TSA Driving sustainable outcomes for end-of-life tyres

TyreStewardship AUSTRALIA

Analysis of the Material Circularity of Management Options for Tyres and Conveyor Belts

Report

January 2025

Australian Government Accredited Product Stewardship Scheme

Analysis of the material circularity of management options for tyres and conveyor belts

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Acknowledgement

Tyre Stewardship Australia acknowledges the Traditional Custodians of the land and waterways on which we live, work, and depend. We acknowledge the unique spiritual and cultural connection, and continuing aspiration that the Traditional Owners have for Country, and we pay respect to Elders, past, present, and emerging.

Publication

This report was originally published in 2024 and has since been updated. You can find additions to this Report at tyrestewardship.org.au. This Report is designed as an iterative document that will be modified and updated as the research advances.

Thanks and feedback

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- Product Stewardship Centre of Excellence: John Gertsakis and Rose Read..

If you have any questions or feedback, please contact Felicity Millard, Circular Economy Advisor by emailing felicity.millard@tyrestewardhship.org.au.

Environment

This Report was designed to be read digitally, with hyperlinked references and sections. Please consider your environmental impact before printing.

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Abbreviations and Key Terms

Abbreviations

ELT	End-of-life tyres
ELT&C	End-of-life tyres and conveyor belts
MCI	Material Circularity Indicator
OTR	Off-the-road tyres
TDF	Tyre Derived Fuel

Key Terms

Definitions of key terms marked with an Asterix are taken from the Australian Standard for Waste and Resource Recovery Data and Reporting, Second Edition (DCCEEW, 2024).

Other definitions are by TSA for the purpose of delineating the meaning of key terms in this Report.

Circular Economy

Looking beyond the current take-make-waste extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits.

It entails gradually decoupling economic activity from the consumption of finite resources and designing waste and pollution out of the system.

Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital.

It is based on three principles: design out waste and pollution; keep products and materials in use (ideally at their highest and best value); and regenerate natural systems (Ellen MacArthur Foundation, 2024)

Indicative assessment

A qualitative judgment based on analysis but without quantitative assessment metrics.

Management option

Options in respect of how tyres and conveyor belts are managed. Including management options at the phases of new product design and production, consumption, and post-consumption.

Material circularity

Refers to the extent that products and materials are kept in use (at their highest value). Key to implementing Principle two of the Circular Economy.

Recycling

Activities that culminate in the reprocessing of wastes into products or secondary materials that are returned to productive use (excluding for energy).

May include collection, sorting and/or reprocessing.

For data reporting purposes, the mass of material allocated to the fate 'recycling':

- Includes all materials received by a reprocessing facility that are processed to the point of being suitable for manufacturing or return to productive use, whether immediately used or stored for later sale or use.
- Includes weight losses to the atmosphere during the processing of wastes (for example, moisture, carbon dioxide from organics degradation).
- Excludes residuals that are sent to landfill or otherwise disposed of.
- Excludes materials received at a recycling facility but not yet processed.
- Is reported as wet weight.

Resource recovery
Activities that culminate in the reprocessing of wastes into products or secondary materials that are returned to productive use, including for energy.

May include collection, sorting, reprocessing and/or energy recovery.

For data reporting purposes, the quantity of waste allocated to the fate 'resource recovery' is the sum of the quantities allocated to waste reuse, recycling, and energy recovery.

Reuse
Reallocation of products or materials to a new owner or purpose without reprocessing but potentially with some repair (for example, repair of pallets for resale, tyre retreading).

Vulcanisation
The process of cross-linking rubber molecules chemically, normally by using sulfur as the cross-linking agent, and through exposure to heat and pressure. A vulcanised rubber is a solid and will retain its shape and dimensions.

Waste
Materials or products that are unwanted, surplus, discarded, rejected, abandoned, or left over, including those materials or products intended for or managed by recycling, energy recovery, treatment, storage, and disposal.

Waste-derived materials cease to be waste and transition to being 'secondary materials' when the following conditions are met:

- They are to be used for a specific purpose.
- A market or demand exists.
- They fulfil the technical requirements for the specific purposes and meet the existing legislation and standards applicable to products.
- Their use will not lead to overall adverse environmental or human health impacts.

The transition from waste to secondary materials is generally deemed to occur at the out-going gate of a reprocessing facility when the outputs require no further processing prior to being returned to productive use.

Waste reuse
Reuse of a product or material that has entered a waste resource recovery facility (for example, the sale of goods from a reuse shop).

Executive Summary

1

Tyres and conveyor belts are complex, highly engineered products and their composition can differ significantly depending on their use. The core elements are steel, carbon black, and natural and synthetic rubber. The rubber is vulcanised around steel and textile reinforcement to form the robust products we recognise.

Tyres and conveyor belts go through three life cycle phases:

1. **Design and production** (materials, design, manufacturing).
2. **Consumption** (use, repair, reuse).
3. **Post-consumption** (recycling, energy recovery, disposal).

Making the most of the resources in post-consumption (end-of-life) tyres and conveyor belts, particularly the rubber compounds, is the immediate challenge.

Australia's rates of **resource recovery for end-of-life tyres (ELT)** falls significantly short - 58% in 2022/23 - of the near 100% level that is achievable for these products (TSA, 2023).

In 2022/23 the recycling rate was only 13% of all ELT (TSA, 2023). This low recycling rate is partly due to almost all Off-the-road (OTR) tyres used in mining being buried onsite resulting in long term risks to the local environment and a complete loss of significant tonnages (~130,000 t) of valuable embodied materials.

If the above statistics were to also include **conveyor belts**, the resource recovery and recycling rate for all end-of-life tyres and conveyor belt (ELT&C) would be even less. TSA estimates that approximately 60,000 to 85,000[1] tonnes of waste conveyor belts are generated in Australia each year and almost all are disposed to landfill or buried on mine sites (TSA, 2023). There are opportunities to support circularity for these conveyor belts, **because they are manufactured locally[2]**. Unlike tyres though, there are no specific regulatory requirements to manage, track and appropriately dispose end-of-life conveyor belts in Australia (NESP Sustainable Communities and Waste Hub, 2023).

In the context of the transition towards a more circular economy, numerous **management options** exist across the product life cycle stages to increase these recovery and recycling rates and facilitate the transition from wasted resources to valuable materials.

There is interest, particularly from the mining companies, in understanding the relative merits of the various management options.

This report analyses the alignment of the range of tyre and conveyor belt management options with the principles of a circular economy and the waste hierarchy[3].

The three principles of the circular economy are:

1. Eliminate waste and pollution.
2. Circulate products and materials (at their highest value).
3. Regenerate nature (Ellen MacArthur Foundation, 2024).

1 Approximately 55,000 t being generated by the mining sector and disposed of onsite in 2023.
2 Onshore conveyor belt manufacturers are: ContiTech (Continental Group Company) VIC, Australia and Fenner Conveyors (Michelin Group Company), various locations across Australia and New Zealand.
3 Refer to Background section for waste hierarchy discussion.

For each management option, the report provides analysis of the alignment to the second principle of the circular economy – keeping materials in use for as long as possible. Referred to henceforth as material circularity.

The report aims to support the ongoing development of, and investment in, management options that are most aligned to the principles of the circular economy and the waste hierarchy.

The results are presented in the 'Options Assessment Tool' that illustrates the indicative level of material circularity for each management option and the alignment with the waste hierarchy.

The 'indicative assessment' of material circularity is based on desktop analysis and industry expertise and considers the outputs (from processing) and the applications that utilise the outputs.

Options Assessment Tool – Key Findings 1.1

The key findings across the product life-cycle phases are included below.

Design Options

Important opportunities exist to improve tyre and conveyor belt **product designs** by incorporating the increasing amounts of recycled content now being produced globally through a maturing range of recycling technologies.

There are also opportunities, particularly for high value large OTR tyre and conveyor belt products, to implement improved **system designs** to change the way these products are supplied, collected, refurbished, and recycled. 'Closed-loop' product supply systems, which have operated in the aviation sector for decades, could be similarly implemented in the mining sector.

Use Options

There are opportunities to extend the use phase, particularly for high value large OTR tyre and conveyor belt products, via the expansion of re-tread and refurbishment. Large and giant OTR tyre re-tread is common overseas. As a major global consumer of these tyres, Australia requires a re-treading industry comparable to those in similar jurisdictions, such as Canada.

Recycling Options

Approximately **20 different recycling options** for ELT&C have been identified. These are the most common options identified to date and new options may become available in future.

The **extent of material circularity across the recycling options varies from high to none**. This demonstrates the need to clearly understand not only the technology used to process ELT&C, but also the **product application**. It is the product application that determines the material circularity and waste hierarchy outcomes.

The Option Assessment Tool also illustrates the important consideration of the **amount of ELT&C processing required** for the range of options. Often the options with the highest material circularity, producing the highest market value products, also require the highest amount of ELT&C processing.

The market maturity of the recycling options varies from long-established and globally mature to globally immature. There are mature high circularity recycling options in Australia currently, and important developing international options such as the use of devulcanised rubber in new tyre manufacturing.

Energy Recovery Options

ELT&C energy recovery options play an important role in end-of-life tyre management globally and are preferable to disposal.

When ELT are used as tyre-derived fuels (TDF) they often displace coal. TDF has a higher calorific value compared to coal and when displacing coal there are **significant CO_2 emissions reductions.**

TDF use in cement manufacturing can reduce costs and CO_2 emissions, while also decreasing the reliance on traditional fossil fuels. When appropriate technical systems are in place TDF use in cement kilns does not impact product quality and regulated pollutants can be removed within contained levels.

However, all energy recovery options (including TDF) lack material circularity, as the rubber compound materials are permanently lost during energy production.

Large energy recovery markets have the potential to build an over-reliance on this option, which can deter investment in options that are required to establish a circular economy. There is a need for a balance of recycling and energy recovery options.

Disposal Options

In Australia it is still an option for the mining sector to legally bury ELT&C at mine sites. As a result, almost all OTR tyres and conveyor belts used in mining are buried onsite.

The Options Assessment Tool illustrates that there are a range of options that are available to recover tyres and conveyor belts, including recycling and energy recovery options.

The solution to onsite burial of mining ELT&C may involve implementing more than one option (i.e. contract design, reverse logistics, re-treading, and recycling and or energy recovery).

This Report is a beginning. We invite suggestions for future iterations. TSA consulted with members of various industries during its development. The stakeholders have identified its value, and the opportunity to expand the analysis in future iterations to include specific metrics such as carbon emissions.

Preface

This Report is about tyres and conveyor belts and the management options[4] for these products over their life cycle phases.

Tyres and conveyor belts go through three life cycle phases:

1. **Design and production** (materials, design, manufacturing)
2. **Consumption** (use, reuse, repair).
3. **Post-consumption** (recycling, energy recovery, disposal).

The Report is structured around and provides information for the management options at each of these phases.

The Report analyses the alignment of each management option with the principles of a circular economy and the waste hierarchy.

The three principles of the circular economy are:

1. **Eliminate waste and pollution.**
2. **Circulate products and materials** (at their highest value).
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or each management option, the Report analyses alignment with the second principle of the circular economy – keeping materials in use for as long as possible – hereafter referred to as material circularity. Referred to henceforth as material circularity.

The Report aims to support the ongoing development of, and investment in, management options that are most aligned to the principles of the circular economy and the waste hierarchy.

- The results are presented in the 'Options Assessment Tool' that illustrates the indicative level of material circularity for each management option and the alignment with the waste hierarchy[5].
- The scope of the analysis includes management options for rubber-based conveyor belts, and all tyres including passenger, truck, bus, and the 'off-the-road' (OTR) tyres used in mining and agriculture.
- The material circularity analysis focuses on the rubber compounds in tyres and conveyor belts.
- The steel used in tyres and conveyor belts is not the focus of the material circularity analysis as it is currently readily recycled once it is separated.

In short, this piece of work assesses management options relative to their indicative level of material circularity and alignment with the waste hierarchy.

4 The assessment method refers to all management options, both proven and emerging. The status of each management option is discussed in the following sections. .
5 Refer to Background section for waste hierarchy discussion.

Background

Our current tyre and conveyor recovery rates

Australia's rate of **resource recovery** for end-of-life tyres (ELT) falls significantly short - 58% in 2022/23 - of the near 100% level that is achievable for these products.

In 2022/23 the recycling rate was only 13% of all ELT (TSA, 2023). This low recycling rate is partly due to almost all OTR tyres used in mining being buried onsite, resulting in long term risks to the local environment and a complete loss of significant tonnages (~130,000 t) of valuable embodied materials.

If the above statistics were to also include conveyor belts, the resource recovery and recycling rate for all end-of-life tyres and conveyor belt (ELT&C) would be even less. TSA estimates that approximately 60,000 to 85,000[6] tonnes of waste conveyor belts are generated in Australia each year and almost all are disposed to landfill or buried on mine sites (TSA, 2023). There are opportunities to support circularity for these conveyor belts, **because they are manufactured locally[7]**. Unlike tyres though, there is no specific regulatory requirements to manage, track and appropriately dispose end-of-life conveyor belts in Australia (NESP Sustainable Communities and Waste Hub, 2023).

Composition of tyres and conveyor belts

Tyres and conveyor belts are complex, highly engineered products and their composition can differ significantly depending on their use. The core elements are steel, carbon black, and natural and synthetic rubbers (refer to Figure 1).

There is variability in tyre composition depending on where tyres are manufactured, the performance requirements, and standards in those regions. Australia does not manufacture tyres, and therefore has a unique mix of tyres, sourced from all over the globe. Data from US and EU sources is available to make assumptions about tyre composition in Australia.

Whilst there is no exact or average composition of a tyre, there are generalisations. For example, to account for the high heat resistance needed, larger tyres have a higher proportion of natural rubbers compared to synthetic rubbers, whereas to provide better grip, smaller tyres have higher proportions of synthetic rubbers.

The type and composition of conveyor belts depend on the commodity they're moving, and this can have varying impacts on resource recovery. For example:

- Mines extracting high weight, high volume and hard rock materials such as iron ore, need steel cord conveyor belts.
- Mines extracting less abrasive materials such as coal use poly- or ply-woven conveyor belts.
- Underground mines need conveyor belts with fire retardants, which are chemicals-of-concern that make recovery and recycling harder (NESP Sustainable Communities and Waste Hub, 2023).

6 Approximately 55,000 t being generated by the mining sector and disposed of onsite in 2023.
7 Onshore conveyor belt manufacturers are: ContiTech (Continental Group Company) VIC, Australia and Fenner Conveyors (Michelin Group Company), various locations across Australia and NZ.

Figure 1: Structure of a passenger car tyre (Harrison et al, 2019).

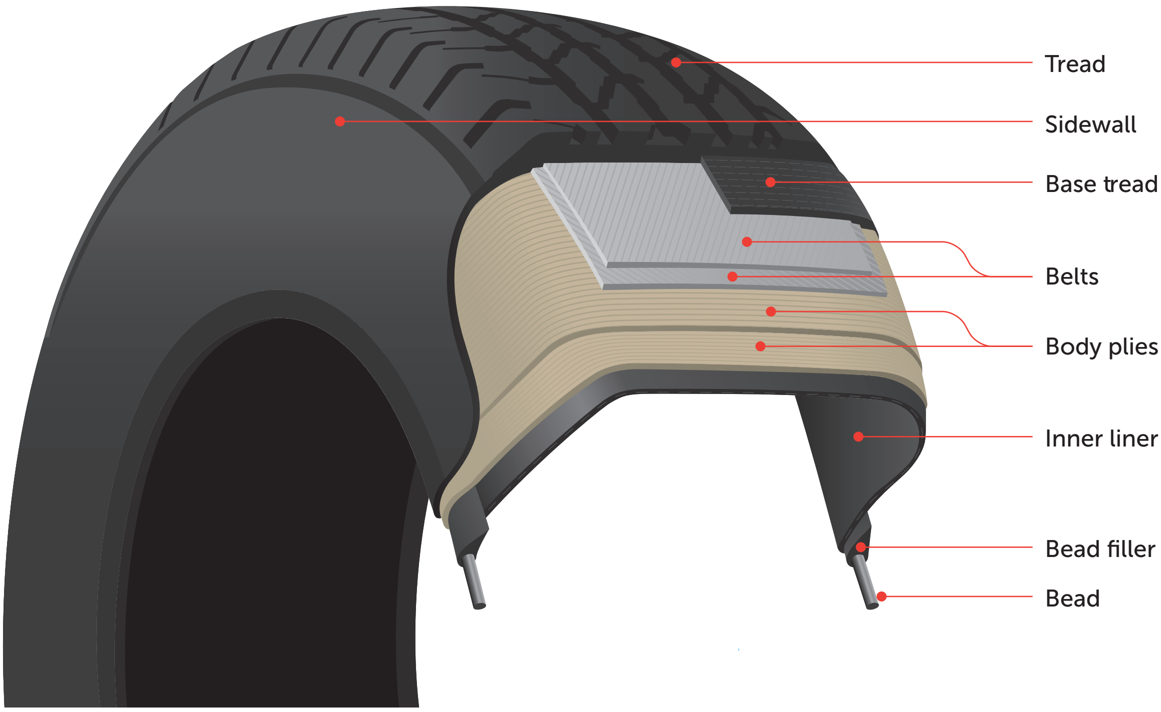
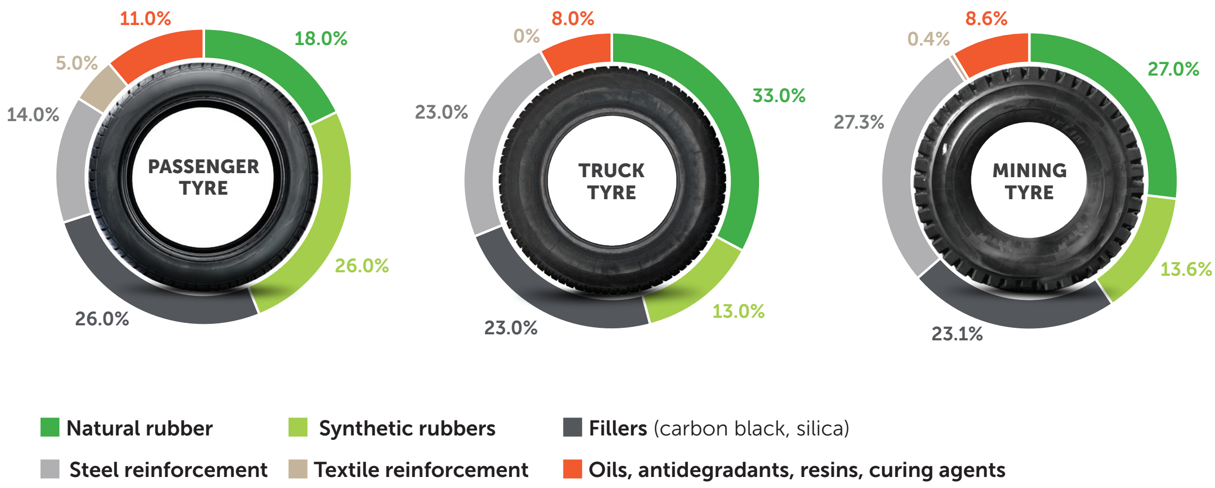


Figure 2: Generalised composition of passenger, truck and off-the-road tyres (TSA, 2024).



