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Novel concepts in environmentally friendly rubber recycling

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Abstract

The pressure on the Rubber Industry to adopt and accept environmentally friendly technologies for the recycling of waste materials is growing. This paper looks at the source of these pressures and questions the approaches currently proposed for the waste rubber problem in the light of novel economic models and technologies based on maximising the recovery of the resources locked into the waste product whilst minimising the additional energy required.

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1 Introduction

Rubber is not regarded as an environmentally friendly material. Once valuable resources (raw materials and energy) have been invested in a rubber product they are effectively locked-in by the vulcanization process. The inability of current technologies to provide environmentally friendly and economic processes to effectively unlock these invested resources has resulted in waste rubber being viewed as a costly problem rather than as a valued asset.

Tyres account for nearly half of the rubber consumed. An estimated 270 million tyres reach their end of life in the US each year, over a billion throughout the world [1]. Each tyre constitutes a particularly difficult problem environmentally; its rubber does not break down to be recyclable as, for example, do glass, paper and metals, its shape harbours insects, its volume encloses much air, it is dangerously combustible.

Ideally, if vulcanised rubber could be returned to an unvulcanized state, as is the case for other recyclable materials, rubber in products including tyres could be recycled into new products of the same value. This means that high quality or high performance products would require high-specification recycled materials.

Current approaches to waste rubber may have the potential to deal effectively with the volume of waste but are not effective in recovering the investment made in the rubber material or products. A considerable further investment in energy and resources is often required that only serves to reduce the economic and environmental return. These approaches focus on rubber waste, “the problem”, rather than “the asset” and typically yield low-specification materials.

Legislation and social pressures, driven by environmental concerns and practical issues such as landfills reaching capacity, are forcing the rubber industry to address the problem of waste materials more acutely. Without a technical solution and a sustainable economic model these pressures will only serve to increase industry costs and further reduce margins throughout the supply chain.

The challenge is twofold – firstly there is a technical issue as technologies must be found that enable true recycling to take place, and secondly an economic issue as new models need to be developed for the rubber industry to include significant material recycling streams.

This paper looks at some of the underlying issues and proposes a different approach to the economics whilst positioning old, new and emerging recycling technologies in the light of the technical challenge.

2 The problem

2.1 Background

Since Goodyear's discovery that by subjecting a combination of sulphur, carbon and rubber gum to heat and pressure a strong durable engineering material can be produced, the global application of vulcanised rubber had grown to a yearly production level of 17.02 Million tonnes by 1999 [2].

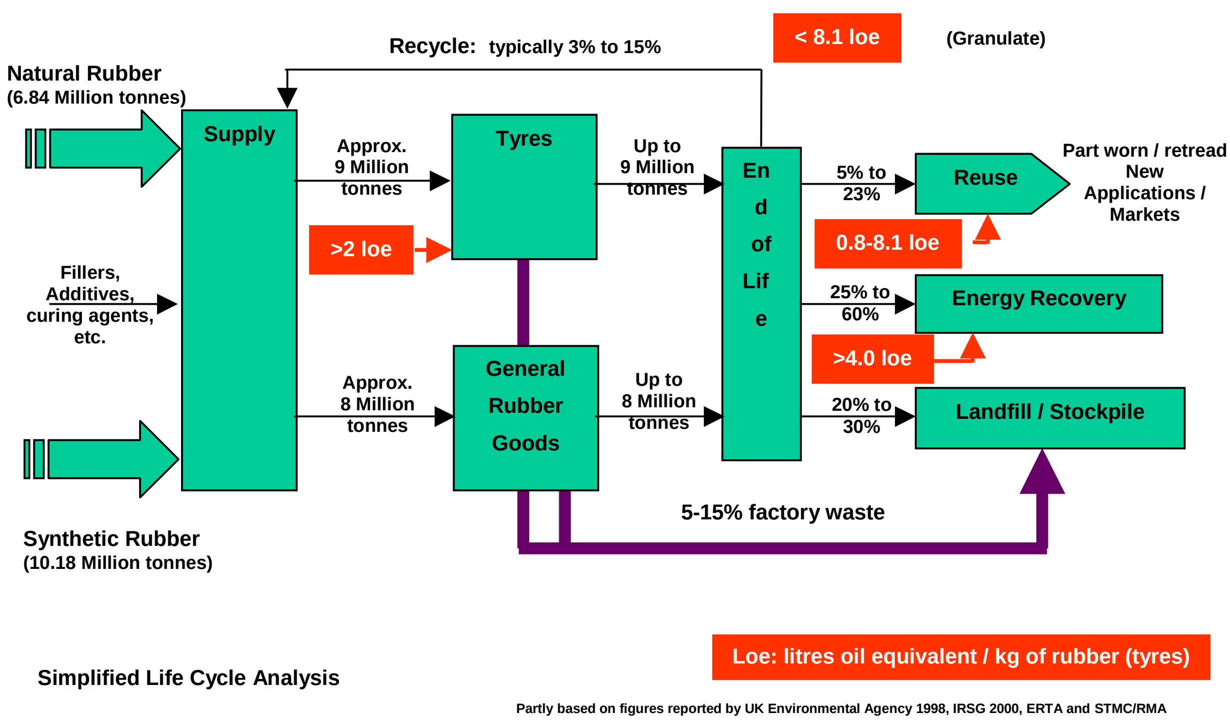

Figure 1: Simplified Lifecycle for rubber products

Approximately 40% of this, some 6.84 million tonnes, was natural rubber whilst the remaining 10.18 million tonnes consisted mainly of oil-based synthetic rubbers. In the same year some 1 billion tyres were manufactured requiring approximately 10 million tonnes of rubber material, including most of the 6.84 million tonnes of natural rubber produced.

