TYRE PARTICLE HEALTH, ENVIRONMENT AND SAFETY REPORT

Australian Government Accredited Product Stewardship Scheme

TyreStewardship AUSTRALIA

Tyre Particle Health, Environment and Safety Report

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Report Disclaimer

This report has been prepared by Tyre Stewardship Australia (TSA). TSA cannot accept any responsibility for any use or reliance on the contents of this report by any third party. The risk assessments outlined in this report are based purely on an internal literature review at the time the report was commissioned. The purpose of the results is to provide information and evaluation to interested parties, not to form part of an official risk management strategy.

Author

Dr Linda Mitchell

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Version 2

TyreStewardship AUSTRALIA

Australian Government Accredited Product Stewardship Scheme

TSA's purpose is to drive sustainable outcomes for end-of-life tyres (EOLT).

Our vision is a circular economy for EOLT which contributes to a sustainable society.

Our mission is to collaboratively ensure the sustainable management, recycling and productive use of EOLT.

Executive Summary

Introduction

The recycling of rubber from end-of-life tyres (EOLT) has great environmental benefits due to the repurposing of an otherwise waste product, as well as additional benefits due to the improved performance features of many tyre-derived materials. Tyre Stewardship Australia (TSA) acknowledges that any utilisation of recycled tyre material must be done so in a manner that is safe to the community and environment.

In Australia in 2020-21, around 459,000 tonnes of used tyres reached their end-of-life. Developing viable, safe and sustainable solutions for EOLT is a priority for TSA. Information and research relating to microplastic pollution, chemical leachate and emissions has recently raised concerns regarding the presence of tyre particles in the community and the environment. The aim of this report was to review, understand, and assess the research regarding the potential health and environmental impacts of tyre particles.

Literature Review

Initially, international studies involving tyre and road wear particles (TRWP), which are tyre particles produced at the road surface were reviewed, to understand the potential risks related to tyre abrasion and microplastics. Following this, international studies involving tyre derived products (TDP) were assessed, specifically TDP that interact closely with people and the environment.

In Australia, TRWP, artificial turf, playground/running surfaces and crumb rubber-modified asphalt were identified as the main tyre particles to prioritise in the current review for any environmental and human health risks.

The abrasion of tyres on a road surface produces micro sized rubber particles, TRWP, which are widely accepted to fit into the category of "microplastics". Artificial turf fields utilise rubber granules as infill to physically support the synthetic grass, providing cushioning and shock absorbance properties, and more weather resilience compared to natural grass.

Recycled rubber particles are used in playgrounds and running tracks by mixing granules with a binder and pouring in place on top of a hard asphalt/concrete surface, demonstrating superior shock-absorbing properties of the surface. Crumb rubber is also commonly added to bitumen binders as a polymer modifier for road surfacing applications, resulting in various performance benefits such as increased service life, improved durability, and crack, rutting and fatigue resistance.

Results and risk assessment

The ecological studies included assessed the potential toxic effects from either leaching of chemicals or physical ingestion of tyre particles. Human health effects were examined and included assessments of exposure either via ingestion, dermal contact, or inhalation.

TRWP are closely examined and summarised from 14 peer-reviewed scientific studies. Rubber granules used in artificial turf are examined in 10 studies, which cover almost 300 sports fields in Europe and the US. Tyre particles in bound surfaces like playgrounds and running tracks are reviewed across three studies, and in crumb rubber modified asphalt and spray seals in seven studies.

Each study was assessed using a relevant risk matrix, to determine whether each application has a negligible, minor, moderate, significant, or critical risk towards human health and the environment.

A summary of the key findings from the current research is outlined below:

1. **TRWP** – the literature indicated that at current concentrations there is a minor risk towards the environment and human health.
2. **Artificial turf** – has been studied extensively and despite ongoing contention related to environmental transport of particles, the literature points to a minor risk towards the environment and human health.
3. **Playgrounds and running tracks** - has been examined globally across several surfaces and found to have a minor risk towards the environment and human health.
4. **Crumb rubber-modified asphalt** – the literature indicated there is a minor risk to the surrounding environment and a minor/moderate fuming risk towards construction workers during asphalt construction. Importantly, recent studies comparing crumb rubber-modified asphalt and conventional asphalt found the fumes and airborne particles are not above SafeWork Australia standards, are not carcinogenic and the inclusion of crumb rubber does not appear to increase negative symptoms for asphalt construction workers.

