavements were first introduced by Charles McDonald in Arizona in 1960s. The performance characteristics of recycled tire rubber asphalt pavements were reported to be improved by the addition of SBS block co-polymers (thermoplastic elastomers) to the hot bitumen.

The merits and the economic benefits of using recycled tire rubber in asphalt were established when thousands of highway miles were paved with RMA. The main advantages of RMA in road construction were reported to be increased resistances to rutting, reflective and thermal cracking, better de-icing properties, reduced traffic noise as well as increased service life and lower life cycle cost.

The use of ground rubber in asphalt pavement has become important since it improves the functional characteristics of the pavement, viz., scrap tire rubber provides added flexibility, reduces crack formation, enhances the service life by decreasing aging, reduces ice formation, facilitates water removal from pavement surface and reduces road noise.

A rubber modified asphalt concrete paving composition was prepared by adding 3% by weight of fine and coarse rubber particles to a dense graded aggregate (stone chips) mixture developed by Takallou and is known as TAK System originated after its inventor.[62] In this process, the rubber particles used was prepared from whole tire recycling.

It may be mentioned that the greatest potential market for scrap tire generated rubber is found as an additive to asphalt pavement. People follow different techniques to hot mix the ground scrap tire rubber with asphalt while laying the pavement. Scrap tire rubber has also been found to be used in crack/joint seals, surface/interlayer membranes, and as an aggregate substitution in hot mix binder.

For production of one ton of rubber modified asphalt concrete mix about 60 lb of ground tire rubber (equivalent to rubber present in five car tires) is required. In other words, for the construction of one mile of two lane highway of 3 inch thickness would require ground rubber from about 16,000 car tires. This indicates a good outlet of the automobile scrap tires for consumption in road construction.

Blending of tire rubber to modify the properties of asphalt remains the largest single market for ground rubber. About 220 million lb, or approximately 12 million tires, were used in the United States[1] in 2001 for this purpose. A consumption of up to 40% of scrap tires by asphalt industries is reported. [82]

The advantages of using scrap tire rubber in asphalt for road construction are the good performance of roads and their longevity in terms of enhanced ductility, crack resistance, skid resistance, and noise reduction.

Only the cost and probable toxic emissions into air can be a major disadvantage of the rubber modified asphalt. The toxic emissions into the air happen due to the hot mixing during processing of the rubber-asphalt mix. Tests and cost analysis indicated that the rubber-modified asphalt increases the cost of road construction by about 50% in comparison to the use of [asphalt] only.[83]

There are two processes, dry and wet, used in preparing the rubberized asphalt taking GRT particle size ranging from 6.35 mm to 40 mesh. In the wet process, first the asphalt is blended with GRT particles and then added into the hot mix. In the dry process, GRT is directly mixed with the aggregates, and the resulting mix is blended with hot asphalt.

In 1968, Sahmaro Petroleum and Asphalt applied a blend of GRT with asphalt as a binder for hot premix, which is a mixture of stone aggregate, sand, and the tire-asphalt binder premixed in a batch- or drum-type mixer. Such mixture was applied as a carpet on top of the road by a paving machine, followed by a steel roller to compact the material.[84]

The process of blending GRT (15 to 30 wt%) with asphalt at temperatures of 300 to 400°C for a period of half to two hours before preparing a mixture is reported to be efficient in improving properties.[85] At ambient temperatures this composition is a tough rubbery elastic material. Others have also reported the consumption of scrap tires in the form of crumb rubber as modifier of asphalt for the highway pavement industry.[86]

## 6.9. Other products made from recycled rubber

A wide variety of rubber products are being manufactured from compounds containing devulcanized or ground tire rubbers. For example, shoe heels and soles, tubes, conveyor belts, technical rubber mouldings, automobile floor mats and flaps, livestock stall mattresses, playground and track surfacing, railroad track crossing, lower layers of floor coverings, various moulded and extruded profiles, sealing plates, battery boxes, and other hard rubber goods are already in running production. The inherent black colour of tire rubber restricts its use for light and coloured compounds unless additional measures are taken to change the colour.

## 6.10. Recovery of hydrocarbon liquid and carbon black

Recovery of liquid hydrocarbon from scrap tire by its pyrolysis is also followed as a suitable method of recycling. Basically thermal decomposition of rubbers occurs in absence of air and oxygen during the pyrolysis process to produce oils and gases for reuse by petrochemical industries. Carbon black as solid by-product residue after pyrolysis can be used as fillers. Boilers, autoclaves, rotary kilns, screw conveyors, and fluidized beds are normally used for carrying out pyrolysis of scrap tires. However, this process produces toxic waste and lacks cost effectiveness due to the low price of crude oil. For this reason and also due to absence of a wide market for the pyrolysis generated oil and carbon black pyrolysis of scrap tire is done on a limited scale.

### 6.11. Tire-derived fuel

Scrap tires serves as a fuel supplement for coal or gas in kilns for producing Portland cement, lime, and steel. This saves 25% coal consumption in cement industries. Electricity is generated by burning scrap tires. But use of scrap tires for fuel supplement losses valuable rubber materials. Whereas for producing one pound synthetic tire rubber around 60,000 BTU energy is consumed 9, but energy recovered by burning one pound rubber is 13,000 to 16,000 BTU. Not only lower energy recovery by burning of tires but it also may lead to air pollution.

## 7. Indian Scenario

### 7.1 Introduction:

In India, about 35 units are engaged in the manufacture of reclaimed rubbers with an estimated installed capacity of 10,78,000 tons. The estimated annual production and consumption of reclaimed rubber are around 64,000 tons and 62,000 tons respectively.

While natural rubber, 90% of which is produced in Kerala, is sold at Rs 150-160 per kg, reclaimed rubber is sold at Rs 25-30 per kg. India The production of reclaimed rubber is growing by approximately by 10-12% per year.

### 7.2 Business opportunity

In general a car tire contains 24-28% carbon black, 40-48% natural rubber (NR) and 36-24% synthetic rubber (SBR/BR). Apart from these inner tube or inner liner is made of butyl rubber. Due to inadequate indigenous production, Indian tire industry import a substantial quantity of different synthetic rubbers and carbon black.

So, by recovering a part of rubbers from the waste/used tires at least a portion of the virgin rubber imported from abroad can be avoided, leading to savings in foreign exchange.

Currently India produces 90,000 MT reclaimed rubber, which is sold at Rs 25-30/kg, there is no report on the production of carbon black, butyl rubber or oil from used tires. Carbon black is the most reinforcing element and the tire industry cannot survive without its adequate supply. Due to insufficient production, Indian tire industries imported about 39,000 MT carbon black and 54% of total butyl rubber requirements in 2008-09.

Clearly there is a good potential for adopting effective recycling techniques and help generate synthetic rubbers and carbon black from used/scrap tires. One can easily estimate the potential of such business opportunity based on a picture of 11.75 MT tire production in the year 2008-09 with a projected growth of 50%.

### 7.3 Present scenario

There are about four or five major players in tire recycling industry in the country - Gujarat Reclaim, ELGI Group of industries, Balaji Group of industries, Rishiroop and Swani. They are mainly located in North India and Maharashtra. Most of the tire recycling units use the pan method for reclaiming rubber but none of the recyclers in India are full-fledged recyclers. They operate by outsourcing some part of their work.

A picture of the indigenous usage of old tires after reclaiming can provide an idea of the state of the art of reclaiming technology. Apart from the usage of whole tires, the uses of tires can be categorized as following:

***Use of rubber crumb*:**

For making floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, and washers, etc.

***Use of reclaim rubber in vehicles*:**

Automotive Industry – About 3-5% rubber crumb and up to 10% reclaim rubber are used in automobile tires. Due to large volume of tire production, consumption of these rubbers is also increasing. Tire carcasses and other automotive parts consume substantial volume of reclaim rubber.

Bicycle industry: Reclaim rubber is also consumed in the manufacture of bicycle tire. About 6-7 lakh bicycle tires are produced every day, out of which more than 80% is produced in Ludhiana. Ralson is the major company in India with a production of about 1.0 lakh bicycle tires and 1.5 lakh tubes per day.

***Useful moulded goods from reclaim rubber***:

These include rubber sheets. floor mats, hose pipes, conveyor belts, v-belts, shoe soles in footwear, tiles, adhesives, sound and vibration dampers, battery containers and many other moulded rubber goods.

***Re-treading:***

Although it does not strictly come within the reclaiming scenario, it is important as it saves a major quantity of rubber in worn out tires prior to discarding as unusable.

In India worn out truck tires are retreated as much as 3-6 times but not the car tires. There are about 100-odd firms engaged in tire rereading in India with prominent names being MRF, Apollo, ELGI, Midas and Indag.

## 7.4 Available reclaiming technology

Three methods for reclaiming rubber are used in the country:

**Heater or pan process:** Any fibre present is separated mechanically and the ground fabric free scrap is blended with reclaiming agents. The same is fed into large horizontal single-shell heater. After devulcanization, the heater cakes are removed, broken up, milled and refined. The temperature range employed during reclamation is 170-210$^{0}$C for a period of four to 12 hrs.

It is the oldest and highly labour-intensive process technology. It causes huge water and air pollution. Based on the Pan technology a small scale reclaiming plant can be set up with an investment of Rs 1 crore to Rs. 2 crore.

**Wet digester process:** Coarsely ground scrap mixed with reclaiming and de-fibre agents and a large excess of water is heated in a digester. After discharge, the devulcanized rubber is washed, dewatered, dried and blended with processing agents such as oil, refined, strained and packed.

It is an expensive technique used by some recyclers in India. installation of a recycling plant following Digester method for producing 5 MT reclaim rubber per day may cost between Rs 5 crore and Rs. 12 crore depending upon the source of the machineries and level of automation. A fully automated plant would cost about Rs 12 crore to Rs. 14 crore.

**Reclaimator process:** Whole tires are cracked to a convenient size, and the fibre is removed mechanically. The relatively fibre-free scrap is ground to approximately 30 mesh before being mixed with chemical agents for reclaiming continuously in a reclaimator. The temperature range is 204-260 $^{0}$C and the devulcanization time is 1-4 min. Reclaimed material is then mixed and blended with small proportions of reinforcing and processing agents. It is a very costly method and is only used for very large-scale production. Small scale processes adopt mechanical shredding, mixing, pressing, pyrolysis, etc.

India is the second largest reclaim rubber producer after China. With the initiatives and support of the government there can be a growth of 50-100% of the reclaiming industries including export options for good quality reclaim rubber to Middle East, Africa, Europe and other Asian countries.

## 7.5 Customer industries for reclaim rubber

Indian Rubber Board has projected an overall growth of 8-10% per year for the reclaim rubber industries. If the prices of virgin rubbers escalate at the current rates, this growth of reclaiming industries is expected to further increase since the price of reclaim rubber today is around 25-30% of the prices of virgin polymer.

## 7.6 Carbon black and tire oil extraction from rubber tires

Carbon black produced by pyrolysis process is more economical compared to carbon black produced primarily from petroleum and is more price efficient to be used as an ingredient in various industries. During pyrolysis thermal decomposition of carbon black occurs in absence of ambient oxygen.

Following are the typical products of scrap tire pyrolysis:

- hydrocarbon gases (mostly reused to fuel the pyrolysis process itself)
- pyrolysis oil (properties similar to that of heavy fuel oil)
- carbon black (can be used as pigment or filler)
- scrap steel

### 7.6.1 Links to video on tire pyrolysis

i. 5 TON TYRE PYROLYSIS PLANT DIVYA INTERNATIONAL, India
https://www.youtube.com/watch?v=F2kyVmRUKXc

ii. Waste Scrap Tyre Recycling Pyrolysis Plant manufactured by ALBEN INDUSTRIES, PLANT INSTALLED IN WADA,
https://www.youtube.com/watch?v=F8zodWnzzQg

## 7.7 A sample picture of reclaim rubber (RR) import to India

**Table: 22**

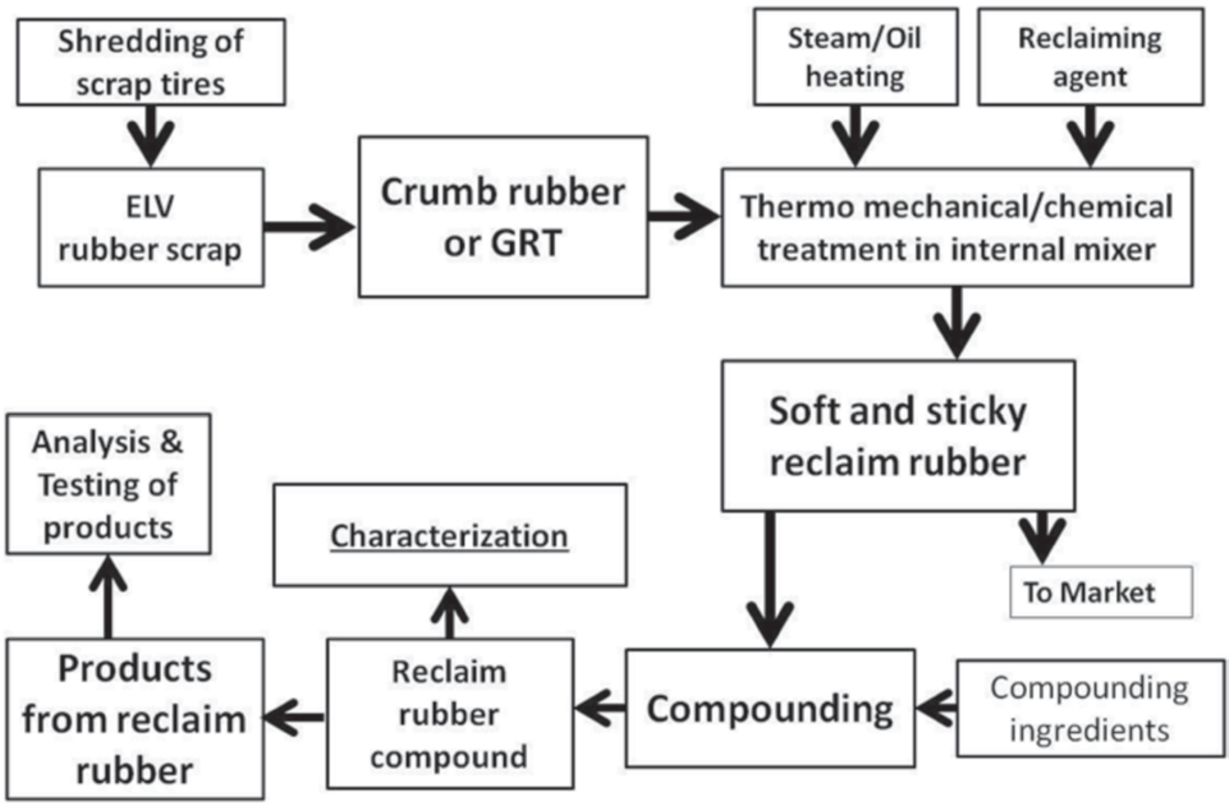
| Date | HS Code | Description | Origin Country | Port of Discharge | Unit | Quantity | Value (INR) | Per unit (INR) |
|---|---|---|---|---|---|---|---|---|
| 24.6.14 | 40030000 | RR Sheet T-9 ( 20 Kg/PC) | Malaysia | Chennai Sea | Kg | 1,000 | 42,388 | 42 |
| 24.6.14 | 40030000 | RR Sheet PCR-100(20 Kg/PC) | Malaysia | Chennai Sea | Kg | 1,000 | 40,975 | 41 |
| 13.6.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 33,120 | 1,377,149 | 42 |
| 13.6.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 12,880 | 535,540 | 42 |
| 31.5.14 | 40030000 | Top grade refined tire RR (R2777) | China | NhavaSheva Sea | Kg | 200 | 16,996 | 85 |
| 10.4.14 | 40030000 | RR Tire C 601(CR41030918)(Rubber sheet)(FTA cert.no.KL -2014-MICECA-26-001910 dt.01.04.2014) | Malaysia | NhavaSheva Sea | Kg | 3,000 | 178,218 | 59 |
| 5.4.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 14,685 | 627,356 | 43 |
| 5.4.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 13,118 | 560,402 | 43 |
| 5.4.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 10,494 | 448,330 | 43 |
| 26.3.14 | 40030000 | RR sheet (Grade-TRR 40P) | Malaysia | Tughlakabad | Kg | 20,480 | 940,497 | 46 |
| 14.3.14 | 40030000 | RR Tire C 601 (CR41030918) (Rubber sheets) (FTA certificate no. KL-2014-MICECA-26-001365 dt.10.3.2014) | Malaysia | NhavaSheva Sea | Kg | 3,000 | 182,788 | 61 |
| 22.2.14 | 40030000 | Butyl RR | U. K. | Chennai Sea | Kg | 8,739 | 140,468 | 16 |
| 21.2.14 | 40030000 | RR Tire C 601(CR41030918)(Rubber sheet) | Malaysia | NhavaSheva Sea | Kg | 3,000 | 192,264 | 64 |
| 11.2.14 | 40030000 | RR in sheet form | China | Tughlakabad | Kg | 22,800 | 902,375 | 40 |
| 11.2.14 | 40030000 | RR in sheet form | China | Tughlakabad | Kg | 200 | 7,916 | 40 |
| 5.2.14 | 40030000 | Butyl RR -ANABOND | U. K. | Chennai Sea | Kg | 249 | 15,643 | 63 |
| 5.2.14 | 40030000 | RR in sheet | China | Chennai Sea | Kg | 46,000 | 2,196,257 | 48 |
| 31.1.14 | 40030000 | RR (TPA) (raw material for disc brake pads) | Japan | Tughlakabad | Kg | 200 | 23,770 | 119 |
| 28.1.14 | 40030000 | RR Tire C 601(Rubber sheet) | Malaysia | NhavaSheva Sea | Kg | 5,000 | 316,623 | 63 |
| 28.1.14 | 40030000 | RR in sheet form 10 MPA | China | Ludhiana | Kg | 14,082 | 605,992 | 43 |

Reference

·www.cbec.gov.in ·www.aces.gov.in

### 7.8 Flow diagram for a pilot plant

The following diagram shows a schematic of the different steps needed for converting automobile rubber wastes to reclaim the rubber for use in value added rubber products.




### 8. Recommendations

- An environment friendly and economically viable reclaiming process needs to be developed for better quality reclaim rubber.
- A Pilot Plant for assessing the techno economic feasibility of the various techniques for recycling of waste rubber from ELVs needs to be set up
- Creating a Centre of Excellence on “Recycle of Rubber from ELV” at Indian Rubber Board, Kottayam to draw up national guidelines based on an appropriate rubber reclaiming technology.

## 9. Conclusion

Already several Indian companies are engaged in the manufacture of different grades of reclaim rubber but in a limited capacity. Apart from selling of these reclaim rubbers in the domestic market they also export a part of their production. A sample picture shown in the **Table 22** in Section 7.7 above on a sample picture of reclaim rubber import into India indicates that to meet the demand of reclaim rubber usage in India the domestic production is insufficient. This dictates the increase of indigenous reclaim rubber production either by the existing industries or by commissioning new industries. Simultaneous research and development activities on advanced rubber reclaiming technology are also essential in India.

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# Past, Present and Future of rubber products manufacturing industry in India

## Introduction :

The rubber industry is one of the key sectors of the Indian economy. India is the fourth largest producer of natural rubber and the third largest consumer of the polymer. As far as consumption of natural and synthetic rubber together is concerned, the country occupies the fourth position.

From the time the rubber product manufacture started in India, in the year 1920, the industry has been mostly inward oriented, catering to the needs of the vast domestic market. But in the recent past, the country had been transforming itself into a major rubber product exporter as well. This is thanks to the economic policies pursued by the government and the market integration brought about by the WTO/Regional Trade Agreements.

## Factors contributing to the growth

Like most of the producing countries, natural rubber production in India was solely export oriented during the first quarter of the 20$^{th}$ century. However, sustained growth of the rubber product manufacturing industries was evident since the mid 1930s.

Historically, the commercial impetus for this growth revolved around three inter-related developments: (1) the implementation of the International Rubber Regulation Agreement (IRRA) in 1934 and the consequent domestic availability of NR at a lower price in India, (2) the entry of foreign companies in rubber product manufacture to capitalize on the advantages arising from cheaper raw material and labour and a growing domestic market and (3) government patronage to the industry in the backdrop of the increased industrial requirements during the inter-war years and the second world war period.

The post-war period witnessed a steady expansion of the industry. But the bulk of the consumption of rubber was accounted for by a few large units. Small scale units also could survive because of the relative profitability of rubber product manufacture and the extent of protection from external competition.

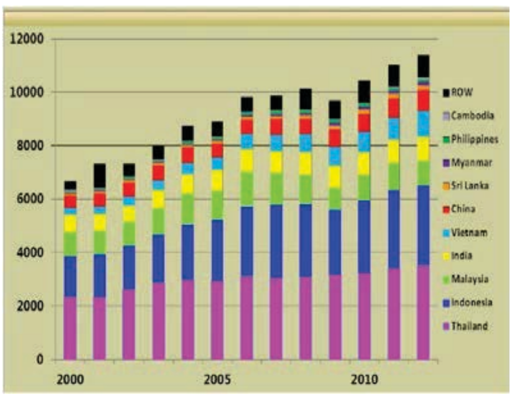
Government patronage to the industry resulted in liberalized import of rubber and other raw materials and protection from imports of rubber products. The net result was the graduation of India from an exporter of raw natural rubber to a net importer of the rubber and an exporter of finished rubber goods, although in a limited manner, by the late 1940s.

One of the important characteristics of the Indian rubber product manufacturing industries right from the beginning has been the dominance of dry rubber based products. The major contributing factors for this unique pattern of development have been a highly protected, import-substituting and inward-oriented production and the supplementary status of the sector, mainly catering to the requirements of the larger industrial base in the country.

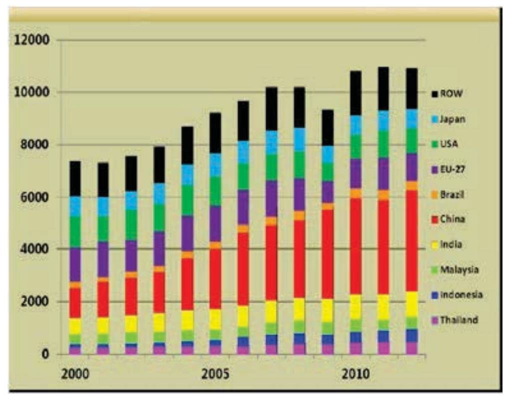
At present there are over 4,300 manufacturing units, including 58 tire factories, turning out products worth US$ 7.7 billion, which is about 1.7% of the total industrial output of the country. The total employment generation by the rubber product manufacturing industry is 465,000. The natural/synthetic rubber consumption ratio is 75:25, while globally the ratio stands at 44:56. The per capita consumption of rubber remaining at 1.0 kg, the market for rubber products in India, with its large population, is likely to grow significantly in the years to come.

## Growth in natural rubber production and consumption

The growth of the industry can be judged from the data on production and consumption of different types of rubbers in the country, which are given in the following figures.




Global natural rubber production




Global natural rubber consumption

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## Observations

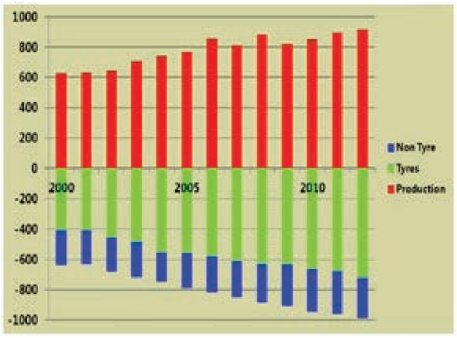
### Natural Rubber producing countries consume a relatively small amount of their precious resource dependent on large volumes of exports

- Leaves the producers at the mercy of the global commodity markets
- Magnifies the boom-bust pricing cycles
- Wedge driven between few players in a simple value chain

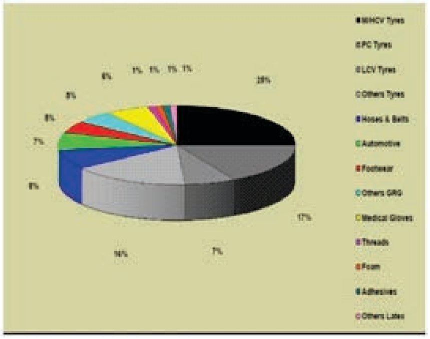
- A wasted opportunity and strategically flawed as export generation rather than inward investment and industrialization as the main driver.

