INDUSTRIAL USAGE OPPORTUNITIES FOR PRODUCTS DERIVED FROM WASTE TYRES IN SOUTH AFRICA

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TIPS supports policy development through research and dialogue. Its areas of focus are industrial policy, trade and regional integration, sustainable growth, and a just transition to a sustainable inclusive economy.

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EXECUTIVE SUMMARY

Waste tyres are a problematic waste stream. While figures provided vary, it is estimated that 10.9 million waste tyres enter the waste stream per annum (about 300 000 tonnes), with an estimated 900 000 tonnes stockpiled. An estimated 93 400 tonnes of tyres were collected for processing in 2021 (about 31% of waste tyres generated), with 22 700 tonnes of collected tyres processed (about 8% of waste tyres generated per annum). The growing volume of tyres and the stockpile are both a financially and environmentally unsustainable situation.

While government has invested in programmes to incentivise the use of waste tyres, this is largely insufficient. As such, government, the tyre industry, and waste tyre processors continue to recognise and promote the significant potential of waste tyres as a valuable material to produce added-value products, replace raw rubber as an ingredient, and generate energy through co-processing. In response and given the interim nature of the DFFE's Waste Bureau programme to manage waste tyres, the South African government, in consultation with the tyre sector is currently engaged in developing the Industry Waste Tyre Management Plan (IndWTMP). The most recent iteration was published in March 2022 for consultation (DFFE, 2022).

Given the extent of the waste tyre situation, this research and report aims to:

- Clarify the specific opportunities for supporting new industrial-scale market opportunities for waste tyre products.
- Assess how to enhance existing markets and remove barriers that hinder market expansion and cause market instability, including determining options for approaching both the demand and supply side for waste tyre-derived product, and the market and regulatory conditions needed to maximise the diversion of waste tyres from landfills.

Research findings are to inform the provision of guidance on and recommendations for:

- The alignment of industrial and environmental policies to foster sustainable management (including the production of goods) from waste tyres; and
- A ministerial stockpile abatement plan, e.g., how the private sector and government can deal with the pre- and post-2012/2013 stockpile.

Status of waste tyres in South Africa

Drawing on extensive desk-based research (published documentation and media), data provided by the Waste Bureau, and interviews with stakeholders in the waste tyre value chain, it is clear that there is much variation about the current magnitude of waste tyre volumes in country, the type of tyre, and their location. While estimates for those entering the waste stream annually can be determined from tyre sales, the stockpile figures published varied considerably. Table 1 illustrates the variance in figures presented along the waste tyre value chain.

Table 1: Key statistics, and data variances, associated with South Africa's waste tyre system, per annum (except for estimated stockpile)

TYRES	MANUFACTURED IN SOUTH AFRICA	SALES	WASTE TYRES ENTERING MARKET	TYRES COLLECTED FOR PROCESSING	WASTE TYRES PROCESSED***	ESTIMATED STOCKPILE ('LEGACY') TYRES
	(PER ANNUM)					
No. of tyres (units)	7.95 million[1]	13[2] – 13.5 million[Ŧ] Of which[1]: 5.5 million (locally manu. domestic sales) 1.3 million (exported†) 9.3 million (imported‡)	11[4,8,9,10] – 12[3] million (10.9* million)			14[3] – 100[4] million (30 – 60 million[7])
Tonnes		300 000[2] tonnes	135 000[9] – 300 000[2] tonnes	93 400[6] tonnes (An estimated 31%[∞] of new waste tyres generated per annum)	22 700[6] tonnes (An estimated 24% of waste tyres collected for processing)	170 000[9] – 30[5] million tonnes** (900 000 tonnes)[2]

Source: Author derived, based on [6]Baloyi (2021); [4]Barker (2019); DEA ([9]2018a, [7]2018b); [2]DFFE (2022); [5]Mandini (n.d.)[this figure is unlikely, but illustrate the variance in figures published]; [8]Muzenda (2014); [9]Nkosi et al. (2019); [10]REDISA (2022); [1]SATMC Lightstone Auto (2021); [3]Shanavas (2020); [7]Supa Quick (2022).

NOTE: Original figures have been rounded. Figures presented illustrate the diversity of data published. No. of tyres (units) are presented separately to tonnes, as some sources often only present units or tonnes. The purpose of this Table is to present the variance in what is published across a variety of media and documentation.

* Author derived: 10.9 million derived using an average attrition rate of 19% on new tyres (DEA, 2018a [20%]; REDISA, 2022 [18%]; DFFE, 2022 [18% - 20%]).

** As per the latest iteration of the IndWTMP (DFFE, 2022) there are an estimated 900 000 tonnes of total waste tyre stockpiles (excluding waste tyres managed in accordance with abatement plans) in South Africa.

† Export market tyre sales of locally manufactured product (SATMC Lightstone Auto, 2021).

‡ SARS Import Quantity (SATMC Lightstone Auto, 2021).

[Ŧ] Author derived, based on SATMC Lightstone Auto (2021) local manufactured sales, export sales of locally manufactured product and imports (assumed sold locally).

[∞] Author derived using 300 000 tonnes as the estimated volume of waste tyres entering the market per annum.

Drawing on the various figures presented in Table 1, Table 2 provides estimates of waste tyres available for processing.

Table 2: Estimated volumes of waste tyres requiring processing

PERIOD	ESTIMATED VOLUME OF TYRES (TONNES)
Per annum	300 000 (DFFE, 2022)
Stockpile*	900 000 (DFFE, 2022)

* Figures on which to base an estimate for the stockpile vary significantly. Such a stockpile would include waste tyres potentially still held in Waste Bureau registered depots, on private land, e.g. mines and on farms, and dumped or landfilled. It is recommended that further research is undertaken to better understand the scale, location and tyre types associated with the stockpile.

Industrial solution opportunities and considerations

Given the scale of waste tyres entering the waste stream annually, and post- and pre-2015 stockpiles, there is an urgency for feasible solutions to be identified and current practices scaled (where applicable).

This research identified a variety of reuse, recycling and recovery solutions, with a selection of focus solutions proposed as viable for scaling. While it should also be acknowledged that dealing with waste tyres may not necessarily be optimal from an environmental perspective, it is better than not dealing with them at all. As such, a set of broader criteria were used to determine feasibility for scaling, including scaling potential, cost, market readiness, technical readiness, capacity, capability, employment potential, environmental and social impact, and barriers and considerations for implementation. The proposed focus solutions deemed viable and scalable include:

- RECYCLING: Rubber crumb
  - Use of waste tyres in crumb rubber modified (CRM) bitumen for road construction.
  - Use of waste tyres in moulded products for flooring, paving, matting and roof tiles.
- RECOVERY: Alternative fuels
  - Co-processing of waste tyres as an alternative fuel in cement plants and brick air-drying kilns.
  - Pyrolysis of waste tyres to produce oils (upgraded to diesel) and carbon black.

Many informants indicated their relationship with the Waste Bureau is a good one, and very supportive. The mechanism of engagement and ordering tyres functions well. The system for ordering waste tyres online was deemed most effective.

However, several challenges were identified with the current and potential implementation of the waste tyre programme and solutions. These can be categorised as cost and financial risk, clarity of understanding, sourcing of technology, government bureaucracy, and the tendering system. Setup and operational costs for many processing solutions are significant inhibitors for investors, entrepreneurs, and the sector. This also inhibits small and medium enterprises (SMEs) from accessing opportunities. As such, current tenders, which run for about five years, are deemed too short to meet payback periods. Another key inhibitor or financial risk is the lack of security of supply, which has prohibited a number of investors from establishing processing plants in the country.

Given these barriers to implementation, key considerations for mitigating these and implementing solutions at scale hinge on a focus on market drivers and aligning the appropriate solutions and technologies to meet these. Therefore, solutions become particularly appealing when aligned with providing a solution for some of the country's main concerns, such as the use of coal alternatives for energy, road construction and maintenance, infrastructure development, and the construction of housing.

To mitigate some of the challenges identified, and to achieve the potential for absorbing waste tyres, the following mitigations are suggested:

- Better government provisioning and less bureaucratic services and processes;
- A more conducive environment to mitigate investor risk;
- Government and/or funder support or incentives to reduce setup, upgrading and operational costs; and
- The creation of a forum to improve the understanding of the waste tyre issues and the identification and implementation of solutions in the country.

Table 3 illustrates the estimated waste tyre absorption potential per solution proposed.

Table 3: Estimated waste tyre processing potential, per solution

SOLUTION	POTENTIAL ABSORPTION PER ANNUM PER BEST PRACTICE* FACILITY			
	TYRE UNITS	ESTIMATED TONNES	PREFERRED TYRE TYPE**	ESTIMATED SET UP COST PER FACILITY
Rubber crumb (for moulded products)	35 600	300	Truck	R170m
Co-processing (cement kilns)	40 000	340	Passenger	R20m-R50m
Co-processing (brick air drying kilns)***	4 500	40		
Continuous feed pyrolysis	36 500	11 000	Industrial/ OTR	R50m-R120m

Source: Author derived, based on insights provided in solution tables above, and average wate tyre weights (Waste Bureau, 2021).

Notes:

* A best-practice facility is that which absorbs waste tyres to its maximum potential. For instance, while current co-processing in South Africa is an estimated 20% waste tyres and 80% coal, best practice could achieve a ratio of 65% waste tyres and 25% coal.

** While most solutions can take different tyre types, technologies may be designed to take specific tyre types or have a preference. For instance, due to OTR tyres having a high oil content, they are often preferred for pyrolysis. This, however, does not mean that OTR tyres cannot be used in other applications.

*** South Africa currently has 14 cement kilns and 10 chamber drying brick kilns (24 kilns in total).

WHAT DOES THIS MEAN FOR POLICY ALIGNMENT AND A WASTE TYRE STOCKPILE ABATEMENT PLAN?

The effective implementation of scalable, feasible waste tyre solutions will require the alignment of core industrial and environmental policies, such as the Automotive Master Plan and the IndWTMP. The Master Plan's objectives to increase levels of local content by 60% in automotive products provides a circular opportunity for carbon black, for example, generated from pyrolysis to be used as an ingredient in the production of new tyres. Other areas of policy alignment include the recognition of tyres as a significant alternative source of fuel in relation to the Integrated Energy Plan, for example, in the use of waste tyres for co-processing in kilns. The South African National Roads Agency's (SANRAL) Horizon 2030 strategy calls for the need to harness the power of emerging technologies to improve road efficiencies. Aligning and acknowledging the potential of waste tyres as an ingredient in bitumen could create continuous demand.

In relation to a waste tyre stockpile abatement plan, recommendations become less specific. For a plan to be constructive and viable, a more considered and accurate understanding of the waste tyre stockpile is required, including regional location of tyres by type and volume. Such an understanding would set a firm foundation for developing a meaningful abatement plan. Additional considerations for developing a plan include alignment of technology solutions with stockpile scale, tyre composition, and location; plan development to be undertaken in consultation with tyre value chain actors; and annual external audits to be undertaken to ensure accountability and efficacy.

In summary, there is sufficient volume to warrant investment in the identification and support of considered scalable solutions. These should be informed by market potential and drivers, as opposed to the possibilities of what a technology can deliver. South Africa, in the main, has the capability to build on current activities and implement and scale waste tyre processing activities. However, some significant challenges, such as setup and operational costs, system processes, and government's ability to influence procurement specifications, need to be overcome and considered strategically.

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ABBREVIATIONS

CRM	Crumb Rubber Modified
CSIR	Council for Scientific and Industrial Council
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and Environment
DSI	Department of Science and Technology (now Science and Innovation)
dtic (the)	Department of Trade, Industry and Competition
EU	European Union
Gj	Gigajoule
IDC	Industrial Development Corporation
IIWTMP	Integrated Industry Waste Tyre Management Plan
IndWTMP	Industry Waste Tyre Management Plan
OTR	Off-the-Road (tyre)
PMG	Parliamentary Monitoring Group
PTE	Passenger tyre equivalent
R&D	Research and Development
REDISA	Recycling and Economic Development Initiative of South Africa
SAAMP	South African Automotive Master Plan
SANRAL	South African National Roads Agency
SARS	South African Revenue Service
SATMC	South African Tyre Manufacturing Conference
SMEs	Small and Medium Enterprises
ZAR	South African Rand

1. INTRODUCTION

Tyres are one of the most problematic waste streams in the country. While figures vary, it is estimated that 300 000 tonnes of waste tyres are generated per annum, and approximately 900 000 tonnes stockpiled (unprocessed) (DFFE, 2022). The processing rate is low; for example, in 2020/2021, only 8% of estimated total waste tyres generated were processed, or 31% of tyres collected for processing.

This is a problem, as dumped waste tyres are resistant to natural biodegradation (Mohajerani et al., 2020; Stevenson, et al., 2008) and, as a result, have a legacy of piling up in industrial-scale quantities across the land – from drainage lines to landfills sites and storage yards. Environmental impacts associated with waste tyres include air pollution from burning to recover steel, water pollution, and land contamination from dumping (Mulenga, 2015; Phale, 2005). The illegal burning of tyres releases toxins and rubber dust particles, which can lead to significant health complications, resulting in increased allergies and respiratory irritations (Baker, 2018; Mulenga, 2015; Muzenda, 2014). The stockpiling and illegal dumping of tyres also provides an economic opportunity for re-sale on the second-hand market. Due to the unroadworthiness of most waste tyres, the failure of these tyres can often lead to increased motor vehicle fatalities (Phale, 2005; PMG, 2021).

This is both financially and environmentally unsustainable. The current situation feels overwhelming, with waste tyres entering the market constantly, and the stockpile ever growing (Mandini, n.d.; Shaw, 2021b). While government has invested in programmes to incentivise the usage of waste tyres, this is largely insufficient.

Government, the tyre industry and waste tyre processors all recognise the significant potential of waste tyres as a valuable material to produce added-value products, replace raw rubber as an ingredient and to generate energy (DFFE, 2022; Sebola et al., 2018). Government recognises waste tyres as one of five priority waste streams that need addressing (CSIR and DST, 2017; Tolulope et al., 2017). The latest iteration of the IndWTMP was published for consultation in March 2022 (DFFE, 2022), with revisions due for publication in the latter half of 2022. In addition, the government's Waste Research Development and Innovation Roadmap sets out a target for 100% end-of-life tyres to be collected and recycled, and a 50% decrease in stockpiles to be achieved by 2024 (Roman, 2018). Given that currently only an estimated 8% of waste tyres collected are recycled, and the stockpile unknown, this target is ambitious, unless drastic interventions are put in place.