Once vulcanised rubber has reached the end of its working life it must be recycled or disposed of. For tyres, in 1998 it was estimated that between 750 million and 1 billion tyres were scrapped globally, weighing some 6 to 10 million tonnes. Approximately 550 million tyres weighing about 5.7 million tonnes were recorded as being scrapped in Europe and the US alone. Although most of the published figures report scrap tyres, it may also be assumed that other rubber products are reaching their end-of life and that the total rubber waste stream may therefore tend towards the production totals of 16 to 17 million tonnes p.a.

Recycling rubber is not simply a case of melting the material down and reusing it, as can be done with materials such as aluminium and glass. Reversing the vulcanisation process is often likened to unbaking a cake and then reusing the eggs. Recovery of useful, uncontaminated materials is even more complex for multi-material laminated products such as modern tyres. Because of these difficulties, scrapped rubber and in particular scrapped tyres, have traditionally been landfilled or stockpiled. The estimated quantity of known stockpiled and landfilled tyres in the US and Europe is in excess of 21 million tonnes with a further 2 to 3 million tonnes being added yearly.

2.2 The pressure to change

There is an increasing pressure to address the problems associated with rubber waste streams. Concerns such as the long-term environmental impact of waste rubber in regard to pollution, environmental loading and energy consumption can be added to a number of practical issues such as the landfill sites reaching their capacity.

Landfilling and stockpiling tyres are not regarded as being environmentally sustainable solutions. The UK Environment Agency has reported a number of problems associated with the landfilling of tyres. If disposed of in large volumes, tyres in landfill sites can lead to fires. They also tend to rise to the surface, affecting long-term settlement and possibly causing problems for future land use and reclamation. Tyres buried in landfill sites are a fire hazard and ignition can cause serious air pollution as well as the pollution of underground water supplies. A fire that started in

1989 in a dump with 10 million tyres in Powys in Wales is still burning. An Environment Agency report [4] also indicates that the effects of the long term leaching of organic chemicals are not known.

Legislative pressure

As a direct response to this problem, a number of countries are legislating against the landfilling of rubber materials. For example, the European Landfill Directive will ban the burying of whole tyres in landfill sites by 2003 and shredded rubber by 2006. A number of landfill site operators have already responded by dramatically increasing the disposal cost of tyres or refusing to accept tyres or rubber waste.

Increasing use is being made of legislation to force industry to tackle the long-term problems of pollution. In 1993 the European Commission set pan-European targets for the year 2000 of 65% recovery (including energy recovery) and 25% retreading, with 10% undefined. Although these targets have yet to be achieved they do form the basis of the EC Landfill Directive.

Future trends

The increase in environmental concern, legislation and financial penalties will continue to act as primary drivers in this field. Economic alternative approaches are therefore urgently required if the Rubber Industry is to meet this challenge effectively.

Resistance to change

Resistance to change the way that we treat waste rubber has a number of origins, which include:

- The lack of technologies capable of economically unlocking the investment in rubber materials and returning them into valuable feedstock
- The market perception that products containing high levels of recycled materials are of lower quality or value than those made from virgin materials
- The low prices of raw materials

The economics are changing as rising material prices, particularly oil-based materials, force up manufacturing costs. In addition processing costs, which are sensitive to both energy and taxes, are increasing, waste disposal opportunities are decreasing and waste disposal costs are increasing.

It will be only a matter of time before the Rubber Industry will be forced to deal with the issue of rubber waste without the traditional response of landfills and stockpiles.

2.3 Current approaches

The generally accepted hierarchy of measures for the management of waste materials [9] as represented in figure 2 shows that the most favourable measures ensure the maximum usage of the resources already invested in the waste product, whilst the least favourable require considerable further investment of resource for very little, or no return.