**Natural rubber consuming countries produce a relatively small amount of natural rubber dependent on large volumes of imports**

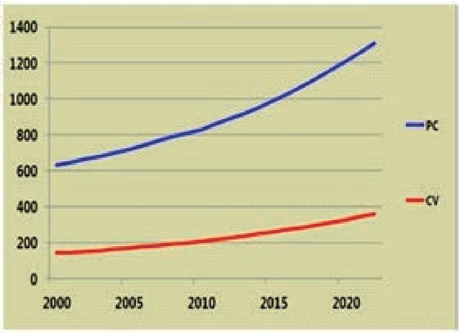
- Leaves the consumers at the mercy of the global commodity markets
- Magnifies the boom-bust pricing cycles
- Wedge driven between few players in a simple value chain
- A wasted opportunity and strategically flawed




**India Natural Rubber Balance**

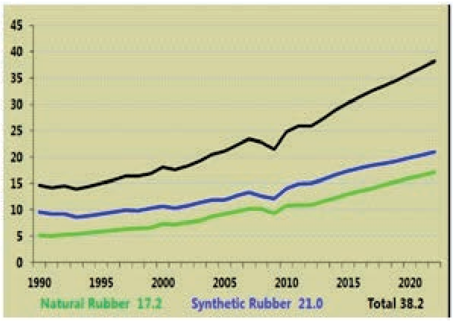



**NR Downstream Industry Applications**

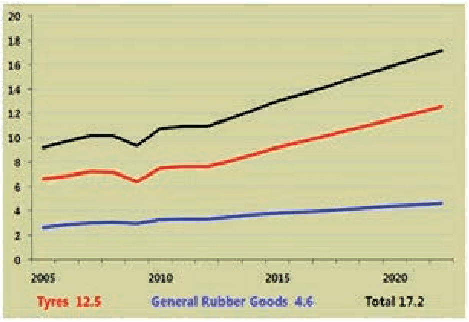



**Global Vehicles in Use to 2022, (Millions of Units) -IMF scenario**


**Global Tyre Production to 2022, (Millions of Units) -IMF scenario**




**Global Rubber Consumption to 2022, (Millions of MT) –IMF scenario**




**Global Natural Rubber Consumption 2022 (Millions of MT) –IMF scenario**

Opportunities need to be created to encourage an environment for inward invest leading to the consumption of more natural rubber at its point of production. Producing countries should create a centrally co-ordinated forum to discuss and review what is in the interest of the country as a whole and development of strategic industries. All stakeholders need to identify and commit to working together on generic projects such as sustainability in order to build trust and transparency between the limited numbers of key stakeholders in the relatively simple value chain.

The game will only change for the better if the producer governments and the small number of consuming industry leaders can work together to define a strategic win-win environment to support rubber cultivation going forward. A picture of price of natural rubber produced in India is shown in Table 6.

**Table 6: Rubber price chart**

| **India Rubber Price (per 100 Kg)** | | | | |
|---|---|---|---|---|
| **Kottayam as on 4/6/2013** | | | | |
| **Category** | **Rs** | | **USD** | |
| | Price | Change | Price | Change |
| RSS-4 | 16,350.00 | -100.00 | 297.90 | -3.11 |
| RSS-5 | 16,100.00 | -100.00 | 293.35 | -3.09 |
| ISNR-20 | 0.00 | -15,700.00 | 0.00 | -287.30 |
| Latex | 0.00 | -10,995.00 | 0.00 | -201.20 |
| **Cochin as on 4/6/2013** | | | | |
| **Category** | **Rs** | | **USD** | |
| | Price | Change | Price | Change |
| RSS-4 | 16,350.00 | -50.00 | 297.90 | -2.19 |
| RSS-5 | 16,100.00 | -100.00 | 293.35 | -3.09 |
| ISNR-20 | * | 0.00 | * | 0.00 |
| Latex | * | 0.00 | * | 0.00 |

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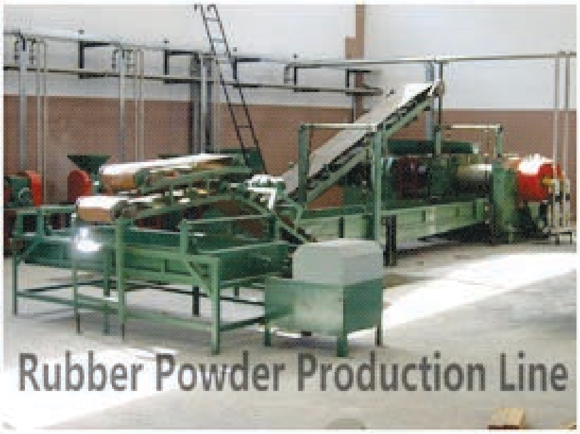
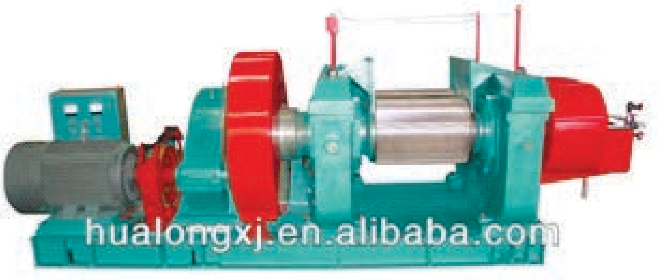
www.nistads.res.in/indiasnt2008/t4industry/t4ind13.htm.

**Reclaiming plants, machineries and links to process video**




Waste Tyre Recycling Plant Manufacturing Unit Fab-India
Turnkey Base with Pollution Control Equipment.
Ahmedabad, Gujarat, India
https://www.youtube.com/watch?v=saM81YnnID4&feature=youtu.be

# Reclaiming scenario in major reclaim rubber manufacturers in India

## Gujarat Reclaim and Rubber Products Ltd. (GRRPL)

GRRPL produces reclaim rubber from whole tire scraps, tread peelings, natural rubber tubes, butyl rubber tubes, molded rubber goods used for different purposes in both tire and non-tire products. Establishing in 1974 GRRPL started production with a modest capacity of only 2,400 MT but with a steady growth it increased its capacity by many folds (40,000 MT in 2010).

In due course of time GRRPL increased its capacity by setting up new factories at different locations in India's north-west (Ankleshwar, Panoli) and south-west (Solapur).

Besides the domestic market, GRRPL supplies reclaim rubber to buyers in 45 countries. It is the largest manufacturer of reclaim rubber in the country and among top three globally.

Out of total sales of reclaim rubber of Rs.140.67 crore for 2010 by GRRPL, domestic sales comprise of Rs. 61 crore (43.36%) and export Rs.79.67 crore (56.64%). One of the key strengths of GRRPL is that it has developed a wide network for raw material procurement and built an extensive chain of raw material suppliers.

With increasing trend of worldwide consumption of virgin synthetic rubbers for rubber compounds, a huge future potential has been generated for the consumption of synthetic reclaim rubber mainly in the non-tire rubber goods manufacturing sector. Accordingly GRRPL has concentrated on the production and sales of synthetic rubber reclaims which command higher value and realization in comparison to NR reclaims. GRRPL has become a pioneer in the manufacture of reclaimed rubber from synthetic rubbers such as butyl, EPDM, nitrile, etc. Synthetic rubber reclaim business accounts for about 45% of its total revenues.

Depending on the type of tires , use of reclaim rubber in a tire can be as low as 0.5% of total polymer for high performance passenger car radials (PCRs) to as high as 12% of total polymer for off the road tires (OTRs) and a further higher value of 35% in case of cycle tires. Indian tire industry, in general, consume about 4% reclaim rubber of total polymer but some companies are also trying to consume 6-7% reclaim rubber.

The growth of global reclaim rubber industry has been estimated from 2% of total polymer consumption in early part of last decade to close to 5-6% currently. China leads in reclaim rubber manufacturing as well as highest consumption proportionately with virgin polymers.

## R. K. Rubber Reclamation Pvt. Ltd., Punjab

R. K. Rubber Reclamation is engaged in manufacturing of different grades of reclaim rubber since 1995, spread over 480,000 sq ft area under one roof.

With group's annual turnover of above 5 million USD, R. K. Rubber Reclamation products are known for their highest quality standards. Besides selling to large Indian customers they also export their products to 15 countries around the globe and they claim that their reclaim product quality has been approved by those companies which are big giants of rubber industries worldwide.

R. K. Rubber Reclamation Pvt. Ltd. claims their manufacturing unit to be the largest plant of whole tire reclaimed rubber in India. They manufacture automotive moulded goods, passenger and truck tires, calendered and extruded rubber products, adhesives, etc. from whole tire scrap.

Its Work Address is: VPO Khosa Pando, G. T. Road, Moga, 142001 (Punjab) India (E-mail: info@reclaimrubbers.com).

## Balaji Rubber Industries (P) Ltd

Balaji Rubber Industries (P) Ltd., a company founded in 1985 by Mr.K. Vaidyalingam, has over the years been recognized in the national and global market in the areas of natural and butyl reclaim rubber.

Balaji Rubber is known for whole tire reclaim and butyl reclaim among the manufacturers of tire, tube and various rubber products in India and abroad. Balaji Rubber Group of Companies has won world reputation by its persistent endeavor, pioneering vision, innovative technology and excellent products with its annual production capacity of around 45,000 MTs/year and caters to the needs of wide cross section of customers across the globe in more than 18 countries.

Reclaimed rubber is a unique product recycled out of scrap rubber such as worn-out tires, buffing dust, tread peelings, inner tubes and other rubber waste products. The finished product is in the form of black sheets.

Specifications of different grades of reclaim rubber are shown in Table 1.

### Few grades of whole tire reclaimed rubber

i. **Superfine grade WTR - 5504:** Reach compliant highly refined reclaim rubber widely used in truck tyres, tread rubber and rubber molded components.

ii. **Superfine grade BRI - 504:** Highly refined reclaimed rubber widely used in truck tires, tread rubber and rubber molded components.

iii. **Medium grade BRI – 522:** Moderately refined reclaimed rubber mainly used in cycle tyres, rubber mats, battery containers and also in rubber molded goods.

iv. **Coarse grade BRI – 540:** Coarse reclaim rubber mainly used in tire flaps, mats, pedal rubber, floor/coir mat

### Butyl reclaim rubber

1. **Butyl reclaim ERP – 501:** Very fine grade reclaim rubber produced out of butyl scrap inner tubes. This is mainly used in automotive inner tubes, inner liner of radial tires, cables and rubber molded components

### Rubber powder/granules

1. **Whole tire/natural powder 30/40 mesh:** Rubber powder ground to fine mesh used in flaps mats, compounds of various rubber products.
2. **EPDM granules 30/40 mesh:** Rubber powder ground to fine mesh used in flaps mats, compounds of various rubber products.

## Specialty reclaimed rubber

1. **High tensile reclaimed rubber HTR - 704:** Rubber powder ground to fine mesh used in flaps mats, compounds of various rubber products.
2. **Natural tube reclaim rubber NTR - 703:** Very fine grade reclaim rubber produced out of natural scrap inner tubes. This is mainly used in automotive inner tubes and rubber molded components.
3. **Halobutyl reclaim rubber HBR - 701:** The halogenated butyl rubber is produced from respective scrap to meet the requirements of customers. These reclaim rubbers significantly increases cure reactivity, compatibility with unsaturated polymers and heat, ozone resistance, vibration damping and used in tire inner liners, pharmaceutical stoppers, construction seals, hoses and mechanical goods.
4. **EPDM reclaimed rubber EPR - 702:** These are copolymers of ethylene and propylene containing in addition a small amount of unsaturation and have outstanding resistance to ozone and weathering and widely used in auto tubes, molded and extruded products. Reclaim produced with these scraps can replace the virgin polymer in the mix without changing the special properties of EPDM polymer.

**Table 1. Specifications of different reclaim rubber grades**

| S. No | Properties | Units | Super fine WTR-5504 | Superfine BRI-504 | Medium BRI - 522 | High Tensile reclaim rubber HTR-704 | NR Tube reclaim NTR-703 | Coarse BRI-540 | Butyl Reclaim ERP-501 | Halobutyl HBR-701 | EPDM Reclaim EPR - 702 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Chemical properties** | | | | | | | | | | |
| 1 | Acetone extract | % | 14±2.5 | 14±3 | 14±3 | 14±3 | 12±4 | 14±3 | 10±3 | 13±3 | 30±5 |
| 2 | Ash content | % | 7±2 | 7±2 | 7±2 | 7±2 | Max 28 | 7±2 | 4±2 | 4±2 | Max 20 |
| 3 | Carbon black | % | 25±3 | 27±2 | 27±2 | 26±3 | 17±7 | 27±2 | Min 28 | Min 27 | 25±5 |
| 4 | Rubber hydrocarbon | % | Min 47 | Min 47 | Min 46 | Min 47 | Min 40 | Min 46 | Min 50 | Min 50 | Max 30 |
| 5 | Volatile matter | % | Max 1 | Max 1 | Max 1 | Max 1 | Max 1 | Max 1 | Max 1 | Max 1 | -- |
| | **Physical properties** | | | | | | | | | | |
| 6 | Specific gravity | | 1.12±0.02 | 1.12±0.02 | 1.12±0.02 | Max 1.15 | 1.25±0.05 | 1.12±0.02 | 1.12±0.02 | Max 1.15 | 1.14±0.02 |
| 7 | Tensile strength | $Kg/cm^{-2}$ | Min 45 | Min 45 | Min 40 | Min 75 | Min 30 | Min 35 | Min 70 | Min 65 | Min 60 |
| 8 | Elongation at break | % | Min 230 | Min 230 | Min 200 | Min 250 | Min 225 | Min 200 | Min 480 | Min 480 | Min 300 |
| 9 | Hardness | Shore A | 60±3 | 60±3 | 60±3 | 55±5 | 65±5 | 60±3 | 55±5 | 45±5 | 55±5 |
| 10 | Mooney viscosity ML(1+4)@100 $^{0}C$ | MU | 30-55 | 25-55 | 25-55 | 40-60 | 20-50 | 25-55 | 30-45 | 40-60 | -- |

## Sun Exim

Sun Exim, a progressive and professionally managed industrial unit engaged in manufacturing of reclaim rubber since 1989, is spread over 480,000 sq ft area. With group's annual turnover of above 12 million USD, Sun Exim products are known for highest quality standards. Properties of different reclaim rubber grades are shown in Tables 2 and 3. Beside large Indian customers, their products are exported to 15 countries around the globe and the quality is approved by the companies which are big giants of rubber industries worldwide.

## Natural and synthetic rubber reclaims

These grades of reclaim rubber have varying smoothness and quality. Improved mixing cycle and die swell display minimal reduction in the utilization of electrical power and minimal reduction of properties like hot air ageing. They produce natural rubber reclaim by using whole tire tread peelings and rubber tubes. It has a wide range of application right from households to industries.

**Table 2. Properties of different reclaim rubber grades.**

| Specification | SR 111 (Super fine) | SR 101 (Medium) | SR 202 (Coarse) | SR 555 (super fine) high tensile | SR 1010 | SR White Latex | SR Butyl | SR EPDM |
|---|---|---|---|---|---|---|---|---|
| Ash% | 8 ± 2 | 8 ± 2 | 8 ± 2 | 8 ± 2 | 30 Max | 35 Max | 4 ± 2 | 15 Max |
| Carbon Black % | 25 ± 2 | 25 ± 2 | 25 ± 2 | 25 ± 2 | 20 ± 7 | - | 32 ± 4 | 24 Min |
| Acetone Extract % | 14 ± 2 | 14 ± 2 | 14 ± 2 | 14 ± 2 | 11 ± 4 | 9 ± 3 | 9 ± 3 | 30 ± 5 |
| RHC By Difference % | 48 min | 48 min. | 48 min. | 48 min | 42 min | 55 min | 50 min | 30 min |
| Volatile Matter % | 1 max | 1 max | 1 max | 1 max | 1 max | 1 max | 1 max | 1 max |
| Specific Gravity (gm/cc) | 1.12 ± 0.03 | 1.12 ± 0.03 | 1.12 ± 0.03 | 1.12 ± 0.03 | 1.25 ± 0.05 | 1.25 ± 0.05 | 1.12 ± 0.03 | 1.15 ± 0.03 |
| Tensile Strength kg / cm² | 50 min | 40 min | 35 min | 70 min | 30 min | 30 min | 75 min | 60 min. |
| Elongation at Break % | 220 min | 190 min | 160 min | 280 min | 225 min | 250 min | 480 min | 375 min |
| Mooney Viscosity ML (1+4) @100°C | 40 ± 10 | 40 ± 10 | 40 ± 10 | 40 ± 10 | 35 ± 15 | 35 ± 15 | 40 ± 10 | 45 ± 15 |
| Hardness (Shore A) | 57 ± 4 | 57 ± 4 | 57 ± 4 | 57 ± 4 | 60 ± 5 | 60 ± 5 | 50 ± 4 | 55 ± 5 |

**Table 3. Some product profiles and physical characteristics.**

| Whole tire reclaim | Product profile (Grades) | Source |
|---|---|---|
|  | **SR 111 (Superfine)** | Made from natural rubber tube scrap. Right from households to industrial products, its use is widespread. Its texture is the smoothest of all. |
| | **SR 101 (Medium)** | Produced from whole tire scrap. Widely used in footwear soles, rubber sheets, bicycle tires and battery containers. |
| | **SR 202 (Coarse)** | Used in threads, conveyor belts, auto tubes, and horse pipes. The texture is slightly coarse and rough. |
| | **SR 555 (super fine) high tensile** | High tensile form of natural rubber reclaim. Used in molded goods, conveyor belts, bicycle inner tube to bunwar sheets. |
| | **SR 1010** | Purest form of natural inner tube reclaim. Used in footwear, mattings to auto tire. |
|  | **SR White Latex** | Natural latex waste. Extracted from white latex rubber. Applications range from molded goods to conveyor belts. |
|  | **SR Butyl** | Butyl automoible tubes from rubber tube scrap. Possesses appropriate elasticity and less porous material. Resistant to ozone, inorganic acid and aging. |
|  | **SR EPDM** | Factory rejects of microwave cured EPDM profiles. Exhibits a fair compatibility with ketones, hot and cold water but less compatible with kerosene, concentrated acids and halogenated solvents. Reflects outstanding ozone, heatand water resistance. |

Apart from the abovementioned companies dealing with reclaim rubber names of few other companies engaged in reclaim rubber business are shown in Table 4.

**Table 4. Some reclaim rubber manufacturing companies in India**

| Sl. No. | Name and address | Activity |
|---|---|---|
| 1 | **Vaibhav Rubbers Pvt. Ltd.** R. L., 94, Sayantara, Milapnagar, M.I.D.C., Dombivli (E), Dombivli - 421201, Maharashtra. Contact: Mr. Prashant V. Parulekar (Director) | Manufacturer, trader and exporter of crumb rubber (CR) from shredded tires, scrap tires, waste tires, all types of scrap tire materials, etc. |
| 2 | **Goldstar Rubber Pvt. Ltd.** V.P.O. Narsala, Hoshiarpur, Punjab. Phone: +91-1882-260356, +91-9815375000, +91-1882-260357 | Offers CR powder and latex reclaim rubber (RR) to international market. |
| 3 | **Aadish International** B-72/4, Wazirpur Industrial Area, New Delhi. Phone:+91-9810157573 | Manufacture CR and RR for making rubber sheets, light weight tires, flaps, etc. |
| 4 | **Fishfa Rubbers Ltd.** Plot No- G-1360, GIDC, Metoda, Near Rajmoti Oil Mill, Rajkot, Gujarat - 360021. Phone: 91-2827-287579, Fax: 91-2827-287578 | Produces RR from scrap NR tubes, butyl tubes, This is one of the leading RR industries situated in Gujarat, |

| | | |
|---|---|---|
| 5 | **Sapphire Reclaim Rubber Pvt. Ltd.**<br>Bhoomi Industrial Area, Plot No. 1/44, n.h. 8-b, Shapar (Veraval), Rajkot, Gujarat – 360024. Contact: Mr. Ketan Kasundra; Phone: 91-281-2225088 | Produces butyl RR forautomobile tubes, tire inner liners, hoses, sound dampers, adhesives, and a wide range of molded goods. |
| 6 | **Omkar Rubber**<br>Vijapur, Gujarat – 382870. Contact: Mr. Arvind Phone: +91-02763-224168, Fax:91-02763-221404 | Manufacturers of white reclaim rubber |
| 7 | **Balaji Rubber Industries Pvt. Ltd.**<br>SURYA TOWERS", 12, Maravaneri, II Cross, Salem - 636 007, Tamil Nadu. Phone: +91-427-2452269, 4047677, 2452271, 2452274; Fax: +91 - 427 - 2452270, E. Mail: info@rubberreclaim.com | Manufacture whole tire RR like Superfine Grade WTR 5504, Superfine Grade BRI 504, Medium Grade BRI 522, Coarse Grade BRI 540 and butyl RR, rubber powder/granules and specialty RR. |
| 8 | **Sapphire International**<br>111 Basti Peer Dad, Leather Complex Road, Jalandhar, Jalandhar, Punjab. Contact: Mr. Achint Kumar, Phone: 91-181-2201954 | Manufacture latex RR from waste gloves, condoms and other latex wastes. |
| 9 | **Talampally Rubbers Pvt. Ltd.**<br>Plot No.139, 140, 141, Kolar Industrial Area, Bidar, Karnataka – 585401. Contact: Mr. Santosh Kumar Talampally,<br>Phone: 91-8482-232771 | Manufacture RR for supplying to manufacturers of solid tractor tires, bus and truck tires, molded products, rubber mats and flaps, flooring material, tire retreading, auto/bicycle tires and tubes. |
| 10 | **Punjab Rubbers**<br>Opp. Jalandhar Kunj Gate No.1, Kapurthala Road, Jalandhar, Punjab – 144013. Contact: Mr. Rahul Mehra; Phone : +91-181-2650360 | Monopoly product with very fine quality having ~50 % active rubber contents. Used in colored tires and footwear industry. |
| 11 | **Star Polymers Inc.**<br>27 Basant Avenue, Maqbool Road, Amritsar, Punjab – 143001.<br>Phone: +91-9855200970, +91-183-3206037, 2783522, 5008845, Fax: 91-183-3206037, 2400085, 2783522,<br>E. Mail: gagan@starpolyrubber.com | Highly refined triple strained RR for truck tires, tread rubber and molded components. Also moderately refined RR for auto tires, mats and molded goods. Lightly refined RR for beltings, sheet, tire flaps, floor/coir mat, etc. |
| 12 | **Swani Rubber Industries**<br>B-13/14, Industrial Area, Phase-1, Mohali, Punjab – 160051. Contact: Mr. Deepak Sharma, Phone: 91-172-5013316/2273242, Fax:91-172-2271385 | Manufacturers of reclaim rubber |
| 13 | **Jai Bajrang Rubbers Pvt. Ltd.**<br>VPO Khosa Pando, Zira Road, Moga Punjab, Punjab. Contact: Mr. Ashish Thapar, Phone: 91-161-5028018, Fax: 91-161-2727055 | Manufacture & export RR of different grades. |
| 14 | **Skyfa Rubbers Pvt. Ltd.**<br>Rajkot, Gujarat – 360311. Contact: Mr. Jasmin; Phone: 0281-91-281-3016739 | Manufacture and export butyl RR from butyl tube. |

| | | |
|---|---|---|
| 15 | **Aryan Rubber Industries**<br>K-39/16, Street No. 3, Samaipur, New Delhi 110042.<br>Phone: 91-11-27566545, Fax: 91-11-27566545 | Exporter, supplier and manufacturer of chlorobutyl RR, EPDM RR and butyl RR. |
| 16 | **Jijas Rubbers**<br>Pulimoottil Building, North Kalamassery, Ernakulam, Kerala – 683104. Contact: Mr. M. Ashokan/Mr. Sishore Ashokan, Phone: 91-484-2543101 | Leading manufacturer & supplier of RR. |
| 17 | **Sun Exims**<br>Sco 37, New Grain Market, Backside Arora Palace, Gill Road, Ludhiana, Punjab –141003. Contact: Mr. Ashish Thapar, Phone: 91-161-2727055 | Manufacture natural and butyl RR obtained from scrap of natural or butyl rubber tubes and tires. |
| 18 | Arihant Oil & Chemical<br>10, Shopping Center, Mayapuri Phase-1, Delhi 110064.<br>Contact: Mr. Sumit Jain (Director/CEO/GM)<br>Phone: 91-11-28117827, Fax: 91-11-41833671 | Manufacture crumb rubber, butyl RR, reclaiming agent and rubber chemicals. |
| 19 | **Super Reclaim**<br>Industrial Area "C", Village Jugiana, G.T. Road, Ludhiana -141420, Punjab. Contact: Jagdish Karnani (Director)<br>Phone: 91-161-2510507, Fax: 91-161-2512191 | Manufacturing butyl reclaim rubber. |
| 20 | **Cochin Rubber Complex**<br>Industrial Area, EDAYAR, Binanipuram P.O. Kochi 683502, Kerala. Contact: Roy Mathew, Phone: 91-484-3252401, 0484 3252401 | Manufacturer of white reclaim rubber |
| 21 | **Super Polymers**<br>Warayana Industrial Complex, Leather Complex Road, Near Shiv Shakti Mandir, Jalandhar 144001, Punjab.<br>Contact: Nitin Puri, Phone: 91-181-2650677 | Manufacture RR from tire curing bladders, whole tire and synthetic rubber products. |

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CHAPTER-4

# Research required In Recovery of Plastics from ELVs

# Research required In Recovery of Plastics from ELVs

## 1. Overview of End of Life Vehicles

Every year, the number of vehicles that are reaching the end of their life is increasing and their disposal is posing serious issues as they are a major source of hazardous and toxic waste. About 25% of a vehicles waste is hazardous. Efforts are on to ensure that generation of toxic wastes from these vehicles are reduced by promoting the concept of reuse, recovery and recycling.