Knowledge gaps and recommendations

The literature review and risk assessment in this report was conducted on the current body of research, however there are still knowledge gaps which, if addressed, would strengthen the findings in this report. A few key knowledge gaps identified include improving the characterisation, transport and exposure pathways of TRWP; long-term environmental impact studies of TDP; and supplementary Australian based research to support key international research findings.

A key recommendation from this report proposed that adopting specific precautionary measures would minimise any unknown or residual risks from tyre particles. These precautionary measures include:

- **TRWP:** waste treatment options, particle capture and removal systems, particle reduction strategies, innovation to modify car, tyre and road designs, and education on driving behaviour and tyre maintenance.
- **Playgrounds and artificial turf fields:** risk management measures, to reduce the loss of particles to the environment in surfacing applications. These include drain filters, containment barriers, correct storage and installation practices, machine and boot cleaners at turf fields, and regular maintenance and repair to damaged surfaces.
- **Crumb rubber modified asphalt:** appropriate safe work practices and personal protective equipment use during road construction for road and pavement workers.

Conclusions

The key findings from this review indicated the following:

TDPs are safe materials to use in Australian markets with an overall minor risk to human health and the environment.

It is recommended that precautionary measures are maintained to eliminate any potential hazards created by mismanagement practices or identified knowledge gaps.

The risk assessments conducted in this report rely on the research available at the time of the review and will require updating when new information and research is published.

TSA will continue to monitor new information and research as it becomes available and undertake research where appropriate and beneficial.

Abbreviations

Abbreviation	Description
ECHA	European Chemicals Agency
EOLT	End-of-life tyres
ETRMA	European Tyre and Rubber Manufacturers' Association
EU	European Union
NESP	National Environmental Science Program
PAH	Polycyclic aromatic hydrocarbon
RMM	Risk management measures
SVOCs	Semi-volatile organic compounds
TSA	Tyre Stewardship Australia
TDP	Tyre-derived products
TRWP	Tyre and road wear particles
VOC	Volatile organic compounds

Assessment of the potential community and environmental risks from tyre particles during vehicle use and in recycled applications.

Introduction

1

Tyre Stewardship Australia (TSA) is an industry program that was formed in 2014 to assist in the development of feasible markets and products for end-of-life tyres (EOLT). This is achieved by supporting recovery processes that reduce the number of tyres that end up in landfill, are dumped illegally, or are exported to overseas industries with poor environmental practices, as well as by creating and supporting opportunities to safely reutilise these resources.

State of play in Australia

In Australia, public concern regarding environmental sustainability has created a push to recycle and reuse resources. An increasing number of tyre recyclers and associations exist to reprocess EOLT and create new materials for various applications.

Conventional tyre recycling involves mechanically grinding tyres down into physically smaller pieces. Once reduced in size, these tyre materials can then be used either as a loose particle or bound into a product. These new materials are known as tyre-derived products (TDP), and are utilised in applications such as road surfaces, industry and commercial flooring, building insulation, artificial turf for sports fields, running tracks surfaces, playground surfaces and fuels.

To align with a vision to develop sustainable outcomes and solutions for the millions of EOLT that are produced each year, TSA has undertaken this research to review, understand and assess the potential health and environmental impacts of tyre particles. Furthermore, as greater awareness has been raised in recent years regarding tyre and road wear particles (TRWP) and their contribution to chemical and microplastic pollution in the environment, these particles have also been included in the scope of this review.