As such, this research aims to clarify the specific avenues for supporting industrial-scale market opportunities for waste tyre products, how to enhance existing markets and remove barriers that hinder market expansion and cause market instability. This includes determining options for approaching both the demand and supply side for waste tyre derived products, and the market and regulatory conditions needed to maximise the diversion of waste tyres from landfills. Research findings are to inform the provision of guidance on and recommendations for:

- The alignment of industrial and environmental policies to foster sustainable management (including the production of goods) from waste tyres; and
- A ministerial stockpile abatement plan, e.g., how the private sector and government can deal with the stockpile.

To set the context, this report provides an overview of the current understanding of South Africa's tyre value chain, and waste tyre magnitude. From this platform industrial solutions are investigated, and potential solutions proposed. This includes potential solutions to reduce waste tyre volume, product output opportunities, and job creation. Implications for opportunity implementation are investigated for feasibility, such as cost, system requirements, and technological readiness. These opportunities and barriers provide insights to set out the levers for implementing appropriate solutions at scale, and policy recommendations and alignment.

2. RESEARCH METHOD

This section presents the method adopted to undertake the research. This is key, as the availability of data on this topic was unclear and often contradictory or dated. Interviews with stakeholders in and associated with the sector therefore proved invaluable for appraising the current situation, solution potential, and ways forward to achieve industrial, scalable impact.

2.1. Data collection methods and sources

The types of data identified and used, with some key questions associated with each, are presented in Table 4. Data and insights were gathered through desktop research, access to raw and secondary data, and through interviews with industry and associated stakeholders.

Table 4: List of data sources per theme of investigation

<table>
<tr><th>DATA</th><th>SOURCES</th></tr>
<tr><td>Waste tyres: Stockpile
- Volume (tonnes)
- Scale of Private (e.g. mines) and government stockpile (by depot)
- By tyre type, geographic location, quality, pre- and post-2012-2013 ("legacy" waste tyres)</td><td rowspan="3">- Waste Bureau, DFFE
- Key informant interviews, e.g., main sources of waste tyres, solution providers, DFFE/the dtic/Department of Science and Innovation (DSI)*; waste service providers, trade associations
- Other research, e.g. journal articles, theses, project reports
- Media

*(*Previously the Department of Science and Technology)*</td></tr>
<tr><td>Waste tyres: Volume entering the system per annum
- Volume (tonnes) per annum
▪ By sources; e.g. mines, tyre type, geographic location; quality
- Waste tyre destination per source; e.g. held on site, sent for recycling, landfill</td></tr>
<tr><td>Waste tyres: Volume diversion to date
- Estimated volume (tonnes) of waste tyres diverted from landfill (excluding stockpile) per annum
▪ By tyre type, source, diversion activity; e.g. recycled, repurposed, mechanical treatment, energy-use</td></tr>
<tr><td>Solution opportunities
- Types of solutions available
- Indicate whether in research and development (R&D) or commercial stage
- Indicate whether already active in South Africa or outside the country</td><td>- Key informant interviews, e.g. solution providers; DFFE/the dtic/DSI; waste service providers
- Other research, e.g. journal articles, theses, project reports
- Media</td></tr>
</table>

Source: Author.

2.1.1. Document review

A variety of sources were reviewed, including reports, academic research, media articles, strategies and plans, government policy and regulation, and company and trade association insights. An initial document search proved invaluable for capturing data on the tyre market (actors, size, value), waste tyre and socio-economic insights, and magnitude of waste tyres entering the waste stream per annum and stockpiled. Waste tyre collection and processing statistics were, in the main, obtained from the DFFE's Waste Bureau.

It was also through this process that an initial set of solutions, opportunities, and potential barriers and considerations were identified.

2.1.2. Interviews with key stakeholders

Interviews with industry stakeholders (informants) across the (waste) tyre value chain, government, and research institutions proved invaluable. In consultation with TIPS, the dtic and DFFE, an initial list of key informants was identified. Through interviews with this initial set of informants, additional informants for interview were proposed. Informants provided data and insights on the current situation and potential solutions for waste tyres. Thirteen interviews were undertaken. The interview process captured:

- The role in the waste tyre industry and involvement in the Waste Bureau programme;
- Understanding of current waste tyre volumes, types, and locations; and
- Proposed industrial solutions (opportunities and challenges) and challenge mitigation (including business model).

Given the sensitivity around solutions, interviews were treated in confidence. As such, individuals and organisations are not quoted or named in this report.

2.2. Solution opportunity indicators

Table 5 provides a list of indicators developed to identify viable, scalable waste tyre solutions. The list of indicators also ensured solutions identified touched several indicator benefits (thereby recognising systems thinking).

Table 5: List of indicators to assess the feasibility of industrial scalable solutions

PROPOSED INDICATOR	DETAILS
Employment	- Employment opportunity - Type of employment - Job numbers / labour intensity - Indirect jobs / employment multiplier - Commentary on nature of job, e.g. precariousness, longevity, decency
Scale	- Volume of waste tyre feedstock - Ability and capacity to sustain high level of intake, including initial absorption of stockpile vs sustained feedstock intake for yearly release of waste tyres into the system - Industrial vs artisanal
Cost / economic	- Initial investment / requirements - Operational costs - Return on investment

	- Considerations: price volatility, subsidy requirement
Socio-environmental impacts	- Environmental impact (CO_2, water, waste, energy) - Social impact (health, community benefit, also see employment)
Policy readiness	- Regulation and policy to enable investment / implementation / support - Regulation and policy gaps / inhibitors, e.g. export
Market readiness	- To absorb solution product - Level of solution product understanding - Future market potential - What is needed to prepare the market to absorb volume, e.g., market stability, survivability?
Technical readiness	- Novelty of technology - Previous use / adaptation in the country (learnings / issues) - Technology source
Capability	- Country's capability, competence, skill, and knowledge to implement / sustain
Beneficiaries	- Types of beneficiaries deriving an advantage from the opportunity, e.g. SMEs
Challenges / considerations	- Level of risk - Partnerships - Previous implementation in the country (learnings)

Source: Author.

3. STATUS OF WASTE TYRES IN SOUTH AFRICA

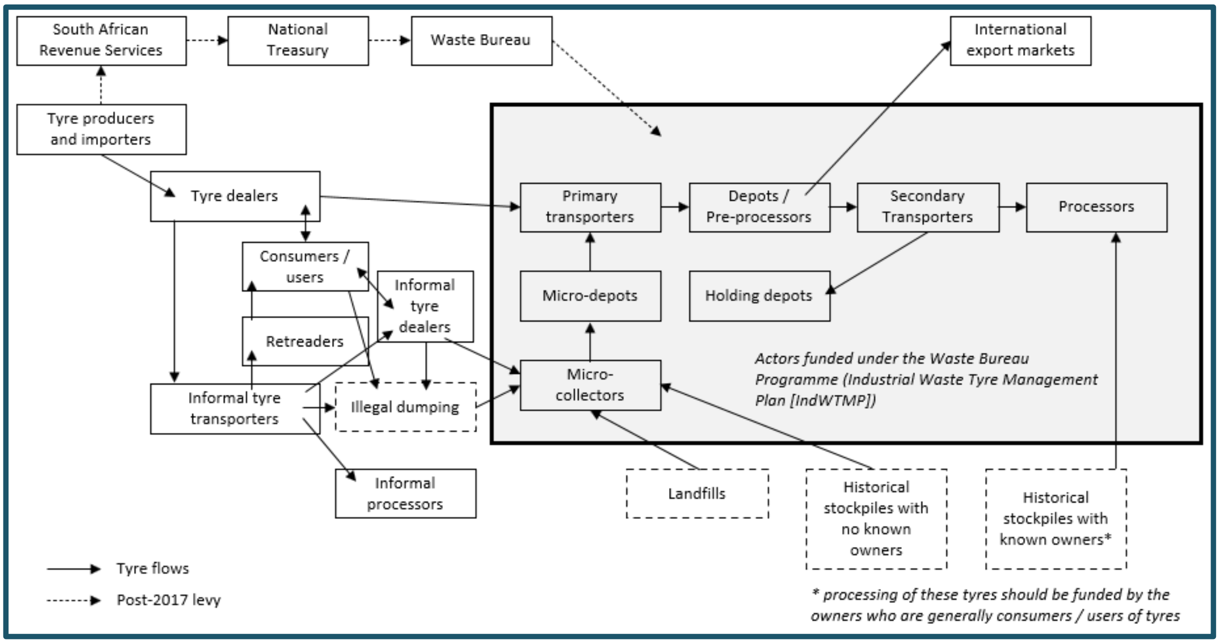
The purpose of this section is to set the current context and understanding of the tyre industry (including upstream activities) and waste tyres in South Africa. This is an important exercise, as a general trawl through online literature presents a mixed and complicated understanding of the situation. For example, dated data is often perpetuated, significant variances in figures exist, or the data is presented for specific activities or parts of the system (e.g., number of tyres manufactured or sold). In addition, it is not easy to understand or keep track of who is involved in waste processing activities, as this is in a constant state of flux, with businesses being established and shortly followed by collapse, or insights are only available on particular activities, e.g. Waste Bureau collection and delivery for contracted processors.

If informed decisions and large-scale investments are to be made, a more robust understanding of what is happening is required.

3.1. South African waste tyre system

Waste tyres are only one part of the tyre system in South Africa. It is therefore important to understand where waste tyres originate to inform decision-making to resolve the issue. Figure 1 presents a detailed overview of the waste tyre system (as per 2018).

Figure 1: Waste tyre system in South Africa



Source: Adapted from Baker (2018).

3.1.1. Tyre manufacturing and dealerships

From the onset, it is important to understand where and how tyres are manufactured, as ultimately it is these tyres that will become waste tyres. It is also critical to understand the process of tyre manufacturing. The vulcanisation process is a significant contributor to the inability for waste tyres to biodegrade (Muzenda, 2014), and the materials used in different tyres will determine the technological solution for, and product outputs from, these tyres. The latter is covered in more depth under Section 4 on Industrial Solution Opportunities.

As per the National Environmental Management: Waste Act 59 of 2008: Waste tyre regulations, 2017, tyre production in South Africa covers the commercial manufacturing or import of tyres and retreadable casings, and the import of vehicles fitted with tyres for distribution (DEA, 2017). An estimated 6 419 people are employed in the formal tyre manufacturing sector (SATMC Lightstone Auto, 2021), with most employed by the main South African tyre manufacturers: Bridgestone South Africa, Continental Tyre South Africa, ContiTech, Goodyear Tyres, and Sumitomo Tyres (DEA, 2018a). Not all tyres used in South Africa are manufactured locally. Local manufacturers have to compete with about 200 importers, mainly from China, Japan and Europe (Frost & Sullivan, 2021; Research and Markets, 2019; Shanavas, 2020). The import market allows for cheaper options, and as local manufacturers close plants producing particular types of tyres – such as Continental Tyre, which closed its ground mining and agricultural tyre production plants – importers can fill the gap (Research and Markets, 2019).

In addition to waste tyre manufacturers and importers, are those involved in the commercial distribution of new and legal repurposed tyres (retreads) (Moremi, 2019). The latter is a contentious area of activity, with numerous contestations recorded in the media around the illegal sale of tyres, notably those destined as waste tyres (see Moremi, 2019; Shaw, 2021a: 2021b). Road safety and driver control is the main issue associated with illegally sold waste tyres. Worn and defective tyres not only reduce the performance of vehicles but in worst case scenarios cause fatal collisions (Wheels24, 2017). As such, numerous suggestions have been proposed to prevent "waste tyres" from being used, such as slashing (AA, 2021). This is not a sustainable solution, and further highlights the significant need to deal with the waste tyre issue in South Africa.

Figures on tyres manufactured, traded, and used in South Africa vary, with an overview provided in Table 6. An estimated 7.95 million tyres were manufactured in South Africa in 2021 (SATMC Lightstone Auto, 2021). There has been a gradual decrease, since a peak in sales of about 10 million in 2016 in the past six years (SATMC Lightstone Auto, 2021). It should be noted that the South African manufacturing sector had the capacity in 2021 (most recent statistics) to produce almost 12 million tyres per annum, which suggests that, in 2021, 66% of this manufacturing capacity was utilised (SATMC Lightstone Auto, 2021). Blue Weave Consulting (2022) suggests that the South African tyre market could grow by 5.3% during 2022-2028.

An estimated 9.3 million tyres were imported in 2021, an increase on the previous year, by almost 2.7 million (SATMC Lightstone Auto, 2021).

Table 6: South African tyre manufacturing and trade figures (2021)

	MANUFACTURED IN SOUTH AFRICA	IMPORTED	EXPORTED	ESTIMATED SOUTH AFRICAN SALES
No. of tyres	7.95 million	9.3 million	1.3 million	13.5 million

Source: Derived from SATMC Lightstone Auto (2021). *Note:* Figures have been rounded.

Tyre type is very important in determining the appropriate waste tyre processing technology. There are several categories of tyres, which in the main are classified as motorcycle, passenger, light and medium commercial, heavy commercial, industrial, agricultural, aircraft, earth moving (often referred to as Off-the-Road tyres), and other pneumatic tyres (DEA, 2018b).

Depending on the type, tyres will contain varying quantities and combinations of rubbers (natural and synthetic) (38%-47%), carbon black (21%-22%), metal (e.g. steel) (12%-25%), textiles (e.g., rayon, nylon, Kevlar) (0%-10%), vulcanisation agents (e.g. sulphur, zinc oxide, additives and various chemicals) (1%-8%) (Muzenda, 2014; Ruwona et al., 2019; Sebola et al., 2018). To illustrate this difference, an average passenger can contain 16.5% steel, while a truck tyre 21.5% (or 18 kg) (Averda, 2018; Ruwona et al., 2019).

For this reason, it is important to generate an understanding of the composition of waste tyres in South Africa (see Table 7). As with many tyre statistics, figures vary, and where differences are identified, these are presented accordingly to illustrate the variance in available data. It is also common practice to present the number of tyres as passenger tyre equivalents (PTE) – the average passenger tyre weight used can also vary between 8kg and 12kg per tyre.