About 75 percent of the end-of- life vehicles are recyclable mainly in the form of steel, aluminum and other metals. .The rest is considered waste and generally goes to landfills.

## 2. Principles of recycling of ELVs

Recycling plastic parts of vehicles can greatly benefit the environment, since recycling plastics of any kind will help reduce the amount of petroleum waste and noxious gases, such as chlorine, that are released into the air.

The main goal of automotive industry is to harvest automobile components for reuse and to recycle the remaining valuable materials that can be used in the manufacturing of new basic materials such as steel, aluminum, plastic, copper, and brass.

Auto recyclers remove parts such as engines, transmissions, doors and bumpers for reuse in other vehicles. Other parts that can also be re-manufactured include starters, alternators and water pumps. Batteries, catalytic converters, tires and some plastics are removed and they are recycled into new products. Fluids such as engine oil, coolant, and gasoline are carefully managed to prevent leakages into the environment by storing them in double-walled tanks and/or secondary containment prior to being reused or recycled.

End of life vehicles are retrieved in five significant steps. They are,

- Draining automotive fluids
- Removing ndamaged parts for resale or re-manufacturing
- Removing of catalytic converters and batteries for recycling.
- Dismantling other parts
- Sorting
- Processing reusable parts
- Grating the rest of the body.

## Draining:

This is the first step that is taken when a ehicle comes for disposal. After removing the tires and cleaning the engine area, the automobile fluid is drained. The parts which are not difficult to access from the exterior are dismantled after draining, which includes body parts that can be retrieve for example bumpers, plastic fuel tank and auxiliary compilations.

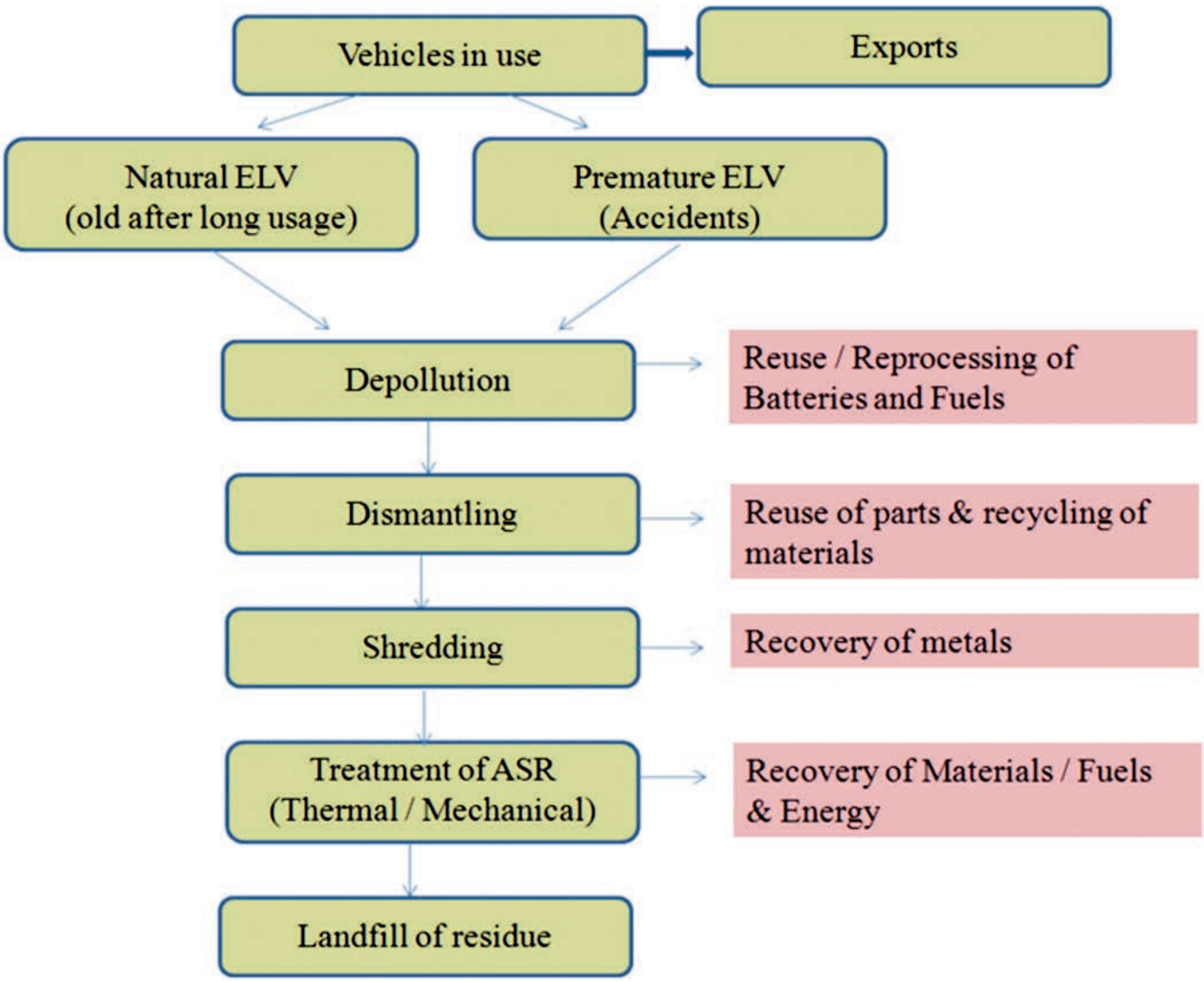



**Fig. 1: Process flow of recycling of end of life vehicles**

## Dismantling and Sorting:

In dismantling process, parts of the vehicle are dismantled as shown in the figure. Some parts are practically wear-free and therefore it is suitable for use again in the existing form in the similar or related model of vehicles. Plastics are sorted, cut into pieces and passed on for reprocessing. The steel and nonferrous metals are then reprocessed and the rest of the body is grated.

## Shredding & Pulverizing:

After removing the recyclable parts such as bumpers (recycled into splash plates or into new bumpers), air bags, batteries, fuel tanks, tires and sometimes even seats, the dismantled vehicle is sent to the shredding facility.

These capital intensive plants are complex material separation operations. The shredder pulverizes the vehicle into fist sized pieces of materials, which are sent by conveyors to sophisticated separation technologies, including magnetic separation, eddy current, laser and infrared systems. The metal recovered by these plants becomes raw material feedstock for steel mills, electric arc furnaces, aluminum and other nonferrous metal smelters to manufacture a variety of products including new vehicles.

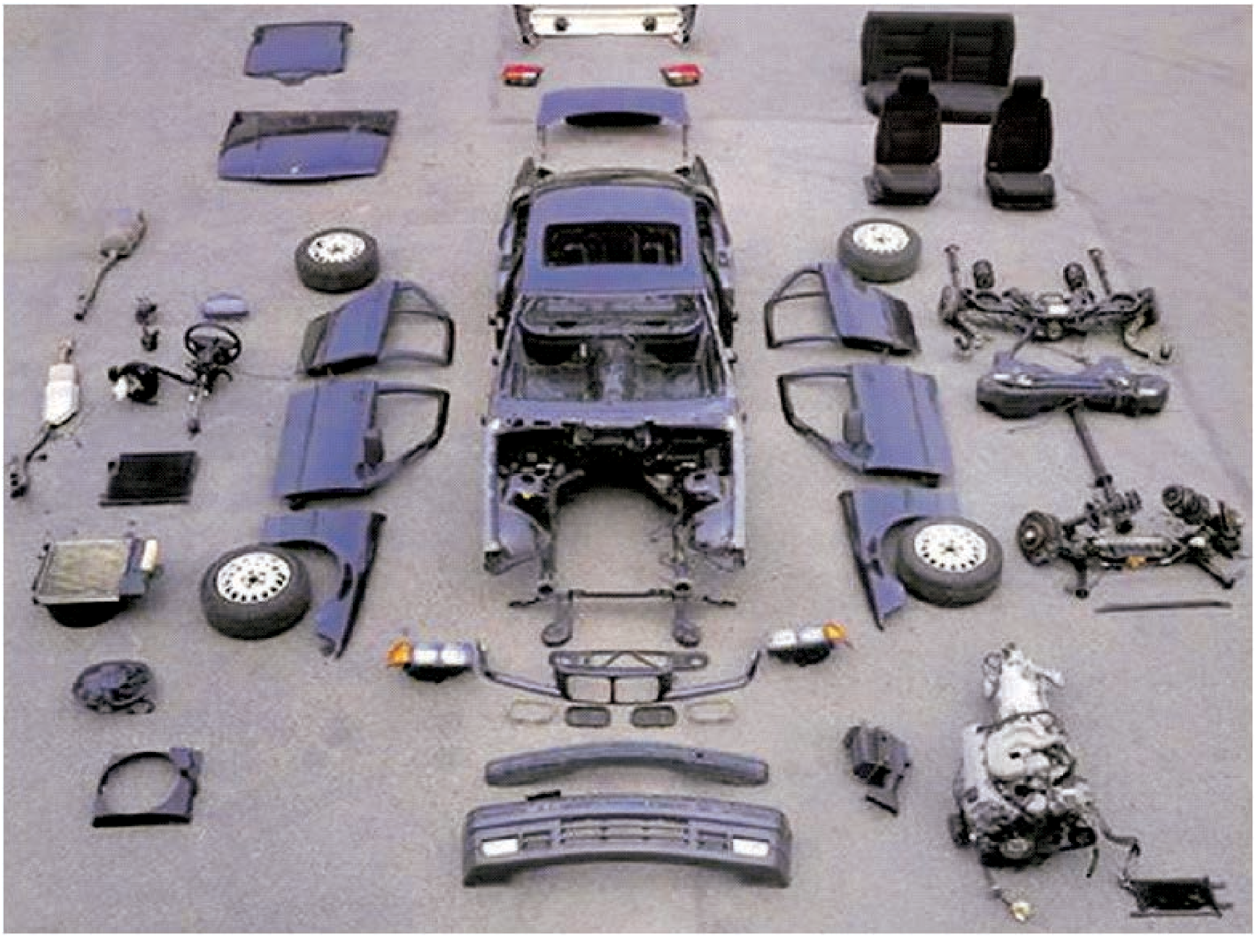


**Fig. 2: Dismantling and Sorting of car**

## INDIAN EXPERIENCE – ELV AUTORECYCLING AT PUDHUPET

## VOLUNTARY SCHEME

### Dismantling of plastics parts from an ELV @ Pudhupet



### Sorting of plastics parts of an ELV at Pudhupet


## Shredded residue:

It is a complex mixture of materials which are extremely hard to separate. It also has a large number of incompatible materials, including moisture, wood, metals, glass, sand, dirt, automotive fluids, plastics, foam, rubber, fabrics, and fibers. In addition, shredder residue is known to contain varying amounts of heavy metals, PCBs, and fire retardants.

Fig.3: Shredded residue

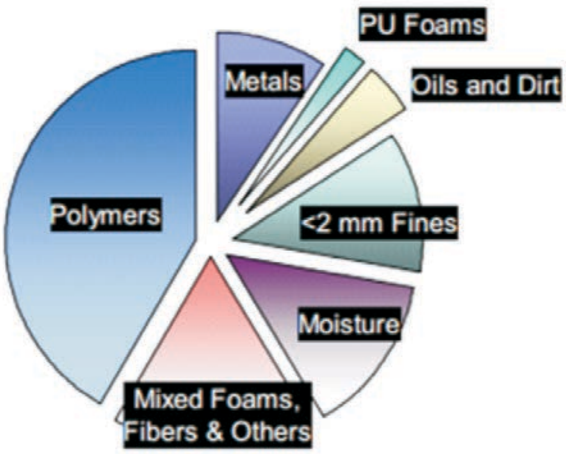



Fig.4: Composition of Shredded residue

## Shredded residue disposal:

The main problem facing the current automobile recycling industry is the way automobile shredder residue is disposed. Two methods of shredded residue disposal are practiced: landfill and incineration.

Land filling continues to be, by far, the most widely practiced technique for disposing of shredder residue. However, the disposal of shredder residue in landfills is already cost-prohibitive in parts of the world or banned altogether. Even though shredder residue is a preferred daily landfill cover, it is still required to be mixed with calcium carbonate ($CaCO_3$) lime to prevent leaching into ground water.

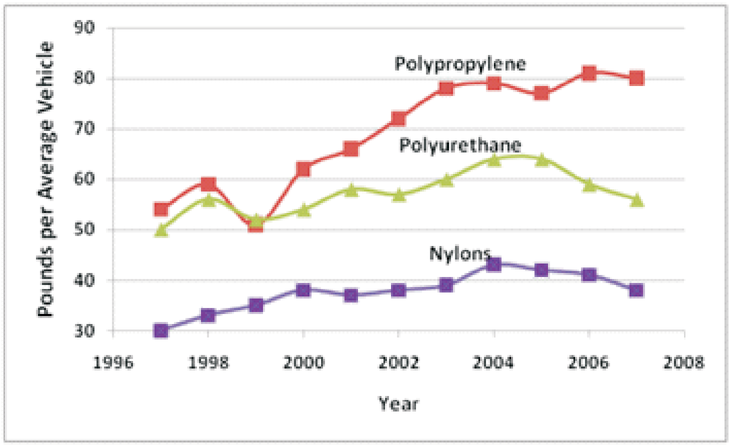
## 3. Composition of ELVs by weight

The following table shows the composition of end of life vehicles by weight.

**Table 1: Material composition of ELVs**

| **Material / Components** | **% by weight** |
|---|---|
| Ferrous metal | 68% |
| Non Ferrous Metal | 8% |
| Plastics & Process Polymers | 10% |
| Tires | 3% |
| Glass | 3% |
| Batteries | 1% |
| Fluids | 2% |
| Textiles | 1% |
| Rubber | 2% |
| Others | 2% |
| **TOTAL** | **100%** |

Approximately 10% of vehicles aremade up of plastics. Usage of plastics is steadily growing due to its good impact and corrosion resistance, low weight and cost. In the last 10 years, the proportion of plastics and its composites in vehicles have increased from 6% to 10%. Fig. 5 shows the use of different polymers in vehicles over the last two decades. The use of Polypropylene in vehicles has widely increased from 50% to 80% within a period of 12 years.



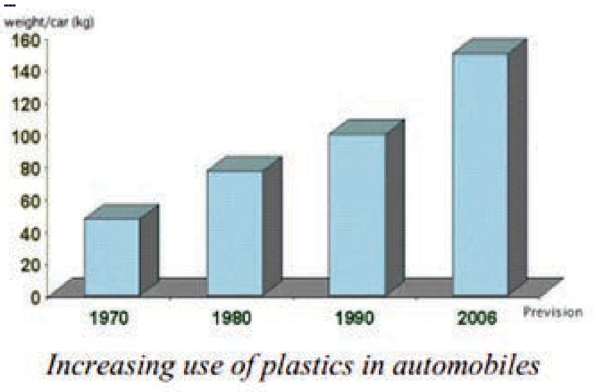




**Fig. 5:Representation of increase in use of plastics in last two decades**

**History- a glimpse into the past:** The first automobiles came out in 1900 and for many years cellulose nitrate sheet was used as side curtains in horse and buggy rigs. Cellulosics were later used for moulding the steering wheel, and some phenolics and ureas were employed for electrical components and control knobs.

The real plastics revolution in automotive industry began in 1950 when thermoplastics made their debut, starting with ABS and going on to polyamide, polyacetal and polycarbonate. The introduction of alloys and blends of various polymers made it possible to tailor properties to fit certain performance requirements that single resin could not provide. The first was probably polystyrene-modified polyphenylene oxide.

Thermo-setting composites made considerable inroads into the automotive industry in 1960s, first in the form of complete monocoque bodies, and in glass fiber reinforced polyester resin, and later with factory-made polyester/glass combinations that could be moulded by compression and a form of injection: Sheet Moulding Compounds (SMC) and Bulk Moulding Compounds (BMC).

Since those beginnings, the use of plastics components in automobiles has undergone enormous growth - particularly during the last 20 years. Vehicle manufacturers are able to cut down costs thanks to the ability of plastics to be moulded into components of complex geometries, often replacing several parts in other materials, and offering integral fitments that all add up to easier assembly, helping to reduce costs on the assembly line.

The light weight nature of plastics has proved to be a great boon to the automotive industry, not only in reducing overall weight of cars, in order to reduce fuel consumption to legislated limits, but also in allowing more sophisticated systems and components - including safety systems - to be included in the modern car, without paying the penalty of additional weight.

In practical terms, this has allowed more sophisticated heating, ventilation and climate control systems, and in-car entertainment and information systems to be installed in the cars of today, apart from providing the additional safety of airbags - all without adding to overall weight. Without plastics, it is estimated that today's cars would be around 200-300 kg heavier. That saves half a liter per 100 km which represents 750 liters for a car with a lifetime of 150,000 km.

Many types of polymers are used in more than 1,000 different parts of all shapes and sizes. Although up to 13 different polymers may be used in a single car model, just three "families" make up some 66 % of the total plastics used in a car: polypropylene (32 %), polyurethane (17 %) and PVC (16 %).

A quick look inside any model of car shows that plastics are now used in exterior and interior components such as bumpers, doors, safety and windows, headlight and side view mirror housing, trunk lids, hoods, grilles and wheel covers. The passenger compartment is dominated by plastics.

Recent years have seen a veritable invasion of the under-bonnet region by plastics with the widespread adoption of large (1.5 to 2.5 kg) mouldings for air intake manifolds. These are not only half the weight of their metal counterpart but also optimize the airflow to the engine, helping to make it more efficient, and also playing a valuable role in reducing noise levels. Moulded in glass fiber reinforced nylon, these are highly sophisticated parts, marking the true arrival of plastics as engineering materials in their own right.

## 4. Plastics in vehicles

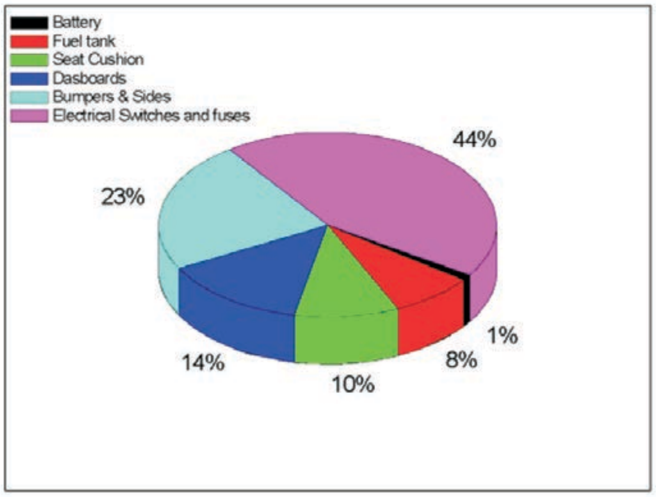



**Fig. 6: Average distribution of plastics in cars**

**Bumper:** Bumper is the first identified part of a vehicle in any head on collision. There are front and rear bumpers. They also protect both the front and back sides of a car against mud, corrosive fluids, etc.

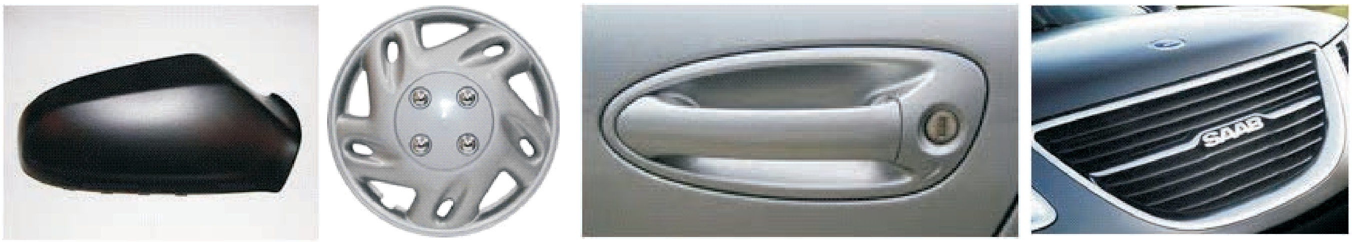
**Fig. 7: Average distribution of plastics in cars**

**Door Panel & Seat:** Seat and door panels made of polyurethane foam suits the needs for auto upholstery the best. The ability to recycle, reasonable costs and flexibility makes them the perfect choice.


**Fig. 8a Door Panels**

**Fig. 8b Seat**

**Trims:** The term trim is used for mirror cases, wheel covers, door handles and radiator grilles. These parts in automobiles are largely made of plastics to increase usage and styling of car's exteriors. Plastics such as PVC, PP, PC, PUR and PS are often used.




**a) Mirror case** **b) wheel cover** **c) door handle** **d) radiator grill**

**Fig.9: Trims**

**Intake manifold:** Fig. 10 shows PA intake manifold of the engine.

**Fig. 10: Intake Manifold**

**Wash lid and tank:**

**Fig. 11: Fuel tank**

**Air duct and consoles:** Helps in supplying same amount as air or heat to rear passengers as that of front passengers. Plastics provide best flexibility in manufacturing despite its complicated shape.

## 5. Separation of plastics from shredded residue

Recovery of materials for recycling to primary products: Individual parts are separated from shredder residue at high purity and without degradation of their properties, with the intent of using them for blending with virgin material or with other re- grind plastics

Recovery of materials for recycling to Secondary products: The thermoplastics content of the shredder residue is processed for the production of secondary products

Following are the methods involved for the separation of particles from shredded residue.

### (i) The Argonne Mechanical Separation System

The Argonne mechanical separation is a continuous dry mechanical separation process. The facility comprise of size reduction equipment, size/shape separation equipment, an eddy current separator, high intensity magnets, air classifiers, and other material handling equipment. The equipment is designed to separate a polymer concentrate with high recovery rates, and to recover any residual metals present in the shredder residue.

**Step 1:** In mechanical separation, highly dense materials (large objects) are first removed for metals recovery and to protect the downstream equipment, including the shredder from damage.

**Step 2:** The shredder residue is shredded to about 1 in. and then conveyed to a two-stage trommel. In the first stage, fines (<1/4 in.) are removed and in the second stage, thin planar and semi-planar pieces are removed through adjustable slots. This fraction consists primarily of plastics, rubber, some metals, and some small foam and fiber pieces.