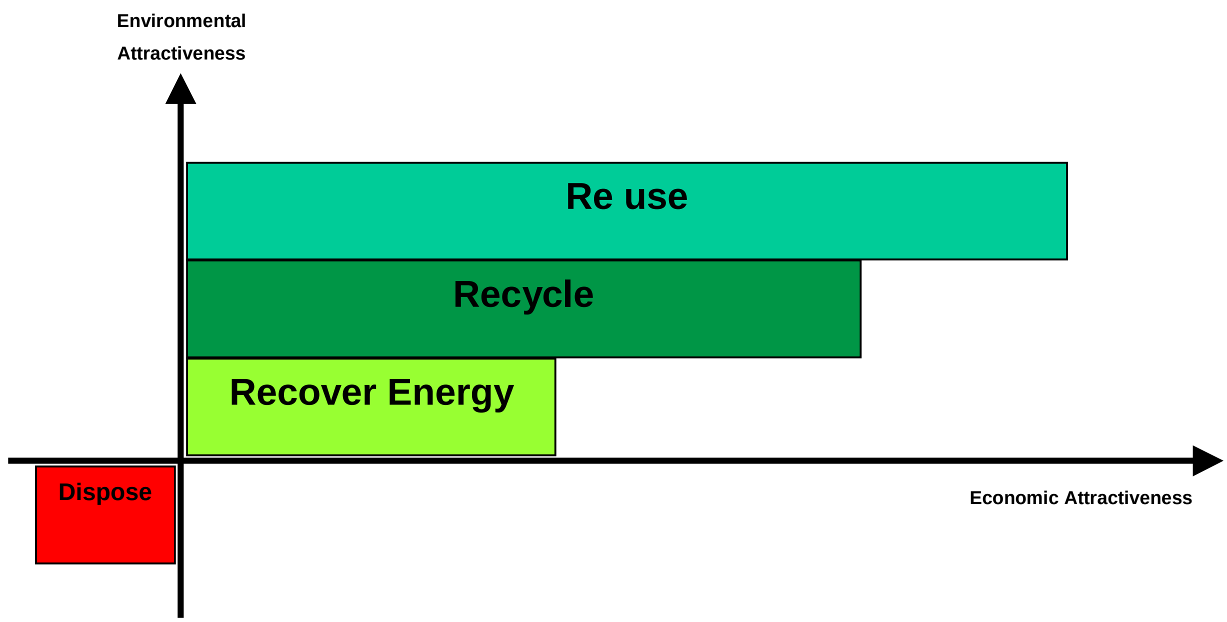

Figure 2: Waste Management Hierarchy

When positioning waste rubber products on this hierarchy, the following observations can be made:

- **Disposal**, which mainly consists of landfill / stockpile and incineration, currently handles a significant portion of the waste stream, although this is set to change as legislation comes into force
- **Energy Recovery** is particularly favoured in the US, handling more than 60% of the tyre waste stream. It is noted that although some countries, such as Finland, are taking steps

to legislate against rubber incineration as a protection against Global Warming, this is currently the main technology applied to rubber waste.

- **Recycling**, whilst currently accounting for 5% to 15% of the waste stream, is important to the thrust of this paper and is therefore discussed in more detail in the following section.
- **Reuse** ranges from the extension of product life (notably the use of part worn tyres for less demanding operating conditions and retreading) through to the use of the product in new application areas, such as in the construction industry.

Although recent efforts in Europe and the US have focussed on managing the disposal of scrapped tyres, a difference in the current implementation can be observed. The reliance on energy recovery in the US is much higher than in Europe although the Scrap Tire Management Council in the USA has reported a 20% decrease in its usage over the last two years, partly as a result of furnace efficiency requirements.

Although Europe is set to follow suit, concerns associated with the environmental impact of the incineration process, particularly in cement kilns, have been expressed. These concerns range from the emissions and by-products generated through to the environmental impact of burning synthetic rubbers which represent high hydrocarbon investments. (During the oil crises in the 1970’s it was estimated that it took 3.5 tonnes of oil to produce 1 tonne of SBR. Whilst current manufacturing efficiencies have been improved, a high level of hydrocarbons is still involved, up to 10 times that of Natural Rubbers. Circa 30-40% Carbon Black filler content further increases the hydrocarbon value.)

It has also been observed that the continuing increases in targets embedded within environmental control legislation tend to reduce the economic feasibility of the total process of incineration.

Given the public concern generated by the topic of Global Warming, it may be prudent to evaluate current and future rubber recycling strategies in terms of the total energy balance throughout their lifecycle in order to determine their “environmental friendliness”.

3 The gap

Examination of the current economic model and technologies employed when dealing with waste rubber reveals a gap between the current approaches and the present and future requirements.

3.1 Economics of the Big Picture

Waste rubber is regarded as a negative (cost) factor in current economic models which are often based on the premise that it is of low economic value and that any approaches employed are to be optimised for bulk efficiency.

This pragmatic approach invariably leads to the conclusion that Energy Recovery is the most viable bulk approach for handling waste rubber. Waste rubber compares favourably with coal and oil in terms of calorific value and can therefore be seen to be a cheap alternative to these fuels. Further arguments have been developed to show that recovering energy from this waste, with careful control of the incineration process, is a fossil fuel alternative. However, this approach is only really of value in the absence of better alternatives that can make use of more of the tyre properties.

A life cycle view

The adoption of a Life Cycle Analysis (LCA) approach identifies a number of issues related to the true value of the waste stream. The investment of resources, which include raw materials, energy, process and logistics investments are identified for each process step up to and including the recycling of the material. Using this approach, a judgement can be made as to the true economic value of the waste material and the environmental impact of a recycling approach.

Material value

As previously indicated, reuse is the most favourable option although it is not always possible as product wear and ageing can degrade a product such as a tyre. Parts of the product subject to high mechanical wear can be replaced at a fraction of the cost of manufacture for the total product as indicated by the example of tyre retreading.

This is borne out by inspection of the market value of various waste rubber streams as shown in figure 3. Here the market spot prices for various tyre waste streams are expressed as a percentage of an average market price for a new passenger car tyre. It can be seen that the prices achievable for part worn or retreaded tyres are considerably higher than for other waste streams, although these are usually less than 30% of the original new price of the tyre. It can also be noted that the price commanded by TDF averages less than 1% of the new tyre value. (As a simple verification, whilst fossil fuels remain at prices around 40 to 50 Euro / tonne, assuming a similar calorific value and approximately 100 passenger car tyres / tonne, the competitive price of TDF would be equal to or less than 0.4 to 0.5 Euro per tyre. New car tyre prices typically range from 50 to 200 Euro.)

Crumb materials command similarly low prices, often less than half those obtained from TDF although these are often incorporated into new products which do command significantly higher prices. (As a reference point, the negative value often commanded by the scrapped tyre is also indicated.)