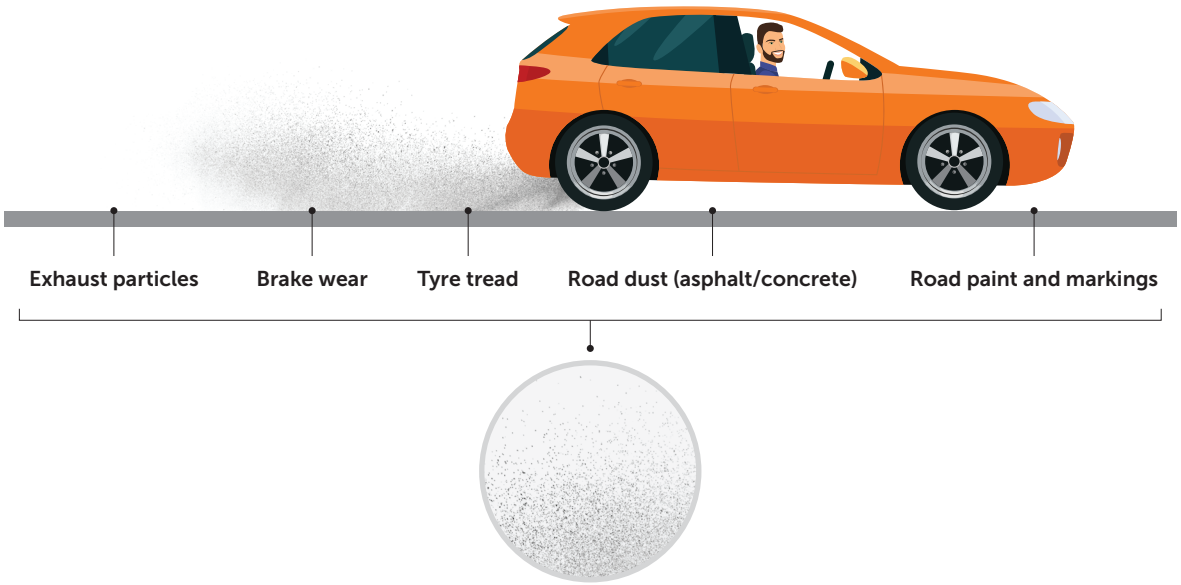
The work first presents an overview of international studies involving tyres 'in-use' (tyres on vehicles) and the potential risks related to TRWP and microplastics. Following this, a review of international studies involving TDP is presented, specifically TDP that interact closely with people and the environment. By identifying where TDP are similarly used in Australia, the findings of these studies have been contextualised for recycled tyre materials in Australia.

In Australia, TRWP, artificial turf, playground/running surfaces and crumb rubber-modified asphalt were identified as the main tyre particles that interact closely with the environment and the community. Each material application was considered individually during the literature review and risk assessment process.

Figure 1: Outlines the source, production and makeup of different types of tyre particles that were considered during the literature review and risk assessment process within the report.

Tyre Road Wear Particles (TRWP)