**Step 3:** The remaining material is then size reduced to separate materials from one another, particularly the metals and plastics that are trapped in the shredder residue.

**Step 4:** The ferrous metals are recovered by the high intensity magnet and the non-ferrous metals are recovered by an eddy current separator.

**Step 5:** The de-metallized polymer concentrate is then granulated to an average particle size of 1/4–3/8 in. and processed on a vibrating screen to remove fines and air classified to remove residual PUF foam pieces, dust, and other light particles.

**Step 6:** The polymer concentrate recovered from shredded residue are subjected to analytical characterization to figure out its composition.

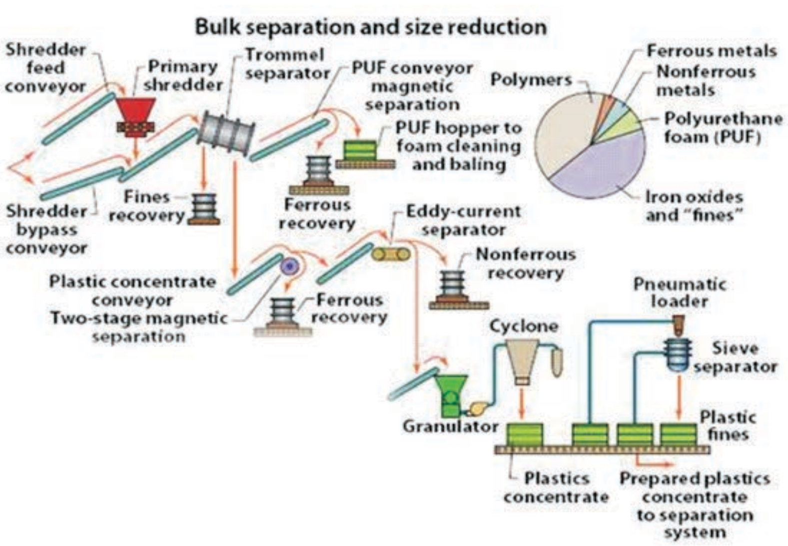



**Fig. 12: Mechanical separation from shredded residue**

## 6. Recycling Process

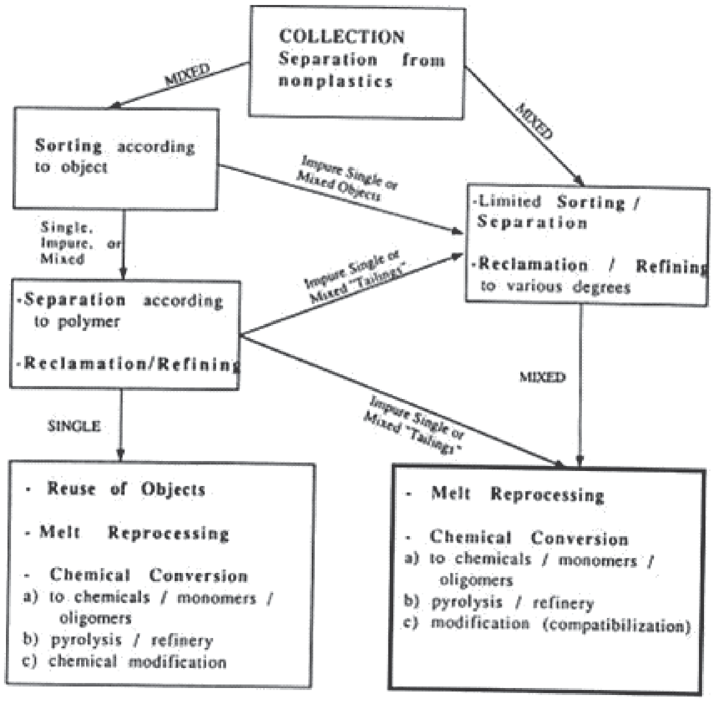



**Fig. 13: Recycling Process – Flow diagram**

**Primary recycling** is the conversion of waste plastic into a new product similar in character to the original one.

**Secondary recycling** is the conversion of plastic wastes into new products that have less demanding physical and chemical characteristics than the original product had. This "cascaded performance" approach is easier to accomplish than primary recycling. Plastic waste can be melted and moulded into new, non-food grade packaging products that are essentially 100% recycled resin.

**Tertiary recycling** is the recovery of basic chemicals and fuels from waste plastics. The technology is available to break down waste plastics to their original polymeric form, clean them, and produce a re-polymerized resin.

**Quaternary recycling** involves burning plastic waste to recover its energy content.

## 7. Recycling Technologies

Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products. Plastics wastes can be recycled by following methods.

a) Mechanical recycling

b) Feedstock or Chemical recycling

## Mechanical Recycling

Mechanical recycling is a method of processing the waste plastics by physical means into plastics products. The mechanical recycling process involves a number of operational steps:

- Separation of plastics by resin type
- Washing to remove dirt and contaminants
- Grinding and crushing to reduce the plastics'particle size. (conversion to flakes or pellets)
- Extrusion by heat and reprocessing into new plastic goods.

Mechanical recycling is the ideal recovery route for identical and relatively clean plastics waste flows, provided there is markets for the resultant recycled products. This type of recycling is mainly restricted to thermoplastics because thermo-sets canot be remoulded by heating.

### Feedstock or Chemical Recycling

Feedstock recycling of plastics (also termed as chemical or tertiary recycling) is based on the decomposition of polymers by means of heat, chemical, or catalytic agent. Chemical recycling or fedstock reprocessing means breaking a polymeric product into its individual parts (plastics or hydrocarbon feedstock –synthesis gas) and feeding them back as raw material to regenerate a new product.

### Feedstock recycling includes

- Chemical de-polymerizatin (glycolysis, methanolysis, hydrolysis, ammonolysis etc.)
- Gasification and partial oxidation
- Thermal degradation (thermal cracking, pyrolysis, steam cracking, etc.),
- Catalytic furious [?] and reforming
- Hydrogenation. (pyrolysis, gasification)

### 8. Convesion methods to produce Fuels

**Pyrolysis:** Pyrolysis is heating of waste in the absence of air (oxygen) and used to separate composite materials into their original constituents. The composites break down into gas, oil, fiber and a small amount of carbon. Te obtained oil and fiber can be reprocessed into composites.

Scrap plastics can be converted into fuel sources by the method of pyrolysis. Following are the steps involved in the conversion.

- **Pre-treatment:** Size reduction, cleaning and removal of moistue.
- **Conversion:** Pyrolytic process is used to convert scrap plastics into gas.
- **Distillation:** Gas is converted into Liquid.
- **Acid removal process –** removal of acids that form in the breakdown of some scrap plastics. These acids require removal because they ca be corrosive.
- **Separation/refining/final blending:** The final steps required to make this product consumer ready depending on the system design.

The following schematic diagram (fig. 14) explains the process of pyrolysis to convert plastics into fuels.

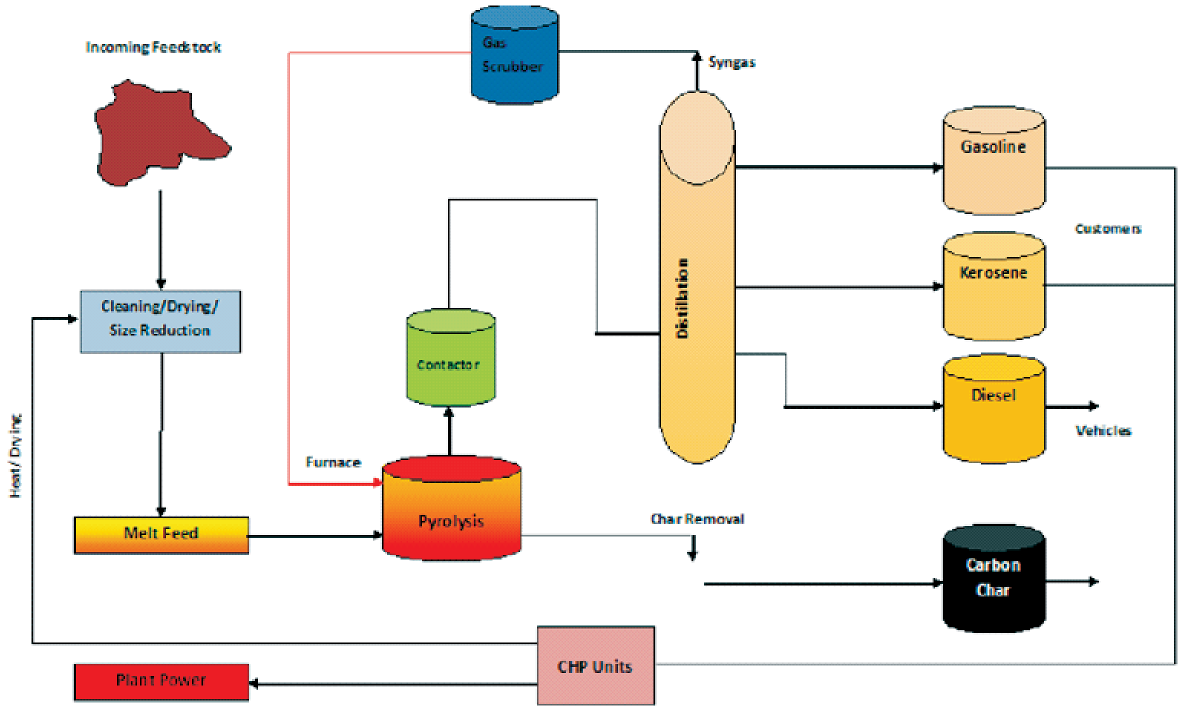



**Fig. 14: Pyrolysis Set up**

## Plasma Gasification

Plasma gasification is a process which converts organic matter into synthetic gas, electricity, and slag using plasma. Plasma gasification is a multi-stage process which starts with feed inputs ranging from waste to coal to plant matter, and can include hazardous wastes.

Plasma gasification refers to the use of plasma torches as the heat source, as opposed to conventional fires and furnaces. Plasma torches have the advantage of being one of the most intense heat sources available while being relatively simple to operate.

Plasma gasification involves the following steps for conversion.

- **Process the feed stock:** to make it uniform and dry, and have the valuable recyclables sorted out.
- **Gasification:** Extreme heat from the plasma torches is applied inside a sealed, air-controlled reactor. During gasification, carbon-based materials break down into gases nd the inorganic materials melt into liquid slag which is poured off and cooled. The heat completely destroys the hazardous substances.
- **Gas clean-up and heat recovery:** The gases are scrubbed of impurities to generate clean fuel, and heat exchangers recycl the heat back into the system as steam.
- **Fuel production:** The output can range from electricityto a variety of fuels as well as chemicals, hydrogen and polymers.

## 9. Recycling of end of life vehicles

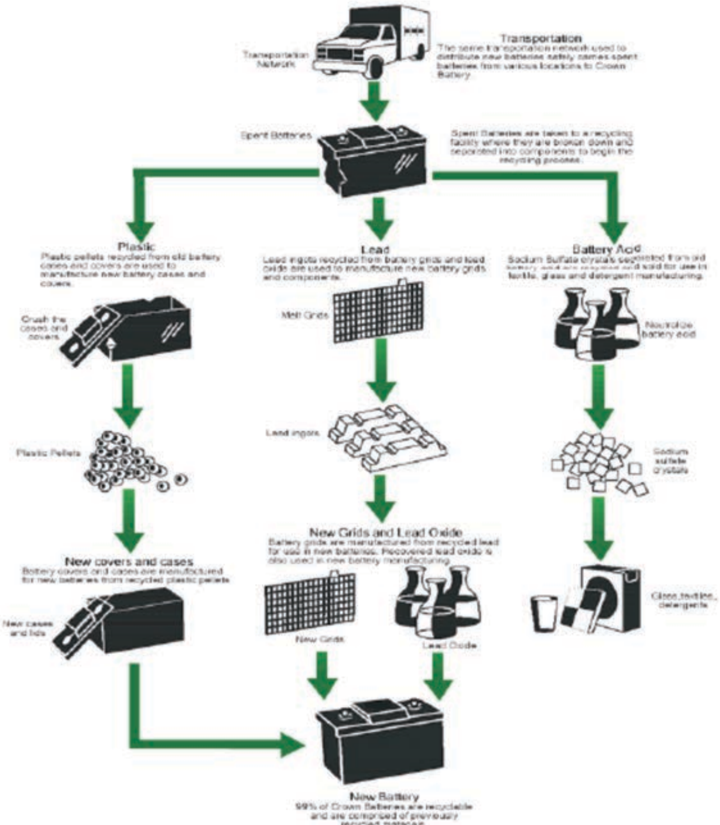



**Fig. 15: Systematic flow of plastic battery recycling.**

**Fig. 16: Scrap Car parts**

Fig. 17: Scrap Car parts

## 10. Identifying and sorting plastics

Plastic is one of the main engineering materials that need special care and attention so far as their waste management is concerned. Different grades of plastics cannot be mixed in the recycling process. Few mixed types can result in a total break down or different chemical, mechanical and physical properties of new product. The situation can become worse if for example a Polyvinylchloride, PVC is mixed with other plastics. PVC emits hazardous chemicals like chlorine.


Fig. 18: Recycling Code for plastics

Plastics are identified by unique codes. However, they are not always seen and when there are large volumes of waste to be sorted, it creates more problems. Besides manual sorting, density –based and selective dissolution are other methods used to sort out plastics.

It is usually difficult to tell exactly which type of plastic is present solely from the type of product. A simple burning test can be done; an infrared analysis may be carried out to help ease the problem of identifying types of plastics. This is usually the most problematic stage in plastic recycling.

a) **Manual sorting:**

The process of identifying waste plastics of different materials by people with a "trained eye" while the materials are being moved by them is known as manual sorting. The materials are recognized by identification codes as given in Fig.18 and by the different distinctiveness of the plastics that differentiates it for visual identification.

**Fig. 19: Manual sorting of plastics**

b) **Density based sorting:**

Density based technique of sorting is carried out in a hydro cyclone or float sink tank. However this approach is not good for polyolefin as their densities are very similar. Since their specific gravities overlap, it is also not viable to differentiate between PVC and PET. Also there is a possibility for the density to be altered by diverse fillers in the materials, which renders it difficult to ensure perfect separation.

In the float-sink severance, the plastics are positioned in a fluid that has a density in-between the materials making it possible for less dense materials to float and the heavier to sink. Common fluids used are: water for the separation of polyolefin from other plastics.

c) **Sorting by selective dissolution:**

Selective dissolution sorting is supported by batch dissolution of assorted plastics using solvents. To obtain a complete separation of the plastics a careful management of temperature and selection of solvent is needed. Identical solvent can be used for taking apart PS, LDPE, HDPE, PP and PVC, since these plastics melt at different temperatures.

PS dissolves almost immediately when the plastics are added to the solvent tank. The PS solution is drained and another batch of solvent at a higher temperature of about 750°C is added to dissolves LDPE. The temperatures keeps increasing till about 1200° C. If PVC and PET are to be separated, a mixture of solvents is used in which PVC dissolves at a lower temperature than PET.

It is very difficult to identify plastics that are painted. One way to tackle this problem in developed countries has been directions from stakeholders to manufacturers to visibly give the detailed material information before selling products out.

Many different types of plastics may look identical, or one type of plastic may appear to have several physical and chemical characteristics depending on the type of additive that has been used. Detailed chemical tests, such as infrared analysis, may be needed to make a definite identification of a polymer.

## Polymer Recovery from Auto Shredder Residue

Normally, most metallic parts of ELVs are recycled while components made of plastic or other non-metals are shredded and disposed in landfills. As more and more vehicles are using composite materials, the percentage of materials sent to landfill is increasing in an alarming rate.

It is mandatory to reduce the quantity of polymer/polymer composite materials sent to the land-fills. Many more efficient methods are there to segregate polymers from ASR, which are discussed in the following sections.

## 11. Review of ASR Recovery Process

The ELV treatment process is shown in figure 20. After the steps of de-contamination, the vehicle is pressed and then shredded by a large cutter to release ferromagnetic materials. ASR is a complex mixture of materials that includes a variety of plastics, fibers, rubber and sponge with minute traces of metals.


**Fig. 20: ASR process**

Although metallic materials can be recovered effectively, the remainder is still highly mingled within the ASR, which makes recycling and recovery very complicated. Its density and moisture content can vary from different recyclers and is dependent on the types of white goods that are shredded with the automobiles.

Following table shows that the amount of recovery could be 12% (by weight of ASR). As there are still valuable metals contained within ASR, there will be a need to further investigate the ferrous and nonferrous metal recovery process together with a method to recover polymers.

In order to tackle this problem with ASR, the root cause has to be understood first, which in this case, is plastics. With the particle size reduced, the mixture can then be run through a magnetic and eddy current separator for an additional filtering, reclaiming more metals in the process. The majority of metals in ASR are easy to reprocess.

| Material/component | Composition (% by weight) |
|---|---|
| Paper | 2% |
| Wood | 3% |
| Non ferrous metal | 4% |
| Wire harnesses | 5% |
| Rubber | 7% |
| Glass | 7% |
| Iron | 8% |
| Fabric | 15% |
| Urethane foam | 16% |
| Resins | 33% |
| **TOTAL** | **100%** |

The major obstacle is the complexity of segregating the different polymer types since many plastics have different configurations such as filler content, additives and colorants, as each plastic piece found in an automobile has its own specific composition to address performance requirements.

Very often, ASR is contaminated with metal clips, screws, foam and bonding agents, making segregation a very costly and labor intensive process. Another issue is the value of mixed plastics, as they have no real industrial application due to their degraded physical properties.

In 2008, Hoffman proclaimed that recycling efforts in the automotive industry is driven by the high value of metals, not polymers. This represents a major challenge since a satisfactory recycling technology does not exist, causing its recycling to be economically unattractive. These factors tend to make many recyclers to overlook the area of polymer recovery.

The current process of recycling and recovery of ELVs can achieve 95% of all ELVs recovery. 70% to 75% of these recovered materials are recycled. However, because material recovery is always determined by how much the recovered material is worth to the buyer and the ease of metal segregation by magnetic and eddy-current separators, metals forms the largest portion of the recovered material.

It is worth mentioning that the value of pure unmixed polymers is in fact higher than steel. One ton of polymers (PET, ABS, PP, PU) in a clean sorted condition is worth approximately AU$200–AU$500 whereas one ton of scrap steel is worth only about AU$130. But, the process to obtain plastics in a "clean and sorted state" is highly labor and energy intensive.

However, the increasing cost of fossil fuels have made the price of virgin polymer to increase, causing the potential value of recycled polymeric materials of good quality to increase. These trends and the arrival of the 2015 European ELV directive are drivers and indicators of the need to find an efficient yet economical method of polymer segregation and recovery.

## Current Segregation Methods

This section reviews some of the more popular polymer segregation methods that are used in the recycling industry currently. Despite technical feasibility of these methods, adoption in industry is low.

### *Float Sink Tank*

The float sink method relies on the concept of how the specific gravities of various materials are relative to the specific gravity of the base solution. This method is one of the simplest available techniques used to separate various materials and in recent years has been used to segregate polymeric materials. If polymers have very close specific gravities, it is possible to add a swelling agent to increase the volume of either one of the targeted polymers, thus effectively reducing its density.

A major drawback of this method is that it is a wet separation process and thus requires drying of the recovered polymers, often overnight in a drying oven at 45 °C, This process cannot be hastened by increasing the temperature of the oven as the polymers could soften should the temperature be set too high.

Another drawback is that it takes a fair amount of time for the polymeric particles in the mixture to settle and it also requires one separation step for each polymer, making this a multi-stage system which makes it a very slow process.

In addition to being slow, after one polymer has been recovered, the residual mixture will have to be washed before being introduced into the float sink tank again to prevent contamination of the base solution. Such processes consume large amounts of clean water.

### *Cyclonic Air Separator*

The cyclonic air separator harnesses the forces of rotation and gravity to separate mixtures without the use of any specialized filters. This process involves the creation of high-speed rotational air flow within the cylindrical container. Particles that are heavier, thus having more inertia, will be unable to follow the airstream and will fall to the bottom of the conical section allowing the heavier and denser particles to settle out faster than the lighter ones.

By adjusting the airflow into the system, particles of different weights can be separated. This process is currently used in filter-less air cleaners to remove dust particles from the environment. This system requires certain parameters to be met in order to be successful. For preparation of the separator, the particulates have to be very dry and have to be of very similar size to each other, requiring the need of a drying oven and a hammer mill, both of which have relatively high energy consumptions.

### *Froth Flotation*

In the froth floatation technique, polymer segregation is achieved by suspending plastics in an aqueous solution of plasticizers and surfactants that makes certain plastics hydrophobic, thus allowing air bubbles to attach themselves on plastic flake when the mixture is aerated. Different polymer types can be made to float by changing the surfactants (collector chemical).

For example, when pine oil reacts with copper, it allows air bubbles to attach themselves to the copper and make it float to the surface. Stuckrad et al. used a floatation method by pre-treating of the surface of the materials. Drying of the materials after separation was required. Argonne National Laboratory developed a 6-stage froth floatation system to segregate polymers like Polyolefin, ABS and Nylons from plastic mixtures.

As this method is a wet process it has very similar disadvantages to the float-sink method. It requires settling and drying times and the cleaning of residual solutions from the previous process to prevent contamination, and lastly it is also a multi-stage system, as only one material can be separated at a time.

***Manual Sorting***

The manual sorting process involves the identification and sorting of different polymer types by people who are trained to pick out different plastic types while the mixture is passing by them on a moving conveyor platform. These polymers are identified by their “Resin Codes” and by other visual characteristics that allow them to be identified by human sight.

Swedish car manufacturers have started marking all their plastic components weighing more than 50g with individual resin codes since the 1990s. This method of separation is sometimes facilitated by the use of various wavelengths of light.

For example, under ultra violet exposure PVC can be easily discriminated from PET, since PET appears very bright, almost incandescent. On the contrary, PVC will take on a dark blue appearance. This form of segregation method is used for the separation of plastic bottles and where the components in question are relatively large enough to justify the extra cost of time and effort involved since this technique is very labor intensive.

The major drawback of this method is high labor costs. It requires workers to work in an undesirable working environment and is very prone to human error, often resulting in lower purity of the sorted polymer which can only be used for low-value applications. Since this process is only capable of sorting larger sized polymer products, it is unsuitable for segregating ASR.

***Mid-Infra-Red (MIR) Spectroscopy***

Infrared light is one of the most commonly used light spectra for spectroscopy related sorting processes. MIR based sorting methods are currently used in the automotive industry to sort common components like plastic bumpers and radiator grills which are carbon-black filled polymers, and has the capability of identifying the plastic type in under 10 seconds.

This technique is very similar to manual sorting. The only difference is that the operator requires very minimal training as all information regarding the scanned plastic component is displayed on a computer screen. For the operator to identify a component's polymer type the component has to be placed against a sampling reader and activate it. MIR light is then reflected off the component's surface and analyzed by the computer to determine the identity of the polymer.

Although MIR spectroscopy is fast and reliable, its drawback is that it uses a reflectance technique. Surfaces that are painted, or treated or is rough will interfere with the readings. After all, ASR is a shredded waste. It will be impossible for the samples to have a smooth surface.

Most infrared identification methods are designed to track larger polymer components like plastic bottles and are not suited for identification of small ASR flakes and as this system was originally intended for single part identification and requires manual positioning of the component on the sensor, trying to automate this system will prove almost impossible.

***Electrostatic Separation***

Over the years various types of electrostatics systems were employed in industries, the more common ones being the free-fall followed by the roll-type electrostatics system. These methods work on the fact that various polymers exhibit different behavior when subjected to an electrostatic charge. This process has the ability to sort polymers from metals and has potential for separating contaminated polymers in a dry process with ease as compared to wet separation methods.

Many of these methods are filed as patents but they are not used commercially. Beck et al. described an apparatus that separated mixed fragments of plastic materials. The apparatus was still experimental and was not designed for large-scale industrial polymer separation.

The separator developed by Stencel et al. used two opposing pressurized fluid streams to charge the polymer particles. The particles rebounded and hit an electric charged chamber with different ports of charge attractions. However, there is serious doubt that this method works.