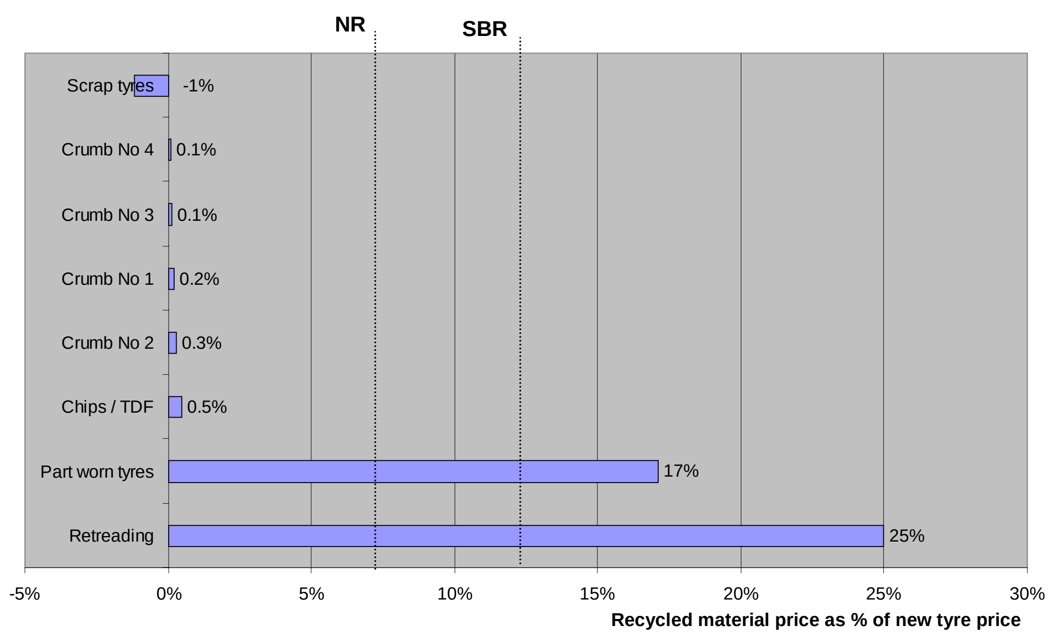

Figure 3: Relative prices of tyre waste streams

Whilst the instantaneous position of each of these points on the graph is open to fluctuation, the gap between the prices commanded for the new tyre and those commanded for the materials in waste tyres is all but total, except for retreads – evidence of a non recycling industry.

Process cost

The gap becomes even clearer when the cost of operating these processes is considered. Although no detailed information is available, published measures of the oil equivalents for key processes can be used as an indicator, expressed as a percentage of figures published for new tyre manufacture (see Figure 4). The relative energy costs include relevant materials, processing and logistics energy costs. Whilst these figures must be treated with caution as they have been collated from a number of sources and therefore still require verification, they do seem to indicate a worrying trend from an environmental view point, namely that waste streams which command less than 1% of the price of the original product require an additional energy input of the same order of magnitude or greater than the original product. This would indicate a case for subsidy rather than profit.

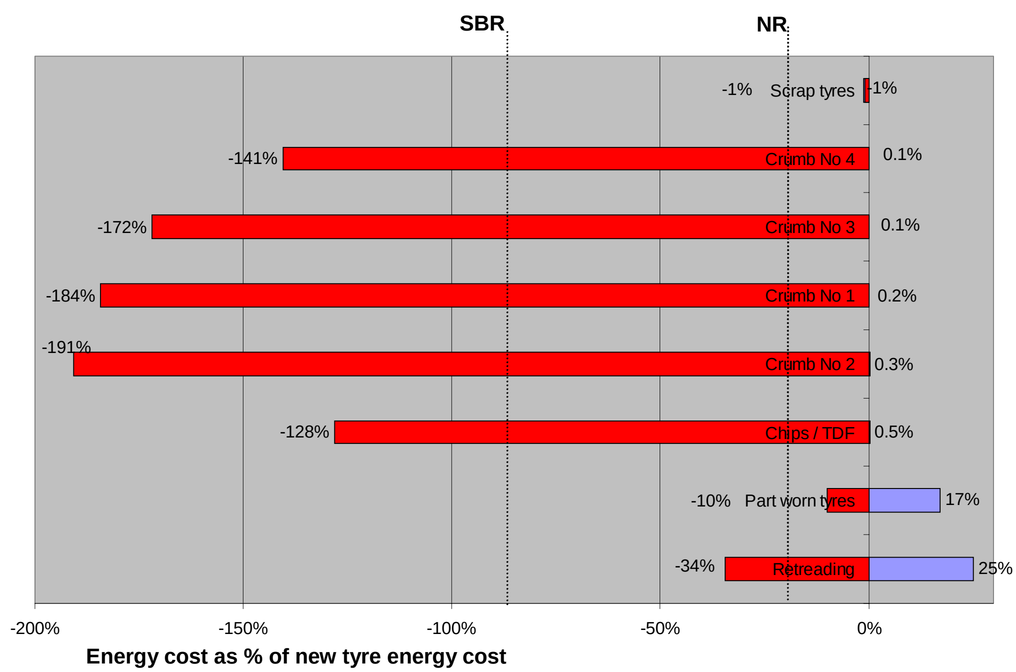

Figure 4: Relative energy cost of tyre waste streams

This result would seem to indicate that the current economic model will only be sustainable if:

- The investment in the initial rubber product continues to be written off once the product enters the waste stream
- The cost of the raw materials, particularly synthetic polymers, chemicals and fillers, are ignored
- Subsidies through taxes, levies and fees are used to close the gap between process costs and market price and between new product and recycled materials

3.2 The factory economics

The general trend identified at the macro level can also be seen at the factory scale where it also