Table 7: Tyres sold in South Africa, by type

<table>
<tr><th>TYRE TYPE</th><th>AVERAGE WEIGHT</th><th>ESTIMATED % SOLD IN SOUTH AFRICA[6]</th></tr>
<tr><td>Passenger</td><td>8 kg - 12kg[1]</td><td rowspan="7">89%</td></tr>
<tr><td>4x4</td><td>13.5 kg[2]</td></tr>
<tr><td>Light commercial</td><td>13.5 kg[2]</td></tr>
<tr><td>Agricultural</td><td>110 kg[2]</td></tr>
<tr><td>Motorcycle</td><td>2 kg[2]</td></tr>
<tr><td>Aircraft</td><td>50 kg[2]</td></tr>
<tr><td>Industrial (incl. solids)</td><td>85 kg[2]</td></tr>
<tr><td>OTR</td><td>520 kg[2]</td><td></td></tr>
<tr><td>Heavy commercial (including truck)</td><td>45.4 kg - 70 kg[4]</td><td>11%</td></tr>
</table>

Sources: [5]DEA (2018b), [6]DFFE (2022), [2]Waste Bureau (2021).

[1] For example, average 7kg-8kg per passenger tyre for end-of-life (DEA, 2018a; Tyre Stewardship Australia, 2020), 7-9kg-9.5kg for a new tyre (DEA, 2018a; Tyre Stewardship Australia, 2020), 8.5kg (Waste Bureau, 2021), 9.1kg (DEA, 2018b), 10kg (Supa Quick, 2022), 10.2kg (including passenger, SUV/4x4 and light truck radial) (DFFE, 2022), 11kg (Law Insider, n.d.), and 12kg (REDISA, 2022).

[4] Average 45.5kg per commercial vehicle (truck) tyre (DEA, 2018b), 65kg (Waste Bureau, 2021), 66.9kg (DFFE, 2022), and 70kg (Supa Quick, 2022).

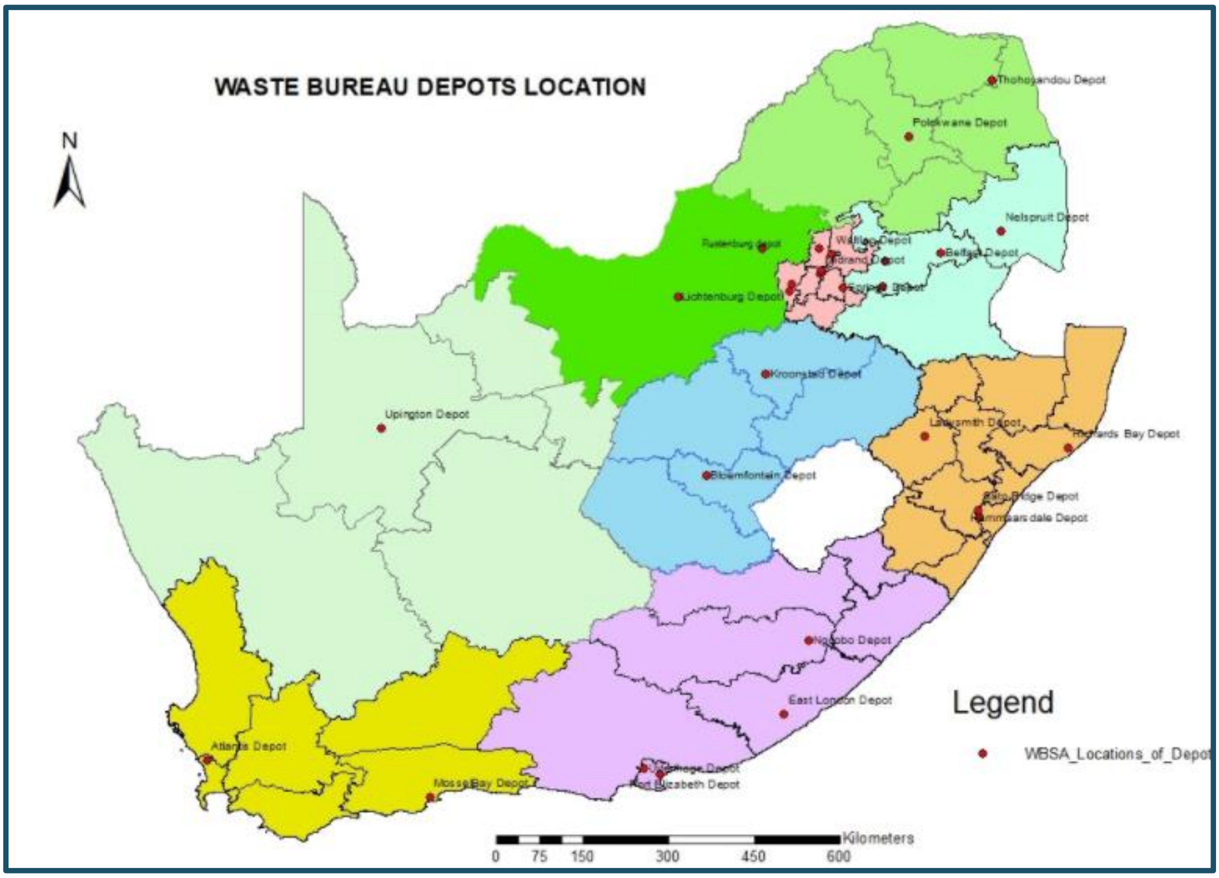
Note: The estimated % will not total 100% due to the variation in sales figures for passenger tyres.

3.1.2. Waste tyre storage and collection

Once vehicle tyres have reached their end of life, they should be properly and legally dealt with. Unless second-hand tyres are sold through reputable dealerships (Wheels24, 2019), it could be illegal and fatal to sell worn tyres (see above), dump or landfill tyres. The storage, collection and allocation of processing contracts is currently managed under the DFFE's Waste Bureau programme.

Tyres are both formally and "informally" stored, with the former in designated Waste Bureau depots, or on sites where waste tyres are generated, such as mines. "Informal" can best be described as waste tyres which are not managed, i.e. dumped, sitting in landfill sites, or on farms. This annual accumulation of waste tyres is commonly referred to as a "stockpile" or "legacy".

Figure 2: Locations of Waste Bureau waste tyre depots



Source: Baloyi (2021).

Waste tyres processed through the Waste Bureau programme are currently stored in 28 depots across the country, with a capacity of approximately 534 000m². Eight depots are in Gauteng, with the rest in the Eastern Cape (4), KwaZulu-Natal (4), Mpumalanga (3), Free State (2), Limpopo (2), North West (2), Western Cape (2), and the Northern Cape (1). Figure 2 illustrates the locations of these depots, with details on size presented in Table 8.

Table 8: Size and location of Waste Bureau waste tyre depots

DEPOTS	PROVINCE	DEPOT SIZE (M²)
Thohoyandou	Limpopo	50 000
Belfast	Mpumalanga	50 000
Kroonstad	Free State	50 000
Ngcobo	Eastern Cape	42 827
Bloemfontein	Free State	42 000
Lichtenburg	North West	30 000
Polokwane	Limpopo	30 000
Springs	Gauteng	28 000
Westonaria	Gauteng	26 961
Randfontein	Gauteng	26 320
Atlantis	Western Cape	22 920
Uitenhage	Eastern Cape	18 800
Klerksoord	Gauteng	18 565
Cato Ridge	Kwazulu-Natal	15 000

Nelspruit	Mpumalanga	11 265
Midrand	Gauteng	9 500
Glen Austin	Gauteng	9 400
Rustenburg	North West	8 500
Tembisa	Gauteng	7 671
PE Markman	Eastern Cape	7 495
Ferrobank	Mpumalanga	7 467
Hammersdale	Kwazulu-Natal	4 678
East London	Eastern Cape	4 612
Ladysmith	Kwazulu-Natal	4 500
Upington	Northern Cape	4 170
Mosselbay	Western Cape	1 300
Waltloo	Gauteng	1 000
Richards Bay	Kwazulu-Natal	1 000

Source: Baloyi (2021).

Government recognises that storage capacity is a critical area of concern, requiring priority attention (Baloyi, 2021). Most depots are reaching capacity, resulting in some depots not accepting waste tyres, and businesses generating waste tyres having to store tyres on site, at a cost, and therefore often illegally, breaching both the licensing and the storage safety requirements (DFFE, 2022; REDISA, 2022; Shaw, 2021a, 2021b). Solutions to mitigate this include transporting tyres to other depots or interim storage sites, such as cement manufacturers and municipal yards (Baloyi, 2021; PMG, 2021; Shaw, 2021a). Transportation of waste tyres to other locations was deemed a costly solution (Shaw, 2021a), especially given the distances between many depots. This situation, raised by many key informants, has had significant knock-on effects on waste tyre processing capacity.

The rationale for the designation of depot sites is unclear and was raised as a point of concern during a Portfolio Committee session on the functioning of the Waste Bureau (PMG, 2021). For example, there are few depots in core mining regions (e.g., the North West, Northern Cape and Mpumalanga), which generate large volumes of tyres. In addition, economically productive provinces such as the Western Cape also lack adequate depots, with location questionable. For example, the closest depot for Cape Town is an hour's drive to Atlantis (PMG, 2021).

The volumes of tyres collected by Waste Bureau depots in 2020/2021 was estimated at 93 400 tonnes, above the target of 74 900 tonnes set for the year (Baloyi, 2021). This represents about 31% of waste tyres generated per annum.

WASTE TYRE REGULATIONS, GOVERNMENT INITIATIVES AND PLAN FOR DEALING WITH WASTE TYRES

Waste tyres are regulated under the National Environmental Management Act (NEMA), National Environmental Management: Waste Act (NEM:WA), the NEM:WA: National Norms and Standards for Disposal of Waste to Landfill, 2013 and the NEM:WA: Waste Tyre Regulations, 2017. The Environmental Conservation Act, 1989 (Act No. 73 of 1989): Waste Tyre Regulations, 2009, banned the disposal of whole tyres to landfill from 30 June 2011 and quartered tyres from 30 June 2014; allowing only the disposal of shredded tyres to landfill. The NEM:WA: National Norms and Standards for Disposal of Waste to Landfill, 2013 introduced waste disposal restrictions on waste tyres prohibiting the disposal to landfill of whole and quartered tyres effective from August 2018. Failure to manage waste tyres as prescribed in the IndWTMP is a criminal offence in terms of section 67(1)(d) of NEM:WA and is punishable in terms of section 68(2) of NEM:WA (DFFE, 2022).

In the latter half of 2017, the **Waste Bureau** took over interim responsibility to facilitate, supervise and implement waste tyre management in the country (Baloyi, 2021; DEA, 2018a; DFFE, 2022; PMG, 2021). This was not its intended function or mandate. While this was meant to be an interim measure, until such time as a suitable plan is agreed (see details on the draft IndWTMP below), the Waste Bureau continue to manage the programme beyond the initial intended period (PMG, 2021). The Waste Bureau arranges delivery of waste tyres to processors for commercial reuse, recycling or recovery (DEA, 2017; DFFE, 2022). Processors are selected through a Waste Bureau tendering process. Once contracted, they order waste tyres through a Waste Bureau online platform. The Waste Bureau co-ordinates the collection and transport of tyres from one of the 28 depots listed in in Table 8 to the processor.

As of 2021, the estimated operating cost of the Waste Bureau to deliver this function was R384 million (PMG, 2021). To encourage reduction, reuse, treatment and recycling, and to reduce disposal to landfill, of waste tyres, a **waste tyre levy** was introduced in 2017 (National Treasury, 2016). The levy is payable to the South African Revenue Service (SARS) by South African tyre manufacturers and importers (DFFE, 2022; PMG, 2021; SARS, 2021; 2022). Specific application details are provided in Schedule 1 Part 3 Environmental Levy, which can be accessed here. As of 17 July 2022, the levy rate is R2.30/kg nett mass per tyre (SARS, 2022).

The use of waste tyres must be granted and facilitated through the Waste Bureau, as follows:

- Usage of waste tyres prior to 2015: for the Waste Bureau the tyres that need permission to be utilised are the ones that arose prior to 2012. These tyres need to be utilised according to an abatement plan which the Waste Bureau needs to approve. For example,. if a mine has tyres from before 2012, they need to submit an abatement plan to the Waste Bureau indicating how they intend to use or get rid of the tyres. This plan needs Waste Bureau approval.
- For tyres arising after 2012, the Waste Bureau is responsible for these. Anyone wishing to use them needs to apply to the Waste Bureau and indicate what the tyres will be used for (Waste Bureau, 2022b).

An industry waste tyre management plan **(IndWTMP)** is being drafted and finalised by the Council for Scientific and Industrial Council (CSIR) for the DFFE. The most recent iteration was put out for consultation in March 2022. Feedback is being reviewed and incorporated, with a final version due for publication in the latter half of 2022 (CSIR, 2022b). The core objectives of the IndWTMP are to:

- Support the establishment of a viable waste tyre processing sector in South Africa to reduce the environmental impact associated with waste tyres, and to support enterprise development and job creation;
- Develop waste tyre processing capacity in South Africa; and
- Develop monitoring systems to enable assessment of progress (Baloyi, 2021; DEFF, 2021).

As of the 25 May 2021, the development of the plan had cost about R2.2 million (PMG, 2021). It should be noted that many of the informants raised concerns about the IndWTMP, indicating it was more a set of guidelines as opposed to a plan.

WASTE TYRE STOCKPILE

One of the significant challenges is how best to deal with the stockpile of waste tyres spread across the country. A waste tyre "stockpile" refers to tyres that are stored at a site continuously for a period greater than two years, and cover an area greater than $500m^2$ (excluding landfill sites) (DEA, 2017). One of the key issues is trying to understand how many tyres are stockpiled or dumped, their location, and what types of tyres they are. This is particularly the case for "informal" stockpiles, such as those not held at recognised depots. These "informal" stockpiles can include, for example tyres dumped in the countryside, stored on farms or mines, and landfilled.

In consulting both secondary data and informants, it became apparent that the magnitude of stockpiled tyres is difficult to ascertain, especially for "informal" stockpiles. The suggested figure for the number of tyres stockpiled at Waste Bureau registered depots is estimated as being as high as 900 000 tonnes (DFFE, 2022). The figures for "informal" tyres are unclear, and while some may be implausible they range from 15 to 100 million tyres (Barker, 2019; DEA, 2018b; Muzenda, 2014; Shanavas, 2020), with the government's *State of Waste* report suggesting a figure of 30-60 million waste tyres (DEA, 2018b). In addition, bar an anecdotal figure suggested for mines (at 30 000 stockpiled tyres for an established mine), no information could be obtained on the more "informal" stockpile locations, or tyre type.

Given that one of the key outputs of this research is to develop a ministerial stockpile abatement plan, the lack of robust data is problematic. It is therefore strongly advised that prior to implementing a plan, more detailed research is undertaken to develop a more accurate understanding of the stockpile, especially the "informal" stockpile. This should include not only the volumes, but location, and tyre type per location. This will significantly aid where best to site interventions, such as depots and the types of processing solution.