Osing et. al. described a process that fragmented ASR into different types of materials. Electrostatic separation was proposed to apply to non-magnetic or uncoated particles. No details of how the electrostatic separation would be carried out were included in the patent.

Geilser et al. used a free-fall mechanism through which different polymer materials were attracted to either side of the chute. The collector had an angle adjustment to allow for variation of location of fall.

More serious separator designs are found in the mid 2000s. Inoue et al. separated PP and PE by triboelectric charging of the materials and applying centrifugal forces to throw them into three collectors: one for PP, one for PE and one for a PP and PE mixture. There was a problem of jamming at the feeder.

Mankosa et al. described a two-stage separation process of waste plastic materials. Some paramagnetic materials were added to the mixture. The paramagnetic materials influenced the properties of the polymers and they were then separated by a magnetic separator into different polymer streams. Each stream then went through a final separation process from the paramagnetic materials by electrostatic means.

Allen et al. used the difference of triboelectric charging properties of polymers and separated them by passing the particles under a rotating drum. Particles of the matching charge were carried away to the collector. Research is continuing on fluidized bed devices for separating tribocharged plastics.

Miloudi et al. investigated the sorting of the various types of plastics (ABS, ABS-PC, HIPS, PC) contained in information technology wastes with a conveyor belt arrangement.

These investigations show that the key to electrostatic separation method is not on the tribocharging of polymers. Effective electrostatic separation requires an efficient pre-agitation mechanism to present the materials to the electrodes.

## 12. Energy recovery byPlastic Waste Recycling Processes

Recycling or reprocessing of plastics is usually known as the process by which plastic waste material that would otherwise become solid waste are gathered, separated, developed and returned to use. According to the EU directive the amount of waste deprived from ELVs and going into landfill must be reduced to 5% by weight of the vehicle 0by 2015.

| | 2006 | 2015 |
|---|---|---|
| Reuse and recycling | >80% | >85% |
| recovering | <5% | <10% |
| Utilization in total | >85% | >95% |
| Final disposal at a dump | <15% | <5% |

Coming up with a resourceful and cost-effective approach to recycling of plastics waste that have accomplished their intended function necessitates collection, categorization and cleaning and as a final point recovery.

Identical plastic waste streams are recycled by mechanical (or physical) processes whereas diverse plastic waste flows are more treated or handled by chemical and thermal processes, for recycling of basic chemicals and /or generation of energy. The processes are briefly elaborated underneath.

Methods of recycling

1. Mechanical recycling
2. Monomerization
3. Blast furnace feedstock recycling
4. Coke oven chemical feedstock recycling
5. Gasification
6. Liquefaction
7. Thermal recycling

**a) Mechanical Recycling**

Mechanical recycling is the material reprocessing of waste plastics by physical means into plastics products. The sorted plastics are cleaned and processed directly into end products or into flakes or pellets of reliable quality. The ways used to reprocess post-consumer plastics may differ from process to process, but normally entail assessment for exclusion of contaminants or further arrangement, washing, grinding, drying and conversion into either flakes or pellets.

Pellets are processed by softening of the flakes of the dry plastic and then extruding them into tiny strands that are severed into minute, standardized pieces. The molten plastic is pushed and forced through a fine screen (filter) to get rid of any contaminants that may have escaped the washing cycle. The strands are cooled, cut up into pellets and stored for sale and shipment.

During the grinding or melting levels, the recycled material may be blended with new polymer or with additives. Mechanical recycling is the ideal recovery process for identical and relatively clean plastics waste flows, provided with the existence of end markets for the resultant recycled products.

**b). Feedstock or Chemical Recycling**

Chemical recycling or feedstock reprocessing means that a polymeric product could be broken down into its individual parts (plastics or hydrocarbon feedstock – synthesis gas) and that these could then be fed back as raw material to regenerate a new product.

Feedstock recycling include chemical depolymerisation (glycolysis, methanolysis, hydrolysis, ammonolysis etc.), gasification and partial oxidation, thermal degradation (thermal cracking, pyrolysis, steam cracking, etc.), catalytic furious and reforming, and hydrogenation.

In addition to conventional handlings (pyrolysis, gasification), new technological methods for the dilapidation of plastics, such as conversion under super-critical conditions and co-processing with coal are being tested. This practice of recycling is not suited for developing countries since it demands a lot of know-how, intensive resources and is quite difficult. Even in industrialized countries, it is still under development and is being put into practice by only few companies.

A number of industries have effectively developed and showed technologies many of which can recycle mixed plastics flows. There has been some interest shown in other areas of chemical recycling, such as depolymerisation of PET or treatment of PVC to make chemicals which can then be used in the production of new plastics (APME, 2002-2003).

**c). Energy Recovery**

Plastics as petroleum based material are rich in oil content even as a waste product. Power recovered from plastic waste can make a major input to energy production. Plastics can be co-incinerated with other wastes or used as source of fuel (e.g. coal) in numerous manufacturing processes such as cement kilns. The energy content of plastic waste can also be reclaimed through other thermal and chemical processes such as pyrolysis.

When plastic waste is frequently recycled, their physical and chemical properties would get depleted. Regular reprocessing could lead to second-rate and low quality products. A point could come when it would not be economically gainful to recycle any further. At such a stage, incineration with energy recovery would be an economically ideal option.

Following schematic diagrams (Fig. 21 to 26 represents the processes for energy recovery from plastics waste).

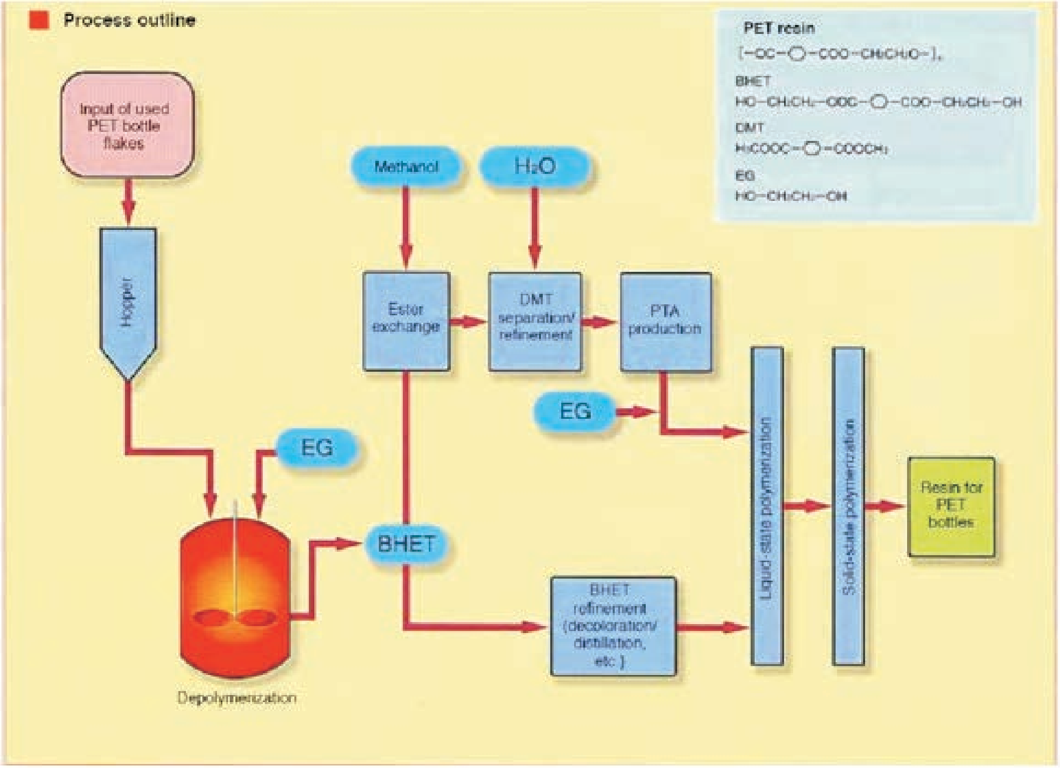



**Fig. 21: Monomerization**

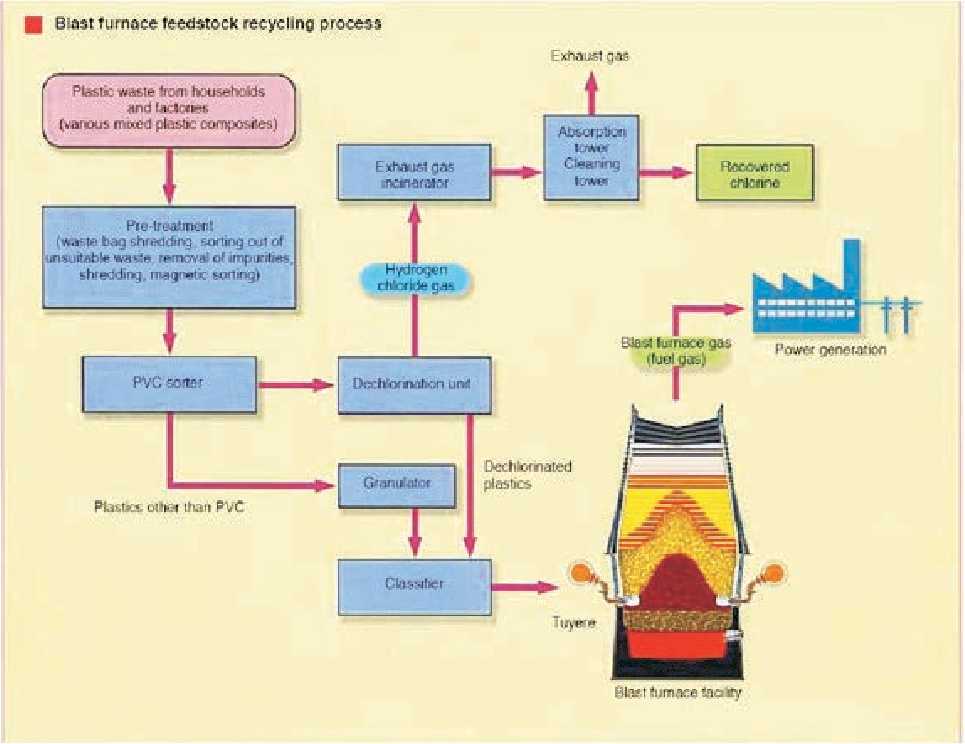



**Fig. 22: Blast furnace feedstock recycling**

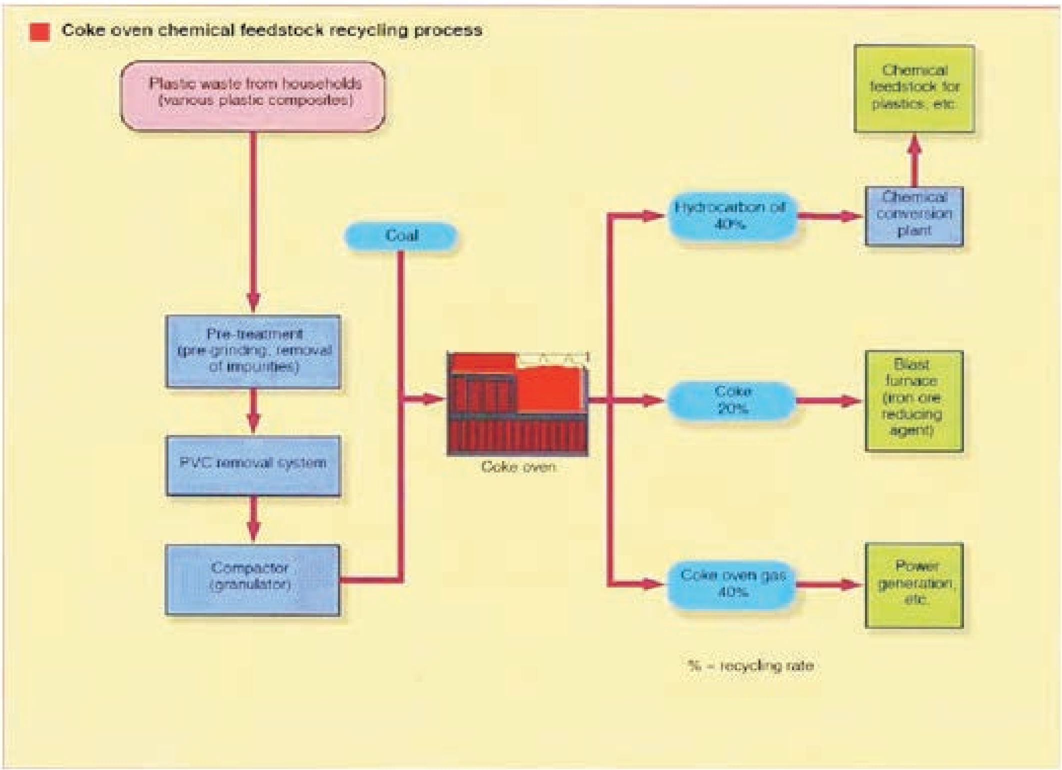



**Fig. 23: Coke oven chemical feedstock recycling**

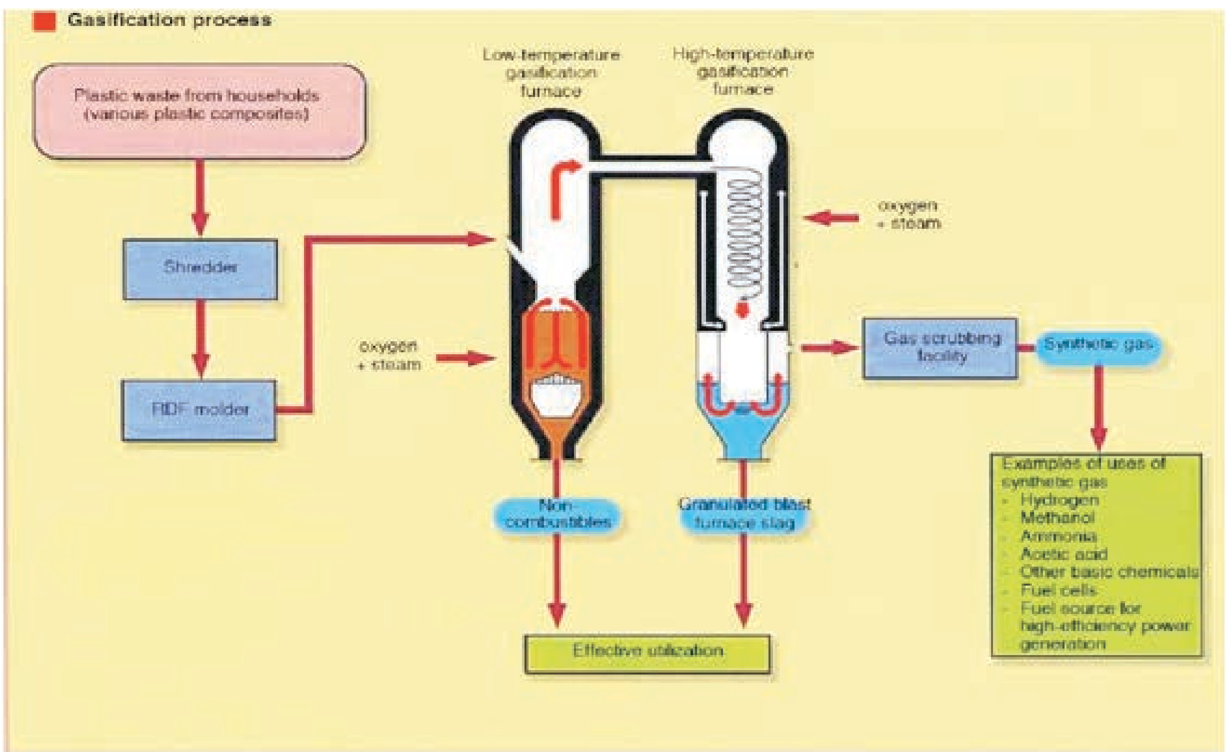



**Fig. 24: Gasification**

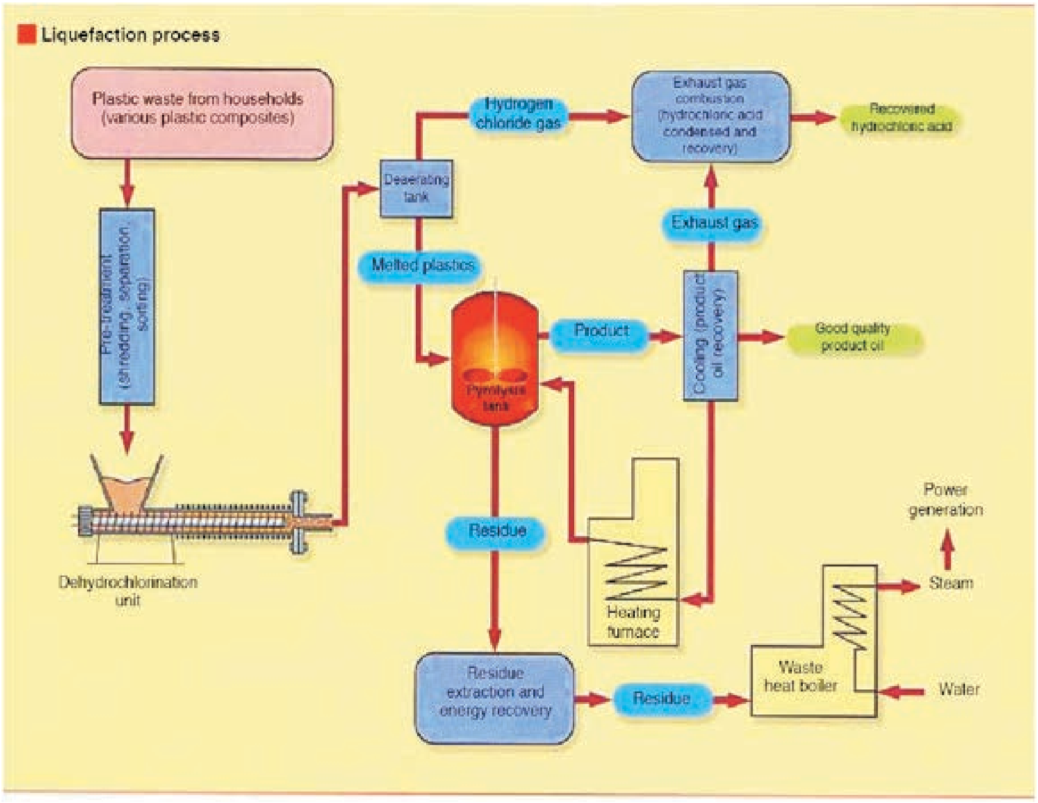



**Fig. 25: Liquefaction**

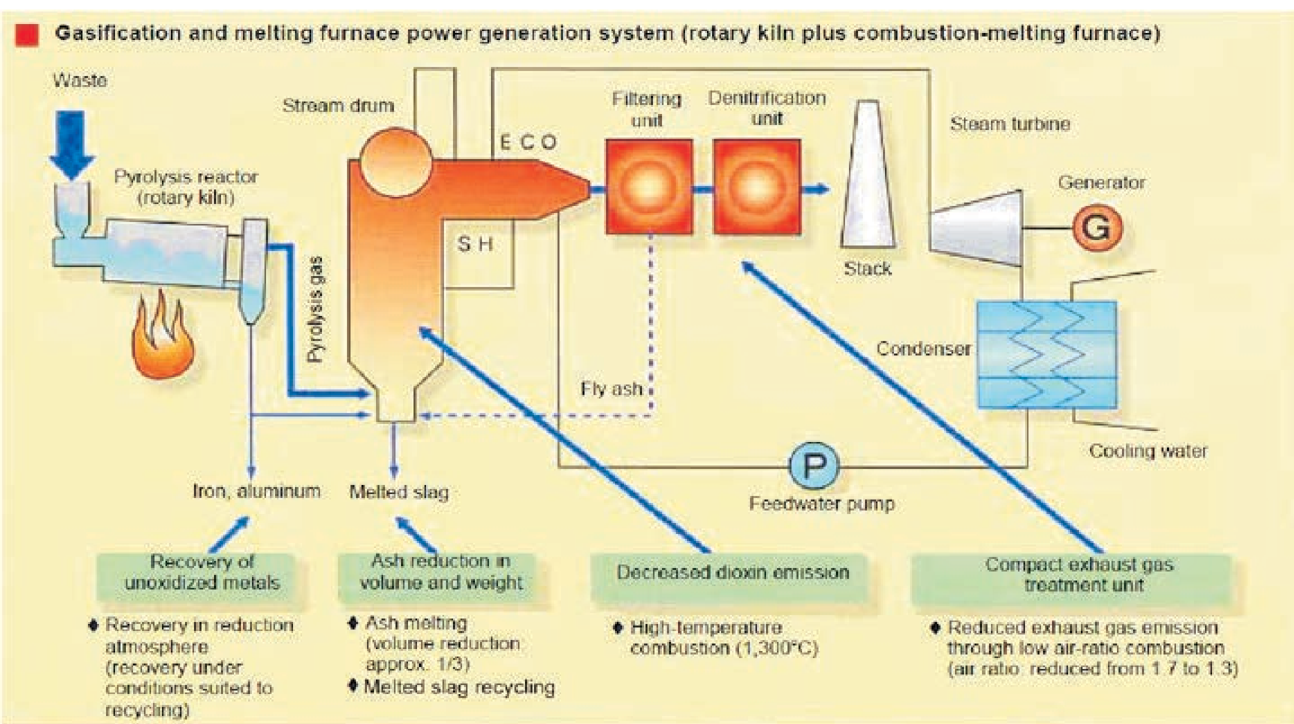



**Fig. 26: Thermal recycling**

■ **Calorie comparison**

| Group | Material | Unit | MJ | kcal | Source |
|---|---|---|---|---|---|
| Fuel | Coal for coke ovens | kg | 29.1 | 6952 | Energy lectures from the Institute of Applied Energy website. |
| | Imported fuel coal | kg | 26.6 | 6354 | |
| | Kerosene | Liter | 36.7 | 9126 | |
| | Fuel oil A | Liter | 39.1 | 9962 | |
| | LPG | kg | 50.2 | 11992 | |
| | Manufactured gas | Nm3 | 41.1 | 9818 | |
| Plastics | PVC resins | kg | 24.1 | 5760 | Ecological efficiency analysis on the processing of plastic containers and packaging Plastic Waste Management Institute, September 2006 |
| | Polystyrene | kg | 40.2 | 9600 | |
| | Polypropylene | kg | 44 | 10500 | |
| | Polyethylene | kg | 46 | 11000 | |
| | PET | kg | 23 | 5500 | Homepage of the Council for PET Bottle Recycling: http://www.petbottle-rec.gr.jp/qanda/index.html |
| Waste (damp) | Paper | kg | 13.2 | 3160 | Council for the Best Technology for Plastic Waste Processing (Eds), Processing and Disposal of Plastic Waste, Nippo Co., Ltd., 1995 |
| | Kitchen waste | kg | 3.9 | 930 | |
| | Textiles | kg | 16.3 | 3900 | |
| | Wood, grass | kg | 6.6 | 1570 | |
| | Incineration waste | kg | 10 | 2390 | |
| | Waste plastic | kg | 36.2 | 8650 | Ecological efficiency analysis on the processing of plastic containers and packaging, Plastic Waste Management Institute, September 2006 |