The challenge of rubber compound recycling

When ELT&C are collected for recycling, the steel is recycled through a mature and commercially viable steel recycling sector. The remaining rubber compound (which includes carbon black, natural and synthetic rubber, and other additives) is more challenging to recycle because of its composite and vulcanised structure.

Options to recycle rubber compounds into high material circularity applications, such as turning used tyres into new tyres, are developing but not yet commonplace. Refer to recycling management options for further discussion.

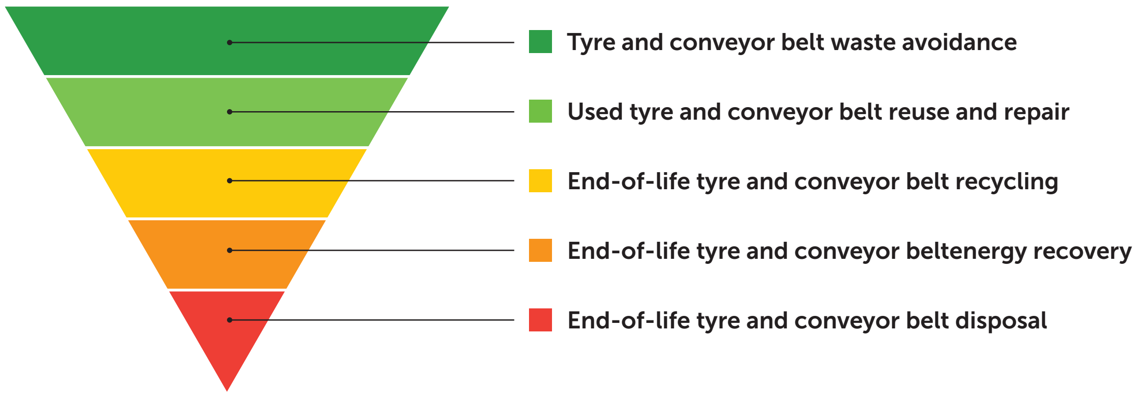
Policy

Australia's *Recycling and Waste Reduction Act 2020* creates a policy framework for reducing the impact of waste material on human and environmental health; realising the community and economic benefits of taking responsibility for products; and developing a circular economy that maximises the continued use of products and waste material over their life cycle.

The circular economy is more than simply 'recycling better'. It adds to the waste hierarchy by identifying the need for interconnected systems to address the connected global challenges of climate change, biodiversity loss, waste, and pollution (United Nations Development Programme, 2023).

Australia's waste policy, National Waste Policy: less waste more resources, defines, in order of preference, the stages of the waste hierarchy from avoiding waste as most preferable, through to disposing of waste as least preferable (Figure 3). The Policy sets targets, including for an '80% average resource recovery rate from all waste streams following the waste hierarchy by 2030'.

Figure 3: The waste hierarchy on tyres and conveyor belts (based on National Waste Policy Action Plan - Australian Government, 2024).



Foundation

The World Business Council for Sustainable Development (WBCSD) End-of-life tire management Toolkit, 2021 mapped tyre 'recovery routes' against the waste hierarchy. The Options Assessment Tool in this Report builds on the foundation provided by the WBCSD Toolkit.

The Options Assessment Tool

The Options Assessment Tool presents material circularity for management options from the highest mat

HIGHEST MATERIAL CIRCULARITY

LOWEST MATERIAL CIRCULARITY

NO MATERIAL CIRCULARITY

WASTE HIERARCHY

Tyre and conveyor belt waste avoidance

- **Product Design:** Low toxicity, resource efficiency, recycled content, renewable materials, dura
- **System Design:** Policies, business models, reverse logistics, enabling technologies

Used tyre and conveyor belt repair and reuse

- Repair and maintenance
- Tyre retreading
- Tyre re-grooving
- Conveyor belt reconditi

ELT&C recycling - processing outputs and applications

- **Devulcanised rubber:** high performance rubber products (tyres, retread, conveyor belts)
- **Pyrolysis carbon:** recovered carbon black use in new tyre and conveyor belt manufacturing
- **Reclaimed rubber:** rubber products e.g. inner tubes
- **Crumb:** road surfacing, e.g. binders for asphalt, spray seals
- **Granule:** permeable pavement
- **Pyrolysis carbon:** char use as lime replacement in asphalt
- **Granule:** composite materials moulded products e.g. posts, bollards, roofing tiles
- **Sections:** agriculture flooring applications
- **Granule:** soft surfaces gym mats, playgrounds
- **Shred or granule:** construction thermal insulation and sound barriers
- **Granule or crumb:** rubber in concrete products (e.g. pavements, prefabricated panels, crash ba
- **Granule:** artificial turf
- **Pyrolysis oil:** chemical production
- **Shred:** rail sub-base to reduce vibration
- **TDA or shred:** non-structural civil applications (i.e. lightweight fill, drainage aggregate)
- **Crumb:** tile adhesives, sealants, etc
- **Granule:** carbon (coke, coal) supplement in steel recycling
- **Crumb:** mining industry explosives additive

ELT&C energy recovery - processing outputs and applications

- **Pyrolysis or gasification gas:** used as fuel/natural gas replacement
- **Pyrolysis oil:** used as a fuel supplement in bunker oil or higher grade fuels
- **Shred or whole:** TDF as coal/natural gas supplement in cement production kiln
- **Shred:** TDF coal supplement for paper pulp mills

ELT&C disposal

- Direct disposal to offsite licensed landfill
- Onsite burial at mining sites
- Tyre derived agg

Legend: **Primary processing:** P1: Sectioning into pieces P2: Shredding P3: Granulation P4: Crumbing
Secondary processing: S0: No secondary processing S1: Low level additional refinement of secondary processing outputs
S2: Moderate level additional refinement of secondary processing outputs
S3: High level additional refinement of secondary processing outputs
ELT&C: End of life tyres and conveyor belts **TDF:** Tyre derived fuels **TDA:** Tyre derived aggregate

Figure 4: The Options Assessment Tool.

erial circularity to no material circularity. This scale aligns with the waste hierarchy.

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Using the Options Assessment Tool

The Options Assessment Tool is composed of several elements, outlined below.

Material circularity

The sliding scale of material circularity is shown on the left-hand side of the tool, from highest to none.

Waste hierarchy

The stages of the waste hierarchy, from avoidance to disposal, are used to group management options down the left side of the tool.

Management Options

The range of management options are listed under each stage of the waste hierarchy.

The Recycling and Energy Recovery management options link the ELT&C processing output and with the output application/s.
For example, a processing output is Granule, and the application is permeable pavement. Taken together, the management option is **Granule: permeable pavement.**

The linking of processing outputs to applications is key because, **only when the product application is defined, can the material circularity and the waste hierarchy alignment be determined.**

Processing

ELT&C recycling or energy recovery options typically require processing of the ELT&C before use in the application. The extent of processing varies significantly and is an important consideration.

The Options Assessment Tool presents: **primary processing and secondary processing**. These are shown in the two rightmost columns of the Options Assessment Tool.

- **Primary processing** is about size reduction and steel recovery: shredding, granulation, and crumbing.
- **Secondary processing** is about further resource extraction: devulcanisation, reclamation, gasification, and pyrolysis.

Phases

The Tool presents the management options by the 'phases', as in life-cycle phases on the right-hand side of the tool (Design, Use, Resource Recovery, Disposal).

Design and Manufacturing management options

These are the options that directly align with the first principle of a Circular Economy (eliminate waste and pollution) and the Avoidance stage of the Waste Hierarchy.

These options can also be effective in enabling material circularity post-consumption.

Consumption (use) management options

These include important options, such as retread, that increase the use phase of the product and reduce ELT&C generation. All these options offer an equivalent material circularity potential.

Recycling options

The core feature of the Options Assessment Tool is the analysis of the circularity of the management options for **recycling**[8].

- Applications that offset the demand for virgin rubber by recycling rubber compounds into tyres and conveyor belts are the most preferred and are therefore at the top.
- Derived rubbers that can be recycled, and then recovered and re-processed again back into another useful product, such as crumb for road surfacing, are the next most circular.
- Single-use applications, such as crumb used in explosives, are not circular as they do not keep the material in circulation..

To reiterate, the outputs along with the application (i.e. ***Crumb: tile adhesive, sealants etc***.) is what is indicatively assessed for material circularity. Without a holistic consideration of ELT&C processing and product application, processing technologies (such as pyrolysis and gasification) could be viewed as highly circular, without taking into account the material's use and its associated life cycle.

Energy recovery options

Management options that direct ELT&C to **energy recovery** play an important role in end-of-life tyre management globally and are preferable to disposal. For example, the export of ***Shred or whole: TDF as coal/natural gas supplement in cement production kilns***, accounts for a large portion of Australia's current ELT&C resource recovery sector. Moreover, onshore use of this output and application is increasing.

However, energy recovery options have no material circularity as the rubber compound materials are lost once used for energy production.

Disposal options

Management options include legal disposal into licenced landfill or permitted onsite burial at mining sites. Illegal dumping and burning of ELT&C are listed as they are still a significant challenge in Australia.

8 In assessing the material circularity of different recycling applications, we have not specifically assessed the economic value or scarcity of the materials the rubber recyclate is replacing, nor the resulting product performance enhancements or risks of using rubber recyclates. However, often the higher material circularity applications directly displace the need for virgin rubber production and/or result in equivalent or improved product performance.

The Options Assessment Tool - Key Findings 6

This section provides an overview of the findings that are illustrated in the Options Assessment Tool. For analysis of any specific option, refer to the relevant sub-section.

Design Options

There are important opportunities to improve tyre and conveyor belt **product design** to incorporate more recycled content that is now being produced (globally) in increasing amounts by a maturing range of recycling technologies.

There are also opportunities, particularly for high value large OTR tyre and conveyor belt products, to implement improved **system designs** to change the way these products are supplied, collected, refurbished, and recycled. 'Closed-loop' product supply systems have been operational in the aviation sector for decades and could similarly be implemented in the mining sector.

Use Options

There are opportunities to extend the use phase, particularly for high value large OTR tyre and conveyor belt products, via the expansion of re-tread and refurbishment. Large and giant OTR tyre re-tread is common overseas. Australia is a major global consumer of these tyres and needs a re-tread industry to service this demand comparable with similar jurisdictions, like Canada.

Recycling Options

Approximately **20 different recycling options** for ELT&C have been identified. These are the most common options identified to date and new options may become available in future.

The **extent of material circularity across the recycling options varies from high to none**. This demonstrates the need to clearly understand not only the technology used to process ELT&C, but also the **product application**. It is the product application that determines the material circularity and waste hierarchy outcomes.

The tool also illustrates the important consideration of the **amount of ELT&C processing required** for the range of options. Often the options with the highest material circularity, producing the highest market value products, also require the highest amount of ELT&C processing.

The market maturity of the recycling options varies from long-established and globally mature, to globally immature. There are mature high circularity recycling options in Australia currently, and important developing international options such as the use of devulcanised rubber in new tyre manufacturing.

Energy Recovery Options

ELT&C energy recovery options play an important role in end-of-life tyre management globally and are preferable to disposal.

When ELT are used as tyre-derived fuels (TDF) they often displace coal. TDF has a higher calorific value compared to coal and when displacing coal there can be **significant CO_2 emissions reductions**.

TDF use in cement kilns is a large mature global energy recovery market. TDF use in cement manufacturing can reduce costs and CO_2 emissions, while also decreasing the reliance on traditional fossil fuels. When appropriate technical systems are in place TDF use in cement kilns does not impact product quality and regulated pollutants can be removed within contained levels.

However, all energy recovery options (including TDF) have **no material circularity** as the rubber compound materials are lost once used for energy production.

Large energy recovery markets have the potential to build an over-reliance on this option, which can deter investment in options that are required to establish a circular economy. There is a need for a balance of recycling and energy recovery options.

Disposal Options

In Australia it is still an option for the mining sector to legally bury ELT&C at mine sites. As a result, almost all OTR tyres and conveyor belts used in mining are buried onsite.

The Options Assessment Tool illustrates that there are a range of options available to recover these tyres and conveyor belts, including recycling and energy recovery options.

The solution to onsite burial of mining ELT&C may involve implementing more than one option (i.e. contract design, reverse logistics, re-treading, recycling and or energy recovery).

Potential additional analysis 6.1

This Report is a beginning. We invite suggestions for future iterations. TSA consulted with members of the mining industry during its development. The stakeholders have identified its value, and the opportunity to expand the analysis in future iterations.

Additional research into each management option could be conducted. Further assessments could include quantitative metrics, such as those outlined below.

Life Cycle Assessments (LCAs) and emissions

Life Cycle Assessments (LCAs) provide a holistic view of a product's environmental impact throughout its life cycle, aiding industries in decision-making and promoting sustainability. LCAs assess various environmental impact categories and help transition to a circular economy by identifying opportunities for circularity. They ensure objective verification of sustainability claims and challenge assumptions about material superiority.

LCAs are useful for specific projects and offer valuable insights for industry to assess the emissions associated with each option. The example of TSA's LCA analysis of crumb rubber in roads demonstrates LCA's practical application in evaluating environmental impacts, see TSA's *Emissions Analysis of Waste Tyre Recovery*.

Other material circularity indicators

Quantitative tools like the 'Material Circularity Indicator' (MCI) calculator, by the World Business Council for Sustainable Development (measure material circularity of products), could offer MCI scores for each life cycle and application.

MCI calculations require detailed product information, including material composition and end-of-life fate. While MCI analysis isn't covered in this report, it could be valuable for assessing management options further where the detail required is available.

Cost and risk management

Although some indicative capital and operational costings are provided, additional research into the markets for outputs, gate fees, licensing fees and logistics costs could be considered. A feasibility study of tyre and conveyor belt management options could also include the total financial cost, reputation cost, regulatory, or business risk.

Design and Manufacturing Options 7

This section discusses the options that directly align to the first principle of a Circular Economy (eliminate waste and pollution) and the Avoidance stage of the Waste Hierarchy. These options can also be effective in enabling material circularity post consumption.

Product Design 7.1

In the design and manufacture phase of tyres and conveyor belts, options to avoid waste should:

- Improve durability and repairability.
- Minimise resource consumption when manufacturing the product by using less virgin raw materials.
- Use more renewable and recovered raw materials.
- Design to minimise energy and resource consumption during product use.
- Avoiding hazardous and toxic materials in the product.