3.1.3. Waste tyre processing

Waste tyres collected through the Waste Bureau programme are processed by businesses that have successfully tendered to do so. In the main, these businesses ranged from those absorbing waste tyres for co-processing (as an alternative fuel) to those processing waste tyres into rubber crumb (Waste Bureau, 2022a). A variety of waste tyre types were received by processors, either whole, baled, or shredded, including motorcycle, passenger, 4x4, light and heavy commercial, industrial, truck and agricultural tyres, with most volumes being attributed to passenger, light and heavy commercial segments (Waste Bureau, 2022). The volumes of waste tyres processed (recovered, recycled or reused) was estimated at 22 700 tonnes for 2020/21 (Baloyi, 2021). This represents about 24% of tyres collected by the Waste Bureau for processing (Baloyi, 2021). Waste tyre processing volumes have been higher, with over 70 000 tonnes collected in 2015 (REDISA, 2022). Given the current processing rates, there is significant room for improvement. For instance, in the European Union (EU), waste tyre recycling rates are 95% (Baker, 2018; Sebola et al., 2018). These figures reiterate the importance of this research to inform potential feasible scalable solutions to increase processing capacity in the country. This is covered in following sections.

3.2. Summary

In summary, there are some critical issues associated with waste tyre storage, collection, and processing in the country. The volume of tyres entering the system annually exceeds the volumes collected and processed through the Waste Bureau. And this is but a blip on the landscape if the "informal" stockpile is as potentially large as suggested. In addition, fundamental systemic issues, such as the backlog and number of depots and processors accredited for storing and processing tyres needs to be critically addressed. This situation is exacerbated by a lack of clarity on waste tyre data. While figures on tyres manufactured, imported, sold, and handled by the Waste Bureau are relatively accurate, the understanding of tyres n the "informal" stockpile is extremely vague. Given the potential scale of the latter, it is crucial that this is resolved if viable scalable solutions for dealing with registered depot and the "informal" stockpiles are to be effectively implemented.

WASTE TYRES GENERATED POST-2015

Part of the remit of this research was to better understand what was happening with waste tyres post-2015. This research suggests that an estimated **66 million (or 1.8 million tonnes)** of waste tyres entered the waste stream over the 2016-2021 period (11 million waste tyres and 300 000 tonnes per annum over six years). Using data provided for the composition of waste tyres held in registered Waste Bureau depots (as of 13 August 2020), the composition of waste tyres for the period 2016-2021 are suggested in the Table below.

Estimated composition and volume of waste tyres for the period 2016-2021

TYRE TYPE	% TOTAL UNITS	% TOTAL TONNES	ESTIMATED TONNAGE*
Passenger	36%	10%	174 200
4x4	29%	12%	222 700
Heavy commercial	21%	44%	785 900
Heavy commercial (baffed)	0,03%	0,1%	950
Light commercial	7%	3%	56 000
Agricultural	3%	9%	170 500
Industrial (including solids)	2%	4%	77 300
Motorcycle	1%	0,1%	1 300
OTR	1%	17%	303 200
Aircraft	0,3%	0,4%	7 800

Source: Author, derived using DFFE (2022). *Figures are rounded.

Note: These figures are derived using loose tyre units held in registered Waste Bureau depots as of 13 August 2020 (DFFE, 2022). It is recognised that the composition can vary per annum and month. However, given figures in the IndWTMP were made public, these were used as an indicator of composition.

While the figures in the Table above indicate the composition and associated tonnages per tyre type, these figures should be interpreted as indicative as they do not consider the composition of waste tyres held privately or dumped during this period.

Given that waste tyres recorded are for those held in registered depots for a given year, it cannot be assumed that those not processed in a given year are not processed in the following year. As such, it is not possible to determine an estimated total volume of additional waste tyres available for processing since 2016. However, for the purposes of this research, the **900 000 tonnes of total waste tyres** (excluding waste tyres managed in accordance with abatement plans) proposed in the IndWTMP (DFFE, 2022) could be considered as available for processing. The ease of processing these tyres may be inhibited by factors such as accessibility, quality, cost, and logistics.

An overview of key statistics associated with the South African waste tyre system are summarised in Table 9. Due to the variance in data and sources, no individual data point was selected in this table to reflect volumes, value, or units. As such, the variation is purposely presented to illustrate the variance in understanding within the sector.

Table 9: Key statistics, and data variances, associated with South Africa's waste tyre system, per annum (except for estimated stockpile)

TYRES	MANUFACTURED IN SOUTH AFRICA	SALES	WASTE TYRES ENTERING MARKET	TYRES COLLECTED FOR PROCESSING	WASTE TYRES PROCESSED***	ESTIMATED STOCKPILE ('LEGACY') TYRES
	(PER ANNUM)					
No. of tyres (units)	7.95 million[1]	13[2] – 13.5 millionŦ Of which[1]: 5.5 million (locally manu. domestic sales) 1.3 million (exported†) 9.3 million (imported‡)	11[4,8,9,10] – 12[3] million (10.9* million)			14[3] – 100[4] million (30 – 60 million[7])
Tonnes		300 000[2] tonnes	135 000[9] – 300 000[2] tonnes	93 400[6] tonnes (An estimated 31%∞ of new waste tyres generated per annum)	22 700[6] tonnes (An estimated 24% of waste tyres collected for processing)	170 000[9] – 30[5] million tonnes** (900 000 tonnes)[2]

Source: Author derived, based on [6]Baloyi (2021); [4]Barker (2019); DEA ([9]2018a, [7]2018b); [2]DFFE (2022); [5]Mandini (n.d.)[this figure is unlikely, but illustrate the variance in figures published]; [8]Muzenda (2014); [9]Nkosi et al. (2019); [10]REDISA (2022); [1]SATMC Lightstone Auto (2021); [3]Shanavas (2020); [7]Supa Quick (2022).

Note: Original figures have been rounded. Figures presented illustrate the diversity of data published. No. of tyres (units) are presented separately to tonnes, as some sources often only present units or tonnes. The purpose of this Table is to present the variance in what is published across a variety of media and documentation.

* Author derived: 10.9 million derived using an average attrition rate of 19% on new tyres (DEA, 2018a [20%]; REDISA, 2022 [18%]; DFFE, 2022 [18% - 20%]).

** As per the latest iteration of the IndWTMP (DFFE, 2022) there are an estimated 900 000 tonnes of total waste tyre stockpiles (excluding waste tyres managed in accordance with abatement plans) in South Africa.

† Export market tyre sales of locally manufactured product (SATMC Lightstone Auto, 2021).

‡ SARS Import Quantity (SATMC Lightstone Auto, 2021).

Ŧ Author derived, based on SATMC Lightstone Auto (2021) local manufactured sales, export sales of locally manufactured product and imports (assumed sold locally).

∞ Author derived using 300 000 tonnes as the estimated volume of waste tyres entering the market per annum.

4. INDUSTRIAL SOLUTION OPPORTUNITIES

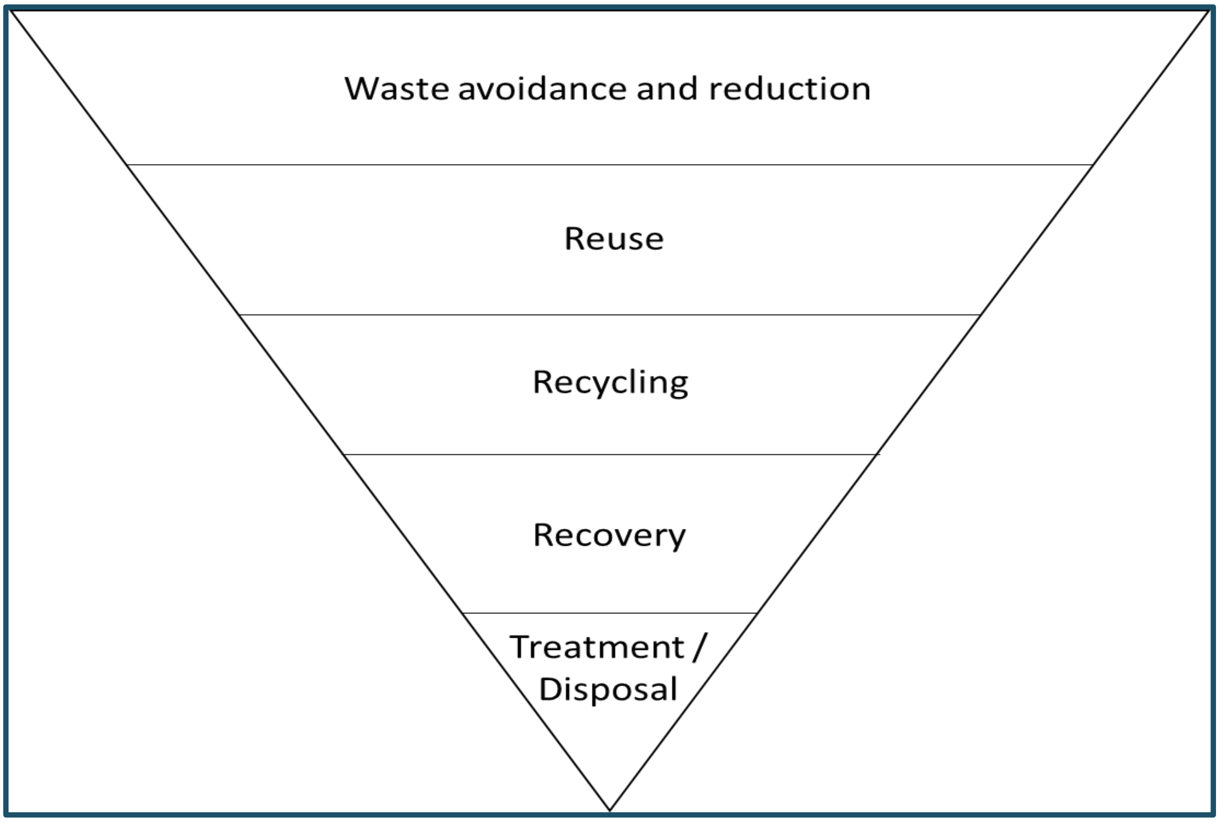
It is suggested that 80% of a waste tyre can be used – provided the casing is not damaged (FleetWatch, 2019). Given this, in conjunction with the volume of waste tyres generated annually (300 000 tonnes) plus the estimated stockpile (900 000 tonnes) (DFFE, 2022), industrial-scale and feasible solutions to deal with these tyres are required as a matter of urgency. For this reason, the dtic and the DFFE have expressed interest for this research to focus on and identify suitable industrial-scale solutions to deal with these tyres. It is, however, recognised that in doing so, criteria such as job creation and entrepreneurial and/or SME development and support should also be considered.

This section presents a variety of initial solutions identified and proposed solutions for implementation. Further refinement and identification of proposed solutions were informed by informant discussions around feasibility and considerations for implementation.

4.1. A variety of solutions and considerations

A variety and choice of solutions exist. These fall into one of three main categories: reuse, recycling and recovery. Hartley et al. (2017) present these in a waste tyre hierarchy of preference, with avoidance the preferred and disposal the least preferred (see Figure 3).

Figure 3: Waste tyre hierarchy



Source: Adapted from Hartley et al. (2017).

Taking this hierarchy into consideration, a further set of criteria was developed to evaluate and guide the selection of feasible and appropriate industrial and scalable solutions (see Table 5). These are employment potential, scale (e.g., volume of tyres consumed), cost (e.g., investment), environmental and social impact, policy and market readiness, technology readiness and capability, and barriers to implementation.

One of the often neglected criteria in innovation and solution selection is market readiness (Jenkin, 2020). Market readiness includes the demand for products produced from technologies and solutions adopted such as oil and carbon black from pyrolysis. This was recognised as a key area of solution selection in research undertaken for the Waste Bureau (in 2018) to investigate markets for recycled, reused, and recovered rubber tyre materials. In doing so, the authors suggest market applications can be classified into four "quadrants" (DEA, 2018a:6) (see Figure 4).

Figure 4: Waste tyre market application quadrant

Market volumes →		
	Quadrant 2: Applications have highest market volumes but not necessarily high market value. Examples: Cement and clinker production; tyre derived fuels; co-processing; scrap steel.	**Quadrant 4: [IDEAL]** Applications have highest market volumes and high market value. Examples: Oil (upgraded to diesel), gases and carbon black produced through pyrolysis.
	Quadrant 1: Applications that have relatively low market volumes and low value. Have the potential to move into Quadrant 2. Examples: Moulded and extruded products; cut and punched products.	**Quadrant 3:** Applications have highest market value but relatively low market volumes. High capital costs hold back progress to Quadrant 4. Examples: Sport surfacing; surface modification; rubberised asphalt; chemicals.
	Level of market value → Capital infrastructure costs →	

Source: Adapted from DEA (2018a:6).

The latest iteration of the IndWTMP also recognises the importance of market demand for considering interventions:

- Create local demand for high value end-products;
- Create local demand for end-products of tyres not currently recycled; and
- Government intervention through policy changes to stimulate demand for tyres as an alternative fuel source (where appropriate) (DFFE, 2022).