**Fig.27 Efficiency Comparison**

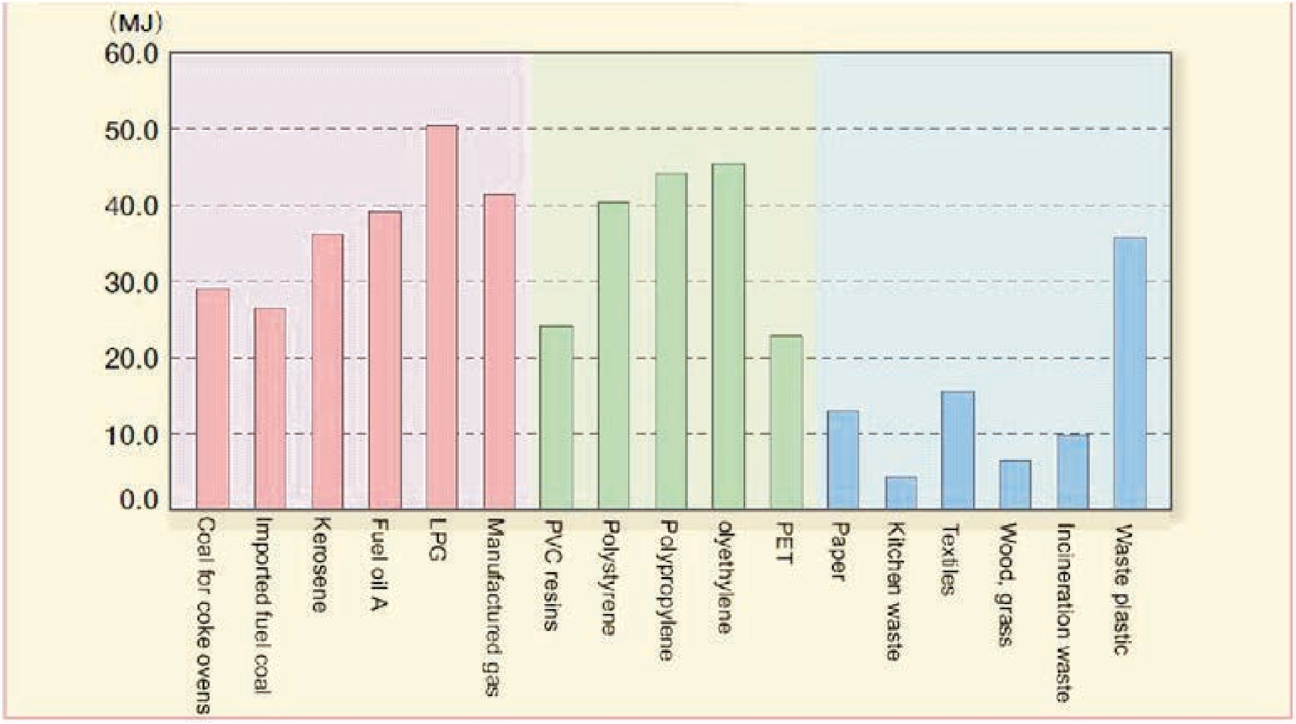



**Fig.28 Energy Value from Various resources**

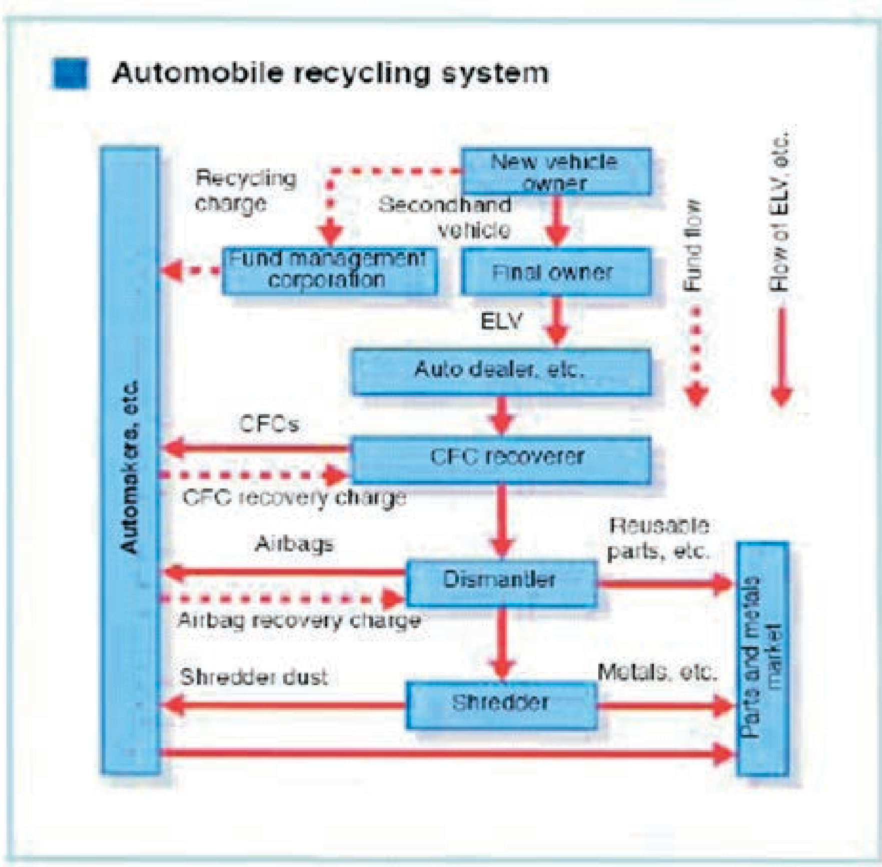



**Fig.29 Automobile recycling system**

**Auto recycling law:** The law on recycling of end-of-life vehicles, popularly known as the automobile recycling law, requires that manufacturers and others recover, recycle and appropriately dispose of the CFCs in car air conditioners, shredder dust from scrapped cars and airbags from the ELVs.

- Manufacturers and importers: Businesses must take back and recycle the CFCs, airbags and shredder dust from ELVs. (CFCs must be broken down.)
- Handling agents: Handling agents take ELVs from vehicle owners and pass them on to CFC recoveries and dismantlers for recycling.
- CFC recoverers: CFC recoverers are required to appropriately recover CFCs and pass them on to automakers. (A recovery charge may be made for this service.)
- Dismantlers: Dismantlers must appropriately recycle and process ELVs and pass on airbags to automakers. (A recovery charge may be levied for this service.)
- Shredders: Shredders must appropriately recycle and process dismantled vehicles (ELV shells) and pass on the shredder dust to automakers.

## 13. Auto recycling: current research and future challenges

**Current Research:** for the past nearly two decades researchers have focused on understanding the recycling infrastructure and describing the material flow, and economic changes within the infrastructure. The current research revolves around better fuel economy and lower emissions.

Manufacturers are incorporating increasing amounts of lightweight and non-metallic materials into vehicles. Lightweight materials in end of life vehicles cannot be completely recycled due to the difficulty in sorting and separation of recyclable materials.

An intensive research is ongoing at Argonne national laboratory for the development and demonstration of technologies to recover and recycle automotive materials within the existing recycle infrastructure. As the outcome of their research, a two stage separation process was developed.

The process begins with bulk separation of all shredder residues into four categories: fines (iron oxides, other oxides, glass and dirt); polyurethane foams; polymers (polypropylene, polyethylene, ABS, nylon, PVC, polyester, etc.); and ferrous and nonferrous metals.

Researchers have now been attracted towards effective improvement of automobile recycling. Life cycle analysis techniques are employed to study the impact of changing automotive material composition on the energy consumption and waste generated.

In the car industry, plastic components are increasingly used to replace metal. Recycling of plastic materials from end-of-life vehicles (ELVs) is still an unsolved problem. The most difficult problem in materials recycling from ELVs is the issue of recovery. The recovered materials from bumpers of ELVs possess high level of mechanical strength and a good thermal stability. New materials with interesting properties were obtained by compounding these samples with wood flower and virgin polymers.

***Company-wise Current Research:***

***BMW group*** has developed their own dismantling and recycling center and now it is the world's most leading facility for recycling. As an outcome of their R & D, natural fibers reinforced recycled plastics (possessing good mechanical property and light weight) are used in door panels and sound proofing. Currently 15% of plastic parts approved for BMW are recycled plastics used in under-body paneling, rear shelves, fuel tanks and wheel housings.

***Ford*** is presently using recyclable bio-products for seats and doors (cushion). According to Ford, its vehicles are now 85 percent recyclable by weight. For the past several years, Ford has concentrated on increasing the use of non-metal, recycled and bio-based materials.

Ford is making its vehicles more eco-friendly through increased use of renewable and recyclable materials such as soy and other bio-based seat cushions and seat backs in Ford Taurus and application of wheat straw-reinforced plastic for the third-row storage bins in Ford Flex. The natural fibers replace energy-inefficient glass fibers commonly used to reinforce plastic part.

***Volvo:*** According to Volvo, its cars are designed to be 85% recyclable and 95% recoverable. Volvo's latest model truck comprise of 30% of recycled materials.

***Mercedes Benz***uses 21.2 kg of recycled, high quality plastics in various parts like under-body panels, wheel enclosure etc., Parts like battery enclosures and bumper cladding of Benz is recycled and reused in the new cars as a closed loop system. Nearly 43 kg of natural materials are used. The interior trim is enhanced with real wood veneers, and the parcel shelf lining is made from flax fibers.

## Future Challenges:

Future Challenges of the automotive recycling infrastructure begins by identifying the latest trends and future needs of the automotive industry. One of the efforts is to reduce the weight of the vehicle and to reduce emission.

Oak ridge Laboratory have studied and reported the life cycle issues due to the weight reduction obtained by change in composition of automotive materials through alternative material.

Two thirds of the fuel consumption is attributed to the weight of the vehicle. This was the reason for reducing the consumption of nonferrous materials in vehicles down from 75% to 68% since 1970. Lightweight materials like aluminum, plastics and composites are used to reduce the weight of the vehicle.

US government and automotive industry has established targets for a new generation of vehicles. They have set a target for 40% reduction in weight within 10 years. Polymer and polymer composite intensive vehicles are the solutions for this target. The consumption of plastic materials is now 20-times greater than 50 years ago.

The following table shows the current weight of the vehicle and the weight reduction targets set under a US government and automotive industry partnership.

| **Sub system** | **Weight of Current vehicle (kg)** | **Weight of targeted vehicle (kg)** | **Mass reduction (%)** |
|---|---|---|---|
| Body | 516 | 257 | 50 |
| Chassis | 501 | 250 | 50 |
| Powertrain | 395 | 355 | 10 |
| Fuel & Others | 62 | 29 | 55 |
| **Total** | **1432** | **891** | **40** |

## Research Challenges:

An intensive research on the following is required.

a) A comprehensive analysis for development of vehicles of future (Light weight for lower fuel consumption).

Most of the metals parts of automobiles are being replaced with plastics and its composites while taking care of functional requirements. Research on development of various automobile components using recycled plastics of ELVs with the similar functionalities is required.

b) Impact of the future vehicle on environment, sustainability and recovery infrastructure.

c) Development of new recycling and recovery technologies for automotive industry of future.

new technologies needs to be develop for (i) sorting of different plastics from ELVs;

And (ii) Recycling of additive added plastics

d) Recycling of Brominated Flame Retardant [BFR] Plastics in ELVs.

Several components like seats and cables of the automobiles may be made of polymers containing brominated flame retardants (BFR). These additives can have an effect on the integrity of the resulting recyclate and may require special consideration during recycling.

The major challenge in recycling of BFR plastics is release of polybrominated diphenyl ethers from the melting of BFR plastics, which is highly toxic and leads to major disorders to human beings when it gets accumulated.

e) Development of value added recyclates with high value recovery.

The vision of the automotive plastics industry is to establish plastics as the material of choice in the design of all major automotive components and systems by 2020.

## A proposal -- establishment of a center of excellence

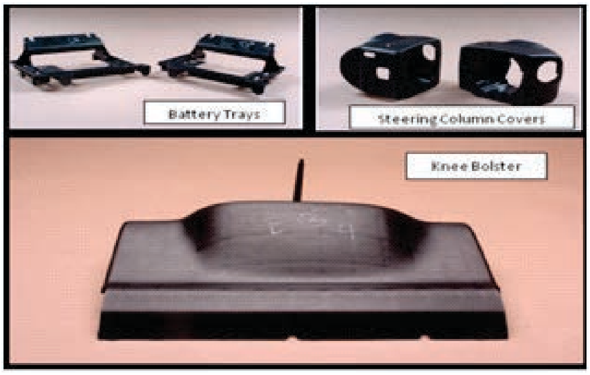
In order to overcome the above challenges, it is essential to redouble and sharpen the focus on the research on ELVs and ASR.

A Centre of excellence on "Recycling of End of Life vehicles" can be developed with sufficient research facilities for promoting the utilization of plastics to automobile industry and to save the environment. The detailed proposal for the development of center of excellence is enclosed as Annexure.

## 10. Applications of Auto recycled plastics

| | |
|---|---|
| **Park benches** made of recycled plastics |  |
| **Plastics waste basket** made of 100% recycled plastics |  |

| | |
|---|---|
| Recycled Plastics Lumber: Can be utilized as a counterpart of wood. Plastic lumber is extremely hardy and prized for marine application.<br><br>Impervious to weather, saltwater, rot, insects, moisture, splintering and free from toxic chemicals like chromated copper arsenate (arsenic), pentachlorophenol, and creosote (which are all found in pressure treated wood), the environment-friendly recycled plastic lumber provides superior performance while also reducing landfill waste. | <br> |
| **Floating Docks** made of 100% recycled plastics.<br>● Non-leaching<br>● Non-toxic<br>● Chemical and petroleum resistant<br>● Water proof<br>● Fade resistant<br>● Slip resistant |  |
| **Plastics Roads** made up of recycled plastics – bitumen mixture |  |
| **Lamp posts** made up of 100% recycled plastics |  |

| | |
|---|---|
| **Roof Shingles** made up of recycled plastics and rubbers |  |
| **ELV Bumpers made of Polypropylene** |  |
| **Composite Tiles from ELV bumper – Polypropylene + Fillers** |  |
| **Recovered PP/PE blend from ELV shredded residue is further used for new Moulded part of automobiles** |   |

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**PROPOSAL**
**ON**

# ESTABLISHMENT OF CENTRE OF EXCELLENCE (CoE) ON PLASTICS RECYCLING – AUTOMOBILE ELV

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## 1. Objective

The objective of this proposal is to establish a center of excellence focused towards the recycling of plastics from End of life vehicles. Proposal covers the establishment of research facilities to carry out the research on recycling individual parts of ELVs, technology transfer and providing training on plastics recycling technology.

## 2. Establishment of Research facilities

Following are the equipment / machinery required for the proposed research and development activities.

| S.No. | Equipment / Machineries | Purpose |
|---|---|---|
| 1. | Pyrolysis set up | Conversion of plastics waste into fuels through pyrolysis |
| 2. | Gasifier | Conversion of plastics waste into fuels through Gasification |
| 3. | Fourier transformed Infrared Spectroscopy (FTIR) | Identification and Characterization of recycled polymers. Also useful for sorting of polymers from shredded residue |
| 4. | X-Ray Diffractometer | Characterization of structural properties of recycled polymers and its composites |
| 5. | X-Ray fluorescence Spectrophotometer | Used for analysis and segregation of plastics containing additives like fire retardants. |
| 6. | Gas Chromatography | Used for quantitative and qualitative analysis of toxic gases evolves during recycling of plastics containing various functional additives. |
| 7. | Scanning Electron Microscopy | Characterizing the surface morphology of recycled polymers and its composites |
| 8. | Twin Screw extruder | Blending of recycled polymers with functional additives. |
| 9. | Mini compounder with injection moulding machine | Compounding and moulding of test specimens of recycled polymers |
| 10. | Universal Testing Machine with climatic chamber | Testing of mechanical properties like tensile Flexural, compressive and shear properties. |
| 11. | Impact tester | Testing of IZOD and CHARPY impact strength of plastics and its composites |
| 12. | Climatic Chamber | Conditioning of sample at high and low temperature to study the influence of plastics and its composites. |

| S.No. | Equipment / Machineries | Purpose |
|---|---|---|
| 13. | Weatherometer | Conditioning the samples under UV exposure (light), temperature and moisture to study the weather resistant of polymer and its composites. |
| 14. | Biodegradation set up | Testing of ability of the composites to degrade under microbial attack. |
| 15. | Dismantling cell | Dismantling of end of life vehicles for further recycling processes. |
| 16. | Cleaning cell | Cleaning of dismantled plastics parts before recycling. |

## 3. Focused Research Area

***Hypothesis 1:***

- Reinforcement of natural fibers into the auto recycled plastics for value added recyclates
- To study the interaction between fiber and polymer through analytical characterization techniques.
- To study the mechanical properties of composites.
- To study the degradability and durability of composites.

***Hypothesis 2*:**

- Dispersion of Nano Fillers (organic and inorganic nanoparticles) into the recycled plastics to reuse the plastic for automobile parts.
- To study the interaction between Nano Fillers and polymer through analytical characterization techniques.
- To study the physical properties of the composites.
- To study the weather resistance of the composites.

***Hypothesis 3*:**

- Development of pyrolysis based recycling technology for recycling of plastics composites parts.
- Reusing recycled thermoset-based composites as fillers for further compounding.
- Evaluation of mechanical properties and durability of recycled composite filler reinforced plastics.

***Hypothesis 4*:**

- Extraction of nanomaterials for Auto Shredded Residue (ASR).

- Dispersion of extracted nanomaterials into recycled plastics waste.
- Analytical study on suitability of those composites for automobile parts.

***Hypothesis 5:***

- To study the ability of biodegradation of recycled plastics.

***Hypothesis 6:***

- Recycling of BFR containing plastics after separation of BFRs from Plastics.
- Separation of plastics with BFRs using XRF and DE-XRT (Dual Energy X-Ray Transmission)
- Quantitative and qualitative studies on the release of toxic gases during recycling of BSR [is it BSR or BFR?] containing plastics.
- To study the miscibility effects of the recycled plastics with and without BFR.

## 4. Training for Students and Industrial Researchers

Training of unemployed and underemployed youth in the entire gamut of identification, segregation, cleaning and recycling of plastics waste derived from automobile ELV [is automobile ELV right? should it not be just ELVs?].

Following are the various fields were in plant training may be provided for students, researchers and industrialists to enrich the knowledge on auto recycling technology and to promote research activities.

- Needs for auto-recycling
- Various auto-recycling technologies
- Reuse of recyclable plastics from automobiles
- Waste Management
- Value addition to the waste plastics
- Waste plastics Composites derived from Automobile ELV
- Applications of recycled plastics.
- Composting
- Biodegradability of recycled plastics

## 5. Technology Transfer

- The outcome of the research finding can culminate in Technology Transfer to leading automobile manufacturers, vendors to auto-giants viz. Ford, Hyundai, Viston, Motherson, BMW, etc.,
- IP generated can be commercialized
- Joint-venture collaborative projects funded by Govt. agency – through PPP mode can be undertaken to operate the COE in self-sustainable mode.

## 6. Budget

Summary of Total Budget:

| Budget | Amount |
|---|---:|
| Manpower | 1,08,00,000 |
| Consumables | 50,00,000 |
| Travel | 10,00,000 |
| Contingency | 15,00,000 |
| Equipment | 10,00,00,000 |
| Training | 60,00,000 |
| Total | 12,43,00,000 |

### 6.1 Budget for Manpower (Research Scholars)

| No of Persons | Year1(Rs) | Year2(Rs) | Year3(Rs) | Total per person | Total (10 Persons) |
|---|---|---|---|---|---|
| Min. 10 JRF @ *12,000/pm* | 1,44,000 | 1,44,000 | 1,44,000 | 4,32,000 | 43,20,000/ - |
| Min SRF 10@*18,000/pm* | 2,16,000 | 2,16,000 | 2,16,000 | 6,48,000 | 64,80,000 |
| | | | | Total | 1,08,00,000 |

*(JRF @ 12,000, SRF @18,000 per month)*

**Justification for Manpower:**

Minimum of 20 researchers may be engaged in this project to carry out this project successfully and also they may work for their doctoral program in the field of recycling of ELV. As an outcome of this proposal, every year nominal number of doctorates will also be produced.

### 6.2 Budget for Consumables:

| Items | Year1(Rs) | Year2(Rs) | Year3(Rs) | Total: |
|---|---|---|---|---|
| Total | 20,00,000 | 20,00,000 | 10,00,000 | 50,00,000 |

**Justification for Consumables:**

Funds will be utilized for the

i) Purchase of Chemicals of high purity (99.99%), solvents, gases, glass wares, and laboratory wares which are essential to synthesis the polymers.

ii) Maintenance charges for equipment procured under this project

### 6.3 Budget for Travel

| Items | Year1(Rs) | Year2(Rs) | Year3(Rs) | Total: |
|---|---|---|---|---|
| Total | 4,00,000 | 3,00,000 | 3,00,000 | 10,00,000 |

**Justification for Travel**

Funds will be utilized

i) Towards the transport charges for attending national and international conferences for Investigators and project staff members.

### 6.4 Budget for Contingency

*Rs. In Lakhs*

| Travel Type | Year1 | Year2 | Year3 | Year4 | Year5 | Total |
|---|---|---|---|---|---|---|
| Total | 5,00,000 | 5,00,000 | 5,00,000 | NA | NA | 15,00,000 |

**Justification for Contingency**

Contingency will be utilized for

i) Registration fee for attending the national and international conferences for Investigators and project staff members.

ii) Charges for materials characterization carried out at different institutions.

## 6.5 Budget for Equipment:

| S.No. | Equipment / Machineries | Estimated Cost (Rs.) |
|---|---|---|
| 1. | Pyrolysis set up | 75,00,000 |
| 2. | Gasifier | 75,00,000 |
| 3. | Fourier transformed Infrared Spectroscopy (FTIR) | 50,00,000 |
| 4. | X-Ray Diffractometer | 75,00,000 |
| 5. | Scanning Electron Microscopy | 1,00,00,000 |
| 6. | Twin Screw extruder | 30,00,000 |
| 7. | Mini compounder with injection moulding machine | 75,00,000 |

| S.No. | Equipment / Machineries | Estimated Cost Rs.) |
|---|---|---|
| 8. | Universal Testing Machine with climatic chamber | 45,00,000 |
| 9. | Impact tester | 25,00,000 |
| 10. | Climatic Chamber | 40,00,000 |
| 11. | Weatherometer | 75,00,000 |
| 12. | Biodegradation set up | 75,00,000 |
| 13. | Dismantling cell | 50,00,000 |
| 14. | Cleaning cell | 75,00,000 |
| 15. | X-Ray Fluoroscence spectrophotometer | 80,00,000 |
| 16. | Gas Chromatography | 55,00,000 |
| | TOTAL | 10,00,00,000 |

**6.6. Training of Students and Research Scholars:**

- Minimum around 100 underemployed/unemployed youths can be trained per year and gainfully employed. Training cost inclusive of boarding & lodging @ Rs.60, 000/per person.

## 7. Deliverables:

- The facilities created at CoE – Plastics Recycling - Auto mobile ELV – can result the following deliverables;
- Around 10 Doctorates can be produced at the end of 3rd year of successful implementation.
- 100 underemployed/unemployed youths can be gainfully employed per year through skill development programs in Plastics Recycling – Automobile ELV.
- Minimum 2 patents are expected to be generated.
- Around 20 research papers can be published per year.


CHAPTER-5

# Post-treatment of Auto Shredder Residues (ASR)

# Post-treatment of Auto Shredder Residues (ASR)

## History of ELV recycling in Japan*

(*As explained by Professor Dr. Kenichi Togawa of Kumamoto University, translated by Mr. Takegawa of Japan Productivity center and rewritten by Captain Mohan Ram)

It will be educative and important for us to study and understand how the efficient and effective Japanese recycling system, evolved over the last fifty years and how order was created out of a relatively chaotic situation which prevailed earlier. The lessons learnt can be useful for determining appropriate policy responses in India, especially in setting up systems for post treatment of auto shredder residues.

Japan's streets and roads were full of abandoned cars during the decade starting from 1970. The problem of abandoned cars was very severe. The Japanese Automotive Manufacturer's Association (JAMA) investigated the issue, by collecting detailed information from local and municipal Governments. JAMA went on to set up an organization "Assistance Association for Collection and Treatment of Abandoned Cars" to help tackle the problem. The organization dissolved itself, after the ELV law was enacted in Japan in 2002.

Toyota Motor Corporation set up a company "Toyota Metal" to study the issue and to implement ELV recycling business. Concurrently, a few big auto recyclers installed shredding machines in their units, for more efficient metal recycling from ELVs. Shredding machines became symbols of eco-friendly car recycling. These machines came in to existence when the number of ELVs became large, crossing a million.

Another problem was encountered in 70's and 80's, especially in Kyoto. Large numbers of used tires were burnt by car dismantlers in the open causing severe air pollution. This became a major environmental hazard. The municipal governments and citizen groups took the issue to the National Government and automotive related industries.

As an outcome of the initiative, a large number of tire incinerators were set up. A tire treatment fee system was charged. The fee was paid to the tire collectors in proportion to the number of tires they collected. The fee enabled movement of tires to the tire treatment facilities.