Product design circular economy considerations for tyres and conveyor belts include:

Intensity	Use less (volumes and types).
Input	Use renewable energy and fuels, low water input & water circulation.
Toxicity	Reduce operational waste and emissions to air, water and soil, with a particular focus on chemicals of potential concern. Ensuring tyre tread contains no chemicals of concern should be a priority, as these materials are released into the environment during use through tyre and road wear particles (TSA, 2022). The Department of Toxic Substances Control in California, on behalf of the U.S. Tire Manufacturers Association (USTMA), identified tyres as a product of concern due to their content of the antiozonant chemical N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) and the potential adverse impact of its transformation product, 6PPD-quinone, on aquatic organisms. The USTMA represents over thirty of the world's largest tyre companies. Tyres have been demonstrated to contain known chemicals of concern (e.g., heavy metals, bisphenol A (BPA), N-(1,3-dimethyl butyl)-N'-phenyl-p-phenylenediamine (6PPD) and its oxidised product 6PPD-quinone (6PPD-Q)), shown to impact human and ecosystem health (NESP Sustainable Communities and Waste Hub, 2023). The EU Registration, Evaluation, Authorisation and Restrictions of Chemicals (REACH) stipulates polycyclic aromatic hydrocarbons (PAH) limits for tyres and re-tread rubber compounds (Commission Regulation, 2009).
Resource efficiency	Optimise the use of raw materials to reduce materials, embodied water, and waste generation through the manufacturing process.
Recycled content	Maximise the use of de-vulcanized rubber, recycled steel, and other recovered materials.

Renewable materials	Replace fossil fuel feedstocks with renewable materials, such as alternative sources of certain rubbers and fillers derived from natural sources. For example, agricultural bioproducts can be used as silica replacements (Continental, 2024), or Guayule, a plant that grows in North America, can serve as a rubber source (Bridgestone, 2024).
Procure regenerative materials	Support natural rubber suppliers and other resources to reduce operational impact on the environment and positive socioeconomic outcomes. The Global Platform for Sustainable Natural Rubber outlines assurance methods for sustainable, equitable and fair natural rubber supply chains. There are also de-forestation and modern slavery regulations to consider.
Design for reusability over single use	Design tyres to be repaired and re-treaded and conveyor belts to be reconditioned.
Considerations of recovery	Ensure materials can go into end-of-life management options safely and efficiently.

International action

Circular Rubber Platform analysed the sustainability reports of leading rubber procuring organisations including major tyre manufacturers in a recent report, highlighting a key trend of increasing use of bio-based and recycled materials (Circular Rubber Platform, 2025).

As all tyres are manufactured offshore and imported into Australia, the main actions Australia can take are in influencing international specifications and setting standards for tyres entering the market that support circular economy practices and increase the demand for tyres which include recycled content.

The World Business Council Sustainable Development (WBCSD), Tyre Industry Project (TIP) is a collaboration of tyre manufacturers to accelerate sustainability development. It includes establishing clear targets for improving the impact of the organisations supply chain, operations, products and services (WBCSD, 2023).

TIP developed a roadmap for tyre manufacturers. It identified that a key impact opportunity was to advance 'innovation in product, service and business model design to enhance low-carbon and circular solutions while ensuring sustainable management of ELT around the world'. TIP is supporting tyre manufacturers to implement sustainable procurement practices that promote transparency and traceability through disclosure statements. It encourages manufacturers to consider an environmental impact assessment to improve material circularity and provide information through published Environmental Product Declarations. TIP also recognises that a circular economy for tyres cannot be achieved soley at a product level but needs a whole of system approach, with active players across geographies, supply chains and governments.

TSA has recently collaborated with CSIRO on the study, "Exploring Global Influences on the Tyre Inudstry". A key insight was that tyre manufacturers, along with regulatory alignment, are emphasising initiatives to meet sustainability objectives (reducing carbon emissions and deforestation) and key performance needs such as safety (e.g., wet grip) and fuel efficiency (e.g., rolling resistance). The replacement of chemicals of concern and reduction in tyre wear appears secondary in these initiatives, perhaps because global regulations regarding these contaminants from tyres are still evolving. With all these factors influencing manufacturing, tyre design has needed to adapt both structurally (tread designs, size, thickness, and reinforcements) and chemically (sustainable rubber sources, recycled raw materials, new fillers, and other additives) (CSIRO, 2024).

Australian manufacturing

While extracting raw materials and manufacturing tyres do not occur in Australia, we can influence specifications and standards for tyres entering the market to support circular economy practices.

Conveyor belts and tyre re-treads are manufactured in Australia using imported raw materials. Design choices can contribute to system lock-ins which can lead to linear materials consumption and poor recycling rates (International Bureau of Recycling, 2023). Reversing the negative impacts of design decisions is challenging and costly. Therefore, policymakers and manufacturers have a central role in developing material circularity.

Opportunities for conveyor belt design waste avoidance include:

Conveyor Belt Design	Ensure design specifications prioritise environmental and human health outcomes
Recycled Content	Explore using recovered carbon black and de-vulcanised rubber from ELT&C in manufacturing, thus creating a closed-loop system. It is reported that tyre-derived polymers, made from de-vulcanised ELT&C, typically perform well in conveyor applications at the 20% level. For 2_{nd} and 3_{rd} tier products, a higher load level of up to 40-50% can be achieved (Tyromer, 2023).
Business models	Support 'total cost of ownership' models to incentivise extended product life and improved maintenance systems.
Reverse logistics and stockpiling policies	Conveyor belts are most often stockpiled on-site. Recovering these materials through reverse logistics and shifting servicing offerings allows manufacturers to retrieve, recondition, or recycle them, potentially reducing long-term stockpiling on-site.

System design 7.2

Australian Design Rules

The Australian Design Rules (ADR 23/00 and ADR 96) outline specifications for tyres, covering:

- Strength
- Construction
- Dimensions
- Endurance
- Performance (in normal and adverse conditions such as deflation)

ADRs provide consumer protection, emphasising quality, safety, and value for money, especially for consumers lacking firsthand knowledge of tyre standards. ADR is integral to the Australian Motor Vehicle Standards system, aligning with the Road Vehicle Standards Act 2018, **but it is not currently enforced** (ADR, 2024).

This lack of enforcement, together with an absence of fuel efficiency standards, means Australians may be buying tyres that don't support a lower emission transport system or material circularity for tyres.

Ownership models and business practices

Businesses buying tyres and conveyor belts should assess the **total cost of ownership**, rather than focusing solely on initial expenses. This creates incentives to use re-treading and servicing options.

For aviation tyres the pricing mechanisms, is commonly per landing, rather than a single unit cost. This in essence is tyres-as-a-service, rather than tyres as a product. This has allowed innovation in tyre retread and has supported high durability design. There is an opportunity and interest by global manufacturers to pilot these tyres-as-a-service model adapted to different sectors, such as mining and agriculture.

Management systems that offer services like maintenance, repair, and collection can promote material circularity by keeping the costs of managing ELT&C in the business. For this to work, robust reverse logistics capabilities are crucial, particularly in remote regions. Aligning these logistics processes with procurement contracts can ensure efficient transportation and retain value.

Councils and fleets introducing re-treading as a tender requirement would also boost material circularity efforts.

Enabling Technologies

Enabling Technologies can support predictive maintenance, and effective management along the supply chain and throughout the phases. These include:

- Application of biological processes in tyre manufacturing and recycling, known as biotechnology.
- Tyre Pressure Monitoring System (TPMS).
- Intelligent and connected tyres transmit real-time data for informed decision-making, enhancing safety and optimizing vehicle usage.
- Radio Frequency ID tagging facilitates circularity by storing unique tyre data, and supporting activities like correct fitting, inventory management, and proof of recycling.

Additional, Tyre-Specific Technologies which directly influence innovations in tyre design and functionality include:

- Non-Pneumatic Tyres: Airless tyres that eliminate the risk of punctures.
- Smart Tyres: Tyres with embedded technology for real-time monitoring and data transmission.
- Chemicals of Concern: Focus on identifying and reducing harmful chemicals in tyre production.
- Self-Healing Polymers: Materials that can repair themselves to extend tyre life.

The Global Data Service Organisation (GDSO) standardises tyre data sharing through a unique item identifier, fostering traceability, transparency and circular outcomes. It improves:

- Ability to be re-treaded.
- Fleet management effectiveness.
- Segregation of tyres at end of life to improve feedstock into processing.

Circular economy policies and guidelines – further reading

7.3

Other Australian national policies and guidelines that drive waste avoidance and support material circularity include:

Updated/ Published	Initiative/ Framework	Description
2018	National Waste Policy	Provides a national framework for waste and resource recovery in Australia, outlining collective responsibilities for governments, businesses, and individuals.
2019	National Waste Policy Action Plan	Sets targets and outlines practical actions to achieve waste avoidance, increased resource recovery, and improved environmental outcomes by 2030.
2020	National Circular Economy Road Map	Developed by CSIRO, this roadmap identifies opportunities for innovation and collaboration to advance Australia's circular economy.
2020	Recycling and Waste Reduction Act 2020	Provides a legislative framework to regulate waste exports, improve recycling practices, and reduce landfill dependency.
2021	National decarbonisation targets – net zero by 2050	Establishes Australia's commitment to achieve net zero greenhouse gas emissions by 2050, including strategies for all key sectors.
2021	Sustainable Procurement Guide	Offers guidance to public and private sectors on incorporating sustainability into procurement processes to promote a circular economy.
2021	ReMade in Australia	Promotes the use of recycled content in Australian-made products, encouraging consumers and industries to choose sustainable options.
2023 and 2024	Circular Economy Ministerial Advisory Group (CEMAG) Reports	Summarizes the findings and recommendations of the CEMAG to accelerate Australia's transition to a circular economy.
2023	Australian Mandatory Climate-Related Financial Disclosure Legislation	Requires companies to disclose climate-related risks and opportunities in alignment with global reporting standards, enhancing transparency.

Updated/ Published	Initiative/ Framework	Description
2023	National Framework for Recycled Content Traceability	Provides a national approach to track and verify recycled content in products, supporting better resource recovery and circular practices.
2024	Circular Economy Productivity Commission Inquiry	Examines the potential of the circular economy to boost productivity and deliver environmental, economic, and social benefits for Australia.
2024	Circular Economy National Framework	Establishes a cohesive approach to advance circular economy practices across Australia, addressing key sectors and systemic challenges.

State and local government policies also support waste reduction through net zero plans, circularity initiatives, funding and supporting policies.

Consumption (use) 8

This section discusses important options, such as retreading, that prolong the consumption, or use phase of the product, thereby reducing ELT&C generation. These options all offer an equivalent material circularity potential.

Tyres 8.1

Tyre use 8.1.1

Wear

An essential aspect of tyre use is tyre 'wear'. Through wear, a notable fraction of the initial mass is lost to the environment without the possibility of recovery. Approximately 15% by weight of passenger tyres (1.2 kg) and 18% by weight of truck tyres (12.6 kg) are lost due to the abrasion of the tread against the road (Valentini and Pegoretti, 2022).

Wear particles collected at the road site consist of an indivisible mixture of rubber compound particles, mineral particles from road abrasion and fine dust deriving from other wear particles such as brake wear. This environmental pollutant is commonly referred to as tyre and road wear particles (TRWP).

TRWP has been identified in microplastic samples worldwide and been detected in all environmental compartments, specifically road dust, air, soil, freshwater and marine. Road run-off is believed to account for about 44% of the microplastic pollution released into the oceans worldwide (TSA, 2022). Further research into the environmental and human health impact of TRWP is needed, and and WCSD TIP is currently conducting additional research (Tire Industry Project, 2023).

Maintenance and repair 8.1.2

During the use phase, maintenance, repair, regrooving and re-treading can extend a tyre's life.

Maintenance

Tyre maintenance focuses on sustaining optimal pressure, alignment, balance, and tread, with regular rotations according to vehicle specifications. TSA has identified ways to extend the life of passenger tyres (TSA, 2023). Maintenance is particularly important for commercial fleets, where there's a commercial incentive to extend tyre lifespans.

Repair

Tyre repair involves addressing damages like punctures, cuts, extending the useful life and avoiding premature replacement. Repair methods include patching/plugging for small punctures, section repairs, and vulcanisation to restore airtightness. Tyre repair is regulated through the Tyre & Rim Association of Australia Standards Manual (TRAA, 2023).

Using technology

Technologies can enhance the efficiency, safety, and quality of tyre repair and maintenance, including:

- Using specialised adhesives, compounds, and methods to improve the durability of the tyre.
- Employing automated inspection systems and robotics for precise and efficient repair tasks.
- Implementing real-time tyre pressure monitoring systems and data analysis for predictive repair and maintenance.
- Using telematics and fleet management systems that employ sensors, the Internet of Things, and predictive analytics to understand tyre performance, track usage and optimise maintenance.
- Applying radio-frequency identification (RFID) and barcode technology to monitor and track a fleet's tyres.
- Developing apps that schedule and remind drivers of maintenance tasks.

Regrooving

Regrooving tyres involves removing the rubber compound from the existing layer to restore tread pattern depth. The tyre must be designed for regrooving, and the practice is regulated by European Tyre and Rim Technical Organisation (ETRTO) and requires a qualified expert to ensure quality and safety (European Tire and Rim Technical Organization, 2023). Regrooving maintains a tread depth of 6 to 8 mm, enhancing tyre grip, extends the tyre lifespan and improving safety.

Some manufacturers create tyres with an even layer of rubber compound, thick enough to facilitate high-quality regrooving without compromising product solidity or durability. It's also possible to regroove a tyre and then re-tread it, but the tyre must be in optimal condition and designed for this type of re-use.

Regrooving is not possible if the tread displays significant damage, such as cuts to cords, tearing, or visible metal ply on the crown.

Regrooving extends a tyre's usable life and reduces the need for new virgin materials and is most common on commercial truck tyres.

Re-treading 8.1.2

Re-treading 'buffings'[9] off the remainder of a worn tyre's tread pattern to expose a new fresh surface, then a new tread is bonded to this surface. The re-treaded tyre can then be put back in service without compromising safety or quality.

Not all used tyres can be re-treaded. For re-treading a tyre must:

- Be designed for re-treading, with thick side walls and high-quality, durable casing (VTI, 2021), for this reason, low-quality, low-price tyres can't be re-treaded.
- Be well maintained and have no significant punctures or exposures to wear such as exposed cords, sidewalls damaged, or irregular wear patterns.

Re-tread process steps

- **Initial Inspection:** Thoroughly inspect the used tyre for any visible damage, such as cuts, punctures, or other defects. Electrical inspection techniques and other specific inspections are used to assess for non-visible faults. If the tyre is deemed unfit for re-treading, it is rejected.
- **Buffing:** Remove the worn tread surface, true up the roundness and prepare the surface for a new tread.

9 'Buffings' are high elastomer content materials, with no steel content which can be easily used in recycling processes.

- **Repair and Fill:** Repair any damage to the tyre casing to return it to optimal condition.
- **Application:** Coat the prepared tyre with a bonding agent that helps the new tread stick to the casing during the curing process.
- **Building:** Apply a pre-cured tread rubber strip to the prepared tyre using a machine to ensure precise application of the tread pattern.
- **Enveloping:** Encase the tyre with an elastic envelope to maintain uniform pressure during the curing process.
- **Curing:** Place the enveloped tyre in a curing chamber to vulanise the new tread to the casing, creating a strong bond. There are two types of curing processes explained below.
- **Final Inspection:** Inspect the re-treaded tyre to ensure quality and integrity, including checks for proper adhesion, balance, and overall quality.

Hot re-treading (or mould cure re-treading)

The entire prepared casing is covered with uncured rubber compound (crown and sidewalls). This is placed in a mould giving the re-treaded tyre its final profile. Vulcanisation takes place inside a curing press heated to approximately 160°C for about an hour, similar to the process of making a new tyre.

Advantages:

- Allows for full performance capacity of original casings.
- The dimensional uniformity makes for more even wear, regardless of the original casing.
- Appearance is comparable to a new tread, with recut sidewalls and marking diagrams, improving the vehicle's appearance.

Cold re-treading (or pre-cure re-treading)

A pre-moulded tread band with its final tread pattern is mounted on the prepared casing. Vulcanisation in an autoclave, heated to approximately 115°C for about three hours ensures cohesion of the whole product.

Advantages:

- Managing the re-treading process speeds up return times.
- Increases tread pattern change possibilities.

Tread types

Tread is made from synthetic and natural rubber, fillers and chemical additives. The portion of each depends on the desired quality. Tyre tread connects with the road and the sidewall. Different tyre types have different tread proportions of rubber in the tread, for example, aviation tyre treads are made almost entirely of natural rubber as they withstand abrasion better than synthetic rubber (Rubber Journal Asia, 2017).

Benefits of re-treading

The ecological and sustainable footprint of re-treaded truck tyres is much lower than that of new tyres. Re-treaded tyres consume 70% less material (rubbers in all applications, oil, bonding solution) and 80% less energy in the manufacturing process compared to new tyres. Carbon dioxide emissions are also 80% lower than for new tyres (European Commission, 2015).