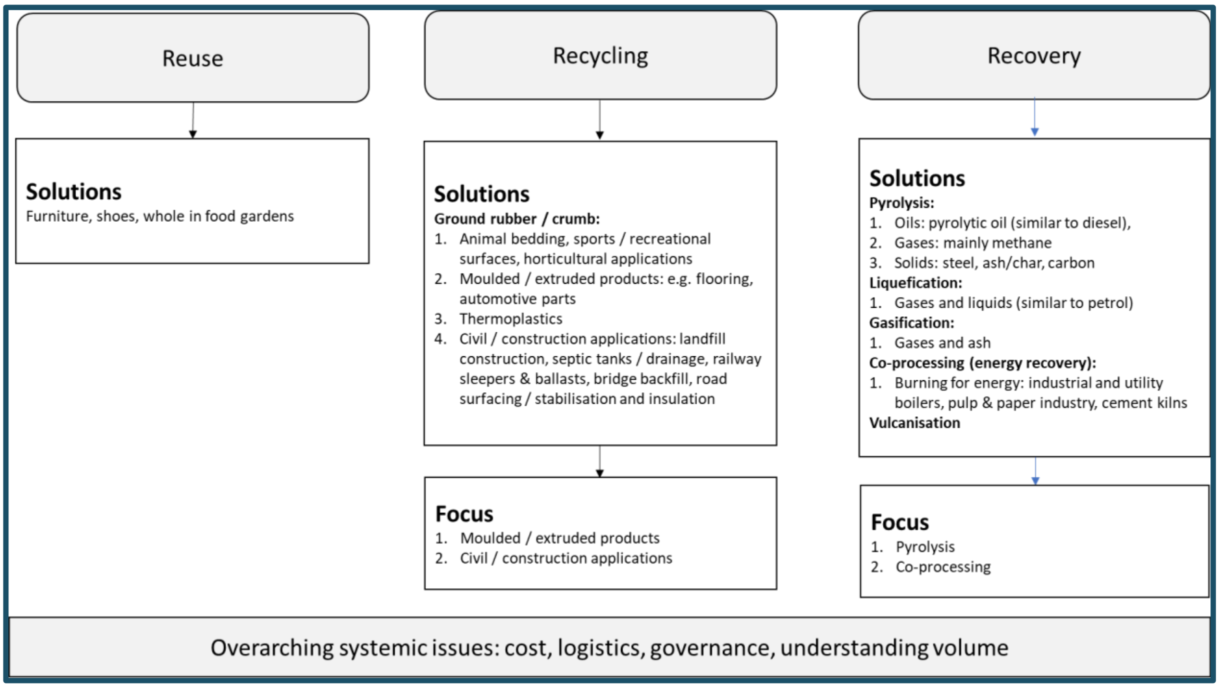
4.2. Initial list of solutions

An initial list of solutions was identified through desktop research. Numerous data sources were reviewed (see list of example sources reviewed to identified solutions in Appendix A). These had a South African focus to capture feasibility, technology readiness, capability and capacity, and potential if scaled. From this exercise, and using Hartley et al's (2017) hierarchy classification, the main solutions identified during this process were:

- **Reuse:** Using whole tyres.
- **Recycling:** Ground rubber or crumb for use in , for example, animal bedding, sports, and recreational surfaces; moulded and extruded products such as flooring, and matting; and civil and construction applications.
- **Recovery:** Pyrolysis, liquification, gasification and co-processing (energy recovery).

Figure 5 presents these initial solutions by category, with a proposed recommendation for further exploration and focus based on the criteria listed in Table 5.

Figure 5: Initial identification of waste tyre solutions

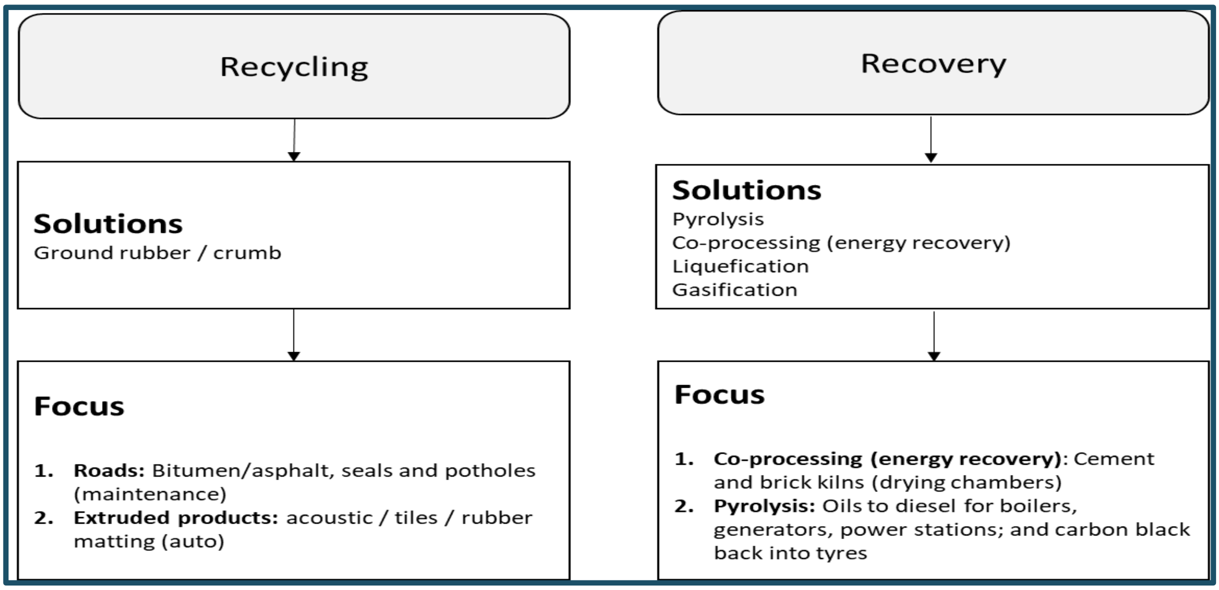


Source: Author.

4.3. Proposed scalable solutions

Following identification of the initial list of solutions, informants within the waste tyre system were interviewed on the status of the waste tyre situation in South Africa, feasible and scalable solutions, and barriers and considerations for implementation. Insights gathered from these interviews provided further clarification and refinement of the initial solutions proposed. Figure 6 presents the proposed focus solutions which are deemed applicable and scalable for dealing with both the current stockpile and annual volumes of waste tyres entering the waste stream.

Figure 6: Proposed focus solutions



Source: Author.

Each proposed solution is explored in more detail in the following subsections and, when feasible, key criteria for assessment provided. It should be noted that in several instances, usually due to confidentiality, details such as cost, or waste tyre absorption rates are not available.

4.3.1. Recycling: Rubber crumb potential

The most common waste tyre recycling process identified and adopted in the country is the conversion of waste tyres via shredding or grinding into rubber crumb or powder. Rubber crumb can have multiple uses and applications, and is used as an ingredient in, or to produce, other rubber products, such as artificial recreational surfaces, flooring and matting, bitumen for roads and new rubber tyres (Baker, 2018; Hartley et al., 2017). It can also form the feedstock for pyrolysis (see Recovery solutions below). Given its potential, good quality rubber crumb in this country is in much demand.

The process for converting waste tyres to rubber crumb is done through removing steel belts, bead wire and fabrics to produce rubber chips. These chips are further ground to produce fine crumb or powders (Baker, 2018; Varghese, 2020). In the main, the process is considered less polluting than other waste tyre conversion technologies, such as co-processing.

Aside from the shredded or ground rubber, the recycling conversion process also results in the production of other materials, such as steel and nylon. This provides an added-value opportunity for processors that can sell the steel to foundries or metal recyclers, and nylon to plastic recyclers. As a result, the shredding and crumbing process can generate little waste.

Focus solutions: Roads and moulded products

Of the rubber crumb applications, two emerged as having the most scalable potential. These are the use of rubber crumb in modified bitumen (CRM) for roads, and the manufacture of moulded products such as flooring, recreational purposes, and roofing. Each of these are explored further below.

Use of waste tyres in crumb rubber modified bitumen for road construction

While waste tyres have significant potential to be used as lightweight fills, culverts and thermal insultation in road construction (Ruwona et al., 2019), it was with much interest in October 2020 (see Business Insider, 2020; Jacobs, 2020; Scott, 2020), that the CSIR released the results of its year-long trial with Much Asphalt to test a 40mm modified bitumen rubber surfacing product containing recycled tyres as a part ingredient. This product was used in the construction of a paved section of road in Roodepoort, Gauteng, to test its performance (CSIR, 2020).[1] With no notable signs of deflection or cracking detected, the trial has been deemed a success.

Table 10 highlights the key areas of possible potential for the use of waste tyres as an ingredient in CRM binders for road construction.

[1] The purpose of the trial was not to test the use of waste tyres as a bitumen ingredient, but to correct and revitalise out of specification CRM bitumen to pass performance specifications and/or for improvement in the performance of standard bitumen from one grade to another. While this clarity is significant when describing the solution, it is important to note that this "invention" would also enable an increase in the use of waste tyres in bitumen and road surfacing in South Africa (CSIR, 2020). It is the latter that is of interest for this research.

Table 10: Waste tyre use in crumb rubber modified (CRM) binders for road construction

INDICATOR	ROAD CONSTRUCTION POTENTIAL
Scale potential	- Current use: Estimate of 7 000 tonnes – 10 000 tonnes of rubber crumb from non-steel reinforced tyres is used in bitumen modification per annum. - Could use a lot more waste tyres in the construction and maintenance (e.g., fixing potholes and repairs) of roads. - Significant potential for use of CRM binders if all planned SANRAL projects come to fruition.
Economic cost	- The construction of roads is costly. The short shelf-life of bitumen is a costly waste. The CSIR trialled CRM binder mitigates this cost by revitalising "out of spec" bitumen. - The use of waste tyres in road construction is cost effective (road industry already using waste tyres).
Market readiness	- Waste tyres have been used in road construction in South Africa since the early 1980s. Use of waste tyres in roads is seen as beneficial to retard cracking, extend pavement lifespan and to reduce ageing of the asphalt binder. - The road construction industry in the country is committed to looking at ways to overcome issues of using waste tyres. - A drive to use more CRM binders in chip seals and asphalt surfacings.
Technical readiness	- CSIR and asphalt industry tested solution brings reputability and better acceptance of CRM binder solution. - CSIR's CRM binder solution is one of a few solutions. Others are known by industry, but not in the public domain.
Capacity	- Not enough rubber crumb capacity to meet potential SANRAL demand. Would need to build more rubber crumbing facilities.
Capability	- Issue of experts leaving South Africa and the need for retention. - Knowledge of using waste tyres in road is good at a national level, but almost non-existent at a municipal level.
Employment	- Construction of more rubber crumbing facilities could lead to more job opportunities.
Environmental and social impacts	- Crumb rubber modified binders can improve bitumen product durability and lifespan.
Barriers	- The manufacturing and placing of bitumen including waste tyres as an ingredient requires special measures and care to achieve the envisaged advantages, which has been a challenge. The CSIR trial was to find and trial a solution to overcome this challenge. - It takes time for a road to be constructed. This can impact on a waste tyre processors' need for consistent supply. - South Africa's road industry works on strict standards and manuals for road construction. CRM binders need to meet these standards and be reflected in manuals for the industry to adopt its usage. Otherwise seen as a risk. - Demonstrations and trials of innovations, and updating of South African Bureau of Standards (SABS) manuals and standards, are a lengthy process. - Need a natural rubber content minimum of 20% for rubber crumb for use in bitumen. This necessitates the need for higher volumes of truck tyres in the process.

Considerations for scale	- Demonstrations and viability of solutions, and inclusion of specifications in standards and manuals, are critical to ensure road industry acceptance. - Waste tyre suppliers and processors of rubber crumb need to meet certain standards set by the road construction industry, such as waste tyre size and density. These standards and manuals are in transition and it could take another year before adoption will take place. - If solution becomes more widely used, the industry will need to develop more experts and increase municipal knowledge of waste tyre usage in road construction and maintenance. - Government to incentivise use of waste tyre content in road construction, for instance, through road construction tenders (such as X% waste tyre content per 100km of road). This would help the road construction industry use more waste tyres. - Need a forward-thinking strategy to utilise more waste tyres in road construction. Link strategy to national, provincial, and municipal road construction and maintenance plans.

Source: Author derived, based on informants interviewed, CSIR 2020; 2022a; and Wu and Herrington (2021).

Use of waste tyres in moulded products

Moulded products manufactured from waste tyre rubber crumb have significant potential, particularly for use in construction, such as roof tiles, flooring and acoustic products, and vehicle production, such as matting, brake pads and pallets. South Africa has a history of producing moulded products manufactured from waste tyres, most notably for flooring and matting. More recently, the potential has been growing, especially given the wide and varying product uses of rubber crumb (CNN, 2021).

Moulded products are manufactured by binding waste tyre rubber crumb with other materials. The process can use minimal water and does not always require heat, unless using thermo-moulding[2] compaction (Gaggino et al., 2013; Scott, 2021). In addition, rubber crumb can be repurposed in factory used rubber by-product (Mavuso, 2013).

Waste tyre use in flooring, paving, and matting

A variety of external and internal flooring and matting products can be manufactured from waste tyre rubber crumb, such as non-slip door mats, mats for workshops and kitchens, floor tiles for office buildings and sports halls, paving and underlays (Eco Green, 2013; FleetWatch, 2019; SA Tyre Recyclers, n.d.). Given the characteristics of rubber, these products are considered hardwearing (lasting up to 60 years), acoustic-dampening, weather resistant and easy to clean. Some of the other main benefits of rubber flooring include onsite levelling to mitigate uneven floors, being cost-effective to install, can be recycled, can carry abnormal and heavy traffic loads, and requires little maintenance (Building and Decor, 2016; Eco Green, 2013).

See Table 11 for an overview of rubber crumb usage in flooring, paving, and matting, including potential, market and technical readiness, and barriers and considerations for scaling current production and usage.

[2] Thermo-moulding refers to a process whereby rubber crumb is heated to render it soft. Pressure is then applied to make the rubber conform to the shape of a mould (Martin's Rubber Company, n.d.).

Waste tyre use in roof tiles

While not commonly known in South Africa, roof tiles manufactured from waste tyres have significant potential, particularly for roofing associated with government housing projects and serviced sites. By way of illustration, by the end of 2019, the government housing backlog was 2.6 million units (Thukwana, 2021). While this figure is only indicative of low-cost housing potential, it does illustrate the demand for homes that require roofing. One such option is the use of moulded roof tiles manufactured from waste tyre rubber crumb.

Some examples exist, albeit on a small-scale, of roof tiles in South Africa being manufactured from waste materials, such as polythene (see Jordaan, 2020), but in the main the practice of using tiles manufactured from waste tyre rubber crumb is limited. However, in countries such as Argentina, the United Kingdom and United States, roof tiles have been trialled and used to great affect (Euroshield, n.d.; Recycling International, 2007; Scott, 2021).

Fine rubber crumb from truck tyres is used to manufacture composite roofing slate, with tyre crumb making up approximately 70% of the final product (Euroshield, n.d.; Recycling International, 2007; Science World, 2015). See Table 11 for potential.