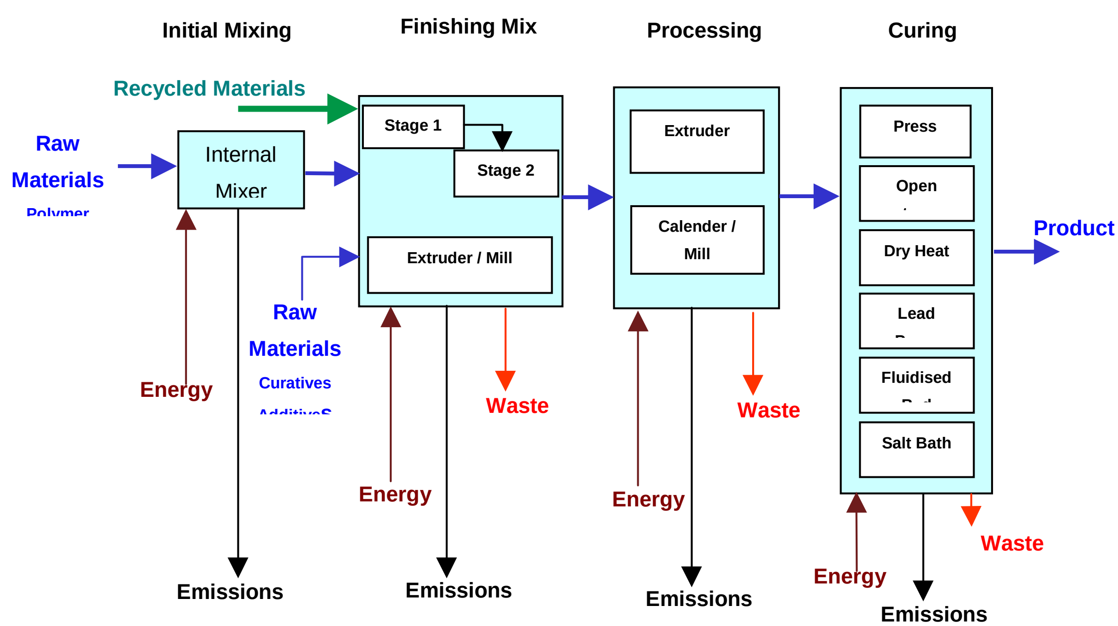

Figure 5: Typical in-factory processes

becomes apparent that the non-tyre and factory waste streams need to be taken into account.

For typical in-factory processes a number of mixing stages can be identified, together with a processing and a curing stage, as shown in figure 5. Whilst the actual technologies used are not important for this discussion, it is important to note that each stage represents an investment in the product in terms of raw materials, energy and process. Factory waste, which typically ranges between 5% and 15% of raw material usage, can be generated at any of the processing stages and typically increases in value as the product nears completion. For example, processes where parts are stamped or cut from strip or sheet usually result in volumes of webbing which form a high value scrap in terms of manufacturer investment.

Although this material has a known history, composition and formulation it is usually treated as a waste and rejected from the factory, often at an additional collection cost. For high value materials this can result in significant production costs.

Very little of the investment is recovered from this type of factory waste with the costs being passed on to the customer and raw material supplier. Increases in waste levies and taxes are likely to directly affect this waste stream although these costs too may be passed on,

In general it can be seen that both at a macro and at a micro level the current approaches are not economically favourable and that this gap will widen as external pressure increases.

4 Novel concepts

If it is accepted that current economic and technical approaches do not meet the environmental, social and legislative pressures being brought to bear on the industry, then what alternatives are there? Maybe it is time to challenge fixed beliefs and open up new directions for the Rubber Industry? Here a number of concepts are briefly outlined, more to initiate discussion than to present a complete solution.

4.1 Rubber as a recyclable material

If rubber can be considered to be a material that could be recycled then a totally different economic model could be envisaged, along the lines of models applied to the glass and steel industries. This would require recycling technologies that retain the highest level of the rubber properties for the lowest additional energy / resource investment during processing.

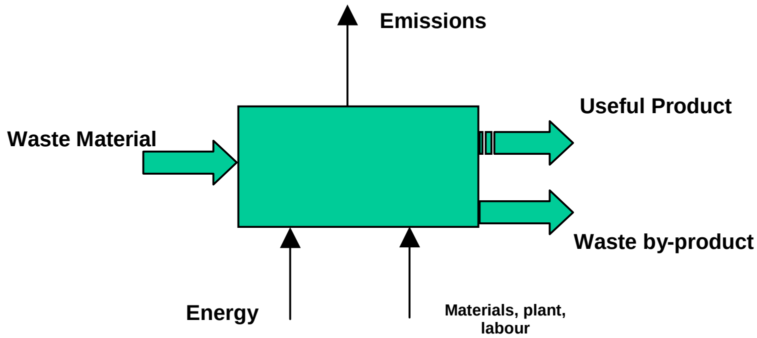

Figure 6: Process criteria

In ascertaining criteria for this technology, use can be made of the cost analysis data from the existing industry to identify rough performance boundaries. The following assumptions can be made for end of life products to be recycled into new products:

- **Useful product:**

  The recycling process should provide a material stream that is competitive in price to that of raw materials[1]. This means that the price commanded by the recycled material must be in the region of 750 Euro / tonne for Natural Rubber products and typically 1400 Euro / tonne for synthetic products such as SBR based on current raw material prices.

  Technical performance (mechanical and chemical) for critical parameters of the recycled materials would need to be within product tolerance, typically within 10% although letting down materials by combining raw and recycled stock may reduce this requirement. In most cases, reformulation of the compound to take recycled material properties into account is not favoured.