Other social and environmental benefits of re-treading tyres include:

- **Reduced demand for raw materials:** Re-treading reduces the demand for new tyres and hence the consumption of raw materials such as natural rubber and petroleum. Goodyear has identified benefits of re-treading truck tyres, including a 29% reduction in land use and a 19% saving in water consumption by reducing pressure on rubber crops (Community Research and Development Information Service, 2015).
- **Energy savings:** The energy required to manufacture a new tyre is considerably higher than that needed for the re-treading process, so re-treading helps conserve energy. Local re-treading also reduces the greenhouse gas (GHG) emissions of transportation throughout the supply chain.
- **Waste reduction:** re-treading minimizes the number of end-of-life tyres.
- **Lower carbon footprint:** The production of new tyres generates more GHG emissions than re-treading, so re-treading helps reduce the environmental impact of the tyre industry.
- **Local jobs and reduced supply chain risk:** Re-treading tyres is a form of local manufacturing, providing employment through the additional maintenance activities required when compared with the current linear single-use purchasing of tyres. Onshore retreading also builds supply chain resilience.

Retreading Case Study:

"If you have flown on a commercial airliner, you have likely taken off and landed on retreaded tyres" (Dunlop, 2024).

When the tread of an aircraft tyre is worn or has reached its maximum number of landings, the tyre carcass may have life remaining. Instead of sending the usable carcass to the landfill or for recycling, it is sent to a tyre manufacturing facility for expert technicians to determine whether it can be reconditioned following mandatory regulations. According to industry experts' certain aviation tyres can be retreaded up to 12 times. Therefore, the aviation industry is seeing the benefits of extending a tyre's life, and reducing the number of carcasses being produced, lessening the reliance on natural resources for tyre production, and decreasing the number of carcasses being recycled (Goodyear, 2020).

Retreading has been standard practice in commercial and military aviation for decades, with the first retreaded tyre being deemed airworthy in the 1950s.

Conveyor belts 8.2

Conveyor belt use and repair 8.2.1

The lifespan of a conveyor belt depends on its application, usage, material volumes, and type. Failures can stem from product issues, damage (e.g. by large rocks), or worn-out casings.

Mines often employ real-time monitoring systems to measure belt thickness and damage, enabling predictive maintenance. The projected lifespan of a conveyor belt doesn't necessarily dictate replacement timing, as belts can be changed during shutdowns to reduce the risk, sacrificing some of the belt's lifespan.

On-site repairs, known as "splicing", involve joining steel cords through a process of matching, heating, and curing.

Conveyor belt refurbishment

8.2.2

Belt refurbishment is similar to tyre re-treading, i.e. using the belt carcass and applying a new rubber covering. Continental's website (2024) states that approximately 80% of all belts can be refurbished and promotes the following benefits of belt refurbishment:

- 65-75% of the new belt price, depending on used belt type and conditions.
- Same life / warranty time as a new belt.
- Reduction of disposal cost / stock.
- Less pollution.

Industry consultation indicates that belt refurbishment is currently not widely adopted in Australia, due to labour costs, logistics of belt removal and transport, and clients often preferencing the convenience of full belt replacement.

Reconditioning is difficult because the steel cord core is the crucial tension layer, which is not able to be seen from the diagnostic scanning and thickness measurements. Advances in diagnostic testing have enabled successful reconditioning which is common practice in Poland's lignite mines (Błażej, R.;et al., 2022).

The environmental benefits of reconditioning conveyor belts are the same as for tyre re-treading but haven't been quantified. As with tyres, most of the environmental benefits would be from conserving resources, reducing demand for virgin materials, energy, water and resources. Conveyor belt reconditioning could reduce waste accumulation on mining sites by keeping used belts within a productive system, thereby simplifying mine rehabilitation.

ELT&C Processing for Resource Recovery 9

ELT&C recycling or energy recovery options typically require processing of the ELT&C before use in the application. The extent of processing varies significantly and is an important consideration.

The Options Assessment Tool presents: **primary processing and secondary processing**.

- **Primary processing** is about size reduction and steel recovery: shredding, granulation, and crumbing.
- **Secondary processing** is about further resource extraction: devulcanisation, reclamation, pyrolysis and gasification.

This section provides an overview of the common approaches and technologies used in primary and secondary processing.

Primary processing 9.1

Primary processing generates inputs for use in energy recovery applications (such as TDF) or inputs for secondary processes that derive products for a range of recycling and energy recovery applications.

Primary processing for car, truck, bus, OTR tyres and conveyor belts share some common stages that are illustrated in the figure below. Each stage is discussed further below. (See figure 5 on the next page).

It's important to consider the cumulative capital and operational costs for each mechanical size reduction stage. The more processing required, the higher the costs to produce the outputs for an application.

Large and giant OTR tyres and conveyor belts typically require the most processing, but also produce high-value recycling outputs due to their high content of natural rubber. Handling and logistics costs can also be significant cost for large and giant OTR tyres.

Most mechanical size reduction technologies are well-proven and have been in use for decades.

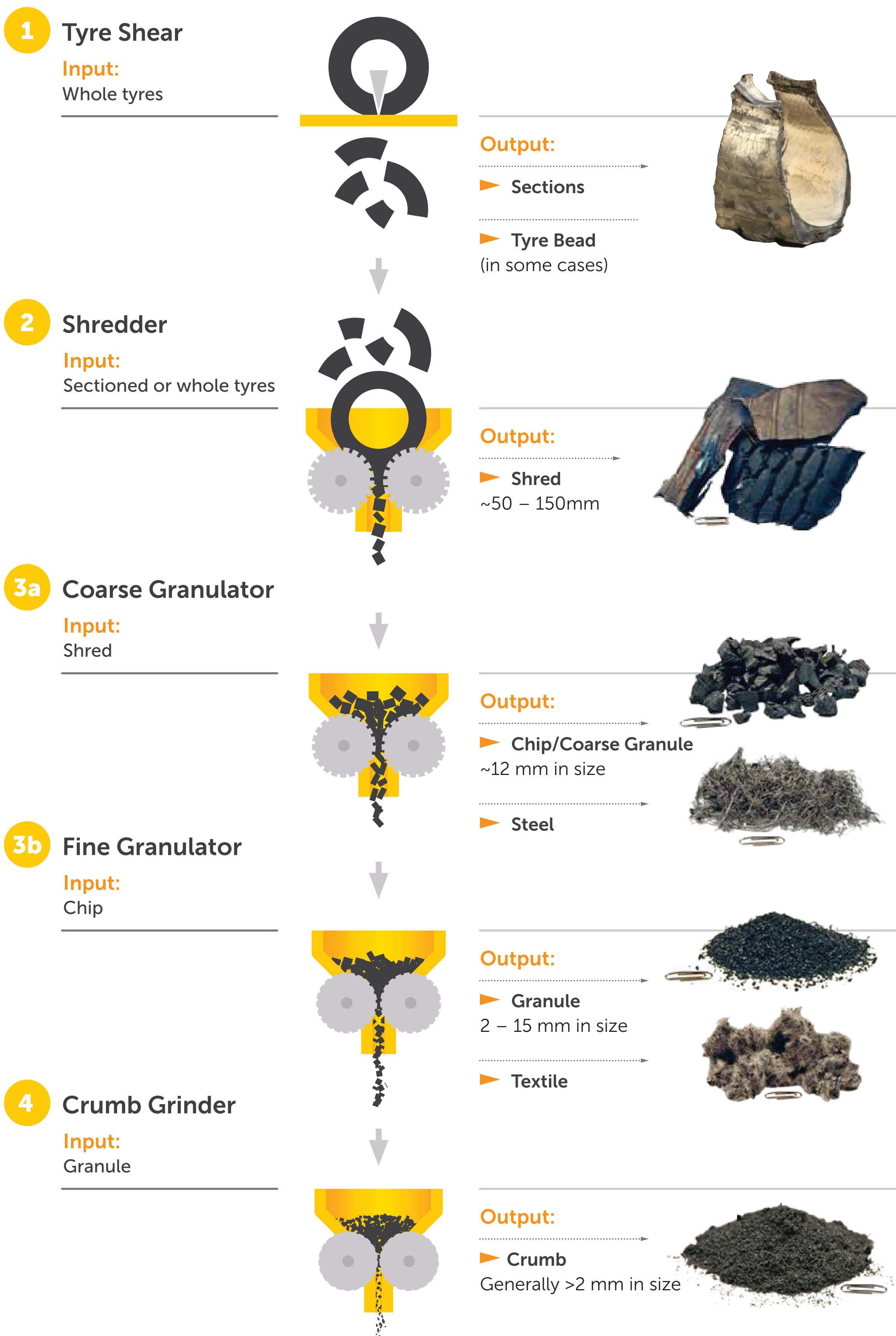
Sectioning of large OTR tyres and conveyor belts

- Sectioning equipment is available to enable size reduction for large ELT&C, such as mining haul truck tyres and conveyor belts.
- Specialist sectioning equipment can remove the steel beads in large tyres to enable size reduction.
- Simple sectioning equipment such as hydraulic 'tyre shears' on an excavator can cut ELT&C into pieces for efficient transport and for the next stages of mechanical processing.

Shredding

- A common stage in the size reduction process is shredding.
- ELT&C (whole or in pre-cut sections) are shredded into pieces of 50 – 150 mm, depending on the intended application.
- Where shredded ELT&C is to be used as a TDF, the shred is typically, 50-80 mm.
- Capital costs for tyre shredders can range from $150,000 for a course shredder to more than $1,000,000 for a high-capacity machine. A reliable, entry-level shredder for producing a uniform TDF product currently costs in the order of $300,000. The output product is suitable for export (SV, 2023).
- Maintenance costs for shredders are typically high, primarily for blade sharpening and replacement.
- Additional operational costs and power consumption also need to be considered.

Figure 5: typical stages of primary processing for end-of-life tyres and conveyor belts.



Granulation (coarse and fine)

- Granulation separates the ELT&C rubber from the steel and nylon components. Almost all (approximately 98%) of the steel is recovered and sold into scrap metal industries at a profit.
- The textile that is removed is typically contaminated with rubber. Currently, there is a lack of end markets, so textile fibres are most often disposed.
- Granulation processes are applied at ambient temperature or at cryogenic temperature, as discussed below.

Ambient temperature granulation

- Course rubber granules are generally 2 – 15 mm. Using ambient temperature, a series of granulators and screens process shredded tyres into a refined, uniform product.
- Finer granules can also be produced with additional processing, to <2 mm.
- Granules are mostly free from contaminants with metal and fabric removed via magnets and air separation respectively.
- The capital cost for ELT&C granulators depends on the extent of processing and how fine a granule is required. Industry consultation found that the capital costs for granulation equipment range $250,000 - $400,000.

Cryogenic temperature granulation

- Cryogenic temperature granulation involves immersing or spraying the rubber products with cryogenic liquids, such as liquid nitrogen, to rapidly cool the rubber compound making it brittle.
- After reaching a critical temperature, the ELT&C are broken up using a hammer mill (or similar) into small pieces. The pieces are then warmed and processed with magnets, cyclones, and screens to remove steel and fibre and separate different sized particles. Granules and crumb rubber which are as small as 0.2 mm are produced.
- Due to the 'shattering' process granules of different shapes and sizes are produced with smooth edges and lower surface area compared to conventional ambient grinding.
- While the rugged surfaces of ambient crumb rubber are preferred for asphalts and roads (due to better surface interaction with bitumen), cryogenic rubber granules have demonstrated more benefits as an artificial turf infill due to improved interactions with the silica in sand and a reduced tendency to hold air bubbles causing it to float in wet weather and drain offsite.
- Cryogenic systems have existed for several decades, and there are various technology examples worldwide. There are currently no known cryogenic ELT&C processing technologies in Australia. This may be due to the added cost of liquid nitrogen, and additional safety considerations for cryogenic liquids, or may be based on the different product size and shape outputs driven by the market (Anderson, 2021).

Crumbing

- The most highly refined product from tyre and conveyor primary processing is crumb rubber (also known as rubber crumb, crumb, or powder).
- In Australia, 30 mesh (which is approximately 0.56 mm mean/average size) is the most common size of crumb rubber, produced using aspirators or similar as the final stage, following shredding and granulation.
- As noted above crumb rubber can also be produced using cryogenic granulation.
- **Micronized rubber powder** is another term to describe processed rubber compound that is at or below 1 mm. Some technologies can produce material as small as 300 mesh, which is an average size of 0.074 mm. Micronized rubber powder can support high-order material circularity applications, including use as a component in tyres, seals, hoses, gaskets, use in automotive applications such as anti-vibration mounts, ans in select polymer chemistries (Lehigh Technologies, 2025).

- Currently crumb rubber is a significant part of the domestic market with applications ranging from asphalt pavements to high value products.

Waterjet size reduction process

- Waterjets are an emerging process that uses high pressure water (rather than mechanical shearing) to wash and cut ELT&C, then further break down both tread and sidewalls into granules and powder. The process strips away the rubber component from textile and steel, to produce different sizes of rubber products, which can then be dried and recovered.
- The technology can process OTR tyres of up to 2 metres.
- As well as producing rubber granules and crumb rubber free from steel and fibre. Waterjet size reduction is not currently commercially operational in Australia.

Secondary Processing 9.2

Secondary processing is about further resource extraction from primary processing outputs, or in some instances from whole ELT&C. While primary processing is well established globally and in Australia, secondary processing technologies are more complex and less established. However, interest is high as these technologies can unlock a new range of product applications with high value and high material circularity.

This section provides an overview of the secondary processing technologies that are currently available, including: devulcanisation, reclamation, pyrolysis and gasification.

Devulcanisation

Aspect	Discussion
Description	Virgin rubbers materials have unique elastic properties. Tyre and conveyor belt rubber vulcanisation is a manufacturing process where polymer chains are crosslinked during a 'curing' step. Sulfur is introduced, which crosslinks the different rubber chains via carbon and sulfur bonds, to create a stronger and more durable material while retaining some of the elastomer. The aim of devulcanisation is to regenerate the elastic rubber properties and produce a re-mixable, mouldable rubber material for remanufacturing. Devulcanisation involves the selective breakdown of the crosslinked sulfur bonds without further breakdown of the rest of the polymer network (Dierkes, Saiwari, 2021). Chemically, this can be challenging as bonds between the carbon atoms in the rubber have a similar strength to the sulfur bonds in the crosslinks. However, devulcanised rubber products can perform similarly to virgin rubber materials, making it the most circular ELT&C derived product with the highest value manufacturing applications. Most devulcanisation technologies require a homogenous rubber crumb material input. Devulcanisation has been successfully demonstrated using various physical (e.g. supercritical CO_2, thermal mechanical, ultrasonic) or chemical (catalysts, amines, or disulfides) processes. All these processes aid in decreasing sulfur crosslinks with minimal breaking of the carbon polymer chain. At the end of the process, the product is generally referred to as a **tyre-derived polymer.** *(continued over)*

Aspect	Discussion
	Rubber devulcanisation to produce tyre-derived polymers is not the same as rubber reclamation. Whilst devulcanisation and reclamation share some processing stages and some applications, devulcanised rubber has higher performance attributes and therefore typically can substitute a higher proportion of virgin rubber (Tzoganakis, Visaisouk, 2019). There are currently no operating devulcanisation facilities in Australia. However, funding has been approved for a tyre recycling and devulcanisation facility that will process 12,000 tonnes of off-the-road tyres each year in Western Australia (DCCEEW, 2024). Globally, Tyromer licences a devulcanisation process developed the by the University of Waterloo in Ontario, Canada. Several plants have been established under licence. Since 2016, a Tyromer facility within AirBoss Rubber has supplied tyre-derived polymer to Kal Tire, which has used it in an OTR re-tread compound with 20% content. A second facility is being established in Ohio, USA to supply a major American brand. OTR, truck and passenger tyres with 15-20% tyre-derived polymer are currently on road trials in North America and Europe and a passenger car tyre maker is optimising a tyre compound with 30% virgin rubber substitution. With financial support from the Dutch government, a third facility has been built in The Netherlands to supply a major brand in the EU (European Rubber Journal, 2021). The thermal mechanical devulcanisation process appears capable of significant capacity, and multiple lines could be set up to increase scale. No examples of operational large scale (i.e. >20,000 t of ELT&C per annum) were identified at the time of writing, however, devulcanisation lines can be modular and two lines of machinery could manage ~20,000 t. Critically, tyre-derived polymer is significantly cheaper than virgin rubber, so there is an economic incentive for manufacturers to develop products using tyre-derived polymers. This would also provide some virgin rubber price spike risk mitigation for manufacturers (Tzoganakis, Visaisouk, 2019). Controlling the ELT&C feedstock used to produce the crumb rubber inputs directly impacts the quality of the tyre-derived polymer. OTR, truck and bus tyres, and conveyor belts typically are well suited to devulcanisation as it contains a higher proportion of natural rubber compared to synthetic rubber. Passenger tyres contain a higher proportion of synthetic rubber, which can also be devulcanised, however, the performance tensile strength and elongation may be reduced by 25% or more. Research has demonstrated that crosslinked natural rubber is generally easier to devulcanise, compared to synthetic rubbers like butadiene and styrene butadiene (Amirkhanian, Letcher, Shulman, 2021). The performance characteristics of the resulting tyre-derived polymer need to be assessed and the appropriate masterbatch formulation tested against the product application control sample. The need to control feedstock and develop specific masterbatch formulations for process considerations and product applications means devulcanisation processes may be best suited to closed loop tyre and conveyor belt supply and collection approaches, particularly relevant for mining OTR tyres and conveyor belts. Whilst steel and fibre are removed from the crumb rubber inputs, all the other non-rubber tyre and conveyor belt additives remain and are not separated during the devulcanisation process. The carbon black, zinc, silica, and additives will remain and will form part of the tyre-derived polymer.