Table 11: Waste tyre use in moulded products, notably flooring and roof tiles

INDICATOR	MOULDED PRODUCT POTENTIAL
Scale potential	- Applications for rubber crumb are wide, varying and growing. - A streamlined rubber shredding facility could process 100 tonnes of tyres per day (about 35 600 tonnes per annum). - Waste tyre crumbing facilities in South Africa can currently process about 9-10 tonnes per day (maximum 190 tyres per day) (about 3 650 tonnes per annum). **Flooring:** - Flooring and tiles can be used for new builds through to refurbishments, with flooring having the ability to accept a range of floor finishes, including ceramic tiles. - Potential for flooring to be used in schools, hospitals, prisons, government subsidised housing, and government buildings. - Mathe Group/PFE International in KwaZulu-Natal recycles about 150 000 used radial truck tyres (c.9 750 tonnes) per annum. - By way of example of potential, ECOsurfaces (in the United States) coverts over 36 200 tonnes of waste tyres into rubber flooring per annum. **Roof tiles:** - Tiles have the potential to be used for government subsidised housing. - By way of example of potential, Euroshield (in the United States and used in over 13 countries) diverts about 75 000 waste tyres into roof tiles per annum. - An “average” American home could divert between 370 to 600 waste tyres.
Economic cost	- Capital for equipment and property setup costs are high. - Payback could be longer than five years. - Can be difficult and costly to test and market products. - Little differential in cost between raw rubber and recycled waste tyre rubber (therefore incentive to purchase the latter). **Flooring:** - Low installation and maintenance costs

	Roof tiles: - Lighter than conventional tiles, therefore transport fuel costs can be reduced.
Market readiness	- Large demand for rubber crumb to develop products from recycled waste tyres. - Need to create demand and make market aware of products. - Both domestic and international demand for flooring-related and recreational products.
Technical readiness	**Flooring:** - Flooring using waste tyre content is currently manufactured in South Africa (see Van Dyck Carpets/MatheGroup /PFE International joint venture). **Roof tiles:** - Currently no notable manufacturers of roof tiles, but given capability to mould flooring, it is possible to adopt the appropriate technologies. Would require further investigation.
Capacity	- Not enough processors to absorb the volume of tyres. Those that exist, few can produce quality rubber crumb. - Only a few manufacturers in South Africa produce moulded products from waste tyres. - Some customers are sourcing flooring from international manufacturers, such as Ecore.
Capability	**Flooring** - The manufacturing of flooring using waste tyres has been happening in South Africa since the 2010s. **Roof tiles:** - Potential capability (to be investigated further). - See technical readiness.
Employment	- Tyre shredding facility capable of c. 50 tonnes per day and on average could employ about 12 employees. **Roof tiles:** - As per the roof tile project in Argentina, SMEs/entrepreneurs can manufacture the tiles, thereby creating jobs. - Opportunity to create jobs in rural areas (not urban-centric solution).
Environmental and social impacts	- Crumbing process from waste tyres can be zero waste. - Products can often be manufactured from 100% waste tyres or waste rubber (buffing) from tyre retreading. - The rubber crumb moulding process often does not require water. - Fire retardants can be added to the mix, thereby reducing house fires. - Replaces less-durable materials such as wood and ceramics.
Barriers	- Significant set-up costs (c. R170 million) inhibits SMEs from entering the market. - No government subsidy or incentive to produce products using waste tyres. - Desire to set up recycling hubs in areas from which tyres can be sourced, such as mining areas, but investment restrictions and bureaucracy around tyre access restrict potential. - Sourcing of waste tyres locally can be an issue. Sometimes, transported long distances from depots in other provinces.

	- Sourcing of local rubber retread waste is not always feasible, as most tyre retreading (60%) take places in Gauteng, and about 15%-20% in KwaZulu-Natal. - Waste management licensing process can be onerous and lengthy.
Considerations for scale	- Need partnerships between government and business to incentivise production and encourage demand, through (government) procurement specifications for schools, shopping centres and sports facilities - Enable and/or encourage vertical integration of operations, such as waste tyre collection depots, waste tyre rubber crumb processor and product manufacturing all in one or in the same vicinity. - For products to be accepted by the construction industry, they need to outperform conventional products and meet the required standards, such as longevity, functionality and aesthetically (where required). - Often a preference for used (radial) truck tyres due to high rubber and steel content, and low fabric content. Technologies are designed to take truck tyres.

Source: Author derived, based on informants interviewed, and Thompson, 2020; Building and Decor (2016), CNN, 2021), Euroshield (n.d.), FleetWatch (2019), Jordaan (2020), Mavuso (2013), Ramdass (2021), Science World (2015), and Scott (2021).

In summary, the use of rubber crumb or powder from waste tyres has significant potential for use in a variety of products. When adopting criteria of potential scale and technical and market readiness, it would be possible to suggest that the following are viable options:

- Use of waste tyres in flooring and matting.
- Use of waste tyres as an ingredient in bitumen for road construction and maintenance.

The country has the technical capability and knowledge to manufacture both the rubber crumb and powder, and products for use. In addition, there is market acceptance and knowledge of the output products. However, in both cases, limiting factors for scaling production include setup and operational costs, sourcing good quality rubber crumb, and too few processors.

Roof tiles in contrast appear to have much potential. Various trials and applications have been put into effect internationally. Given the successful trial of roof tiles containing waste tyre rubber crumb in Argentina, the viability of this option in South Africa appears good. In addition, the manufacturing of roof tiles could take place in rural areas and/or in areas identified for housing developments, in particular low-cost housing. It is therefore worth exploring this opportunity further.

4.3.2. Recovery: Alternative fuels

Waste tyres are well recognised for having high volatile and low ash contents, and with a heating value greater than coal or biomass. These properties make tyres an attractive alternative to coal (Muzenda, 2014). Recognised technological processes for converting waste tyres into alternative fuels and other by-products include co-processing, pyrolysis, gasification and liquefaction (Hartley et al., 2017; Muzenda, 2014). Depending on the technology used, waste tyres can either be fed into equipment whole or shredded. A brief overview of each is provided in Table 12.

Table 12: Brief descriptions of waste tyre recovery solutions

RECOVERY SOLUTION	BRIEF DESCRIPTION
Co-processing (energy recovery)	A process that involves the combustion of waste tyres in conjunction with other fuels, such as coal, to recover and generate energy. Waste tyres may be used in conjunction with traditional fuels, such as coal.
Pyrolysis	A thermochemical process which decomposes materials – without the use of oxygen or air – to extract and purify chemicals and other products (e.g. carbon black) from waste tyre compounds.
Gasification	A thermochemical process whereby air, oxygen, hydrogen and/or steam oxidates tyres to produce mainly gases, e.g. carbon monoxide and hydrogen (syngas), and carbon dioxide, light hydrocarbons and char.
Liquefaction	A thermochemical process whereby solvents are used to convert waste tyres into a petroleum-like liquid and gases.

Source: Author derived, based on Bianco et al. (2021), Edwards (2016), Muzenda (2014), Oboirien and North (2017), Sharma et al. (2000), and Slater (2015).

Focus solutions: Co-processing and pyrolysis

Of the four potential recovery solutions listed, two emerged as having the most potential. These are co-processing and pyrolysis.

Co-processing of waste tyres as an alternative fuel

Given the energy potential of waste tyres, they are seen as an attractive alternative to coal. It is suggested that one tonne of coal can generate 15-29 gigajoules (GJ) of energy, in comparison to a waste tyre, which can generate 36 GJ per tonne (steel removed) (Lowitt, 2020).

The co-processing of waste tyres has been successfully demonstrated and is currently practised by the South African cement industry (e.g. PPC Cement and Intercement), and brick manufacturers for drying bricks in chambers. Current operations illustrate the feasibility for adopting waste tyres as an alternative fuel. In addition, the cement and brick-making industry suggest that – albeit overcoming certain hurdles – there is much potential to increase usage in the country. For example, in 2017, it was estimated that 88% of South African cement plant energy was generated by burning coal (Lowitt, 2020). In part, through co-generation, this coal could be replaced by waste tyres. However, in the case of brick manufacturing, not all facilities are able to use waste tyres. It is a suitable solution for those that use hot air-drying chambers.

Waste tyres can be used whole, shredded, or baled, with the latter requiring some form of pre-processing and therefore an additional cost to using whole tyres. Importantly, the use of whole or shredded cannot be interchanged, with technologies designed for a one or the other. Passenger tyres are preferred as a best fit for the design of waste tyre feeder conveyor belts.

Table 13 provides an overview of the co-processing of waste tyres, including potential, market and technical readiness, and barriers and considerations for scaling current production and usage.

Table 13: Co-processing of waste tyres as an alternative fuel in cement plants and brick drying kilns

INDICATOR	CO-PROCESSING POTENTIAL
Scale potential	- Waste tyre substitution rates in plants and kilns could be as high as 65% (with 30% being more reasonable). **Cement plants:**

	- Suggested potential is 20% coal substitution in South Africa's 14 cement kilns. - A cement kiln could absorb 10 000 to 50 000 tonnes of waste tyres per annum. Currently, South African plants co-processing absorb 3 000 to 11 000 tonnes per annum. - PPC Cement is committed to expanding the use of waste tyres across its operations. **Brick kilns:** - About 10 kilns in the country could use waste tyres as an alternative fuel. - A brick drying kiln could use 3 600 to 4 800 tonnes of waste tyres per annum.
Economic cost	- Costs associated with purchasing emission control technologies is high and prohibitive. - Use of waste tyres saves on coal purchase costs if located far from to coal production. - Capital expenditure for adopting and setting up co-generation technologies is costly. This includes upgrading current kilns. An estimated R20 to R50 million per kiln – depending on the technology adopted and kiln type.
Market readiness	- Desire by the cement and brick-making industry to use waste tyres. They have demonstrated and recognise the potential.
Technical readiness	- Would need to increase technical readiness of more kilns to scale, including risks and issues associated with setting up technologies. - Technologies currently used in South Africa can be easily replicated.
Capacity	- Aside from the setup cost implications, South Africa does have the infrastructural capacity to convert to waste tyres as an alternative fuel.
Capability	- While South Africa has the knowledge and skills for waste tyre co-processing, this could be enhanced as knowledge requirements are specific, such as a redesign of the system. - Scaling of co-processing activities would require process engineers and chemists for quality control; and mechanical, automation, and electrical artisans.
Employment	**Cement kilns:** - Per kiln, an estimated 10 direct jobs (loading and handling waste tyres, cleaning blockages and inspections).
Environmental and social impacts	- A mechanism for reducing a reliance on coal. - Need to manage chlorine and sulphur dioxide build-up in kilns. - Air emissions need to be monitored and tightly controlled. **Cement plants:** - Use of waste tyres as an alternative fuel can decrease carbon emissions from combustion by 5%-10%.
Barriers	- General population perception of co-processing – black smoke and not in my backyard. - Consistent supply of shredded and baled waste tyres has implications on stability of the co-processing system. Lack of supply has cost implications when restoring to 100% coal. - Location and depot size – capacity to hold and distribute volumes required.

	- Tyres smaller than passenger tyres cannot be used with passenger tyres. These smaller tyres need to be disposed of and stored, which adds to the cost. - Scalability of use depends on environmental licensing, legislation, and associated costs, such as installing air pollution scrubbers. Currently, meeting licensing requirements is costly, onerous, and lengthy.
Considerations for scale	- Need to consider waste tyre/coal mix for stability of energy input during kiln run. This is important for planning, especially if waste tyre access becomes an issue. - Tyre quality is important as it can impact on kiln operation and negatively affect production, such as residue build-up (chlorine, sulphur dioxide). - Enable and/or support setup of on-site shredders (vertical integration of processes). - Ensure security of supply. - Preference for shredded or baled passenger tyres, i.e. with steel removed (reduces transport costs and technology dimensions). - Government to consider a tax incentive to encourage waste tyre co-processing technology installation and use.

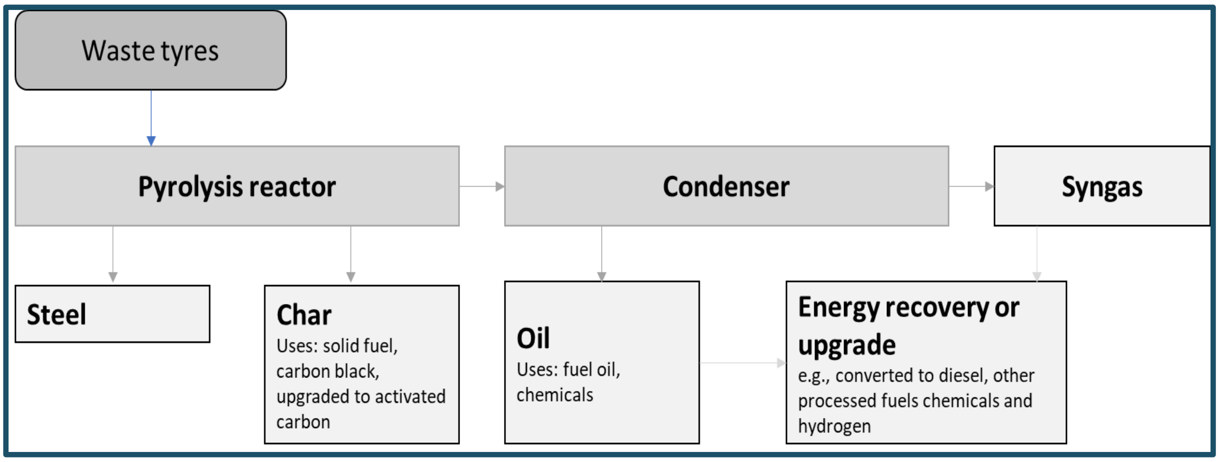
Source: Author derived, based on informants interviewed, Lowitt (2020); and PPC (2016).

Pyrolysis of waste tyres

Compared to the co-processing of waste tyres, pyrolysis is a more complex process. Pyrolysis is a thermochemical process which decomposes materials – without the use of oxygen or air – to extract and purify chemicals and other products (e.g. oil, char and steel) from waste tyre compounds (Edwards, 2016; Hartley et al., 2017; Muzenda, 2014; Ruwona et al., 2019; Slater, 2015).

The process and associated product outputs are illustrated in Figure 7. The production of these products has garnered much interest in South Africa (Slater, 2015). For example, oil generated from the pyrolysis process can have a higher calorific value than co-processed waste tyres and coal. If further processed, this oil can have multiple uses as a fuel in industrial boilers, vehicles, furnaces and power plants (Nkosi et al., 2019; Ruwona et al., 2019). This upgrading process removes contaminants, such as zinc, aluminium, iron, titanium, sodium, lead and nickel (Nkosi et al., 2019). However, it does require additional technology and cost.

Figure 7: Waste tyre pyrolysis process and output products



Source: Author adapted from Muzenda (2014) and Williams (2013).

While the concept of pyrolysis is not new in South Africa, it has not been fully explored or successfully realised (Nkosi et al., 2019). Attempts have been made to introduce and operate pyrolysis technologies, but with little success. An estimated 80% of pyrolysis plants have closed in the past five years. It has been suggested this is mainly due to the high setup, operational and environmental legislation adherence costs (Nkosi et al., 2019; and informants interviewed). In addition, the technical nature of the process requires a sophisticated level of knowledge and skill to both design and operate pyrolysis technologies, such as feed size, temperature and pressure, heating rates and reactor configuration (Nkosi et al., 2019; Williams, 2013). This challenge is not only witnessed in South Africa, but also acknowledged worldwide, for example pyrolysis plants failing to meet environmental emission requirements (Yaqoob et al., 2021), and/or investors and operators overcome by cost and technical complexity issues (Brock et al., 2021; Tangri and Wilson, 2017).