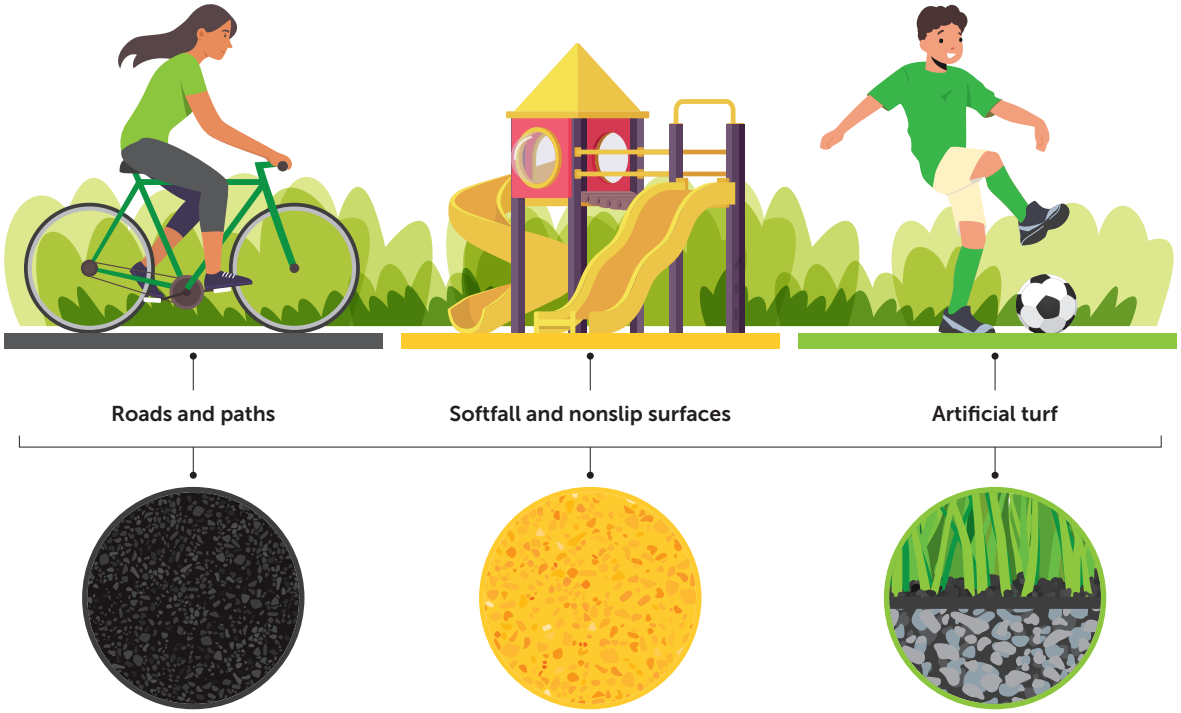
TRWP can be made up of a mixture of dirt, dust, road markings/paint, exhaust particles, tyre tread and other foreign materials on the road. The production, size and makeup of these particles are influenced by factors such as driving behaviour, road condition and road dust material and debris.



TRWP are generally between 5-250 µm in size, and transported into the environment by water and air.

Tyre-Derived Products (TDP)

TDP are manufactured using materials from recycled tyres. TDP are produced from EOLT rubber (tread, sidewall, casing) at processing facilities. These facilities are designed and engineered to create different sized particles and form these quality end-products.



Crumb rubber (0.5-1.2 mm)
Added to bitumen binders and adhesives.

Rubber granules (1-5 mm)
Bound in a surface using a binder, such as polyurethane. Can form the surface layer, or performance underlayers.

Rubber granules (1-5 mm)
Included as performance infill.

Studies on tyre and road wear particles:
Literature Review

2

The abrasion of tyres on a road surface produces micro sized rubber particles which are widely accepted to fit into the category of "microplastics".[1] The abrasion of tyres is caused by friction between the tyre and road surface and is an essential aspect to ensure safety during variable conditions and driving behaviour. The debris formed during tyre abrasion on the road consists of an approximate 50:50 mixture of tyre tread particles and road surface material, collectively termed *Tyre and Road Wear Particles*.[1,2]

TRWP have been identified in microplastic samples worldwide and road run-off is believed to account for approximately 44% of the microplastic pollution released into the oceans worldwide.[3] In fact, TRWP has been detected in all environmental compartments, specifically road dust, air, soil, freshwater and marine.[4] Since TRWP are reported to contribute to a significant proportion of global microplastic pollution, it is crucial to identify the individual role these particles play in ecotoxicity.

A major concern for these particles is not only their fate, but their transport life cycle. During transport processes there is the potential for particles to break down further, leach chemicals they contain, and absorb and re-release chemicals present in the surrounding environment. Furthermore, particulate matter has the potential to cause physical harm if ingested by aquatic life or humans, and subsequent toxicity if they can penetrate cell membranes or are retained in the gut.[1]

Thus, the literature review included studies that evaluated the ecological risks associated specifically with TRWP and rubber particles. Studies have primarily focused on the potential toxic effects of leaching of chemicals from tyre materials, with a few including physical effects, and have been summarised in Table 1.