Aspect	Discussion
Capital expense	A standard devulcanisation machine for 4,000 t per year is approximately US$3 million (Future of Tyre Recycling Conference Available for Viewing | Tyre and Rubber Recycling, 2023).
Product applications summary	Devulcanisation essentially reverses the curing stage of the tyre and conveyor belt manufacturing process. Tyre-derived polymers can be used to replace virgin rubber, at varying amounts depending on the product application, and material circularity potential varies by application. Devulcanised rubber applications include: • New tyre and conveyor belt manufacturing. • Re-tread rubber for tyre re-tread and conveyor belt refurbishment. • Rubber moulded products such as automotive parts, shoe soles, and smaller non-vehicle tyres such as wheelbarrow wheels.
Advantages	Tyre-derived polymers can be used to replace virgin rubber and establish material circularity for ELT&Cs. Tyre-derived polymers are cheaper than virgin rubber. Product application performance can be designed to use tyre-derived polymer at the appropriate rate depending on the application. Several plants are operational in the US and EU; however, their capacity is not known. The energy requirements for the devulcanisation processes can be low, depending on the method of devulcanisation. For example, Tyromer reports approximately 250 kwh per tonne for the devulcanisation portion of the operations.
Disadvantages	The tyre-derived polymer quality is impacted by the composition of the ELT&C feedstock that is processed into fine granule or crumb, which could limit the ability to devulcanise rubber compound uncontrolled collections. Large scale plants are not yet operational (globally), however, a recycling and devulcanisation facility is planned for Western Australia for processing 12,000 t of off-the-road tyres each year. A 8,000 t facility is currently being developed in India. Significant energy is required to produce rubber crumb. To gather insights into the environmental benefits of offsetting the virgin rubber product an LCA is required.
Conclusions	Devulcanising crumb rubber from ELT&C is one of the largest opportunities globally to implement ongoing material circularity for rubber. Tyre-derived polymer is significantly cheaper than virgin rubber, so there is an economic incentive for manufacturers to develop products using tyre-derived polymers. More investment in the use of tyre-derived polymers by tyre and conveyor belt manufacturers is needed for this opportunity to be realised. Globally, Tyromer licenses a devulcanisation process for ELT and several plants are operating in the US and the EU, however, plant capacity is varied and can be modular. For example, the 90 mm line can run approximately 600 kg/h, while the 110 mm line can run approximately 1000 kg/h. The thermomechanical devulcanisation process appears capable of significant capacity and multiple lines could be set up to increase scale. However, no examples of large-scale operations (i.e. >20,000 t of ELT&C per annum) were identified at the time of writing. *(Continued over)*

Aspect	Discussion
Conclusions *(continued)*	There are currently no operating devulcanisation facilities in Australia, although at least one facility is planned for Western Australia. To stimulate the circular economy, future regulations of ELT&C in Australia should aim to incentivise the use of tyre-derived polymers in new product imports, and onshore re-treading and conveyor belt manufacturing.

Reclamation

Aspect	Discussion
Description	Tyre and conveyor belt rubber vulcanisation is a manufacturing process where polymer chains are crosslinked during a 'curing' step. Sulfur is introduced, which crosslinks the different rubber chains via carbon and sulfur bonds, to create a stronger and more durable material while keeping the elastomer properties. Rubber *reclamation* typically uses a combination of heat, chemical agents, and intense kneading[10]. The rubber *reclamation* and *devulcanisation* processes can share similar physical and/or chemical processing stages and some output product applications. As discussed above, *devulcanisation* involves the *selective* breakdown of the crosslinked sulfur bonds without further breakdown of the rest of the polymer network. However, *reclamation* processes re-establish some rubber plasticity by breaking down carbon to carbon bonds in addition to some of the carbon to sulfur and sulfur to sulfur bonds. This results in a useful product for many applications; however, the performance characteristics of reclaimed rubber are typically lower than devulcanised rubber. The rate of virgin rubber substitution is lower for reclaimed rubber, compared to devulcanised, in high performance applications (i.e. new car tyres and mining conveyor belt manufacturing) (Tzoganakis, Visaisouk, 2019). Rubber reclamation processes can use rubber granule inputs, rather than crumbed rubber, saving on the energy required for primary processing. At the end of the process, the product is generally referred to as a **'rubber reclaim'.** There are currently no facilities dedicated to producing rubber reclaim in Australia. There are some examples of rubber being 'reclaimed' in Australia via composite product manufacturing, discussed in the related application sections below. These facilities are not dedicated to *producing reclaimed rubber* for a range of applications, rather, they blend granules directly into a manufacturing process (typically using heat) and this may enable some reclamation of rubber properties. China is the world's largest reclaimed rubber producer, producing 5,000,000 t in in 2018 (Rubberworld.com, 2019). Such large production tonnages illustrate that rubber reclamation processes are capable of significant capacity and scalability. China's huge manufacturing base of lower performance specification rubber products drives the high demand for rubber reclaim. Circular Rubber Technologies (CRT) recently received approximately AU$3M from Emissions Reduction Alberta to assist in the construction a AU$16M commercial-scale thermomechanical plant to produce rubber reclaim in Alberta, Canada. The facility will focus on OTR tyres, which have a high natural rubber content (Emissions Reduction Alberta, 2024).

Aspect	Discussion
Product applications summary	Rubber reclamation recovers some of the elastic properties of virgin rubber and provides a product that can be readily moulded into new products or blended into rubber products with lower performance requirements. Rubber reclaim can be used to replace limited amounts of virgin rubber, depending on the product application, and material circularity potential varies by application. Rubber reclaim applications include (Hongyu Recycled Rubber, 2021): • Tyre, tread and conveyor belt manufacturing (at lower rates of application when compared to devulcanised rubber). • Bicycle tyre and tube manufacturing. • Shoe manufacturing. • Rubber sheet and waterproof membrane. • Hard rubber casings. • Moulded plastic rubber products. • Moulded fibre and rubber products.
Advantages	• Rubber reclaim can be used (at limited application rates) to replace virgin rubber and establish some material circularity for ELT&C. • Rubber reclaim can be cheaper and less energy intensive to produce than devulcanised rubber (tyre-derived polymer). • Wide range of applications for rubber reclaim. • Significant rubber reclaim market currently operates in China.
Disadvantages	• Rubber reclaim application rates are low or not suitable for high performance product applications. • Typically used in lower performance applications, that may have limited potential for additional lifecycles (e.g., shoes). • Energy is required to produce rubber granules or crumb for reclamation. • Some reclamation processes may be restricted in future due large volumes of chemical solvents used and potential human health and environmental risks (TIP, 2019).
Conclusions	Rubber reclamation processes are operating at scale in China, currently. Rubber reclaim is cheaper than virgin rubber, requires less primary processing than devulcanisation, and has a wide range of low-performance product applications. The material circularity potential for rubber reclaim varies by application and many reclaim applications have limited potential for future recovery. Rubber reclaim application rates for high performance applications are more limited than devulcanised rubber. There are currently no dedicated rubber reclaim facilities in Australia.

Pyrolysis

Aspect	Discussion
Description	Pyrolysis provides an option for energy efficient materials recovery from waste tyres and other rubber products (including conveyor belts). The three products from ELT&C pyrolysis are a **pyrolysis oil, a pyrolysis gas, and a residual carbon product**. Steel can also be recovered for recycling via pyrolysis if it is not removed during the primary processing of the ELT&C. Pyrolysis can be used to process inputs with no primary processing (i.e., whole tyres) or tyres that have been processed into shred, granule, or crumb. Pyrolysis involves heating the tyre feedstock to temperatures typically in the range of 400-600°C in the absence of air (and therefore oxygen), resulting in the thermal decomposition of the tyre to yield a pyrolysis vapour and a residual carbon product. On cooling of the pyrolysis vapour, a condensable oil fraction and non-condensable gas fraction are obtained. There are many different approaches to the design and operation of tyre pyrolysis plants, both internationally and in Australia, with different operators having different approaches to feed preparation, reactor design and reactor operation, often using propriety technology. Approaches to pyrolysis of ELT&C include: • Processing whole tyres (with no or minimal feed preparation) or tyre shred, granule, or crumb, with or without removal of steel belts. • Static batch reactors, rotary kilns, kilns with internal screws or augers, or vertically orientated reactors. Reactors may be indirectly heated by combustion of pyrolysis gas or other fuel source, or electrically heated. Reactors may operate under vacuum or pressure, or in a batch, semi-batch, or continuous mode. To date, no approach to ELT&C pyrolysis has achieved market dominance. There are tyre pyrolysis plants in Australia at the early operational or commissioning stage; demonstration scale; and under construction. Several additional proposed tyre pyrolysis projects are at the early stage of investigation. In 2022, about 5,000 t of ELT were processed through pyrolysis plants in Australia. The quantity of tyres to be processed via pyrolysis is expected to increase as the plants under commissioning enter commercial operation. Weibold claims that in China pyrolysis is currently one of the most common EOL tyre recycling routes, for the estimated 12 million tonnes of tyres generated per year, and that pyrolysis capacity in China is set to expand significantly (Weibold, 2023). Numerous pyrolysis facilities have also been established across other parts of Asia, Europe, and North and South America. **Note:** the levels of emission and occupational health and safety controls for pyrolysis plants vary by jurisdiction. It should not be assumed that pyrolysis plant operations in other jurisdictions would be permitted and / or viable in Australia. *(Continued over)*

Aspect	Discussion
	Despite the large number of pyrolysis facilities that have been established globally, Weibold estimates that less than 3-5% of all ELT generation is currently processed via pyrolysis operations (Weibold, 2023). The high number of pyrolysis facilities and low rate of processing tonnages reflects the challenges that the pyrolysis industry has been working to resolve over the past few decades, namely: • Developing the processing technology to suit the ELT being processed (feedstock), the extent of primary processing required, and the consistency of outputs. • Refining pyrolysis outputs (oils and carbon in particular) and establishing stable and profitable offtake markets for high value applications such as new tyre manufacturing. • Gaining regulatory approval/s for the pyrolysis process, facility establishment, and for the use of the outputs in product applications.
Product applications summary	Pyrolysis is a process to thermally decompose carbon-based materials and will produce outputs in the form of a vapour that can be condensed to collect a hydrocarbon oil fraction, a non-condensable gas fraction, together with a residual carbon-rich solid fraction. If steel is not removed during primary processing, it will remain as scrap in the reactor, as temperatures are well below the melting point of steel. **Tyre Pyrolysis Oil** Typically, the yield of pyrolysis oil from the thermal decomposition of the natural and synthetic rubbers, on a steel free mass basis, is approximately 40-50%. The pyrolysis oil is obtained on cooling and condensation of the pyrolysis vapour. The crude pyrolysis oil is dark brown/black with an acrid smell. The pyrolysis oil is a complex mixture of chemical compounds (a mix of hydrocarbons, aromatic compounds, and some organic compounds containing oxygen, sulfur, or nitrogen). Approximately 100 individual organic compounds have been identified in pyrolysis oil. The properties of crude pyrolysis oil are comparable to No 6 Fuel Oil, also known as bunker oil. The crude pyrolysis oil finds applications as a heavy fuel (bunker) oil with minimal additional processing other than filtering to remove fine carbon and ash. Pyrolysis oil can be used as a fuel in furnaces, kilns, boilers, or suitable engines such as large marine engines or stationary engines for power generation. Crude pyrolysis oil can also be potential feedstock of chemicals such as benzene, toluene, ethylbenzene, xylene (BTEX) chemicals which have a potential market in the petrochemical industry. Extracting this fraction is only possible with additional processing (distillation etc.) and refining, and the remaining fractions in the pyrolysis oil would still require a market. Crude pyrolysis oil does have a moderately high sulfur content (0.6 to 1.6%wt), which limits its use as a direct fuel replacement in most applications. The extent of additional refinement that is required for pyrolysis oil will vary by application. For high value applications, significant extra refinement may be required. **Tyre Pyrolysis Gas** Pyrolysis Gas is the non-condensable gas fraction remaining after cooling of the pyrolysis vapour. The yield of pyrolysis gas from tyre pyrolysis is typically 10-20% on a steel free mass basis. *(Continued over)*

Aspect	Discussion
	The pyrolysis gases are mainly H_2, CH_4, C_2 to C_4 alkanes and alkenes, together with H_2S, CO, and CO_2. The pyrolysis gas has a high calorific value and is typically used for pyrolysis reactor heating with natural gas or pyrolysis oil used for start-up or supplementary reactor heating. Pyrolysis gas does contain odorous sulfurour compounds including hydrogen sulfide (H_2S). H_2S is corrosive and oxidises to sulfur oxides (SOx) during combustion. Emissions of SOx into the atmosphere are limited by regulations. Prior to use or storage, the pyrolysis gas is usually scrubbed to remove particulates and H_2S. In some applications, pyrolysis gas is used in gas engines for electricity generation or supplied to boilers. For use in gas engines, the pyrolysis gas will need to be scrubbged to meet the H_2S fuel limit as set by the engine manufacturer, typically approximately 50 ppm. **Tyre Pyrolysis Carbon** Pyrolysis carbon is the residual solid fraction remaining after tyre pyrolysis. Pyrolysis carbon yield is typically 30-40% on a steel free mass basis. Pyrolysis carbon is carbon-rich (~80% carbon) and includes the various grades of carbon black added to the natural and synthetic rubbers during tyre manufacturing. The fillers and inorganics (zinc, silica (SiO_2), clay) contribute to the approx. 20% ash content of pyrolysis carbon. If the tyres processed through the pyrolysis facility are contaminated with soil, sand or other extraneous material, the contamination is also collected with the pyrolysis carbon. Steel wire contamination can be removed by magnetic separation. Some sulfur is retained with both the carbon and the ash fractions of the pyrolysis carbon. This can make pyrolysis carbon unsuitable for direct replacement of carbon black in rubber products. Pyrolysis carbon can be refined to improve quality and allow for higher value applications such as recovered carbon black use in new tyre and conveyor manufacturing. There are also lower value applications that require less refinement of the pyrolysis carbon such as char used as a filler in rubber and plastic products, and lime replacement in asphalt.
Advantages	• The ability to generate outputs that can be used in high value recycling applications and energy recovery applications. • The ability to operate at a large-scale assuming process outputs and applications have established markets. • The technology is well developed globally.
Disadvantages	• Due to a history of facilities being built and then not operating or operating at a limited throughput: concerns remain regarding the ability of pyrolysis processes to generate outputs that can be used in high value applications that are stable and profitable. • To use pyrolysis oil and carbon outputs in high value applications is likely to require significant additional refinement that could add significant costs. • Assuming the recycling of all steel, pyrolysis oil, and carbon – there is still a material loss of 10-20% of the input materials that are converted to syngas (that is typically used to heat the pyrolysis kiln).

Aspect	Discussion
Conclusions	Pyrolysis provides an option for energy efficient materials recovery from waste tyres and other rubber products (including conveyor belts). The three products from ELT&C pyrolysis are a pyrolysis oil, a pyrolysis gas, and a residual carbon product. Australia has limited capacity, currently, however this is increasing. Numerous pyrolysis facilities have also been established across Asia, Europe, and North and South America. The levels of emission and occupational health and safety controls for pyrolysis plants vary by jurisdiction. It should not be assumed that pyrolysis operations in other jurisdictions would be permitted and or viable in Australia. The high number of pyrolysis facilities globally and the low rate of processing tonnages reflect the challenges that the pyrolysis industry has been working to resolve over the past few decades, namely: • Developing the processing technology to suit the ELT being processed (feedstock), the extent of primary processing required, and the consistency of outputs. • Refining pyrolysis outputs (oils and carbon in particular) and establishing stable and profitable offtake markets for high value applications such as new tyre manufacturing. • Gaining regulatory approval/s for the pyrolysis process, facility establishment, and for the use of the outputs in product applications.

Figure 6 (see next page) illustrates ELT&C pyrolysis inputs, process, outputs, and the additional processing that is likely to be required for different product applications. Refer to the relevant recycling or energy recovery options for discussion of these pyrolysis product applications.