  Further, the recycled material stream would have to meet the typical industry supply criteria such as delivery guarantees, quality specifications and delivery format. Recycled materials for higher specification may also need to undergo a more rigorous sorting before recycling to ensure compatibility of formulation as most manufacturers

[1] Although the recycled materials will contain fillers, curing agent residues and other expensive processing additives, it is assumed here that these will exert a low order effect on the overall material price.

do not want to have to constantly reformulate to meet the deficiencies of the feedstock. For products such as tyres and seals, failure to perform can be a life threatening issue.

- **Resources (energy and materials):**
  Processing costs should be of the same order as those for raw material feedstocks.[2]. This means that typical processing for NR based products would be of the order of 16 GJ/tonne (approximately 4.5 litres of oil equivalent) whilst SBR would be of the order of 160 GJ/tonne (approximately 22.5 litres of oil equivalent)[3]. It should be noted that this is an integral energy balance that includes recovery, logistics and processing.
- **Emissions and waste by-products:**
  In order to maintain the environmental balance, emissions and waste by-products from the recycling processes should be less than the emissions and waste by-products generated by the initial material manufacturing processes.

For in-house recycling the following assumptions can be made:

- **Useful product**
  As this recycled material is already in-house, market price is less of an issue as long as the material is available in a form suitable for reprocessing although there are clear economic arguments to be made for focussing on materials that have a high initial cost or high energy/resource demands. The windfall from reduced raw material and waste disposal costs should be included in the economic analysis. For operations where an external operation deals with the waste and returns the recycled materials, similar price constraints apply as for end-of-life material streams.

  Technical performance requirements remain the same as for general recycling, although given the detailed knowledge of material history a closer match to the original material may be expected. Given the typical in-house fall-off rates, in-house recycled materials need only comprise 5 to 15% of the final product composition.

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[2] It can be argued that recycled materials could be regarded as compounded stock and therefore capable of being introduced at a later stage in the manufacturing process with associated energy savings. As this introduces another variable which will be a function of the process into which the material is to be introduced, it is not included in this rough order-of-magnitude estimate.

[3] These figures are based on old calculations and require revision to reflect advances in manufacturing process efficiencies

As the material will have been subject to in-house inspection and controls, the history of the scrap is well known.

- **Resources (energy and materials)**
  Processing costs should be of the same order as raw material feedstocks described above although, depending on the stage within the process generating the waste, initial processes may be skipped when incorporating the recycled materials

4.2 Recycling technologies

The lack of an economical recycling technology that can unlock the true economic value of waste rubber by providing a recycled material with properties approaching those of virgin feedstock is the major barrier to the implementation of models based on rubber as a recyclable material. The ideal form of recycling is through devulcanisation in which the vulcanisation process is reversed to provide a soluble material for re-use. In simplistic terms, a technology that can break existing crosslinks whilst causing minimum damage to the polymer backbone and result in a material which can will readily take part in further crosslinking processes is all that is required.

Five categories of recycling technology are identified here, namely:

- Downcycling
- High Energy Breakdown
- Chemical Modification
- Biological Breakdown
- Mechanochemical Recycling

These can be roughly positioned by examining their consumption of resources in terms of energy, materials and chemicals, plant / process and the emissions and waste that result from the recycling process. If this is viewed against the ability to retain the properties of the original material then a simple classification can be made as illustrated in figure 7. An ideal technology would tend towards a low Resource Consumption and high Property Retention.

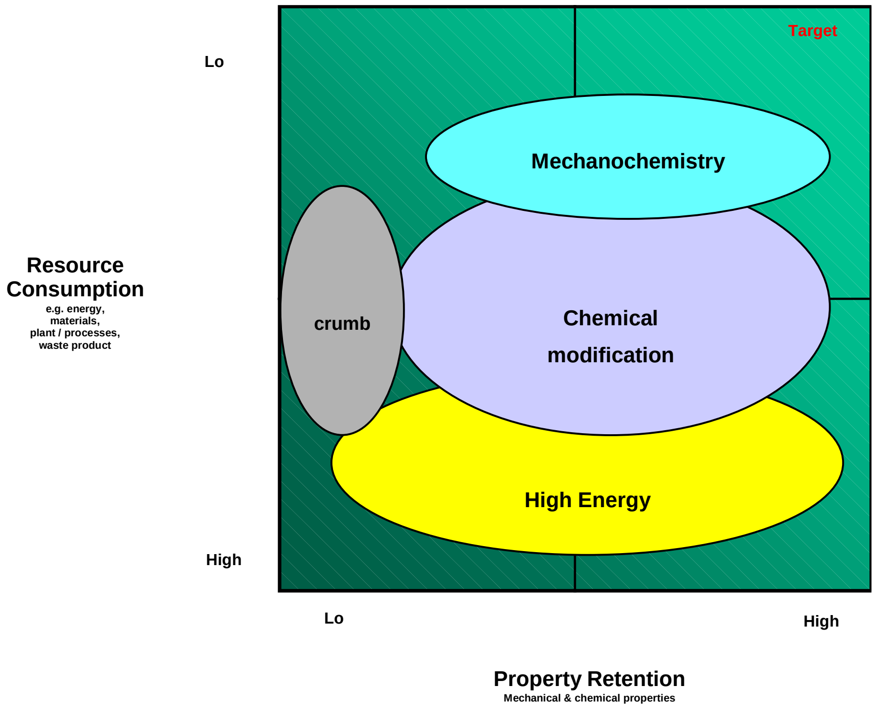


Figure 7: Rough relative positioning of recycling technologies

These categories represent a very rough bundling of technologies. Typical examples of technologies that would fall into these categories are:

Downcycling

- Mechanical size reduction (shredding and crumbing)
- Chemical breakdown

The term "downcycling" is sometimes used when describing processes in which the properties of the recycled material are significantly reduced when compared to the original material or compound. For rubber this often indicates either a significant change in mechanical properties as a result of backbone breakage or a change in chemical properties as a result of chemical additives.