In addition to ecotoxicity, it is also important to address the potential impact of microplastics on human health. Microplastics and tyre particles have been detected in low levels in air, soil, drinking water, seafood, and other dietary sources.[5] Exposure may occur via ingestion, dermal contact, or inhalation. The preliminary studies identified that have assessed the health effects of TRWP towards humans have been summarised in Table 2.

Table 1: Ecotoxicity of tyre particles

Source	Organism	Ecotoxicity conclusions
Tyre particles from new rubber – (chemical leaching)	*R. subcapitata* (microscopic algae), *D. magna* (crustacean) and *X. laevis* (frog embryos).[6]	Zinc, low pH levels leading to mortality and deformation
Tyre particles – (chemical leaching)	*R. sylvatica* (frog larvae).[7]	Developmental delays from zinc levels
Tyre particles from worn tyres shredded – (chemical leaching)	*D. magna* and *C. dubia* (crustaceans), *P. subcapitata* (algae) and *D. rerio* (zebra fish eggs).[8–10]	Zinc and organic compounds – immobility, mortality, growth inhibition
Tyre wear particles from a road simulator – (chemical leaching)	*P. subcapitata* (algae), *D. magna* (crustacean), *P. promelas* (cyprinid) and *H. azteca* (crustacean).[11,12]	No acute toxicity and limited chronic toxicity observed (growth inhibition and larvae mortality). Overall low risk.
Tyre particles in sediment – (physical particle)	*G. pulex* (crustacean).[13]	Particles discovered in the gut, but no negative effects observed

Source	Organism	Ecotoxicity conclusions
Tyre particles – (chemical leaching) Tyre particles – (physical particle)	*H. azteca* (crustacean).[14]	(Chronic) Mortality, reproduction, growth inhibition after 21d exposure. Varying toxic effects between leaching and physical particle.
Tyre wear particles – (chemical leaching)	*Oncorhynchus kisutch* (salmon).[15]	Acute toxicity linked to 6PPD-quinone, an anti-ozonant transformation product present in some tyre mixtures.

Table 2: Human health risks of tyre particles

Source	Test subject	Conclusions on toxic effect
Airborne tyre particles	Latex-sensitive patients – inhalation pathway.[16]	No clear evidence that tyre particulates increase incidence of asthma or allergy.
TRWP from ambient particulate matter	Rat biological study –inhalation pathway[17]	A general no observable adverse effect level measurement.
Air particles from high vs low traffic areas	Rat biological study –inhalation pathway.[18]	A trend of slightly greater adverse effects in high traffic areas – cytotoxicity and inflammation.
Organic extracts from tyre particles	Human lung epithelial cells (A549) – inhalation pathway.[4]	Negative effects on cell morphology and inducing reactive oxygen species. **NB** only applicable if organic extracts become bioavailable.

Studies on Tyre Derived Products:
Literature Review

3

In Australia in 2020-21, around 459,000 tonnes of used tyres reached their end-of-life. Developing viable and sustainable solutions for EOLT is a priority for TSA. An increasing push to utilise recycled materials, and therefore TDP, introduces additional considerations regarding the risks towards humans and the environment. Materials like rubber crumb and rubber granules have been used in asphalt and artificial turf applications for over 50 years with no definitive health effects. However, increased knowledge on pollution has placed TDP in the spotlight and necessitate further consideration regarding their environmental and health impacts.

Studies involving the types of TDP that are currently used in Australia in significant volumes and interact closely with the environment and people were selected for inclusion in the risk assessment. The materials containing TDP that were identified as warranting investigation are artificial turf, playgrounds and running track surfaces, and crumb rubber modified asphalt.

Artificial turf fields are advantageous compared to natural grass surfaces due to lower maintenance requirements, and the flexibility to be used in different climates and seasons. Rubber granules can both physically support the plastic fibre blades and provide cushioning and shock absorbance during sport activities.