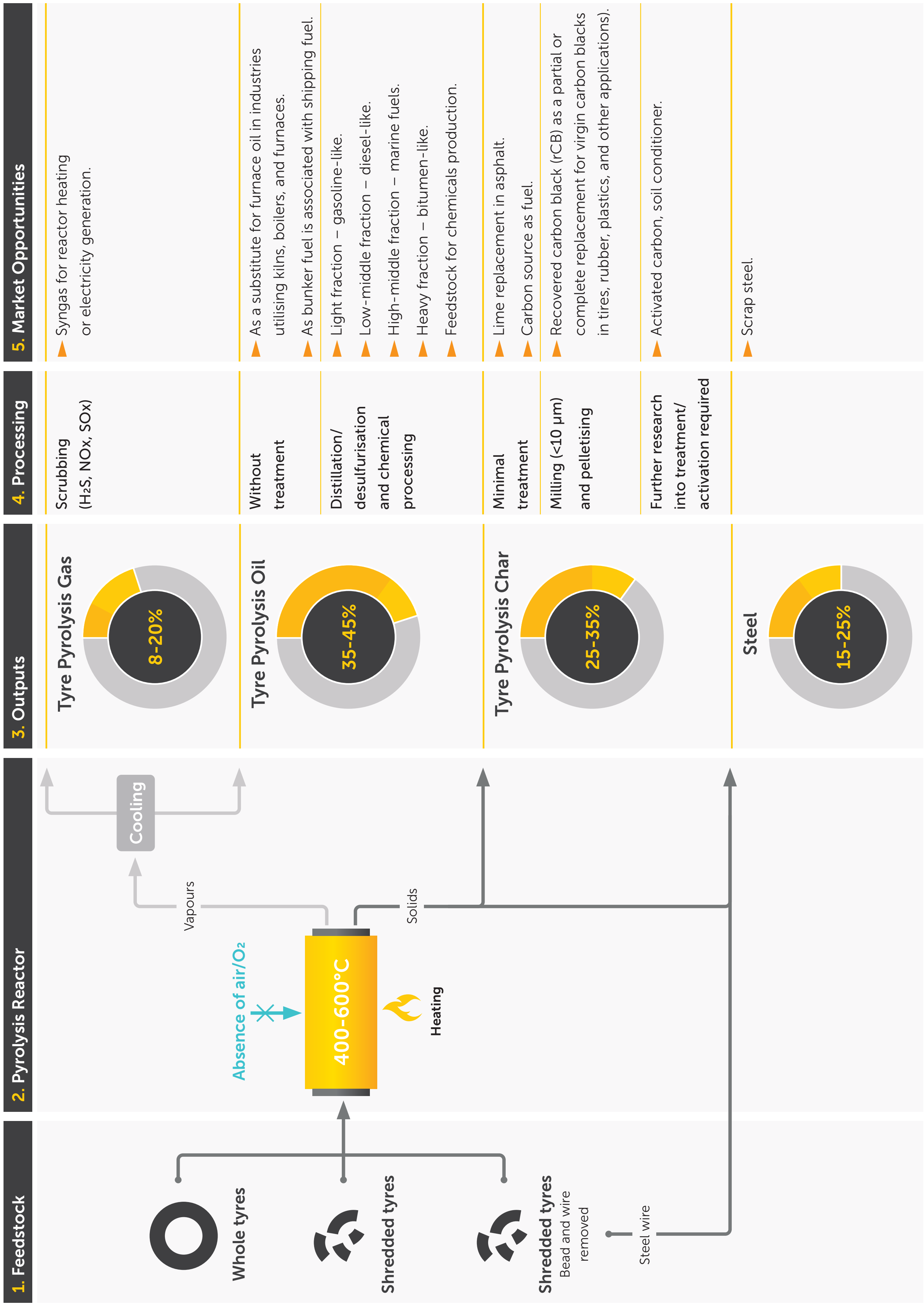


Figure 6: Pyrolysis process variations, outputs, and applications summary.

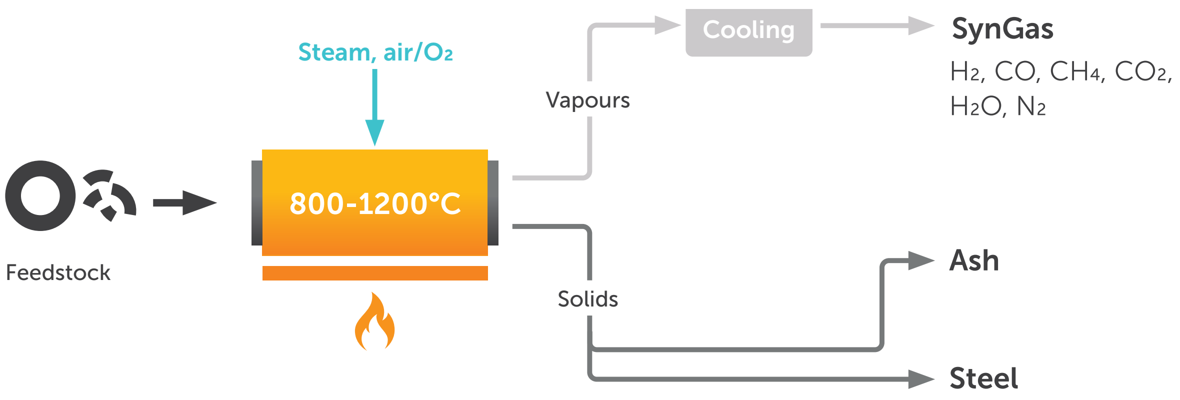
Gasification

Gasification technologies share common elements with pyrolysis. Key differences are that gasification uses controlled amounts of air/oxygen and higher temperatures of 800 – 1200°C to generate a synthesis gas (or syngas) high in carbon monoxide and hydrogen. Gasification also produces carbon outputs (ash/char) and oil, albeit in lower quantities than produced using pyrolysis.

The syngas can be used for the synthesis of chemicals (hydrogen, ammonia, urea, methanol) as a combustible gas for power generation (gas turbines, gas engines) or heat raising applications.

Gasification is a more complex process than pyrolysis and there are no commercial examples of gasification plants exclusively using ELT&C.

Gasification process



Management Options - Recycling

The core feature of the Options Assessment Tool is the analysis of the circularity of the management options for **recycling**. Each of the recycling options included in the tool is discussed below. For some recycling options there's a lot to discuss and for others there is little additional information available. The aim of this section is to provide an overview of the option, not an exhaustive analysis.

Devulcanised rubber (tyre-derived polymer): high performance rubber products (tyres, re-tread, conveyor belts)

Devulcanised rubber (tyre-derived polymer): high performance rubber products (tyres, re-tread, conveyor belts)	
Description	**New Tyres:** Tyre-derived polymer has been proven to work in both tread and sidewall applications in new passenger, truck, and OTR tyre. The most common addition level is about 15%. Several manufacturers are already using tyre-derived polymers globally, however, there is limited information on the tonnages being consumed. **Re-tread rubber:** Tyre-derived polymer can be used at are rate of 15-20% virgin rubber replacement (up to 20-30% for OTR). Tyromer claims that over 10,000 OTR tyres have been re-treaded with tyre-derived polymer. **New conveyor belts:** Tyre-derived polymer can be used at 20% virgin rubber replacement or higher for lower load applications (claims of up to 50%) (Rubberworld.com, 2019). Devulcanisation is a commercially available technology with highly circular outputs.
Abated virgin materials	Rubber compound (natural rubber, synthetic rubber, and carbon black)
Material circularity	High
Maturity of global markets	**Developing global market with strong growth potential.** Tyre-derived polymer is significantly cheaper than virgin rubber so there is an economic incentive for manufacturers to develop products using tyre-derived polymers (Rubberworld.com, 2019). Tyre-derived polymer can also provide some virgin rubber price spike risk mitigation for tyre and conveyor manufacturers.
Maturity of Australian markets	**Immature currently, strong growth potential.** There is an opportunity to use tyre derived polymer in onshore conveyor belt manufacturing. Australia is currently not re-treading giant OTR tyres, which is common on other countries such as Canada. There is an opportunity to implement 'closed loop supply contracts' for OTR tyres that utilise tyre derived polymer by: • Backloading company brand used tyres. • Re-tread the tyres using brand derived tyre derived polymer (onshore). • Process end of life brand only tyres into tyre derived polymer for new tyre production or to produce retread. Primary and secondary processing, onshore, some tyre derived polymer export for manufacturing.

Devulcanised rubber (tyre-derived polymer): high performance rubber products (tyres, re-tread, conveyor belts)	
Summary advantages	• Tyre-derived polymers have been successful used in supplementing virgin rubber in new tyre, re-tread, and conveyor belt manufacturing. • Devulcanisation could process large volumes of OTR tyres. • Tyre-derived polymers can be cheaper than virgin rubber. • Tyre and conveyor product application performance can be designed to use tyre-derived polymer at the appropriate rate. • Several tyre-derived polymer plants are commercially operational in the US and EU; however, their capacity is not known. • Australia manufactures conveyor belts onshore that could utilise tyre derived polymer formulations.
Summary disadvantages	• The tyre-derived polymer quality is impacted by the input ELT&Cs processed into crumb, which could limit the ability to devulcanise crumb from uncontrolled collections. • Australia has no devulcanisation capacity currently. • Significant energy is required to produce crumb rubber for devulcanisation; however, this is offsetting virgin rubber production impacts.

Pyrolysis carbon: recovered carbon black use in new tyre and conveyor manufacturing

Pyrolysis carbon: recovered carbon black use in new tyre and conveyor manufacturing	
Description	This discussion is based on a TSA Pyrolysis case study (TSA, 2024). Pyrolysis carbon can undergo further refinement to produce a recovered carbon black (rCB) that can be used abate the use of carbon black. This requires at least milling/grinding processes to a superfine product (<4 μm) and then pelletising to allow safe handling, adding additional refinement costs. Virgin carbon black is a fine powder with high surface area composed almost entirely of elemental carbon. Worldwide annual production is about 8 million tonnes, and the most common use is as a pigment and reinforcing filler in tyres (70% market share) and other rubber products (conveyor belts, hoses) (20%) (Rubberworld.com, 2022). Carbon black improves wear resistance and protects rubber against degradation by ultraviolet light. Currently, rCB does not meet the chemical and physical properties for use in tyre applications that require high or medium-high reinforcement such as tread (that requires N100 and N200 carbon black grades). However, rCB can be used as a part replacement of some of the lower grades of carbon black (N500, N600, N700 series) that can be used to partially substitute Carbon Black use in tyre inner liners and sidewalls, and some conveyor belts (Weibold!, 2021). Pyrolysis carbon which is refined into rCB has potential to be a highly circular option, however, requires high level of primary, secondary and refinement processing.
Abated virgin materials	Various grades (N500, N600, N700 series) of carbon black which are derived from oil (Weibold!, 2021).
Material circularity	High

Pyrolysis carbon: recovered carbon black use in new tyre and conveyor manufacturing	
Maturity of global markets	**Developing global market with strong growth potential**. Global cooperation by the tyre industry is currently underway to create standards and test methods to identify the requirements of rCB for use back into tyre manufacturing. R&D into the further refinement of rCB to meet specifications is still required (ash removal, surface activation etc). Industry sources report a current rCB market value of US$650 per tonne, this compares to a current virgin carbon black price of approximately US$2,000 per tonne (Business AnalytiQ, 2024).
Maturity of Australian markets	**Immature currently.**
Summary advantages	• rCB can be used as a part replacement of some of the lower grades of carbon black used in tyre and conveyor manufacturing. • This application market is still developing, however, is one of the largest opportunities to establish circular rubber material flows. • rCB is currently approximately 30% of the cost of virgin carbon black (Business AnalytiQ, 2024).
Summary disadvantages	• Additional costs to refine pyrolysis carbon to rCB. • Currently, rCB does not meet the chemical and physical properties for use in tyre applications that require high or medium-high reinforcement such as tread (that requires N100 and N200 carbon black grades). • rCB typically has higher ash and volatile matter content compared to conventional carbon black. • rCB application opportunities are currently offshore and onshore market development opportunities are likely to be limited, due to a lack of onshore manufacturing of tyres.

Reclaimed rubber: rubber products e.g. inner tubes

Reclaimed rubber: Rubber products e.g. inner tubes	
Description	Reclaimed rubber can be used to replace limited amounts of virgin rubber, depending on the product application, and material circularity potential varies by product. Some reclaim rubber products include: • Bicycle tyre and tube manufacturing. • Tyre, tread and conveyor belt manufacturing (at low rates of application when compared to devulcanised rubber). • Hard rubber casings.
Abated virgin materials	Reclaimed rubber can be used to substitute virgin rubber, in limited amounts, depending on the product.
Material circularity	High to moderate, depending on the product application.

Reclaimed rubber: Rubber products e.g. inner tubes	
Maturity of global markets	**Mature global market with strong growth potential.** Global demand for reclaimed rubber has been increasing and is projected to grow at a rate of over 10% compound annual growth rate until 2030. Growth is expected to be driven by the need to offset costs of virgin rubber in applications like tyre manufacturing and retreading and moulded rubber goods manufacturing (Grand review research, 2024). Currently, reclaimed rubber is valued at approximately $400 per tonne (Statista, 2024), approximately 30% of the cost of virgin rubber at $1,500 per tonne (Trading Economics, 2024).
Maturity of Australian markets	**Immature currently. Likely limited growth potential.**
Summary advantages	• Reclaimed rubber can be used (at limited application rates) to replace virgin rubber and establish some material circularity for ELT&Cs. • Reclaimed rubber costs approximately 30% of the cost of virgin rubber. • Reclaimed rubber can be cheaper and less energy intensive to produce than devulcanised rubber (tyre derived polymer). • Wide range of applications for reclaimed rubber . • Mature global market for reclaimed rubber.
Summary disadvantages	• Reclaimed rubber application rates are low or not suitable for high performance product applications. • Energy is required to produce granules or rubber crumbs for reclamation. • Lack of Australian market, exporting would likely be required.

Crumb: road surfacing e.g. asphalt binders and road sprayed seals

Crumb: road surfacing e.g. asphalt binders and road sprayed seals	
Description	TSA publication *The benefits of surfacing roads with tyre derived crumb rubber* provides a detailed description of this important recycling option. Crumb Rubber Modified (CRM) binder in road **'sprayed sealing'** can be applied at a higher rate than bitumen without CRM resulting in benefits including: • Service life is significantly increased. • Durability of skid resistance is improved. • Resistance against reflective cracking. • Improvement in waterproofing. CRM **binder in asphalt** allows higher binder application rates in certain asphalt types without excessive 'drain down' or 'bleeding' due to the high viscosity of the binder (Lo Presti, 2013). The higher binder film thickness comes with considerable durability benefits. High binder film thicknesses retard oxidative aging, which is especially important in open grade (porous) asphalt mixes.
Abated virgin materials	Polymer modified binder (PMB), derived from crude oil. Depending on the grade.

Crumb: road surfacing e.g. asphalt binders and road sprayed seals	
Material circularity	High. Of the limited international documented studies reviewed, no major issues were identified. Asphalt reclamation, processing, production, and subsequent paving were all documented as being undertaken in the same manner as conventional reclaimed asphalt pavement (RAP, which is commonly used as an aggregate for road paving) (WARRIP, 2023).
Maturity of global markets	**Mature global market with strong growth potential.** Global demand for CRM binders has been increasing. Growth is expected to be driven by sustainable procurement looking to increase recycled content in infrastructure.
Maturity of Australian markets	**Mature with strong growth potential.** CRM binder has been used in sprayed sealed roads in Victoria since 1975. Australian Asphalt & Pavement Association specifications for producing CRM open-graded and surface course mixes and local network trials in both Queensland and Western Australia. TSA has also invested $4.2M in the roads sector, to increase demand, and support procurement of CRM roads (TSA, 2023). Additional procurement requirements for recycled content in roads for local and state governments will increase the demand for CRM binder. This is a trusted application in the road surfacing industry and demand pull is predicted given the high material circularity.
Summary advantages	• CRM binders have circular, mature market applications that provide significant and proven product performance improvements. • Advantages of CRM binder when compared to neat bitumen (Austroads, 2021): • Higher resistance to deformation at increased road temperature, reduced degree of rutting, improved driving comfort even on higher axle loads. • Improved adhesion and bonding with aggregates, less windscreen damage and improves safety. • Higher softening point, high flow resistance and higher impact resistance, takes heavy vehicular traffic. Increased viscosity avoids bitumen softening and flushing onto the surface of the sprayed seal. • Improved skid resistance, better road grip, and smoother vehicle brake application, which potentially reduces the chances of an accident. • Higher elongation and tensile strength, increase elasticity. • Reduced thermal sensitivity, which avoids all types of cracks under stress. Excellent ability to resist reflection cracking. • Anti-stripping properties. • High resistance to moisture/water absorption and hence reduction to damage to roads during rains. • Improved durability through the ability to use higher binder film thickness in sprayed seals. • Cost-effective binder relative to other polymer-modified bitumen, crumb rubber pricing is at par or below. • Longer road pavement life and lesser maintenance. • 5-9% reduction in GHG emissions can be achieved by replacing conventional polymer modified binders with crumb rubber in asphalt roads and sprayed seals" (TSA, 2022).

Crumb: road surfacing e.g. asphalt binders and road sprayed seals	
Summary disadvantages	• Odour: the unpleasant acrid odour of heated mix, although poses no additional human or environmental health concerns, is a common concern among workers (TSA, 2022). • The capital cost of updating machinery, as the mixture has a higher viscosity. • Timing, CRM binder has a shorter shelf life and must be used within a specific window. • Energy requirements to produce crumb rubber.