When downcycled, typically by mechanical crumbing, rubber is often used as a filler in another material which is sold either as a base material or incorporated into a suitable product or application. It is often found that the finer the crumb, the easier it is to incorporate into fresh recipes. Typically only the bulk properties of the crumb are used although sometimes additional performance characteristics are achieved through chemical modification. The economics indicate that the new materials, products and applications must command prices that are sufficiently higher than the base crumb. These materials often require new markets and new products (and applications) which classically represents the most difficult of marketing challenges requiring time and resource to develop.

A number of applications have already been identified for rubber crumb, such as bulking materials in asphalt road surfaces and other civil engineering applications although there are limits to the volume that can be included. A number of products have also been identified for materials with reduced performance such as rubber playground surfaces, car mudflaps, mats and carpet backing material. The limited uptake of these materials reflects the effort required in developing these new markets, products and applications.

Chemical modification

- Chemical breakdown of crosslinks
- Surface Activation
- Material Dissolution

From the point of view of Chemistry, the vulcanization process links up the raw rubber chains into a gigantic single molecule. “Devulcanizing” is the process of unlinking all these chains again so that they can again behave virtually as the original raw rubber and mixtures with carbon black as virtually that of the “compounded stock” from which rubber products are made.

Chemical Devulcanization has been an aim all the way back to Charles Goodyear’s discovery of vulcanization in 1839. Full chemical devulcanization has yet to be achieved mainly due to the complexity of the rubber chemistry coupled with the large range of material formulations and the need for a resultant material which cannot contain chemicals that upset the curing reaction when added to a compound stock. Academically, some thermal chemical reactions can so convert a vulcanisate. Warner [17] has summarised such chemicals, which have been found to be chemical probes capable of splitting various sulphur bonds. Unfortunately, none has led to a commercial process yet and no chemists have foreseen one.

An alternative approach is to reduce the rubber material to a small particle and then to chemically “reactivate” the surface to enable it to take part in further curing reactions. This can be done by either chemically treating the surface of the crumb or by coating it in a latex film. Both these approaches have met with limited success to date.

A new phenomenon of an alcohol devulcanisation was announced earlier this year by Goodyear, but it currently seems to be just a chemical curiosity.

High-energy breakdown

- High Energy excitation (e.g. Microwave and Ultrasonic)
- Pyrolysis
- Coalite

An alternative approach to devulcanization is through the use of high-energy fields to excite the material to a point of crosslink rupture. Typical excitation sources are in the ultrasonic and microwave spectrum. Larger scale plants are in operation although resource consumption (high-energy inputs) may be a limiting factor.

Through pyrolysis, rubber can be thermally degraded in the absence of oxygen to form component materials such as gas, oil and carbon which can be sold as base materials or energy sources. The environmental balance of pyrolysis plants is based on the premise that the only way to unlock the resources within waste rubber is to return it to component materials. As such it represents a high resource consumption.

Coalite have recently announced in the UK that a useful fuel / oil can be obtained from tyres that have been “processed” for 9 hours at 600^{o} C in their specially designed ovens.

Biological breakdown

For sulphur crosslinked materials research indicates that microbes with sulphur affinity may be introduced to rubber waste streams to break down the crosslinks. Such technology may be forthcoming within the century.

Mechanochemical solubilising

- High Shear Mixing

The basis of Mechanochemistry is the change in the chemistry of a material when mechanical energy is applied. Initially this was applied to increase the understanding of the effects of mastication on uncured material stocks. Watson and co-workers in the 1950's showed [6] that the softening of rubber by cold mastication was due to the rubber chains being so extended in their central sections that a main-chain bond there was ruptured. The ruptured ends were free radicals. Normally these free ends were terminated by combining with oxygen. They could be arranged to react otherwise, combining in pairs in absence of oxygen, reacting with an added small-molecule radical acceptor, adding to the surface of a reinforcing filler and initiating free-radical chain reactions.

Based on this principle, W.F. Watson in the 1990's conducted a series of laboratory scale experiments (2g sample size) using a novel mixer to show that a rubber network, sufficiently extended, would rupture preferentially at crosslinks. These were likely to be regions of stress concentration and the sulphur bonds at the crosslinks were of less bond strength than the carbon-carbon bonds of the chain segments between crosslinks. It was further expected that bonds within the crosslink rather than adjoining bonds in the chain segments would split. See figure 8 below. This work has been patented (PCT/GB96/00956) and the mixer termed a High Shear Mixer (HSM).

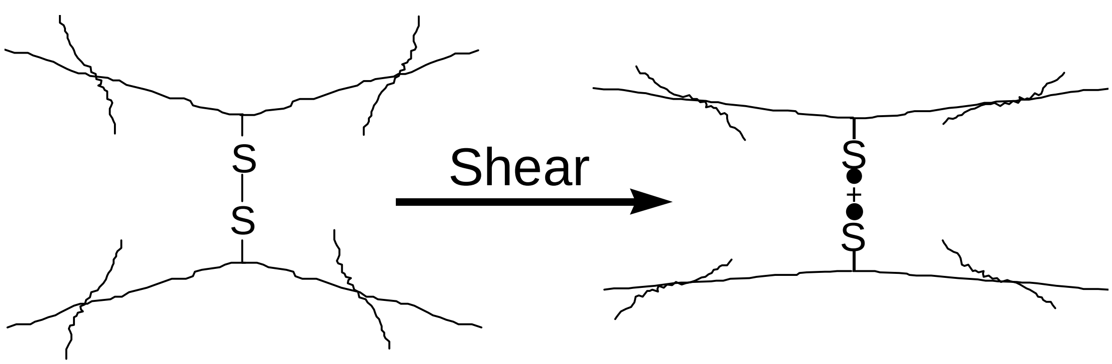


Figure 8: Effects of selective shear on vulcanised bonds

This early work has been extended to include a wide range of viscoelastic polymers, including NR, SBR, BR, EPR, EPDM, CR, and NBR and an initial 1000 times scale-up to a 2kg batch size in 1998.