Recycled rubber particles are also used in various racing and running tracks, and as ground cover in playgrounds and schools. Rubber granules are combined with a polyurethane binding agent and poured into place on top of a hard surface such as concrete or asphalt.[19] The inclusion of rubber material is appealing as it has demonstrated improved shock-absorbing properties which improve performance and reduces the severity of potential injuries of children using the playground.[20]

Crumb rubber has been used in Australian roads in sprayed seals since the mid 1970's and has seen increased usage in rubber modified asphalt and binder applications.[21] The recycling of rubber from tyres is economically beneficial due to reducing the amount of costly polymer and petroleum derived bitumen products in traditional asphalt additives.[22] During road construction, asphalt binders are heated to form a liquid, mixed with aggregates, laid on the road and then compacted. The temperature of materials during road and pavement construction often need to reach up to 160 °C to create the necessary liquid phase. Emission of volatile substances such as organic compounds and polycyclic aromatic hydrocarbons (PAHs) are known to increase as temperatures increase.[23]

Table 3 represents the literature studies that have examined the different environmental and health impacts of these tyre material applications.

Table 3: Human health and environmental risks of tyre-derived products

Application	Chemicals	Exposure routes	Conclusions
Artificial turf France 2007[24] -2 fields	Organic and metal concentrations	Percolate ecotoxicity	No ecotoxic effects in the lab study and outdoor artificial turf study were linked to the organisms tested.
	VOCs and aldehydes	Emission exposure	No health concerns towards users were found.
Artificial turf New York 2009[25] -2 fields	Heavy metals – including Zinc/ Lead	Chemical leaching	No significant impact on both surface water and groundwater quality.
	VOCs and SVOCs	Ambient air testing, wipe, and vacuum	No observed health concerns towards users.

Application	Chemicals	Exposure routes	Conclusions
Artificial turf Review 2014[26]	VOCs, PAHs, heavy metals, and particulates	Chemical leaching and air quality	Low overall contamination in the aquatic environment, apart from zinc. No significant health risks associated with fields with rubber granulate.
Artificial turf US 2017[27] -soil study	PAHs, VOCs, metals	Earthworm and soil microbes	Soil microbial activity unaffected. Earthworm survivorship no different between soils, however worms did experience slower growth.
Artificial turf EU (ECHA) 2017[28] -100 fields	PAHs, metals, phthalates, benzothiazoles, VOCs, SVOCs	Airborne levels and migration	No elevated cancer risk from PAHs. Phthalates, benzothiazoles and metals was below levels considered a health risk. VOCs may cause eye and skin irritation indoors.
Artificial turf Netherlands 2018[29] -100 fields	PAHs, benzothiazoles, phthalates and heavy metals	Oral, dermal and inhalation migration experiments	Similar results to ECHA study - No evidence to suggest significant health risks.
Artificial turf EU 2020[30–32]	PAHs, metals, benzothiazoles, phthalates, VOCs	Migration, air quality and evaluation studies	Calculated cancer risks for PAH exposure were less than 1 in 1 million and the evaluation for non-carcinogenic substances indicated no health concerns.
Playground ground cover Canada 2003[33]	Organic extract of tyre rubber	Leachate aquatic toxicity	Potential threat to marine organisms from undiluted runoff, but activity decreases rapidly through transport processes and over time.
		Genotoxicity	Does not pose a health hazard to children.
Playgrounds/ running tracks US 2007[34]	Metals, PAHs, VOCs, allergens	Oral and inhalation migration scenarios	Low likelihood of negative health effects in children.
Playgrounds/ Artificial turf Spain 2021[35]	PAHs	Concentration levels	Average PAH concentrations were lowest in outdoor playgrounds, then indoor playgrounds, then artificial turf pitches. All recreational surfaces complied with relevant ECHA PAH limits.
Crumb rubber modified asphalt US 1995[36]	Trace metals, VOCs, SVOCs	Chemical leaching into surface and groundwater	Levels were too low to be considered environmentally hazardous, according to US guidelines.
Crumb rubber modified asphalt US 1998[37]	Water pollutants, PAHs, benzothiazoles.	Chemical leaching into surface and groundwater	Water quality did not indicate an increased risk toward the environment or human health. PAHs were not elevated levels. Benzothiazole levels were elevated, but unlikely to be harmful to the aquatic environment.