Granule: permeable pavement

Granule: permeable pavement	
Description	Permeable and crack resistant supporting layers for urban surfaces and public spaces (such as pavement and footpaths and cart paths and bunker liners used in golf courses). The permeable pavement is made of a mix of virgin rock and up to 60% crumb rubber.
Abated virgin materials	Porous concrete and porous asphalt.
Material circularity	High
Maturity of global markets	**Mature**
Maturity of Australian markets	**Mature.** Porous Lane is commercially available at scale after support from TSA (TSA, 2024).
Summary advantages	• Drainage to support stormwater management, avoids expensive stormwater updates. • Can enable passive irrigation and improve urban tree health (flexible material minimises tree root heaves). • Reduces urban heat island effect. • Reduces and treats run off. • Decreases risk of downstream erosion. • Can replenish groundwater tables. • A noticeable decline in total suspended solids (TSS) and a significant drop in major heavy metals (attached to the TSS) and hydrocarbons happens due to the filtration feature of the product. • No negative effects from leachate or microplastics. • Highly durable with a design life of 25 years. Minimal product maintenance requirements. • Damage can be patch replaced. • At the end of use, the material can be recycled and reused.

Granule: permeable pavement	
Summary disadvantages	• Requires street sweeping of the surface every six months to maintain permeability and can require vacuum sweeping or pressure washing to recover permeability if clogging occurs. • Upfront costs are higher than alternative materials.

Pyrolysis carbon: char use as lime replacement in asphalt

Pyrolysis carbon: char use as lime replacement in asphalt	
Description	Pyrolysis carbon with minimal additional processing (referred to as 'char') can be utilised as a filler in roads to enhance their mechanical properties, such as tensile strength, hardness, and abrasion resistance.
Abated virgin materials	Lime replacement or fossil fuel derived product filler agents.
Material circularity	High
Maturity of global markets	**Immature** Published conceptual research and lab testing, however commercial projects have not yet been completed.
Maturity of Australian markets	**Immature** Research and development stage with no commercial projects.
Summary advantages	**For lime replacement in asphalt:** • **Improved performance:** Pyrolysis carbon enhances the stability, durability, and resistance to rutting and cracking of asphalt pavement. • **Environmental benefits:** The use of pyrolysis carbon reduces the need for virgin lime, contributing to resource conservation and greenhouse gas emission reductions.
Summary disadvantages	**For lime replacement:** • **Quality control:** Ensuring consistent quality and properties of pyrolysis carbon derived from waste tires is important for its successful application in asphalt mixes. • **Compatibility:** Compatibility between pyrolysis carbon and asphalt binder is crucial to ensure proper adhesion and performance of the asphalt mix.

Granule or crumb: composite materials moulded products e.g. posts, bollards, roofing tiles

Granule or crumb: composite materials moulded products e.g. posts, bollards, roofing tiles	
Description	Granules are combined with polyurethane glue and pressure moulded often surrounding a structural component.
Abated virgin materials	Virgin rubber, steel, wood, concrete and hard plastics.
Material circularity	Moderate and dependant on the product application. The granule or crumb often mixed with polyurethane glue and therefore more challenging to recycle.
Maturity of global markets	**Mature**
Maturity of Australian markets	**Mature: various products commercially available.**
Summary advantages	• Life expectancy is far greater than the equivalent products manufactured from steel, plastic or wood as they will not rot, crack, rust or split. • Resistant to UV, moisture, oil, and extreme weather conditions. • Lightweight, reduce transport, handling, and installation labour costs.
Summary disadvantages	• Moderate material circularity as many not easily be recycled at end-of-life.

ELT&C sections: agriculture flooring applications

ELT&C sections: agriculture flooring applications	
Description	Sections of conveyor belts are cut and used as flooring by the agricultural sector. Additionally, woven tyre matting is used to support livestock transport and management.
Abated virgin materials	Virgin rubber or concrete.
Material circularity	Depending on final outcomes can be high/moderate. As the product will likely have majority of the rubber compound removed through wear before reaching end of life. The used flooring could go back into primary processing with the associated outcomes.
Maturity of global markets	**Mature**. The main operator is Rubbergem, which operate in Australia and in more than 20 countries throughout Asia, Europe, North America, and Oceania.
Maturity of Australian markets	**Mature.** Rubbergem has been operational since 2001 and exports internationally.

ELT&C sections: agriculture flooring applications	
Summary advantages	• Requires minimal processing with no additives, low-cost matting product. • The product is durable and an affordable option. • Reduces slipping and injury of livestock. • Longevity – it is reported that conveyor belt mats last four times longer than other flooring solutions. • Minimal upkeep required.
Summary disadvantages	• Only premium conveyor belts are used, to ensure even rubber compound coverage and therefore quality of product. • Woven tyres are still in the R&D phase. • Limited market awareness.

Granule: soft surfaces gym mats, playgrounds

Granule: soft surfaces gym mats, playgrounds	
Description	Various soft surfacing products manufactured using rubber granules are commercially available. Playgrounds and pathways use black or coloured granule in base and surface layers, bonded together to form a soft surface to reduce injuries from falling. This is applied by mixing the rubber granules with a binder or resin, such as polyurethane, and poured into place, meaning it can take any shape required. Granules are used to create indoor and outdoor sport surfaces (including gymnasiums), either as rubber underlay or within the surface itself. These materials are often manufactured in facilities as squares or strips to create bound rubber mats, and then sold in sections.
Abated virgin materials	Polymer materials: Virgin rubber ethylene propylene diene monomer (EPDM), thermoplastic vulcanisates and thermal plastic granules.
Material circularity	Moderate – material can be shredded and re-used in base impact layers applications. However, due to the use of polyurethane glue recycling could be more difficult.
Maturity of global markets	**Mature**
Maturity of Australian markets	**Mature.** Australian Standards for playground specifications, requirements and testing are available and feature rubber.
Summary advantages	• Reduces the risk of playground head injuries. • Slightly better impact performance than virgin rubber. • Has high durability and a long-term life span. • All-weather surface – semi-permeable, allowing quick drainage of water, anti-slip. • Equal access for disabled and mobility impaired users. • Contains materials that best manage UV stability based upon Australian conditions. (Sports & Play Industry Association, 2023)

Granule: soft surfaces gym mats, playgrounds	
Summary disadvantages	• Some surfaces have been shown to break apart over time. This is not consistent across the board and may be due to parameters such as temperature and humidity, not following appropriate standards/guidance during installation, or not sufficient coating of the crumb rubber with binders. • Technical requirements of surface layers are dependent on seasonal climatic conditions. • Colour-fading of coated rubber granules, not seen in virgin coloured rubber. • Specific instillation requirements: polyurethane rubber crumb binders are susceptible to temperature and humidity; therefore, it is recommended that the installation of *in-situ* systems does not take place when the ambient temperature is outside the range 4°C to 35°C, or the relative humidity exceeds 90%.

Shred or granule: construction thermal insulation and sound barriers

Shred or granule: construction thermal insulation and sound barriers	
Description	Tyre shred is known to have low thermal conductivity and can be used as a thermal insulation material to limit frost penetration, and frost heave in roads. Thermal insulation applications include road and street structures, fill in pipeline construction, or fill for housing sites. Shred or granule can be used to manufacture noise reduction barriers to reduce noise along railways or highway infrastructure. With four tyres is possible to produce one square meter of noise-reducing wall (VTI, 2021).
Abated virgin materials	Construction materials such as lightweight clay aggregate, cellulose, and fibre.
Material circularity	Moderate – material can be shredded and re-used in base impact layers applications. However, if polyurethane glue is used recycling could be more difficult.
Maturity of global markets	**Immature** with some potential for growth as increase desire for alternative materials increases.
Maturity of Australian markets	**Immature** with some potential for growth as increase desire for alternative materials increases.
Summary advantages	• Acoustic mats and screening can be used under floors and concrete surfaces, including wet areas to improve thermal insulation. • Improve the overall acoustic performance of wall panels. • Cost effective thermal insulation layers in cold climates.
Summary disadvantages	• Heavier than alternative insulations, which can cause instillation and labour cost increases.

Granule or crumb: rubber in concrete products (e.g. pavements, prefabricated panels, crash barriers)

Granule or crumb: rubber in concrete products (e.g. pavements, prefabricated panels, crash barriers)	
Description	Low density, higher strength modified concretes that may be amenable to structural and non-structural needs, while imparting excellent acoustic damping and shock absorption properties. Use of rubber-containing lightweight concretes whose performance is less dependent on strength retention, for example, impact resistant traffic management devices (or crash barriers).
Abated virgin materials	Aggregates such as sand, gravel, and cement.
Material circularity	Moderate
Maturity of global markets	**Developing** with a potential upward trend as research and development increases for alternative materials for concrete (Rigotti and Dorigato, 2022).
Maturity of Australian markets	**Developing** with some commercial projects in Australia supported by TSA, University of Melbourne, SafeRoads and Tlok (TSA, 2023).
Summary advantages	• Toughness, crack resistance, freeze-thaw resistance, and properties related to water absorption, like corrosion resistance, thermal insulation, and acoustic absorption are improved. • The concrete mix weighs less than traditional concrete reducing transportation cost. • Reduced material cost (lower density than other materials).
Summary disadvantages	• The compression and flexural strength may be reduced. • Lack of knowledge on performance characteristics, industry familiarity of this technology. • Lack of standards and codes relevant to construction sector. • Lack of specifications for use in procurement processes (and therefore reduced uptake by local government road mangers, and willingness of suppliers to invest in training and methods.)

Granule: artificial turf

Granule: artificial turf	
Description	Artificial turf (or synthetic turf) provide performance and play benefits for use mainly in various field sports. A turf carpet with synthetic fibres is supported by performance infill in the form of rubber granules, to stabilise the carpet, provide impact attenuation and other benefits.
Abated virgin materials	Sand, cork, bark, and other bio-based fillers. Polymers: EPDM, thermoplastic elastomer (TPE).
Material circularity	Low: unlikely to be recovered after use.
Maturity of global markets	**Mature:** Globally used. Future outlook: Microplastic restrictions in Europe will majorly affect this market. The new rules prohibit the sale of microplastics and of products to which microplastics have been intentionally added and that release those microplastics when used. For artificial turf, the ban applies after 8 years to give pitch owners and managers the time to switch to alternatives and allow for most existing sport pitches to reach their end of life (American Chemical Society, 2024).
Maturity of Australian markets	**Mature:** commonly used in Australia.
Summary advantages	• Superior sports performance and impact attenuation (comfort and protection to players as they run and fall on the surface). • Shock absorption. • Infill supports the turf pile for better ball travel. • Hard-wearing and durable. • Can be used in diverse climates (all-weather, all-year round).
Summary disadvantages	• Infill dispersion and environmental concerns. Due to being a loose infill, particles can disperse into the environment. To avoid migration, significant measures are required (design, maintenance, construction, containment barriers, drainage silt traps, boot cleaning stations, end-of-life removal). • Infill can heat up on hot days and cause discomfort to players. • Dust control (EN 15051-1 standard) to minimise dust content.

Pyrolysis oil: chemical production

Pyrolysis oil: chemical production	
Description	Tyre pyrolysis oil (TPO) can be a potential feedstock of the production of chemicals such as benzene, toluene, ethylbenzene, xylene (BTEX chemicals) which have a market in the petrochemical industry. Extracting this fraction is only possible with additional processing (e.g. via distillation) and refining, and the remaining fractions in the TPO would still require a market.
Abated virgin materials	Fossil fuels.
Material circularity	Low material circularity, dependant on the TPO chemical product application.
Maturity of global markets	**Immature** due to high level feedstock specifications required for chemical production and processing. A significant market potential given demand for petrochemicals.
Maturity of Australian markets	**Immature.** Some pilot commercial pyrolysis plants in Australia, however, the focus is on syngas or rCB rather than oil.
Summary advantages	• Versatility. Pyrolysis oil can be used as a feedstock to produce various chemicals. • Significant market potential if feedstock specifications can be met.
Summary disadvantages	• Pyrolysis oil requires large amounts of refinement following the primary and secondary processing of ELT&C. • Technical challenges. • Economic viability: high levels of refinement and processing required. • Product quality. • Scale-up issues with pyrolysis.

Shred: rail sub-base to reduce vibration

Shred: rail sub-base to reduce vibration	
Description	Tyre shred has been applied in the underlying layer of the railway ballast to reduce the vibration transmitted by the trains moving on the railway track. Reference projects used two tyre shred layers (200 mm thick) and vibrations were reduced by up to 30% (VTI, 2021).
Abated virgin materials	Aggregates and virgin rubber.
Material circularity	Low: unlikely to be recovered for recycling.
Maturity of global markets	**Developing** with a potential upward trend as increased demand for recycled materials in infrastructure.

Shred: rail sub-base to reduce vibration	
Maturity of Australian markets	**Developing** major rail infrastructure projects have been supplied by Australian rubber manufacturers.
Summary advantages	• Large-scale, materials can be designed to reduce noise, limit vibration, and withstand harsh rail environments (Baron Rubber, 2024).
Summary disadvantages	• Absence of technical assessment and design parameters for the application of tyre rubber to absorb energy and vibrations. • Lack of specifications and the rail construction industry is hesitant towards the adoption of new technologies.

TDA or shred: non-structural civil applications (i.e. lightweight fill, drainage aggregate, embarkment fill)

TDA or shred: non-structural civil applications (i.e. lightweight fill, drainage aggregate, embarkment fill)	
Description	ELT&C materials are used as lightweight backfill material in retaining walls.
Abated virgin materials	Aggregates such as sand and gravel.
Material circularity	Low: likely unable to be separated from other aggregates and therefore not recovered.
Maturity of global markets	**Developing:** Significant research has been undertaken globally on the use of TDA in various applications, particularly as lightweight fill-in embankments. TDA could see an upward trend given the increased cost of virgin materials and demand for recycled content in construction. TDA is commonly used in North America for civil applications.
Maturity of Australian markets	**Developing** with the potential to increase as demand for recycled materials over virgin materials increases (Big Build Vic, 2024.
Summary advantages	• Higher safety levels against sliding and overturning compared to those from using sand as a filler which allows engineers to design retaining walls with less steel reinforcement, resulting in cost savings. TDA is approximately 66% lighter than soil and drains approximately 10 times more effectively. • TDA provides eight times more effective thermal insulation compared to gravel. TDA forms a non-capillary, hydrophobic layer, preventing moisture from entering foundations, enhancing durability, and reducing structural damage in cold climates, therefore increasing freeze-thaw mitigation. • TDA has a better vibration absorption property than earth backfill materials, which reduces noise, increases comfort, improves safety, enhances durability, reduces maintenance, and increases lifespan (Park, DeNooyer and Wahhl, 2023).
Summary disadvantages	• Potential for pollution into the natural environment.

Crumb: tile adhesives, sealants, etc.

Crumb: tile adhesives, sealants, etc.	
Description	A flexible rubber modified tile adhesive and sealant for walls and floors.
Abated virgin materials	Polymer based adhesives or virgin rubber.
Material circularity	Not circular: material cannot be recycled or reused.
Maturity of global markets	**Mature:** Rubber-based tile adhesives are commonly used products. There is potential to increase the market share.
Maturity of Australian markets	**Mature:** available for sale in Australia, however, not manufactured in Australia.
Summary advantages	Can be used as a direct replacement for conventional products with high levels of adhesive qualities (Dunlop, 2024).
Summary disadvantages	No material circularity.

Shred or crumb rubber: TDF as energy and carbon black supplement for steel production

Shred or crumb rubber: TDF as energy and carbon black supplement for steel production	
Description	In modern electric arc furnace steelmaking, carbon is injected into the furnace using ELT&C crumb rubber or shred. This carbon makes a small contribution to the heat requirements of the process. Its main role, however, is to create a gas from the reaction products in the slag layer, causing the slag to foam. This foam protects the furnace lining, reduces heat loss, and lowers electrode consumption.
Abated virgin materials	Fossil fuels: coal and coke.
Material circularity	Not circular: single use.
Maturity of global markets	**Immature:** still at R&D and trial phase.
Maturity of Australian markets	**Immature:** some investment and commercial partnerships with university research is supporting the development of this market (UNSW, 2024).

Shred or crumb rubber: TDF as energy and carbon black supplement for steel production	
Summary advantages	• Reduces the oxides of nitrogen (NOx) emissions. • TDF is less expensive than fossil fuel. • Superior insulation of molten bath and decreased heat loss through the slag. • Improved shrouding of the electrodes. • A longer electric arc and improved heat transfer from the arc to the steel (Zaharia, 2009).
Summary disadvantages	• Operational difficulties can occur with the tyre feeder system. • Additional operating and capital costs.