The story became the subject of a comic book 'Burning Town'! (http://bookmeter.com/ b/4759202153)

Suzuki and Nissan Motor companies also associated themselves with setting up auto recycling companies, in the 70's. These activities taken by the automotive manufacturers acted as a major stimulus to the existing dismantlers in Japan. They served as models and set up the standards for emerging car recycling industry.

A serious incident occurred in a peaceful island in Japan's Inland Sea and became notorious as Teshima Island problem. Huge volumes of Auto Shredder Residues had been illegally dumped in landfills in the island over a long period. The offending company later became bankrupt and went out of business. The pollution was serious with high concentrations of heavy metals and dioxins. People were prohibited from entering the vicinity. The incident led the National Ministry of Welfare to legislate Pre-Treatment Guideline for car dismantlers. (Described in detail later in this chapter)

There was a market of waste oil and waste batteries in Japan, until the beginning of 90's. They were salable products also in Japan. However after the Pre-Treatment Guideline was issued the activities decreased.

Okinawa in particular did not have any systems for managing waste oil and discarded batteries. They became a major source of soil pollution in Okinawa. Their municipal government and a big shredding company, 'Takunan Shoji' (URL: http://shoji.takunan.co.jp/) made strenuous efforts to persuade Okinawa's small dismantling companies comply with the Guideline. Thereafter the situation improved gradually.

Furthermore, Japanese Waste Regulations were revised. Car dismantlers had to get the approval for ELV collection and storage to implement car recycling business from Municipal Governments. This facilitated the improvement of dismantling facilities for recycling cars.

It took several decades for automotive recycling to take shape in Japanbefore the ELV law (2002) was implemented in Japan. The ELV law was not the starting point. There was a history of a series of actions by different players towards improvements before the law. The situation was facilitated by awakening of public consciousness which triggered the improvements. The social mood motivated car makers, battery makers, Governments and citizen groups get together to solve the problem.

The law abiding nature, innate discipline and civic consciousness of the Japanese people helped the initiatives to succeed. Once laws are passed, Japanese tend to abide by them. They do not violate rules. That is a typical and admirable feature of Japanese culture.

Thereafter, several big shredding companies like Seinan Company, Kanemura and Harita Metal entered dismantling business in Japan. There is a recent trend for Japanese car recycling business to corporatize and go for bigger units. The number of ELVs is also showing a declining trend which may render smaller units unviable and accelerate the process of consolidation.

A detailed presentation made by was made by Professor Arata Abe of Yamaguchi University on history of vehicle recycling industry in Japan during the 2nd Working Group Meeting on ELV, 20-21 August 2015, Putrajaya, Malaysia traced the growth of different components of the industry in detail.[1]

## Post Treatment of Auto Shredder Residues

An investigation of post treatment of Auto Shredder residues may appear to be speculative and futuristic in the Indian context, especially since there is not even one shredder operating in India! As brought out in the market study, current ad-hoc recycling systems controlled by the informal sector, do not lead to efficient recycling of ELVs. The present system, methods and volumes do not lend themselves to shredding of auto body hulks, which is a capital intensive and large scale operation.

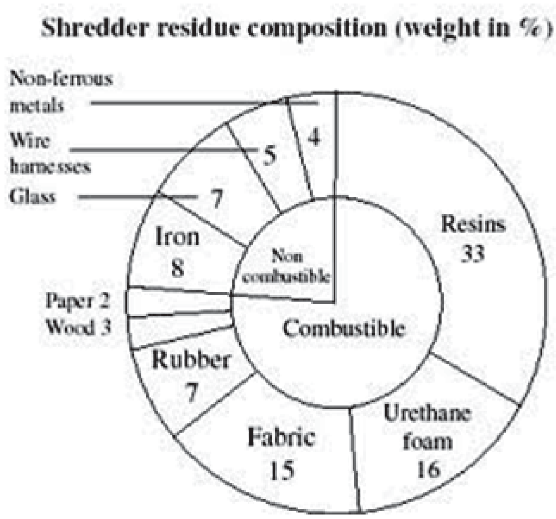
It is incredible that India which produced 2.3 million cars and over 20 million vehicles last year, does not have a single shredder in operation for recycling ELV hulks.

One of India's leading steel scrap merchants Ms. Nathani Steels installed and tried to operate a shredder in Mumbai in the seventies. They found it commercially unviable and shifted the unit to the Middle East! Shredders are capital intensive and high productivity equipment which can pay their way only if sufficient material is available on a consistent basis.

India has no alternative but to modernize and to upgrade the existing informal sector and set up new modern recycling facilities to deal with the huge increase in ELVs which is going to occur soon. Japanese experience showed that shredders start entering the market when the ELV numbers crossed one million, a stage already reached in India.

When recycling of ELVs takes proper shape in India with efficient dismantling units with proper depollution, removal of toxic items and recovery of reusable parts, large number of auto body hulks consisting mainly of high quality alloy steel will be produced, which can be handled efficiently and economicall, only through shredding.

After Steel and nonferrous alloys are removed from the shred by magnetic and eddy current separation respectively. The residue which is left is a complex mixture of ferrous and non-ferrous metals, rubber parts, plastics of varying compositions, wood, fabric, ceramics, and Dust etc.(See figure[2] below). The mixture can also vary from time to time and batch to batch




Chapter 2 of this report, has brought out that a huge volume of ASR amounting to 2.8 million tons will be generated in 2020 increasing to over 6 million tons in 2030.[3] This huge amount of residues will require enormous areas of land for landfills. Around twenty percent by weight of a car would become ASR, unless efficient Post treatment of ASR is put in place. It is for note that the total recovery by weight from an ELV has increased from 85 to 95 % in European Union and Japan by 2015. Only the US with its huge land mass is still resorting to dumping ASR in designated landfills, for purely economic reasons.

## Health Hazards of ASR

The bodies of automobiles after stripping and dismantling, end up at metal shredders at the end of their life cycles. The shredders crush the hulks into small chunks of metal, sell the metallic scrap for profit. In the US, many recyclers treat the leftover sludge — called "fluff" — with a cement coating, which allows them to dump the waste in regular landfills, as opposed to hazardous waste disposal sites.

The fluff often ends up in gas tanks with residual gas and fumes, motor oil from parts, steering column fluids, brake fluids and painted metal parts. The fluff can turn toxic and hazardous, as it contains lead and other chemicals that are part of the scrap metal process. Without proper after treatment which removes heavy metals and toxic substances, it is unsafe to dump the residue in ordinary landfills instead of specially designated hazardous material landfills.

The dangers of unregulated discharge of ASR were realized after major problems were experienced in Teshima in Kagawa prefecture, Japan.[4]

In 1975, an industrial waste disposal company, Teshima Sogo Kanko Kaihatsu, planned to install a hazardous waste disposal plant on the west side of Teshima Island in Kagawa prefecture, Japan. The prefecture government did not initially permit the company, as the local residents opposed the plan. In 1978, the company came up with a fresh proposal offering to treat only non-hazardous wastes for recycling. After several hearings, the Kagawa Government gave permission to the company.

However in reality, large quantities of shredder dust, tires and waste oil were brought to the island. They were openly-burnt without recycling, ignoring the residents' complaints.

In 1990, the prefectural police carried out an investigation of the company, suspecting noncompliance with the Japanese Waste Disposal Law. As a result, the Company ceased operations leaving massive piles of industrial wastes on the island. Thereafter, residents of the island asked the Environmental Disputes Coordination Commission, established by the central government under the Law Concerning the Settlement of Environmental Pollution Disputes, to order the complete removal of wastes. They also demanded compensation for the damage caused from the Kagawa prefectural Government, the disposal company, and the discharging companies.

The commission investigated the pollution problem of Teshima Island at a considerable expense. Thereafter, it mediated between the applicants and Kagawa prefecture, using the survey data.

In 1997, a temporary agreement was reached, stipulating that

(1) The Kagawa prefectural government conceded that it failed in the management of the disposal company

(2) The prefecture pledged to build a waste disposal plant on Teshima Island and dispose of the wastes completely and

(3) It would set up a technological examination committee to ensure appropriate treatment of Teshima's industrial wastes.

The technological examination committee carried out examinations of waste disposal processes, and discussed countermeasures to deal with contaminated groundwater. In 2000, a final arrangement between the Teshima litigants and the Kagawa prefectural government was reached. It was agreed that the governor would apologize to the residents for failing to prevent serious damage, and agree to complete removal of the wastes. In addition, 21 companies agreed to pay some portion of the cost of countermeasures. The owner was sentenced to 10 months in prison and fine of 500,000 Japanese Yen for his actions. However, he was given 5 months' probation during which if he did not commit any new crime he would not serve the ten-month jail term. Eventually he did not serve any jail term.

Later, it transpired that actual amount of waste dumped in the Island exceeded 1,000,000 tones. The cost of the waste treatment was about 100 billion Japanese Yen (approximately, billion dollars). The central Government bore 60% of the cost and the prefectural Government the balance 40%.

This incident led to legislation in Japanese ELV regulations making OEM's responsible for ASR handling, in addition to CFCs and Airbag disposal.

## Shortage of Land for Landfills

Land usage is intensive in highly populated India. It is a scarce resource with multiple claimants. Already serious issues are being faced with areas for disposal of municipal wastes, in major cities like Bangalore. Land will never be made available for dumping auto related waste. It is therefore important that India proactively embraces techniques for Post shredder treatments and minimizes and treats residues going into landfills. The US approach of dumping ASR in landfills will not work in India.

This is certain to become a major challenge in the near future. We have to be proactive and prepared for the time when ASR will be generated in large volumes from recycled ELVs. We have to ensure that adequate and effective post shredder treatment units are available in tandem with increase in residues and that we are not faced with a huge problem of disposal of residues.

The systems developed for India should make greater use of manual labor wherever feasible and resort to mechanization and automation only where necessary and inevitable.

## ASR treatment in developed nations.

Commercially viable processes have been developed both in Japan and Europe, for treatment of Auto Shredder residues, to recover useful materials and as feedstock for furnaces for energy recovery. They have achieved residue levels of less than 5% by weight of the vehicle going in to landfills, meeting the 2015 mandates comfortably.

There are two basic approaches to ASR post treatment.

1. Mechanical processes which use systems of magnetic separation, eddy current separation and high speed air and water streams for mechanically segregating different materials by density

2. Pyrolytic/chemical processes for recovering materials and producing energy.

Japan- based automobile companies formed two consortia to tackle the issue. The first group TH comprised Toyota, Honda, Audi, BMW, Daihatsu, Hino, Peugeot and Volkswagen. The second group ART consisted of Daimler-Chrysler (now separated), Ford, Fuji Heavy industries, Isuzu, Mazda, Mitsubishi Fuso, Nissan, Nissan Diesel, PAG imports and Suzuki. The teams developed both mechanical sorting systems and chemical/pyrolysis techniques. Both systems are now fully developed and are successfully operating in Japan. Both have met the 2015 mandated limit of reducing ASR residues by 70%, effectively to less than 5 % by weight of the vehicle.

A summary of ASR post treatment facilities and description of some of the chemical processes for ASR treatment can be seen in the slides below.[5]

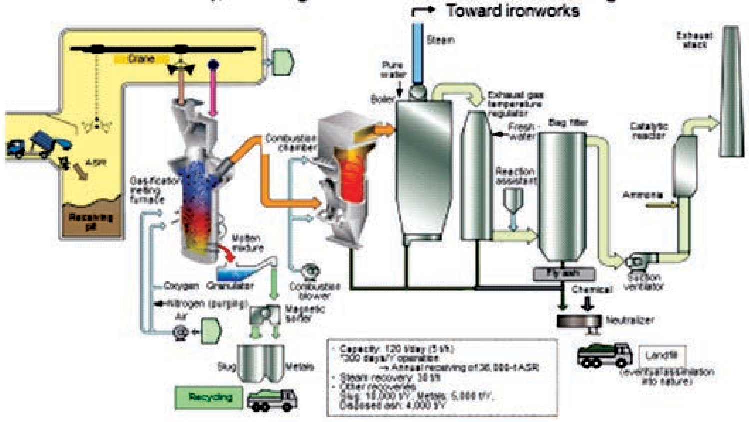
Thermal recycling treatment method and resource recovery 2/38

| Treatment method | ASR applications and resource recovery | | |
|---|---|---|---|
| | Fuel substitution | Thermal recovery (Steam/electricity) | Gas recovery (Fuel gas) |
| Gasification melting furnace | -- | ○ | ○ |
| Incineration furnace + melting furnace | ○ | ○ | -- |
| Fluidized bed furnace | ○ | ○ | ○ |
| Carbonization furnace (Includes reduction furnaces) | -- | ○ | ○ |
| Cement process | ○ | -- | -- |

【A】 3/38

Nippon Steel ASR Thermal Recycling Plant, Nagoya

- Location:Tokai, Aichi (at Nagoya Works of Nippon Steal & Sumitomo Metal Corp.)
- Featuring:Specially designed shaft furnace (used for general waste incineration); use of generated steam in steel making

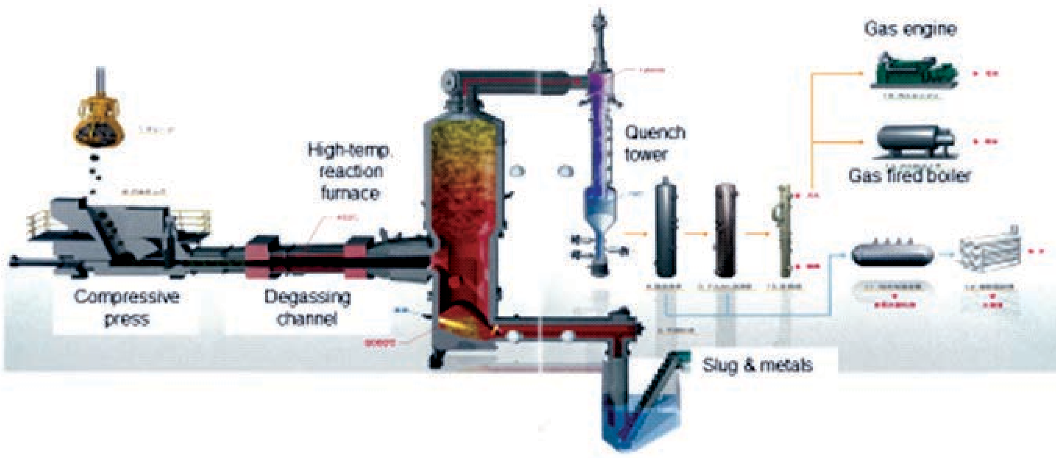


## 【B】ASR Thermal Recycling Plant

(with a gasification melting or a (thermo-select) furnace)

4/38

- Operator: ORIX Environmental Resources Management Corp. (plant located at Yorii, Saitama Pref., Kanto)
- Features: ASR, mixed with general community wastes, is transformed into slug and flammable gas in a gasification melting (thermo-select) furnace.

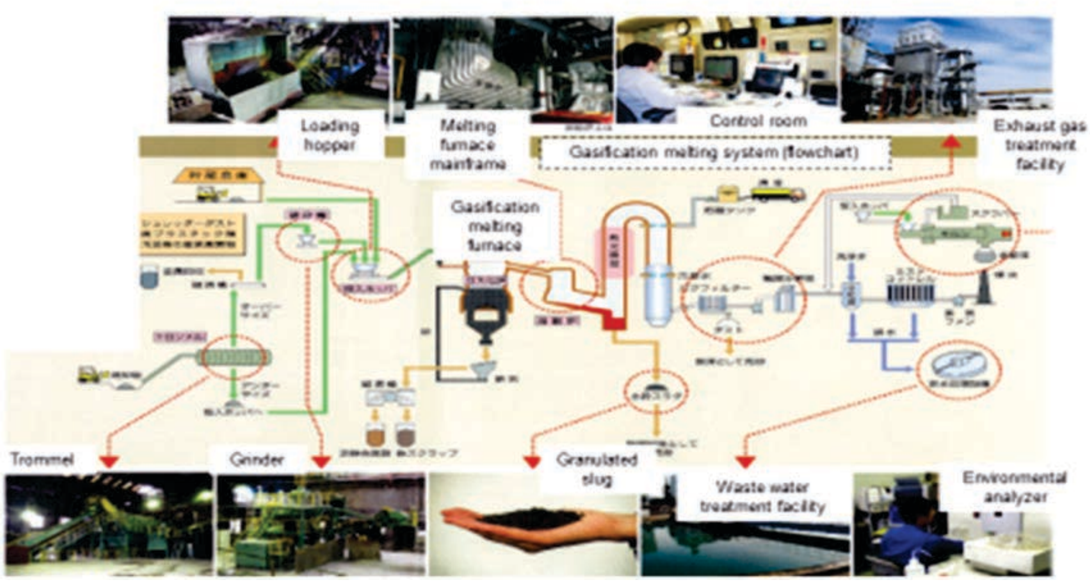



## 【C】ASR Thermal Recycling Plant

(with a fluidized bed furnace)

5/38

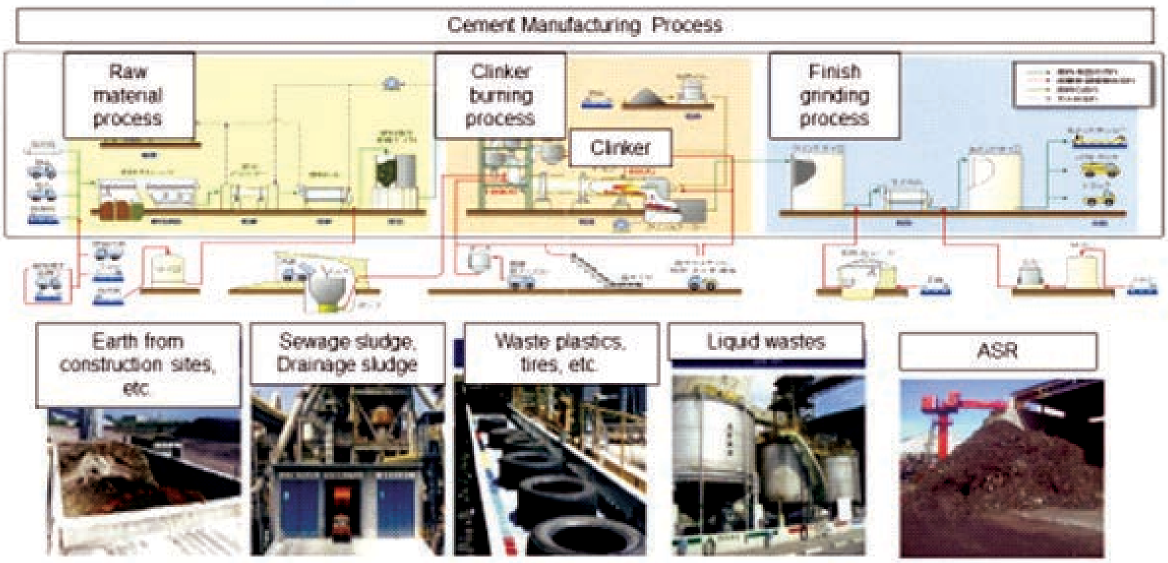
- Operator: JX Metals Mikkaichi Recycling Co.,Ltd. (plant located at Kurobe, Toyama Pref., Hokuriku)
- Features: ASR, mixed with general shredder residue, is transformed into reusable metals, flammable gas and remnant waste in a fluidized bed furnace; the remnant waste is further transformed into melted slug by burning the flammable gas.



# 【D】ASR Thermal Recycling Plant (within cement manufacturing process)

6/38

- Operator: Mitsubishi Materials Corp. (plant located at Kanda, Fukuoka Pref., Kyushu)
- Features: ASR, mixed with various types of wastes, is burned to generate thermal energy for use in cement manufacturing.




1/38

# Number of Facilities Involved in ASR Recycling(As of July 2013)

| Treatment mode | No. of facilities | Example |
|---|---|---|
| Smelting process | 1 | - |
| Gasification melting furnace | 8 | A、B |
| Incinerator + Melting furnace | 7 | - |
| Fluidized bed furnace | 6 | C |
| Carbonizing furnace (incl. reducing furnace) | 3 | - |
| Cement manufacturing process | 13 | D |
| Sorting process | 14 | - |
| Total | 52 | |

A European study considered relative performances of different post shredder treatment processes, both mechanical and chemical. http://ec.europa.eu/environment/waste/pdf/study/ annex3.pdf.[6]

Available information from operators and technology owners allows some appreciation of the environmental effectiveness of the PSTs. The information suggests that PSTs (Post Shredder treatments) range in their reported effectiveness in terms of the overall rates of recycling and recovery of material treated from around 50% (Galloo and Citron – although the Citron process is intended to recover the 50% waste material when operating at industrial scale) to 100% (Sult and R-Plus).

In terms of recycling, the reported implications for the overall rates of recycling and recovery of the PSTs are summarized in Table 2, based on the treatment of the residual 20%. This shows that all the technologies (with the exception of Galloo), based on the information provided, are able (with market and depollution practices) to achieve overall rates of recycling and recovery of 95% or more. It also indicates that all the PSTs (with the exception of Schwarze-Pumpe) are able to achieve in excess of the 85% recycling rate.

In the case of thermal treatment plants this is mainly because of the separation and recycling of residual metal fractions. In the case of mechanical separation plants the overall rates are achieved through recycling of all fractions, especially plastics.

## Processes suitable for India

Of the two, the mechanical separation systems appear to be slightly less capital intensive than chemical systems. We recommend them as better suited for initial implementation under Indian conditions.

The mechanical separation processes are derived from processes widely used in the mining industry for ore treatment and benefaction and have been successful in the recycling industry meeting the stringent targets which kicked in from January 2015.

Successful examples of the mechanical treatment are at ARN at Tiel Holland and at Toyota Metal, at Handa city, Aichi Prefecture in Japan. These processes are well-established and can be suitably adapted for Indian conditions, after sufficient volume of ASR is generated. The plants require considerable investment in facilities and land area. They will become viable only when the volumes of ASR generated warrant the investment.

The ASR treatment plant in Tiel, Holland is highly automated with minimum use of manual labor. The Toyota plant at Aichi Prefecture, Japan, however engages labor to some extent for manual segregation of large Aluminum, copper and plastic pieces from the shredder residue in moving conveyors, before feeding to the ASR treatment system. This approach can be extended for India with increased manual sorting.

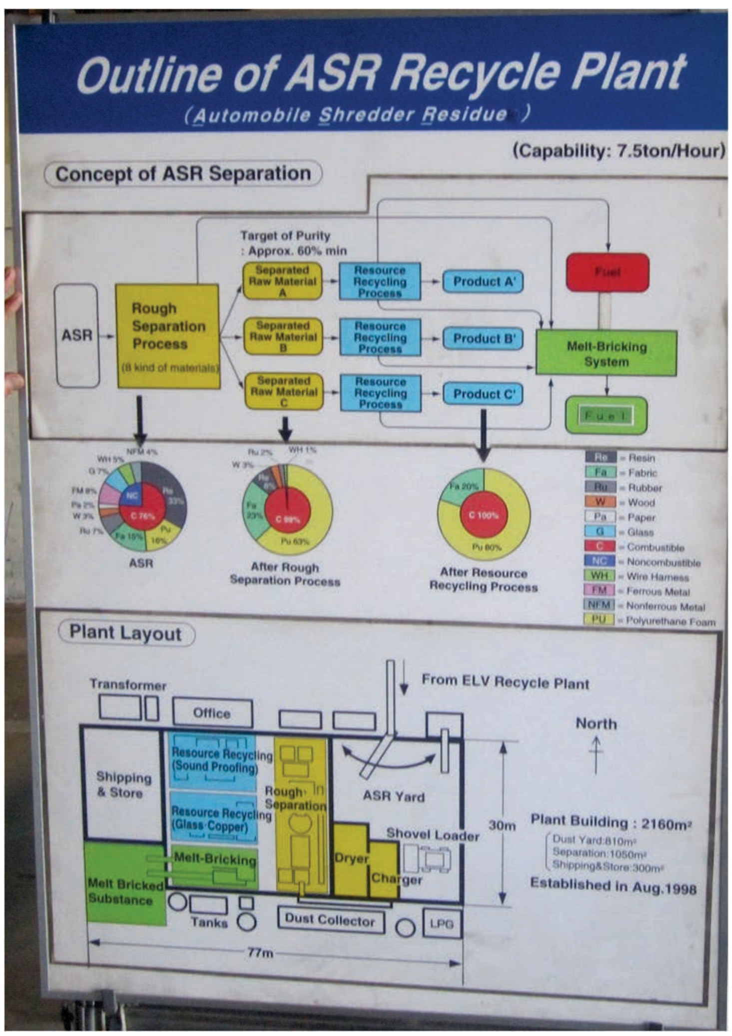
Successful examples of the treatment are at ARN at Tiel Holland (http://www.arn.nl/)[(7)] and at Toyota Metal, at Handa city, Aichi Prefecture in Japan.