Application	Chemicals	Exposure routes	Conclusions
Crumb rubber modified asphalt US 2001[38]	Particulates, PAHs Organic sulphur compounds, VOCs, CO, H_2S, SO_2, O_3	Air emission samples and health questionnaires	Crumb rubber asphalt had slightly higher emissions and symptoms than conventional asphalt during construction activities, however safety recommendations were given for both types.
Crumb rubber modified asphalt US 2003[39]	Metals, benzothiazoles,	Chemical leachate	Contaminants were naturally removed during their transport through soil, rendered the leachate non-toxic to the aquatic organisms tested.
Crumb rubber modified asphalt Sweden 2018[40] Lab and field experiments	Benzothiazole and PAHs	Air emission exposures at two mixing temperatures for crumb rubber and conventional asphalt.	No overall evidence to suggest a higher risk when using crumb rubber asphalt compared to conventional asphalt in terms of asphalt worker exposure in any working area.
Crumb rubber modified asphalt US 2019[41] Lab and plant experiments	VOCs	Emission levels of VOCs at 120°C, 140°C and 160°C.	VOCs are sometimes harmful to the environment and human health, there are no concluding results regarding the health hazards associated with the elevated VOCs in crumb rubber modified asphalt.
Crumb rubber modified asphalt Australia 2019[42]	VOCs, PAHs, suspended particles, benzothiazoles, bitumen fumes	Air emissions, exposures, and health questionnaires	Crumb rubber asphalt had higher benzothiazole levels, lower total suspended particles, lower bitumen fumes compared to conventional asphalt and no carcinogenic emissions in either asphalt type. All emissions were below Australian SafeWork emission standards– with no evidence regarding a greater risk of rubber asphalt compared to conventional asphalt.

Abbreviations: PAH – polycyclic aromatic hydrocarbon, VOCs – volatile organic compounds, SVOCs – semi-volatile organic compounds, ECHA – European Chemical Agency.

Results and discussion

4

The potential risks associated with different tyre particles were characterised based on exposure pathways towards humans and the environment, and the potential hazards related to this exposure. Based on potential hazards and consequences, the risks were rated according to both magnitude and likelihood and subsequently given a risk rating according to a relevant risk matrix. A risk matrix, created for the purpose of this work, and the detailed characterisation of each risks assessment can be found in the Appendix. A summary of key findings is presented here.

Key findings on size differences between each type of tyre particle.

Each tyre particle was treated separately during the risk assessment, due to varying complex interactions with the surrounding environment. A key differentiating factor between particles was their size distribution. Particle size distribution influences the transport, interaction and fate of materials within the environment. Due to differences in size, the results from TRWP studies cannot be compared with results from TDP studies and must be treated separately. Other differences that also exist between each particle types can include their composition and the volume produced. The risk assessment in the following sections considered particles separately, based on size and whether the material is bound in place.

A general size range for each particle can be seen in Figure 2, alongside common everyday objects to assist with size comparison.