Crumb: mining industry explosives additive

Crumb: mining industry explosives additive	
Description	Crumb rubber is blended into traditional ammonium nitrate fuel oil (ANFO) in explosives to increase blast efficiency (via a slower reaction rate) and improve the ability to blast in wet conditions.
Abated virgin materials	Fossil fuels and oils, specifically ammonium nitrate fuel oil (ANFO).
Material circularity	Not circular
Maturity of global markets	**Immature:** not common practice internationally
Maturity of Australian markets	**Immature.** ELT use in explosives has been documented in Australia. Potential to increase, however, the presence of existing patents may be a barrier to competition.
Summary advantages	• The addition of crumb rubber slows the reaction rate of the explosive. The slower burning fuel allows for a detonation reaction and can improve the explosives usability in wet conditions. Compared with ANFO, incorporating different grades of rubber in the product produced an explosive with reduced shock energy, but increased 'heave' energy, which boosts the efficiency of rock removal in the blast. Therefore, less explosives are needed compared to regular methods, making it more cost-effective. (TSA, 2018). • Higher tolerance for wet conditions. • Reduced plume. • Commercially viable (mobile high shear) mixing regime.
Summary disadvantages	• Minor barrier in relation to ensuring supply for some components (e.g. prilled ammonium nitrate pellets). • Lack of familiarity across related markets and regulators (e.g. in other Australian jurisdictions). • Lack of material circularity.

Management options that direct ELT&C to **energy recovery** play an important role in end-of-life tyre management globally and are preferable to disposal.

However, energy recovery options lack material circularity, as the rubber compound materials are lost during energy production.

Each of the energy recovery options included in the tool is discussed below.

Tyre derived fuels and emissions reductions when displacing coal combustion

When ELT are used as tyre-derived fuels (TDF) they often displace coal. Table 2 shows the energy content per tonne and scope 1 emissions from combustions of TDF and coal.

Table 2: Emissions from solid fuel combusted (DCCEEW, 2022)

Solid fuel combusted	Energy content factor (GJ/t)	Scope 1 emission factor (kgCO_2-e/GJ) Combined gases
Passenger car tyres	32	63.03
Truck and off-the road tyres	27.1	56.13
Bituminous coal	27.0	90.24
Brown coal (lignite)	10.2	93.82
Coking coal	30.0	92.03

The table above illustrates two key points:

- TDF has a higher calorific value compared to coal.
- When displacing coal with TDF there is significant CO_2 emissions reduction.
- You can read more about these emission standards in TSA's Tyre Emission Factor Report.

Pyrolysis or gasification gas: used as fuel/natural gas replacement

Pyrolysis or gasification gas: used as fuel/natural gas replacement	
Description	Tyre Pyrolysis Gas (TPG) is the non-condensable gas fraction remaining after cooling of the pyrolysis vapour. The yield of TPG from tyre pyrolysis is typically 10-20% on a steel free mass basis. The TPG has a high calorific value and is typically used for pyrolysis reactor heating with natural gas or TPO used for start-up or supplementary reactor heating. In some applications, the TPG is used in gas engines for electricity generation or supplied to boilers. For use in gas engines, the pyrolysis gas will need to be scrubbed to meet the H_2S fuel limit as set by the engine manufacturer, typically approximately 50 ppm (Williams, 2013).

Pyrolysis or gasification gas: used as fuel/natural gas replacement	
Abated virgin materials	Fossil fuels: natural gas.
Material circularity	Not circular.
Maturity of global markets	**Mature.** The use of TPG in offsetting onsite energy requirements is commonplace within operating pyrolysis facilities. TPG energy recovery is a mature market application and can be used in onsite or offsite to offset fossil fuel natural gas use.
Maturity of Australian markets	
Summary advantages	• Energy recovery from TPG is a proven application that can be used to offset the energy requirements of pyrolysis or gasification processes. There is also a large market for syngas to offset natural gas costs and fossil fuel consumption offsite, without significant additional syngas refinement requirements.
Summary disadvantages	• TPG contains H_2S that is corrosive and oxidises to SOx on combustion and SOx emissions are restricted. • Some TPG refinement is typically required to remove particulates and H_2S. • Use of TPG as a fuel has no material circularity.

Pyrolysis oil: used as fuel supplement in bunker oil or higher-grade fuels

Pyrolysis oil: used as fuel supplement in bunker oil or higher-grade fuels	
Description	During the thermal processing of tyres and conveyor belts via pyrolysis, tyre pyrolysis oil (TPO) is obtained on cooling and condensing of the pyrolysis vapour. The oil is a crude product, a mixture of numerous chemical compounds and properties comparable to No 6 Fuel Oil (commonly referred to as 'bunker oil'). The TPO can be used as a fuel in furnaces, kilns, boilers, or suitable engines such as large marine engines or stationary engines for power generation. Crude TPO typically requires minimal additional processing other than filtering to remove fine carbon and ash for use as a bunker fuel. Crude TPO has a moderately high sulfur content (0.6 to 1.6% wt.), which limits it's use as a direct fuel replacement in most applications. The extent of TPO refinement required needs careful consideration for this application.
Abated virgin materials	Bunker fuels, crude oils, or post additional refinement, diesel fuel.
Material circularity	Not circular.
Maturity of global markets	**Developing global market with significant growth potential**. Demand for alternatives to fossil fuels is projected to increase strongly as pressure to decrease fossil fuel use increases.

Pyrolysis oil: used as fuel supplement in bunker oil or higher-grade fuels	
Maturity of Australian markets	**Immature with significant growth potential.** Australian markets for TPO are less developed than export markets. Export of TPO may be required.
Summary advantages	• Crude TPO typically requires minimal additional processing for use as a bunker fuel. • There is significant market potential for TPO fuel substitution applications as pressure increases to reduce fossil fuel consumption.
Summary disadvantages	• Further refinement via distillation and desulfurisation is typically required for use as a diesel blend or replacement. • Use of TPO as a fuel has no material circularity. • Additional processing steps compared to other TDF which increase the impact associated with the material.

Shred or whole: TDF as coal/natural gas supplement in cement production kilns

Shred or whole: TDF as coal/natural gas supplement in cement production kilns	
Description	TDF is used to supplement the significant energy required to make cement clinker in kilns fired with coal or natural gas. Whole or shredded tyres are fed into the kiln at a controlled rate to not impact clinker yield, quality, or impact emissions. The relatively high calorific value of the tyres and the sophisticated emissions control systems required on cement kilns have enabled TDF use to become one of the most significant tyre management options globally. The extremely high temperatures (over 1,500°C) and long residence time of TDF combustion in cement kilns ensure that any complex organic compounds are destroyed. Concrete made from cement manufactured using TDF has the same construction and environmental properties as if it had been made using traditional fossil fuels. The steel wire in TDF becomes part of the cement clinker, which may offset iron required in the cement manufacturing process. TDF use in cement manufacturing is considered an energy recovery application as the principal application of the TDF is the recovery of embodied energy. There is no material circularity for the rubber compounds in TDF, which is the focus of the circularity analysis.
Abated virgin materials	Fossil fuels: natural gas, coal.
Material circularity	Not circular.
Maturity of global markets	**Mature.** The use of TDF as a solid fuel in cement kilns is a relatively common practice internationally. Most of Australia's passenger ELT are currently exported, for use as TDF. TDF has historically been less expensive than fossil fuels. The global TDF market was valued at US$ 307.4 million in 2022 and is projected to reach US$ 342.9 million by 2029, at a compound annual growth rate of 1.6% during the forecast period (Transparency Market Research, 2021).

Shred or whole: TDF as coal/natural gas supplement in cement production kilns	
Maturity of Australian markets	**Developing.** TDF use in cement kilns has occurred in Australia in the past. At the time of writing, only small tonnages of TDF were being used. In May 2024, the Tasmania Government awarded a grant to support Tyrecycle's Bridgewater facility to produce TDF to be sold locally to displace coal in cement kilns and for other industrial processes (Tasmanian Government, 2024). There is still significant growth potential for TDF use in cement kilns in Australia.
Summary advantages	• Large mature global market that is projected to continue expanding till 2030. • Reduces fossil fuel consumption and equivalent CO_2 emissions compared to burning coal. • Extremely high temperatures and long residence in the kiln ensure harmful compounds are destroyed. • Concrete made from cement manufactured using TDF has the same construction and environmental properties.
Summary disadvantages	• TDF used as a fuel in cement kilns has no material circularity. No rubber compound materials are recycled back into the economy. • The large market for TDF, has the potential to build an over-reliance on this application, which can undermine investment in options that are required to establish a circular economy.
Conclusion	TDF use in cement kilns is a large mature global market that is projected to continue expanding utill 2030. TDF use in cement manufacturing can reduce cost, fossil fuel consumption and CO_2 emissions; does not produce harmful emissions when modern emissions control systems are in place; and does not impact product quality. However, TDF use as a fuel in cement kilns has no material circularity. No rubber compound materials are recycled back into the economy. The large market for TDF has the potential to build an over-reliance on this application, which can undermine investment in options that are required to establish a circular economy.

Shred: TDF coal/natural gas supplement for paper pulp mills

Shred: TDF coal/natural gas supplement for paper pulp mills	
Description	Pulp and paper manufacturers use TDF shred as a supplement to wood/timber wastes, where they are the primary fuel used in pulp mill boilers, typically combined with coal. TDF has a significantly higher calorific value than wood wastes. Using wood waste with low or variable heat and moisture content can also cause issues, which are not present for TDF. The low cost of TDF, the consistent heating value, and low moisture content have made TDF an attractive fuel in the pulp and paper industry. Modern pulp and paper mills can typically use TDF without requiring major modifications to emission control equipment. Sometimes the TDF used in the paper industry needs to be tyre granule that is free of steel as it can clog the systems. Also, the mills sometimes sell the resulting ash to farmers who require the ash to be free of steel (United States Environmental Protection Agency, 2016).
Abated virgin materials	Fossil fuels: coal or natural gas and virgin timber chips.
Material circularity	Not circular.
Maturity of global markets	**Mature.** TDF use to offset coal use in paper and pulp manufacturing is a mature market globally and is projected to increase, see TDF in cement kiln discussion. The paper and pulp industry are likely to continue to increase their use of TDF to decrease fuel costs and improve emissions and combustion efficiency.
Maturity of Australian markets	**Immature** market in Australia currently.
Summary advantages	Large mature global market that is projected to continue expanding. Reduces fossil fuel consumption and equivalent CO_2 emissions compared to burning coal.
Summary disadvantages	TDF use for paper and pulp industrial boilers has no material circularity. No rubber compound materials are recycled back into the economy. The large market for TDFs, has the potential to build an over-reliance on TDF applications, which can undermine investment in options that are required to establish a circular economy.

Management Options – Disposal 12

Each of the disposal options included in the tool is discussed below. Illegal dumping and burning of ELT&C are discussed as they are still a significant challenge in Australia, however, they are **not** an 'option'.

OTR tyre and conveyor belt disposal – regulatory framework summary

Currently in Australia, almost all OTR tyres and conveyor belts used in mining are still buried onsite resulting in long term risks to the local environment and a complete loss of the significant tonnages of valuable embodied materials.

In Australia, the current regulatory framework for OTR tyre and conveyor belts permits onsite burial, which is out of step with global management practices, see TSA's Tipping the Balance report. There are currently inconsistencies in the regulatory approaches applied to onsite and offsite OTR tyre and conveyor belt management options.

Direct disposal to an offsite licensed landfill 12.1

The disposal of tyres is regulated under state legislation with licensing conditions imposed on landfill operators to control the management of tyres at licensed landfill sites.

There are significant landfill construction engineering requirements that are summarised below.

A common specification for the **basal lining of an 'inert' waste (only) landfill** in Australia consists of four construction elements:

- Sub-base construction
- Compacted clay liner at least 0.5 m
- Drainage layer/leachate collection system
- Geotextile.

There are also **cell capping requirements** that are similar to the basal lining requirements outlined above.

New inert waste landfill cells must typically be separated from groundwater by 2 m (the natural, unpumped level). Offsite licensed landfills also require the payment of the relevant jurisdiction **landfill levies that vary and are approximately ~$100 per tonne for inert wastes. The landfill gate fee will be charged in addition to the landfill levy.**

Finally, most jurisdictions require tyres to be **shredded before landfilling (i.e. whole tyres are banned),** adding another significant cost to offsite licensed landfill disposal.

Disposal of inert waste (including OTR rubber products) must comply with landfilling regulations specific to the corresponding jurisdiction, including the payment of waste levies in all sectors, except for mining.

Onsite burial at mining sites

12.2

Disposing of used OTR rubber products onsite at mining sites is a low- or no-cost option currently in Australia, due to the exemptions from offsite licensed landfilling requirements outlined above.

Mining organisations can view the inconsistency with offsite landfilling requirements as a justification to continue onsite burial. TSA is actively engaging with mining organisations to support recovery options for OTR ELT&C. For more insights refer to the Tipping the Balance report.

Allowing mining organisations to bury waste at mine sites hinders the recovery and recycling of OTR ELT&C in remote and regional areas. In some countries, such as Chile, legislation has evolved to stop the burial of ELT and enable recovery. The legislation in Chile requires 100% recovery of giant mining tyres by 2028, and its implementation has been instrumental in enabling Kal Tire company to invest in, develop and build a new pyrolysis facility for mining tyres (TSA 2023).

In some cases, though, the legislation has not been supported with commercialised solutions, which has resulted in stockpiling. It is crucial to consider the balance between legislation and the availability of commercialised solutions. It is clear throughout the report that commercialised solutions exist. The problem is therefore not technical, but rather the collective efforts and investment needed to create a circular economy across the tyre and conveyor belt supply chain.

Tyre-derived aggregate use in landfill

12.3

TDA can have multiple applications in landfill operations, including:

Drainage layer in a leachate collection system

TDA is used in the leachate collection system to:

- Provide drainage.
- Limit freezing of underlying clay barriers (in cold climates).
- Protect the liner system from damage during construction and operation.

TDA for this application is generally a maximum size of 7.6 cm.

Leachate recirculation trenches

Leachate recirculation trenches are used to reintroduce collected leachate back into the waste. TDA can be used as a backfill around leachate recirculation trenches, typically replacing materials such as granular soil.

Gas collection trenches

These trenches are usually found beyond the footprint of the landfill to control the lateral migration of landfill gas. TDA used in this application replaces granular soil as the bedding material for gas extraction pipes in the collection trenches.

Daily cover system

TDA can be used as daily and intermediate cover material typically in a 50/50 mix of TDA and soil. Some applications also specify TDA be no larger than 10cm by 25cm in size. These applications are common practice in North America and are largely responsible for the clearance of tens of millions of stockpiled

ELT. They are referenced in the ASTM D6270 *Standard Practice for Use of Scrap Tyres in Civil Engineering Applications* (ASTM, 2020).

Although TDA materials have functional value, they cannot be recovered once used.

Illegal dumping or burning 12.4

Illegal tyre dumping

Tyre dumping has environmental and human health risks, and the financial burden of clean-up is placed onto local governments or private property owners. Dumped tyres heighten the risk of mosquito-borne diseases, are a fire hazard, detract from the visual amenity of the area and take funds away from other community priorities.

This problem is exacerbated by the involvement of rogue operators who profit from collecting and abandoning tyres in rented warehouses, or private or public property. The surge in reports through the platform *Snap Send Solve* underscores the severity of this issue, revealing a consistent increase in dumping rates between May 2022 and November 2023 (18 months), with over 80% of reported incidents involving 10 tyres or more (Snap Send Solve, 2023).

Illegal tyre fires

In remote and regional areas of Australia, stockpiled tyres are often burnt. Although not easy to set alight, the nature and composition of tyres mean that once alight, tyre fires burn hot and fast and are extremely difficult to extinguish.

Tyre fires generate smoke, oil, and contaminants that harm the soil, waterways, and air, posing significant risks to human health and the environment while producing large volumes of thick, toxic smoke.

Water used in firefighting operations also becomes contaminated, with runoff commonly seeping into groundwater and surface water, presenting a serious risk to the surrounding environment (TSA, 2019).

Tyre fires are commonly caused by arson, ignition in on-site machinery, or bush or grass fires in rural areas. Factors that influence and increase the risk and impact of tyre fires are:

- How facilities are managed and operated.
- The size of tyre stockpiles.
- Where and how long tyres are stored.
- How tyres are stacked, the amount of exposed surface area and air pockets within stockpiles.

Illegal tyre export

12.5

In March 2020, the Australian state and territory governments, and the Australian Local Government Association, as members of the former Council of Australian Governments (COAG), agreed that the export of waste glass, plastic, tyres and paper be regulated by the Australian Government.

This was regulated through the Recycling and Waste Reduction Act 2020 and the Recycling and Waste Reduction (Export—Waste Tyres) Rules 2021 (DCCEEW, 2020). Exporters of the items listed below need a license and must declare each consignment to DECCEW:

- Tyres that have been processed into shreds or crumb of not more than 150 mm for use as tyre-derived fuel.
- Tyres for re-tread by an appropriate re-treading facility, for example, one that is verified by TSA's Foreign End Market Verification program.
- Tyres to an appropriate importer for re-use as a second-hand tyre on a vehicle.
- Tyres that have been processed into shreds, crumbs (when the shred or crumb are not for use as tyre-derived fuel), buffing or granules.

Baled tyres or tyres in pieces larger than 150 mm were banned from export, but industry intelligence indicates this practice is still occurring with unknown end uses and volumes illegally leaving Australia.

TyreStewardship AUSTRALIA

Australian Government Accredited Product Stewardship Scheme

TSA0368/01.2025