(http://www.toyota-global.com/sustainability/report/vehicle_recycling/pdf/vr_all.pdf)[8]

These processes are well established and can be suitably adapted for Indian conditions after sufficient volume of ASR is generated. The plants require major investment in facilities and considerable land area. They will become viable only when the volumes of ASR generated warrant the investment.

The flow chart and schematic of the Toyota Metal Plant at Aichi prefecture Japan is shown below. The plant is designed for a capacity of 7.5 tons of ASR per hour. Assuming generation of 15% of ASR by weight of car, it handles ASR from 50 tons of car hulks per hour, amounting to about sixty cars per hour. Working three shifts days a week, the process plant can process ASR of around 8000 ELVs per week and 30000 ELVs per month. Around 5% of the ASR finally ends up to landfills, after compacting. This amounts to recovery of 98 to 99% by weight of an ELV, which is phenomenal.

The operations flow chart and broad layout of the Toyota Metal plant at Handa City in Japan are placed below. Also is a photograph showing manual segregation of auto shredder residue before treatment in a conveyor belt at the Toyota Metal Plant. (Photographs by Captain Mohan Ram). Such separation helps remove larger and more visible plastic, rubber, metallic and wood elements from ASR and makes subsequent treatment more efficient. It is for note that this step is missing in the Dutch plant due to high labor costs and automation. This step is highly desirable in India and can make segregation more efficient.



## Landfills Regulations

### US standards

Modern landfills are specifically designed to protect human health and the environment by controlling water and air emissions. Landfills must comply with the federal regulations (40 CFR Part 258)[9] or equivalent state regulations. Some of the federal regulations in 40 CFR part 258 include:

**Location Restrictions -** landfills must be built in suitable geological areas away from faults, wetlands, flood plains or other restricted areas.

**Composite Liners Requirements -** include a flexible membrane (geo-membrane)overlaying two feet of compacted clay soil lining the bottom and sides of the landfill, protect groundwater and the underlying soil from leachate releases.

**Leachate Collection and Removal Systems -** sit on top of the composite liner and removes leachate from the landfill for treatment and disposal

**Operating Practices -** including the compacting and covering of waste frequently with several inches of soil to help reduce odor; control litter, insects and rodents; and protect public health

**Groundwater Monitoring Requirements -** testing of groundwater wells must be done to determine whether waste materials have escaped from the landfill

**Closure and Post closure Care Requirements -** including covering landfills and providing long-term care of closed landfills

**Corrective Action Provisions -** control and cleanup of landfill releases and achieves groundwater protection standards

**Financial Assurance -** provides funding for environmental protection during and after landfill closure

## Leachate Collection

Landfill leachate is generated from liquids existing in the waste as it enters a landfill or from rainwater that passes through the waste within the facility. The leachate consists of different organic and inorganic compounds that may be either dissolved or suspended. An important part of maintaining a landfill is managing the leachate through proper treatment methods designed to prevent pollution into surrounding ground and surface waters.

Based on recent EPA studies, a liner and leachate collection system constructed to current standards typically has a liquid removal efficiency of 99 to 100 percent and frequently exceeds 99.99 percent.

The leachate collection system collects the leachate so that it can be removed from the landfill and properly treated or disposed. Most leachate collection systems have the following components

Leachate collection layer - a layer of sand or gravel or a thick plastic mesh called a geo-net collects leachate and allows it to drain by gravity to the leachate collection pipe system

Filter Geotextile - a geotextile fabric, similar in appearance to felt, may be located at the top of the leachate collection pipe system to provide separation of solid particles from liquid. This prevents clogging of the pipe system

Leachate Collection Pipe System - Perforated pipes, surrounded by a bed of gravel, transport collected leachate to specially designed low points called sumps. Pumps, located within the sumps, automatically remove the leachate from the landfill and transport it to the leachate management facilities for treatment or another proper method of disposal

Federal requirements mandate that treatment must meet drinking water quality standards, which are set to prevent harm to public health, or more stringent state standards to protect sensitive environments (high quality streams, trout streams)

## Groundwater Monitoring

Nearly all municipal solid waste landfills (MSWLFs) are required to monitor the underlying groundwater for contamination during their active life and post-closure care period The exceptions to this requirement are small landfills that receive less than 20 tons of solid waste per day, and facilities that can demonstrate that there is no potential for the migration of hazardous constituents from the unit into the groundwater. All other MSWLFs must comply with the groundwater monitoring requirements found at 40 CFR Part 258, Subpart E–Ground-Water Monitoring and Corrective Action.

The groundwater monitoring system consists of a series of wells placed up gradient and down gradient of the MSWLF. The samples from the up gradient wells shows the background concentrations of constituents in the groundwater, while the down gradient wells show the extent of groundwater contamination caused by the MSWLF. The required number of wells, spacing, and depth of wells is determined on a site-specific basis based on the aquifer thickness, groundwater flow rate and direction, and the other geologic and hydro geologic characteristics of the site. All groundwater monitoring systems must be certified by a qualified groundwater scientist and must comply with the sampling and analytical procedures outlined in the regulations.

Recent studies in USA indicate that the harmful effects of landfill have been seriously underestimated. [10]

## European regulations

The Landfill Directive, more formally Council Directive 1999/31/EC [11] of 26 April 1999 on the landfill of waste, is a European Union directive issued by the European Union.

The Directive's overall aim is "to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from the landfilling of waste, during the whole life-cycle of the landfill". This legislation also has important implications for waste handling and waste disposal.

The Directive is applicable to all waste disposal sites and divides them into three classes

1. Landfills for hazardous waste
2. Landfills for non-hazardous waste

   and

3. Landfills for inert waste

Waste disposal into landfills is restricted by banning certain waste types, which may pose a risk.

The following wastes may not be disposed of in a landfill and must either be recovered, recycled or disposed of in other ways: liquid waste, flammable waste, explosive or oxidizing waste, hospital and other clinical waste which are infectious, used tires, with certain exceptions and any other type of waste which does not meet the acceptance criteria laid down in Annex II.

To avoid further risks, allowed wastes are subject to a standard waste acceptance procedure, which dictates the following terms: 1, Waste must be treated before being landfilled 2.Hazardous waste within the meaning of the Directive must be assigned to a hazardous waste landfill 3. Landfills for non-hazardous waste must be used for municipal waste and for non-hazardous waste 4 Landfill sites for inert waste must be used only for inert waste

Criteria for the acceptance of waste at each landfill class must be adopted by the Commission in accordance with the general principles of Annex II. The acceptance criteria and the acceptance process are further specified in the Council Decision 2003/33/EC.

Table below is illustrative of the cost of disposal of waste in landfills in different countries. The costs will increase as land becomes scarcer and also with distance from the shredders due to logistic costs. Landfill costs can make a serious dent in revenues of ELV recycling and make the whole business unviable

ASR Landfill Costs in Different Countries [12]

| Country | Cost ($/t) |
|---|---|
| **E.U. countries** | |
| Austria | 140 |
| Belgium | 55 |
| Denmark | 70–110 |
| France | 40–60 |
| Germany | 60–170 |
| Italy | 75–80 |
| Netherlands | 70–90 |
| Spain | 20–60 |
| Sweden | 90–100 |
| United Kingdom | 30–35 |

**Eastern European countries**

| | |
|---|---|
| Poland | 25–30 |
| Czech Republic | 30 |

**Non-E.U. countries**

| | |
|---|---|
| Australia | 20 |
| Japan | 135–160 |
| Norway | 50 |
| United States | 50–60 |
| South Africa | 25–40 |
| Switzerland | 120 |

In India the Ministry of Environment and Forests has promulgated regulations for municipal solid waste landfills- http://www.moef.nic.in/legis/hsm/mswmhr.html. [13] In fact, these are more observed in breach than compliance. It will be prudent to specify untreated ASR as a hazardous waste in India, as done in California and not to mix it up with normal municipal solid wastes. Unfortunately currently the informal sector engage in automotive recycling dumps its waste with general municipal waste.

Reliable estimates of landfill costs are not available for different locations in India. IIT Delhi [14] estimated the costs as rupees 250-500 per ton of Municipal Solid waste and rupees 2000/- per ton of Hazardous waste, which will go up as more and more waste is generated.

## Development needs for ASR treatment in India.

The processes abroad are established and working well. They can be suitably adapted for Indian conditions after sufficient volume of ASR is generated. The plants require major investment in facilities and considerable land area. They will become viable only when sufficient volumes of ASR are generated to warrant the investment.

In view of the above developments, it will be fair to conclude that there is no requirement for carrying out basic research in Indian universities or laboratories, for developing processes ab initio, for treatment for Auto Shredder Residues. We however have to adapt the systems successfully operating abroad to suit Indian conditions. To this end, we must build pilot plants for understanding the technology and processes of ASR treatment. This will enable India to be better prepared when ASR has to be handled in large quantities, after recycling and shredding are established in industrial scale in India.

The pyrolytic/chemical process plants have to be set up near large Steel plants or chemical industries. There is no such restriction on mechanical sorting systems. We recommend adopting the mechanical system initially in India.

To start with the size and scale of the first plant in India can be made smaller, say less than half of the Japanese plant. We can also increase the extent of manual segregation before shredding to increase yield. The processes used in the plant are not rocket science but well established separation technologies used in industry.

It is recommended that a pilot plant may be installed at the Modern Mineral Processing Laboratory and Pilot Plant, Nagpur (originally set up with the assistance of the United Nations). [15] In the initial stages, and the pilot plant may have to be operated with imported ASR. This has to be resorted to in the absence of shredder operations in India.

The plant will enable India to develop appropriate techniques which make effective use of abundant manual labor and processes which are ideally suited to our conditions. India can use technical expertise from companies like Toyota and Suzuki, which operate large automotive plants in India and have taken an active interest in promoting efficient automotive recycling here. It will also provide India adequate lead time to be prepared for setting up full scale plants, when the output of automotive recycling warrants it. A center of excellence in ASR treatment can be set up at Nagpur.

The center might also work on development of decentralized units of smaller capacities which can be set up near auto shredding units and dismantling centers of ELVs. To start with, the first plant in India can be made smaller to handle smaller volume.

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[1] Presentation on “History of vehicle recycling industry in Japan”- Professor Arata Abe, Yamaguchi University- 2nd Working Group Meeting on ELV, 20-21 August 2015, Putrajaya, Malaysia

[2] Typical composition of ASR- End of Life Recycling in European Union- N.Kanari, J.L. Pineau and S.Shallari- JOM 2003

[3] Feedback Consultants report- Chapter 2 of this report- page

[4] Lecture by John Gbassa of Sangho Kaigo Nigeria on “Safe Disposal of End of life vehicles (ELV) and appropriate legislation” National Conference on vehicle roadworthiness inspection- Abuja July 2012.

[5] Review on Practices and Actions for ELV Recycling in Japan- Takashi SHIMAMURA (Recycling & Waste Reduction Subcommittee)- JAMA-ACEA recycling Consultations March 19,2015

[6] http://ec.europa.eu/environment/waste/pdf/study/annex3.pdf.

[7] Website on ASR post treatment facility at TIEL Holland http://www.arn.nl

[8] Website on Toyota Handa city PST plant <http://www.toyota-global.com/sustainability/report/vehicle_recycling/pdf/vr_all.pdf>

[9] US Federal regulations on Landfills 40 CFR Part 258- http://www.epa.gov/region9/waste/solid/laws.html

[10] http://assets.climatecentral.org/images/made/09_21_2015_Bobby_Magill_CC_Landfill_gas_1050_713_s_c1_c_c.jpg

[11] European Council Directive 1999/31/EC7 of 26 April 1999

[12] R. Zoboli et al., “Regulation and Innovation in the Area of End-of-Life Vehicles,” EUR 19598 EN, ed. F. Leone (Milan, Italy: IDSE-CNR, March 2000) plus Case Studies

[13] http://www.moef.nic.in/legis/hsm/mswmhr.html Indian regulations on landfills for municipal solid wastes - Ministry of Environment and Forests.

[14] web.iitd.ac.in/~gazala/CEL120/Landfilling.pdf

[15] Modern Mineral Processing Laboratory and pilot plant, Nagpur -http://ibm.gov.in/index.php?c=pages&m=index&id=81&mid=17791

# Summary and Recommendations

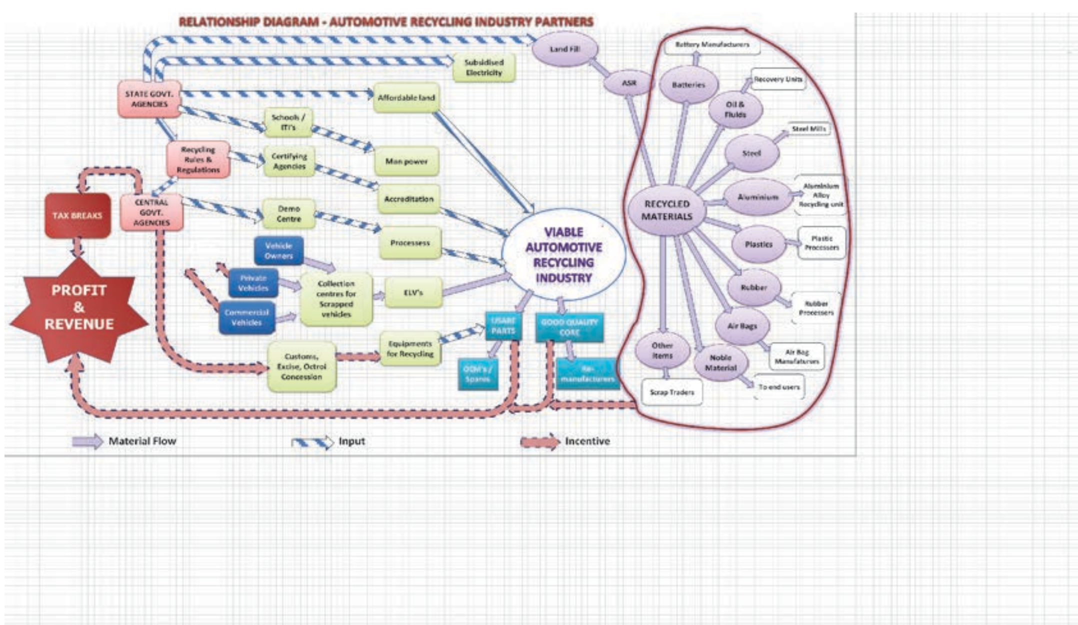
## Background

The automobile industry is a major driver of economic growth in India. It contributes over five percent of the nation's GNP and provides employment directly and indirectly to over three million. Taking into account the low penetration of automobiles and steady increase in individual incomes, it can be safely forecast that growth of automobile production and sales will be sustained for the foreseeable future.

The increasing population of automobiles has brought in its wake many problems; deterioration of air quality due to vehicular pollution, crowded and overloaded roads, alarming increase in traffic accidents and fatalities and has brought to fore, the issue of disposal of vehicles becoming due for scrapping. The efficient disposal of end of life vehicles will be a major problem requiring immediate solution.

We cannot keep on adding automobiles in India's roads, without developing a matching system for disposal of vehicles which have reached end of life. No society can operate with midwives only and no undertakers[1]. India has to follow the example of advanced nations and set up an efficient and economically viable system for handling ELVs. We have to set up vibrant industries for recycling ELVS, to handle the anticipated huge increase in vehicles for scrapping.

Automotive recycling is a complex business with a wide spectrum of stakeholders including: Central and State Governments, Pollution Control boards, Auto component manufacturers, Automobile manufacturers, regulatory authorities like RTOs, dismantlers, recyclers, used parts trade, collectors of ELVs, scrap processors and industries using recovered materials. (Please see diagram below- Captain Mohan Ram)




The issue of modernizing the recycling units and industry is currently being tackled by Governments and industry. There is tangible albeit slow progress. In addition to the automobile industry, Ministry of Road Transport, ARAI and Ministry of Heavy industry, the Central Pollution Control Board (CPCB) is also studying the issue. Following a study[2] (done by GIZ and Chintan), the CPCB is in the process of preparing a set of guidelines.

## Market Study

Chapter 2 of the project report gives the findings of a market study on projected volumes of ELV and magnitude of rubber, Plastics and ASR to be disposed of in the future, carried out by Feedback Consultants (private) Limited for INAE. The ELV projections have been done by postulating average life of different types of automobiles and using production statistics of the past years. The actual situation on the ground was studied in detail at two centers Mayapuri Delhi and Shivaji Nagar, Bangalore and extrapolated nationally.

The results clearly indicate that recycling of ELVs will soon become a major challenge which needs to be tackled at national level. It also projects the quantities of rubber (tires mainly), plastics and ASR which would be generated in the future.

Postulating an average life of 18 years for a car, 12 for a Light commercial vehicle 12for mopeds, scooters and motorcycles, 15 for auto rickshaws, and 10 years for Heavy Commercial Vehicles, the estimate numbers for ELVs[3] for 2015, 2020 and 2030 are projected to be 5.5. 8.7 and 26.7 milliosn.

With the expected increase in ELVs, there is no alternative for India other than changing over to modern recycling methods and practices of advanced nations, adapting them to suit local conditions. The small units currently operating in the unorganized sector in India, have to be upgraded in technology and relocated away from residential areas. New larger scale units employing modern methods will need to be established. The situation calls for creation of a whole new modern industry.

Recovery and handling of metallic elements like Steel, Aluminum, and Copper etc. is straightforward. India can handle their volumes with a proper system. The more difficult constituents of ELV treatment are rubber (tires), plastics and shredder residues. This study is concerned with the handling of rubber. Plastics and shredder residues left over after automobiles are recycled. It is based on the premise that India will soon develop a modern ELV recycling industry. It focuses on handling these three elements.

**The extent of generation of Rubber and plastics by 2020 and 2030 are estimated as**

| Tonnage of scrap (Tons) | | |
|---|---|---|
| | **2020** | **2030** |
| | | |
| Rubber | 32500 | 87250 |
| | | |
| Plastic | 126,700 | 306,090 |

## Rubber

Chapter three of the report discusses in detail the handling of rubber (mainly used tires) from ELVs. It lists different processes available for recovery of rubber as de-vulcanized reclaim rubber or use as thermal feedstock by producing oil or direct combustion. Recovery of reclaim rubber is more economical and energy efficient than burning tires for feedstock. A major problem with most methods for recovery of rubber are they are polluting themselves with adverse effects on the environment! A system of using eco-friendly agricultural products promises a sustainable solution, with least adverse effects on the environment. The chapter discusses different processes employed world over and also analyzed the Indian scenario in detail.

It recommends setting up a Centre of Excellence in ELV rubber recycling with special focus on tires at the National Rubber Laboratory at Kottayam, Kerala, and the leading rubber research facility in India.

## Plastics

Chapter four of the report discusses in detail currently available systems for recovery and process of Plastics from ELVs. The use of plastics of different kinds is steadily increasing in automobiles due to mandated improvements in fuel consumption and consequent move towards light weighting of automobiles. Engineered plastics are replacing metals for various parts. Different grades of plastics polypropylene, polystyrenes, poly carbonates etc. are now extensively used in automobiles.

Recycling of plastics in ELVs present special challenges, especially in India where waste plastics often enters the municipal waste stream. Burning of plastics in the open releases highly toxic dioxins into the atmosphere and is an increasing hazard. Chemical processes have been developed to avoid release of dioxins. Manual separation by density is also widely in use to recover plastics. The recovered materials are used as feedstock for less severe applications or as fuel for energy.

Recycling regulations require the different grades of Plastics to be provided with distinctive markings, as per AIS 129 also. The situation with respect to recycling and recovery of plastics continue to be unsatisfactory.

The report recommends setting up a Centre of Excellence for recycling plastics from ELVs at CIPET, Chennai which would need additional investment t the existence infrastructure.

## ASR

Auto shredder residue is a complex mixture of leftover material when metallic like Steel, Aluminum, Copper etc. are removed from shredded hulks. It is a complex mixture of fabric, insulation, steel, Aluminum, Copper, wood, plastics, cement, dust etc. It is either dumped in landfills ((US) or treated further to recover useful materials (Metals, Plastics etc.), used as fuel in furnaces with the balance going into landfills.

Currently there is no shredder operating in India. The economics of business does not warrant their use. Shredders are high investment, high productivity machines. They become viable only when sufficient number of auto hulks are available. Typically a shredder handles the output of fifteen to twenty medium sized dismantling units. It will be a few years before operation of shredders in large scale becomes viable in India. Even then, it is better to have numbers of smaller shredders serving a local area, rather than large shredders due to the logistic costs of transportation of hulks and shredder materials.

ASR will arise only when shredders are in operation. India needs however to have the technology and ability to set up ASR treatment facilities at short notice. Dumping of residues in landfills is not viable in India due to scarcity of land and high costs. In the US ASR continues to be dumped in landfills due to large availability of land and dumping of residues is far more economical than treatment. This is not the case however in Europe and Japan, which have stipulated that less than 5 % of an automobile will become residues for landfills.

Para 5 of the report briefly discusses the technologies and systems developed in Europe and Japan and recommends that the mechanical separation processes developed by a consortium led by Toyota may be suitable for Indian conditions. It will be a few years before ASR is generated in volumes. In the meanwhile it will be prudent for India to set up pilot plant facilities for handling ASR. This will help develop techniques adopted to Indian conditions so that we would be ready to install full scale plants when needed and hit the ground running.

## Recommendations.

### Generic Recommendations (not connected to this study)

1. Setting up a viable regime for recycling of ELVs should be taken up as a priority task by Central Government in partnership with automobile industry in a mission mode.
2. The existing small scale units in the informal sector operating in residential areas would need to be relocated and to be upgraded.
3. Labor currently working in the informal sector should be retrained in modern methods.
4. Tax breaks and duty concessions may be given for new units entering the business.
5. Land should be made available for recycling at concessional rates.
6. Inspection and Maintenance regime has to be strengthened to ensure vehicles which are unfit are declared as ELVS.
7. The idea of declaring vehicles as ELVs after a fixed period of usage may be seriously considered to remove polluting stock from circulation.
8. Rules currently cleared regulating design and manufacture of vehicles from recyclability point of view and operation of dismantling units should be gazette and enforced.
9. Recycling of end of life vehicles should become an integral part of the curricula of automobile engineering degree and diploma courses.
10. It is better to have a larger number of lower capacity shredders than invest on a large shredder which might end up underutilized.

**Specific recommendations arising from this study (on Rubber, Plastics and ASR post treatment)**

1. A center of excellence on recycling of rubber from ELVs should be set up in the National Rubber Board at Kottayam, Kerala. Recycling of ELVs should be added to the main objectives on National Rubber board.
2. Focus should be on getting larger quantities of reclaim rubber which can be put to other uses rather than as use of scrap rubber as fuel.
3. Research on using renewable agro-product based solvents for de-vulcanization of rubber is to be encouraged and developed by building lab scale and pilot scale plants. .
4. Dumping of used tires at unauthorized sites and landfills is to be prohibited.
5. A center of excellence on recycling of different types and grades of plastics from ELVs should be set up at CIPET Chennai in a phased manner.
6. Grading of plastic components as envisaged in the draft rules AIS 129 is to be strictly implemented.
7. A pilot plant for post treatment of ASR should be set up at the Modern Mineral Processing Laboratory and Pilot Plant, Nagpur set up with the assistance of the United Nations.

## References


[1] SIAM status report at IRT 2002 at Liverpool – presented by Captain Mohan Ram

[2] The Story of a Dying car- Chintan

[3] Study done for this project by Ms. Feedback Consultants (Private) Limited.

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