Whilst work on SBR and NR tyre compounds reported in 1998 indicated the potential of the technology, recent work has revealed very promising results. For example, recycled SBR tyre compound which has been let down and cured, with more than 80% recycled material in the sample, has yielded UTS values in excess of 16Mpa and which are within 80% of the original material values, with EB above 350%. Already providing a useful material for a number of applications, further optimisation of the process may result in a technology that is capable of fulfilling the recycling role using mixing energies which are of the same order of magnitude as established mixing technologies already in the industry.

A European funded 2 year CRAFT project was started this month in which 9 partners in Germany, the Netherlands, Portugal and the UK will be actively assessing this technology, looking to both scale it up and apply it to existing and new products and processes.

5 Discussion

5.1 Historical note

The authoritative "History of the Rubber Industry" published by Hoffman in 1952 contributed to by prominent members of the rubber industry states that, before World War II, of the total of 2 million tons of rubber goods manufactured annually, some 360 thousand tonnes consisted of "reclaimed rubber" [some 18%]. While the "reclaimed rubber" gave tensile strengths of only around 5Mpa compared with 20 Mpa for new materials, it still constituted a usable material suitable for a number of products produced by the current industry.

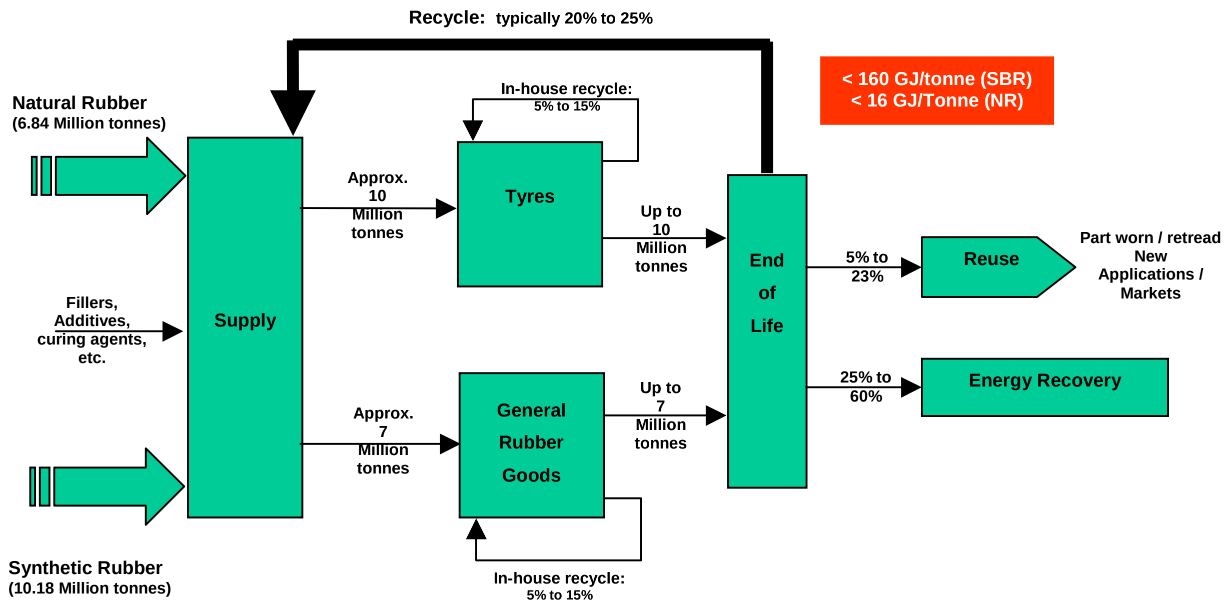
5.2 Rubber as a "Recycling Industry"

Returning to the simplified life-cycle model presented earlier, the following modifications could be considered:

- The elimination of the waste stream to landfill / stockpiling which will result in an additional 20% to 30% of waste materials to be processed
- The inclusion of in-house recycling streams that will return much of the 5% to 15% in-house scrap into product

- The strengthening of the recycling stream to enable 20% to 25% of materials to be returned to the supply chain. These would typically be "high value" materials based on economic and environmental criteria.

These changes are reflected in Figure 9.



Simplified Life Cycle Analysis

Figure 9: Life Cycle for a rubber recycling industry

Whilst it is too early to predict the impact of changes such as these on the Rubber Industry, the following issues are clear:

- Whilst considerable pressure is being brought to bear on the Industry to move towards a recycling model, care must be taken to ensure that any new economic model ensures a better future for the entire industry including, in particular, the Natural Rubber producers if the diversity of materials is to be maintained.
- The premise that rubber waste is of no or low value and therefore an environmental burden needs to be changed. Bodies currently co-ordinating the mass destruction of

waste rubber need to adopt a new premise that reflects the true economic and environmental value of waste rubber and set economic and technical targets accordingly.

- Finally, environmentally friendly recycling technologies are being developed to unlock the materials and energy in rubber waste and end of life products, including scrap tyres. These must be encouraged and judged using clearly defined technical and economic criteria.

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