While there are questions around technical viability and cost at present, the potential should not be dismissed, albeit it with a considered lens and approach. Table 14 provides an overview of pyrolysis of waste tyre potential in relation to market and technical readiness, and barriers and considerations for scaling current production and usage.

Table 14: Pyrolysis of waste tyres

INDICATOR	PYROLYSIS POTENTIAL
Scale potential	- Potential to produce added-value products such as oil (which can be upgraded to diesel), gases and char (carbon black). - Of most potential is upgrading of oil to diesel as a fuel source in industrial boilers and power plants. - A continuous feed pyrolysis facility could process 10 to 100 tonnes of waste tyres per day (up to 36 500 tonnes per annum). - Can absorb any tyres, including OTR (this is not the case for rubber crumb or co-processing). OTR tyres have high oil content, and are therefore an appropriate solution for mines.
Economic cost	- Costly to convert or install and operate pyrolysis technologies (c.R50 million to R120 million for continuous feed pyrolysis investment). - Pyrolysis technologies stipulated by the market are often more costly than what could be purchased from China. - Cost implications to produce upgraded products such as diesel or good-quality carbon black from base products from the process. - Costly to adhere to strict environmental regulations.
Market readiness	- The market exists, particularly for oil-derived products such as diesel. - Market will stimulate the quality, and often the pyrolysis technology that needs to be used.
Technical readiness	- Currently, do not have adequate processing equipment to derive products using pyrolysis. - Need to ensure technologies that are developed meet stringent pyrolysis product buyer requirements.
Capacity	- Current capacity is low, with numerous examples of plants established and closing.

Capability	- Requires high-skill knowledge to design and operate pyrolysis technologies, such as engineers and petrochemists. - South Africa has the capability to manufacture pyrolysis technologies.
Employment	- 19-20 jobs could be created per continuous feed site. This could be increased by processing by-products or upgrading products. - Could be seen as an opportunity to transition jobs from traditional oil industry. - High setup and operational costs inhibit SME inclusion in the market.
Environmental and social impacts	- Continuous feed pyrolysis is a low-emission process - Gas produced from the pyrolysis process can be used to run the pyrolysis equipment. - Dealing with the potentially hazardous residue from the process, especially when upgrading products.
Barriers	- Entry-level setup costs inhibit entry into the market. - International investor risk, such as lack of security of supply. - Upgrading of some output products, e.g. oil to diesel, requires additional conversion technologies. - A switch to using waste tyre-derived oil/diesel will impact current diesel suppliers to large industrial and power plants. - Lack of understanding of the pyrolysis process and potential. - Compared to other solutions, tyre quality is not really an issue. - Buyers of pyrolysis product will often stipulate quality requirements, and associated pyrolysis technologies or equipment to use.
Considerations for scale	- Support continuous feed pyrolysis technologies as more efficient than batch feed systems. - Reactor design is a significant factor that affects process parameters, product output and quality. - Strict environmental licensing and regulation requirements.

Source: Author derived, based on Edwards (2016), Muzenda (2014), Nkosi et al. (2019), Recor (n.d.), Williams (2013), and informants interviewed.

In summary, waste tyres have much potential as an alternative to coal, and other products, such as oil upgraded to diesel. In current readiness to scale, co-processing is the most viable of all the solutions presented. The market (cement and brick-making industry) is ready, and the technology is available. However, costs to convert current kilns to co-generate energy from tyres, and the installation of air emission technologies, is a critical inhibitor to uptake.

The market potential for pyrolysis is clear, in particular, its beneficiation and added-value potential. However, it is a highly technical process with a number of process options available. In addition, several entities have set up pyrolysis plants, which have failed. This failure could blight any future potential in the country. Given some of the issues and barriers associated with the adoption of pyrolysis, it is highly recommended that a detailed, considered plan is adopted in consultation with interested parties – investors, pyrolysis technology designers, and product buyers – prior to any implementation commitments. The plan should target the most viable market demand, such as large industries and power plants. Following this, the most appropriate location, and pyrolysis processes, can be determined (as opposed to the reverse).

4.4. Summary

In summary two overarching areas of opportunity exist in recycling and recovery. Each of the solutions proposed have significant potential, with the country being the most ready or capable to adopt the use of waste tyre rubber crumb and co-processing.

Given the volumes of waste tyres generated per annum, and within the stockpile, Table 15 sets out and illustrates the estimated waste tyre absorption potential per solution.

Table 15: Estimated waste tyre processing potential, per solution

SOLUTION	POTENTIAL ABSORPTION PER ANNUM PER BEST PRACTICE* FACILITY			
	TYRE UNITS	ESTIMATED TONNES	PREFERRED TYRE TYPE**	ESTIMATED SET UP COST PER FACILITY
Rubber crumb (for moulded products)	35 600	300	Truck	R170m
Co-processing (cement kilns)	40 000	340	Passenger	R20m-R50m
Co-processing (brick air drying kilns)***	4 500	40		
Continuous feed pyrolysis	36 500	11 000	Industrial/ OTR	R50m-R120m

Source: Author derived, based on insights provided in solution tables above, and average wate tyre weights (Waste Bureau, 2021).

Notes: * A best-practice facility is that which absorbs waste tyres to its maximum potential. For instance, while current co-processing in South Africa is an estimated 20% waste tyres and 80% coal, best practice could achieve a ratio of 65% waste tyres and 25% coal.

** While most solutions can take different tyre types, technologies may be designed to take specific tyre types or have a preference. For instance, due to OTR tyres having a high oil content, they are often preferred for pyrolysis. This however does not mean that OTR tyres cannot be used in other applications.

*** South Africa currently has 14 cement kilns and 10 chamber drying brick kilns (24 kilns in total).

5. REFLECTIONS ON CURRENT PRACTICES AND LEVERS TO MAXIMISE WASTE TYRE USAGE

Prior to discussing the levers to maximise the use of waste tyres in relation to the scalable solutions suggested, it is worthwhile reflecting on the current waste tyre collection and processing system. This will aid in providing insights to inform the levers, and policy recommendations.

5.1. Reflections on current practices

As highlighted in Section 3 on the current waste tyre situation in South Africa, at the moment, the process for collecting, transporting, delivering, and identifying solution providers falls within the current remit of the Waste Bureau. Desktop research and informant interviews provided insights into this current model and ability to scale, and these are reflected below.

5.1.1. What is working well?

It is prudent to highlight what is working well with the current system. Procedural mechanisms that usually blight processes were not identified, with many citing that the paperwork and payment processes work well. The transition to the online ordering system was deemed a huge improvement.

Most contracted processors commented that their relationship with the Waste Bureau is sound and supportive.

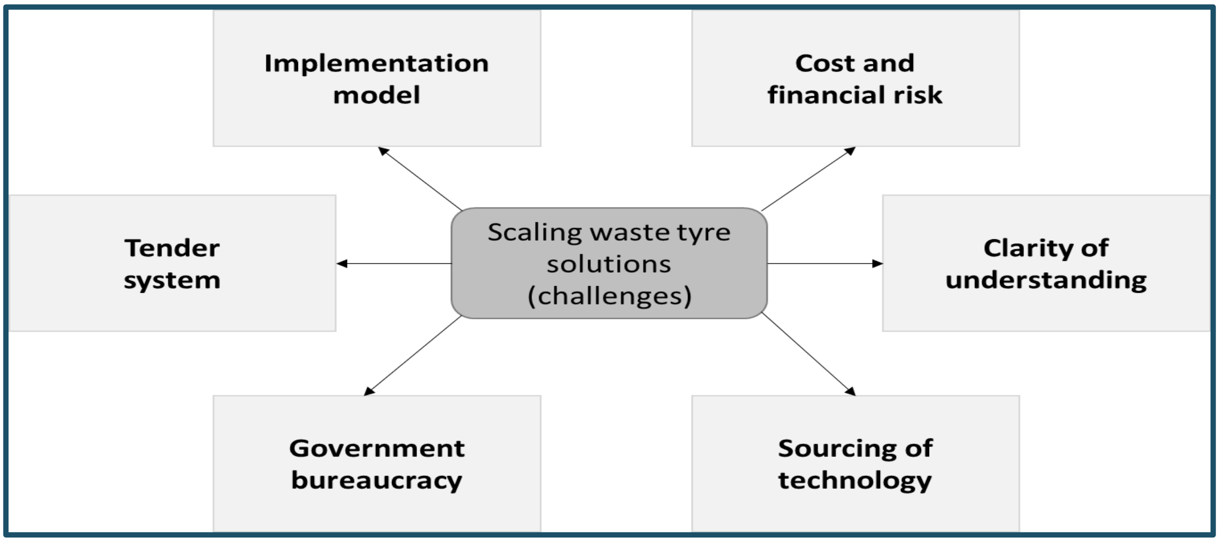
Tyres delivered to processors were deemed in relatively good condition and requiring little cleaning. Tyre delivery was in the main deemed timely. The zero-cost for delivery was considered helpful, given the other high costs to set up and operate processing plants.

While air emission regulations were considered an inhibitor, in the case of waste tyre regulations, this was not deemed the case.

5.1.2. Main challenges to scale waste tyre usage

The main challenges identified with current and potential implementation can be categorised in five themes: Cost and financial risk; clarity of understanding; sourcing of technology; government bureaucracy; and the tendering system (see Figure 8). Each are covered in detail in the following subsections.

Figure 8: Challenges associated with scaling waste tyre usage



Source: Author.

Cost and financial risk

Investment, capital expenditure and operational costs were cited as significant inhibitors to market entry and expansion (both current and proposed). Technologies and equipment are expensive, ranging from R20 to R170 million to set up. This is exacerbated by the fact that most equipment is imported. Energy costs to operate processing plants or co-processing kilns are also substantial. Storage of tyres on site also carries a cost. Additional cost considerations include technology and infrastructure upgrades, new builds and purchase of property.

The price competitiveness of virgin rubber and coal can limit the attractiveness of using waste tyres. Raw virgin rubber and recycled rubber prices are often similar to waste tyres, with many manufacturers preferring virgin rubber due to similarity in cost and quality. In the case of coal, the transport of waste tyres can be more expensive than purchasing coal if processing plants are in coal mining regions.

Location and cost are also applicable to the sourcing and delivery of waste tyres. Currently, waste tyres can be sourced in one province and delivered to a processor in another. This model has cost implications.

The high upfront costs have proved difficult for many, especially if starting from a zero-finance base. It is acknowledged that traditional banks may find some investment opportunities, such as pyrolysis, risky, but even those which can deal with innovative risk and understand the technologies, are not keen to fund technologies due to their high cost and poor record of success.

Investors interested in waste tyre solutions also require some form of security, either in the length of agreement (usually 10 years) or security of feedstock (waste tyres). Neither are easy to come by, or not possible to guarantee – as is the case with security of feedstock. The Waste Bureau is not able to provide this. This has prohibited some large-scale investors from investing in processing plants in the country.

LEVERS TO MITIGATE COST AND FINANCIAL RISK

- Agreement term length to be 10 years or more.
- Provision of waste tyre feedstock security to processor investors.
- Consider some form of incentive (tax or subsidy) for waste tyre processors to mitigate setup and upgrade costs.
- While zero cost for waste tyre delivery is acknowledged, some form of subsidy or financial support for processors to mitigate operational costs should be considered, such as a tax rebate for using tyres or cost per tonne of waste tyres handled.
- Waste Bureau to consider paying for product output (processed) rather than waste tyres absorbed.
- Waste Bureau to consider adopting a regional model for tyre collection, delivery, and use.
- Enhance the knowledge and understanding of waste tyre technologies, operations, and costings in traditional banks.
- Financial risk could be mitigated by knowing there will be consistent processed product demand, e.g. for use in roads, or public buildings. Government to consider procurement specifications, such as stipulating the use of waste tyres in construction materials, or as a percentage of road surface.

Sourcing of technologies

Many technologies and equipment used for processing waste tyres are determined by customer need and their specification requirements. For example, if a customer specifies a known make of equipment (from Germany for instance), it is not feasible for a processor to purchase a similar piece of cheaper equipment manufactured from another suppliers (from China for example). The former can be up to 10 times more expensive. However, it should also be noted that while alternative equipment may be cheaper, it was often cited as producing products of less quality to those from more expensive equipment.

While South Africa does have the capability of manufacturing many of the proposed solution technologies, most are imported at great cost.

LEVERS TO MITIGATE COST OF SOURCING TECHNOLOGIES

- Enable and incentivise local production of focused waste tyre solution technologies and equipment.
- Government, IDC, or funding agencies could consider providing existing processors with equipment to upgrade and scale operations.

The tendering system

The present tendering system does not adequately cover the volume of waste tyres required for processing – both those stockpiled and entering the market annually.

In reference to the financial risk, current processor tenders are deemed too short, particularly for investors that require an adequate payback period. This may not fall within the current five-year tender timeframe. In addition, the solution focus can also change from one call to the next. This can result in low investor confidence and therefore commitment.

Concern was raised by some informants about the allocation of processor contracts to those that have little evident experience in operating processing technologies or facilities, or do not currently operate plants. While it is acknowledged that SME development is a core component of the government's economic recovery, the high-cost implications associated with processing could be a risk and a challenge for SMEs.

LEVERS TO MITIGATE TENDERING SYSTEM CHALLENGES

- Agreement term length to be 10 to 15 years to provide investors with confidence, allow for adequate payback periods and business planning.
- Options for renewing contracts should be considered, especially given the current lack of capacity. This would enable those that currently operate and have experience to build on this and scale their operations.

Clarity of understanding

Many informants noted that the tyre manufacturing and waste tyre sector, in general, does not have a clear understanding or visibility of what is happening in waste tyre governance, technology opportunities, or the location of waste tyres.

Data and insights on waste tyre volumes, tyre type and locations are sketchy. As such, this makes it difficult to develop government, investor, business, or sectoral plans. Aside from knowing where regional waste tyre depots are, there is little insight on the location of tyres sitting in stockpiles.

This is an important insight for planning processing plant locations, and the type of technology most suitable for a location.

The lack of understanding of technologies is problematic, leading to a situation in which potential profitability often outweighs decisions of feasibility. This was cited as a particular issue within government, where planning and tender allocation decisions could be better informed if there was an improved understanding of the different waste tyre technologies, their potential, and barriers to implementation. Recycling and processing waste tyres is complex, and uninformed decisions can turn out to be costly, especially given the high investment and operational costs.

Linked to this, the availability and access to knowledge is often *ad hoc*, with no central forum or knowledge base to exchange knowledge and insights. Such a mechanism could enable a more connected network of actors within the waste tyres system, and therefore avenues for sharing knowledge and implementing solutions.

LEVERS TO IMPROVE CLARITY OF UNDERSTANDING

- A more detailed understanding of waste tyre location by region, tyre type and volume is required.
- Government/Waste Bureau and potential processor operators to become more versed in waste tyre processing technologies, their potential and limitations.
- Establish a waste tyre forum which encompasses actors across the tyre value chain (including government, industry, academia, and civil society) to:
  - Develop a strategy to implement the waste tyre IndWTMP (which is considered a guideline within the industry, rather than a plan).
  - Share knowledge to overcome barriers and to identify and discuss solutions
  - Establish potential partnerships.

Funders could also be included, to enable solutions to be seen.

Government bureaucracy

One of the key issues raised by processors and those wishing to invest in waste tyre solutions in the country was bureaucracy. Processes are considered overly bureaucratic and “tick boxy”, lengthy and onerous. As a result, the process is inefficient.

While it was acknowledged by processors that licensing for processing plants and waste management activities is bureaucratic, environmental licensing and legislation was, however, cited as particularly problematic. Meeting licensing requirements (for air emissions for instance) is costly, onerous, and lengthy. It was noted that, given the different types of licencing required to operate as a processor, there is a need for the units (within DFFE) responsible for issuing licences to be aligned.

Within this theme, albeit indirectly linked, is the issue of Waste Bureau access. While several processors indicated their relationship with the Waste Bureau was good, many did, however, indicate the difficulty in accessing individuals to discuss urgent matters, such as immediate capacity issues with depots or backlogs, or pricing.

LEVERS TO REDUCE GOVERNMENT BUREAUCRACY

- Waste Bureau to consider mechanisms to reduce funding process steps and length.
- Waste Bureau to consider moving from weekly to monthly consolidated reports for depot managers and processors.
- Review and alignment of waste management, environmental and air emission licensing requirements.
- Develop a process for maintaining consistent engagement with current depot managers and processors and interested parties (also see recommendation for a forum. This could also mitigate a lack of access or the Waste Bureau being a singular source of information).
- Given the business development focus of waste tyre processing, to consider whether the dtic is better positioned to oversee the waste tyre management programme, either through a Memorandum of Agreement with DFFE or as co-leads.

Linked to this theme, albeit indirectly, is the consideration to ring-fence the waste tyre levy funds generated, to ensure that they are channelled directly to the management of waste tyres. Currently funds generated by the levy are not ring-fenced within National Treasury.

6. CONCLUSION AND POLICY RECOMMENDATIONS

The research clearly indicates the significant potential for processing waste tyres in the country, with a number of feasible, scalable solutions identified to tackle annual waste tyre generation and the stockpile. Solutions identified become particularly appealing when aligned with providing a solution to some of the country's main concerns, such as:

- Use of coal alternatives for energy;
- Road construction and maintenance; and
- Infrastructure development and construction of housing.

Using these market drivers to inform waste tyre solutions, the following emerged as notable scalable solutions:

- Waste tyre rubber crumb as part ingredient in bitumen;
- Waste tyre rubber crumb to produce moulded products for flooring, matting, paving and roof tiles;
- Waste tyres as a co-processing alternative to coal in the heating of cement and chamber drying brick kilns; and
- Conversion of waste tyres via pyrolysis to produce added-value products, such as oil (upgraded to diesel), and carbon black (which can be used in the manufacturing of new tyres).

These applications mirror the three largest uses of waste tyres in the United States (US EPA, 2016), which is considered globally to have one of the most effective waste tyre management programmes in the world.

Aside from the manufacturing of roof tiles, all the above solutions have been trialled or implemented in South Africa. Some, such as the use of waste tyres for heating in kilns, and rubber crumb in bitumen and moulded products, have been successfully adopted in the country. Pyrolysis, while practiced, has been less effective – predominantly due to cost and technical complexity.

While these solutions emerged as feasible opportunities, several challenges persist, particularly when considering the need for scale. These are cost and financial risk, clarity of understanding, sourcing of technologies, government bureaucracy, the tender system, and the waste tyre programme implementation model. Considering these challenges, insights emerged from the research, which highlighted the need for:

- Better government provisioning and less-bureaucratic services and processes;
- A more conducive environment to mitigate investor risk;
- Government and/or funder support or incentivisation to reduce setup, upgrading and operational costs; and
- Creation of a forum to improve the understanding of the waste tyres issues and identification and implementation of solutions in the country.

Drawing on the insights garnered from the research, recommendations are presented below on how industrial and environmental policies may be better aligned and for the development of a ministerial stockpile abatement plan. These proposed recommendations take into consideration the latest iteration of the draft IndWTMP (released in March 2022) (DFFE, 2022).

6.1. Proposed recommendations for aligning industrial and environmental policies

The effective implementation of scalable, feasible waste tyre solutions would require the alignment of core industrial and environmental policies, such as the automotive sector's Master Plan and the IndWTMP. It should also be acknowledged that dealing with waste tyres may not necessarily be optimal from an environmental perspective but is better than not dealing with them at all. Areas of alignment include increasing production capabilities, and the production of added-value products (overall and in a more effective manner). Government's industrial policy recognises that this is a long-term agenda, and that technologies continue to evolve (the dti, 2014). This echoes the views of informants who suggested the short-term nature of Waste Bureau contracts.

Waste tyres are a by-product of the automotive industry, as such one of the most relevant industrial policies requiring alignment between waste tyre management and associated environmental policy is the South African Automotive Masterplan (SAAMP). One of the ambitions of SAAMP is to increase the levels of local content by 60% in automotive manufacturing (the dtic, 2018). This would include tyres. This ambition could act as a driver to create market demand for waste tyre pyrolysis products, such as carbon black, for use in locally manufactured tyres. Another area of alignment is SAAMP's proposed enterprise development objective. This could incorporate and extend to enterprise development (i.e. processor development) for waste tyres (CSIR, 2022a).

The Master Plan also has an objective to grow South Africa's vehicle production to 1% global output (the dtic, 2018). This has two implications: a potential increase in waste tyres generated per annum entering the waste stream, and the potential to increase demand for product generated from processed waste tyres. The increase in waste tyres entering the waste stream therefore needs to be taken into consideration in any waste management and circular economy plan going forward, and in turn align with the IndWTMP.

Aside from SAAMP, alignment with other beneficiation activities and associated policies would also be beneficial, notably energy and infrastructure development. In the case of energy, this speaks to government's Integrated Energy Plan, which aims to ensure the country's security of energy supply. Given the calorific attributes of waste tyres in comparison to conventional fuels, such as coal, waste tyres should be integrated into energy policy and strategy as a viable energy source. This is particularly relevant for co-processing in cement and brick chamber drying kilns, and pyrolysis to produce oil for upgrading into diesel.

Given the significant potential for use of waste tyres as an ingredient in bitumen for roads, alignment with SANRAL's Horizon 2030 strategy should be explored. SANRAL manages more than 22 000 km of roads across the country (PMG, 2020). These roads, and those in the pipeline, will require ongoing maintenance. Policy to deliver and implement the strategy's objectives should be cognisant of the potential to scale the use of waste tyres in road construction and enable uptake by setting procurement requirements which include a percentage of waste tyres per prescribed distance. This could drive market demand for bitumen containing waste tyres. Such an ambition would align with the Horizon 2030 strategy which aims to respond to "harnessing the power of emerging technologies in the fields of engineering, construction, information and communication to deliver more effective road solutions and higher levels of safety and efficiency" (SANRAL, 2021:5). These same policy alignment ambitions could be adopted at provincial and municipal level.

The creation of sustainable jobs is a requirement in both industrial and environmental policies, with particular reference to SMEs. As is evident from this research, waste tyre processing has the potential to create both labour-intensive and high-skilled jobs. However, given the significant investment and operational costs associated with many scalable waste tyre solutions, it is unlikely that SMEs would be able to enter the market in the numbers that may be desired by government. Employment could be created through SMEs in part-processing or the production of some moulded products. Environmental policy, such as the IndWTMP, and policies relating to the circular economy should be cognisant of job creation feasibility and should refrain from applying a broad-brush human capital approach to job identification.

Ultimately, both industrial and environmental policies should recognise and aim to reduce the environmental externalities associated with waste tyres by identifying suitable solutions to reduce the stockpile and waste tyres entering the system annually. To ensure this alignment, policy developers and implementers within the dtic, the Department of Mineral Resources and Energy, DSI, SANRAL and DFFE (among others) should collaborate and/or be consulted to reduce policy overlap or misalignment.

6.2. Proposed considerations for a ministerial stockpile abatement plan

Given potential stockpile figure of 900 000 tonnes (with some sources suggesting much higher numbers especially when taking into account waste tyres on private lands, dumped and landfilled), an abatement plan is required to recover and process these waste tyres. The purpose of a waste tyre stockpile abatement plan would be to indicate the manner and timeframe in which the estimated waste stockpile can be recovered, temporarily stored for processing, processed and market demand supported. All features of the plan need to ensure the handling of waste tyres is safe, and complies with national, provincial, and local waste management and air emission regulations. This aims to ensure all potential risks are recognised and mitigated.

Drawing on the research and abatement plans generated for similar activities, such as South Africa's waste water abatement plan (see, for instance, Van der Merwe-Botha and Manus [2011]), the following considerations for the development of a ministerial stockpile abatement plan are proposed:

- Improved understanding of the stockpile;
- Alignment of technology solutions with stockpile scale, composition, and location;
- Development in consultation with tyre value chain actors; and
- Undertake an annual external audit to ensure reputability and accountability.

6.2.1. Improved understanding of the stockpile

It is evident that there is no clear or unified understanding of the magnitude of stockpiled waste tyres. This includes both "formal" (e.g. acknowledged through regulation as cited on a property) or "informal" (not formerly registered, e.g. on farms, in "the veld" or illegally dumped) channels. It would be remiss of government to develop an abatement plan without a more informed qualitative understanding of the waste tyre stockpile. This research has begun to set out an estimate, in alignment with the IndWTMP, which could inform the criteria for undertaking research to determine the true magnitude of stockpiled waste tyres in South Africa. For example, a not too dissimilar exercise was undertaken by the CSIR to better understand the magnitude of food waste in the country (Oelofse, 2013; Oelofse et al., 2021). This research could provide a useful framework.

Drawing on insights from interviews and gaps in current estimates, it is proposed the following information is obtained and determined:

- Total waste tyre stockpile (volume, number of units, ZAR)
- Regional / district level understanding of waste tyre stockpile, by:
    - Geographical location (formal and informal), location/activity type (e.g. farm, mine, industrial), tyre type (as per industry classifications), age, condition/state (whole, baled, shredded).
    - Volume, number of units, ZAR.

Secondary data available does not adequately provide insights on the above. Therefore, it is proposed that an approach is developed to gather primary data through surveys and site visits.

The value of undertaking this research cannot be underestimated, as it is on this data that strategic, critical, and financial decisions will be made to implement an abatement plan, identify suitable solutions, and inform financial or regulatory support. In addition, such an exercise would also strengthen the rollout of the IndWTMP.

6.2.2. Alignment of technology solutions with stockpile scale, composition, and location

Not all technologies are suitable for all tyres. For example, due to their high oil content, OTR (i.e. land moving or mining tyres) are preferred for pyrolysis, passenger tyres for co-processing, and radial truck tyres for rubber crumb. Therefore, dependent on tyre type and volume location, more suitable applications should be considered for a given location.

It is also advised that those developing the abatement plan are familiar with the various technologies, their requirements, challenges, and potential for implementation. Where feasible, visits to live operations should be arranged to increase knowledge, and therefore aid informed decisions.

6.2.3. Abatement plan development in consultation with the tyre value chain actors

It is advised that the abatement plan be developed early on in consultation with the broader waste tyre value chain. This would help to ensure buy-in and therefore more likely acceptance of implementation plans. It would also provide an opportunity for the collective to better understand the current waste tyre situation in South Africa, and to engage in and propose viable solutions. Table 16 provides a list of potential stakeholders for consideration.

Table 16: Proposed stakeholders for abatement plan consultation

GOVERNMENT		
National	DFFE	Waste Bureau, Operation Phakisa, Air Emissions, Climate Change
	the dtic	Green Industries, SMEs, Automotive Master Plan, National Cleaner Production Centre South Africa (NCPC), TIPS
	DSI	Waste Research Development and Innovation
Provincial	Departments	Economic Development, Waste Management
Municipal	Departments	Local Economic Development, Waste Management, Utilities, large metros, and district municipalities
INDUSTRY		

Trade Associations	South African Tyre Manufacturing Conference (SATMC), Tyre Equipment Parts Association (TEPA), Tyre Importers Association (TIASA)
Tyre manufacturers, main importers, dealerships	Bridgestone South Africa, Continental Tyre South Africa, ContiTech, Goodyear Tyres, Sumitomo Tyres, and main importers
Waste tyre depots and logistics	Main actors including but not exclusively Waste Bureau contractors
Wate tyre processors and users	Main actors involved in co-processing, rubber crumb manufacture / products, and pyrolysis (including but not exclusively Waste Bureau contractors)
ACADEMIA AND RESEARCH INSTIUTIONS	
CSIR, Higher education institutions involved in innovation, waste management and engineering	
CIVIL SOCIETY AND OTHER	
GreenCape, National Business Initiative, Recycling and Economic Development Initiative of South Africa (REDISA), WWF South Africa	

It is advised that this consultation is task focused, with the intended output being an abatement plan, accompanied by an implementation (business) plan, guidelines for municipalities, and a reporting and monitoring plan. For example, funding from the SA-EU Dialogue Facility could be considered for this process.

6.2.4. Annual external audit

Monitoring and reporting of the abatement programme will be necessary to ensure accountability and responsible delivery. It is proposed that DFFE commissions an annual external audit of the plan processes and activities undertaken. The purpose would be to determine whether the management and oversight of the plan (and implementation) is effective at both reducing the waste tyre stockpile, enabling, and scaling appropriate processing capability, and is managed with due diligence and business integrity.

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APPENDIX A: REVIEW OF EXAMPLE SOURCES TO IDENTIFY SOLUTIONS

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