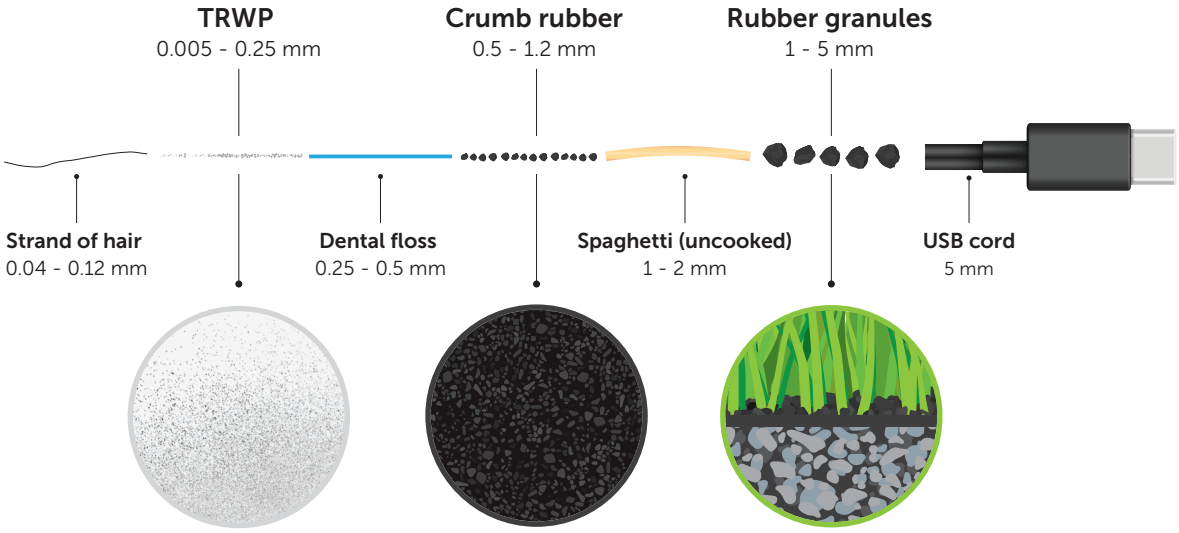


Figure 2: Size comparison of different tyre particles and common everyday objects.

Tyre and road wear particles:
The potential risks towards human health and the environment

4.1

There have been several toxicological studies regarding microplastics and the aquatic environment. Zinc accumulation was identified in several studies and was attributed as the cause of negative effects seen in marine organisms, particularly a slowing of growth trajectories. These studies generally exceeded average environmental concentrations and used lab produced tyre particles. Particles collected in a road simulator and at more relevant environmental concentrations demonstrated a low toxicity risk to aquatic systems. However, due to the unique and diverse components of tyre particles and the differences in concentrations used during testing, these studies do not provide consistent or conclusive evidence for TRWP aquatic ecotoxicity. A recent study has found a potential link between the toxicity to a salmon species in the US and an anti-ozonant chemical by-product, 6PPD-quinone. Importantly, these studies are currently being replicated in Australia, to better understand the local impact of TRWP to aquatic organisms.[43]

Whilst the information regarding the ecological risks of microplastics is limited, and there is a significant contribution from TRWP to global microplastics, the general literature on microplastic pollution suggests that exposure levels are, on average, lower than the predicted no-effect level and it is unlikely that ecological effects will be widespread.[5]

Preliminary studies have been conducted to examine the health effects of microplastics and TRWP towards humans, with minimal health hazards identified. Whilst this is an ongoing area of study, several working groups have concluded that there is currently no evidence to suggest a widespread risk towards human health caused by microplastic and TRWP pollution, instead suggesting that precautionary measures be taken to address public concerns, such as waste treatment, particle capture and removal systems and particle reduction strategies.[44]

A thorough risk assessment was conducted based on what is currently known in the literature regarding TRWP and can be found in the Appendix (Table 4 and Table 5). The review of this literature was assessed in detail and deemed that at current concentrations, there is a minor risk towards the environment. With the continuing increasing concentration of TRWP in the environment, this may change in the future, due to possible chemical risks. Current studies regarding the health effects of TRWP towards humans, in particular the inhalation of particles, was deemed to have a minor risk.

Tyre derived products: The potential risks towards human health and the environment 4.2

Rubber granules are used as an infill material in artificial turf fields and the health and environmental risks have been examined in several international studies. Studies involving human health risks were frequent, covered broad locations and thoroughly examined different exposures routes. Importantly, the oral, dermal and inhalation exposure of both the physical granulate particle and the chemicals released were examined. The studies agree that there is no increased risk of cancer or other negative health effects from playing on fields with rubber infill. Similarly, the environmental risk assessments identified generally agree there is minimal risk to surrounding environment, although zinc levels were flagged as a potential contaminant of concern to consider in the future.

The close interaction of people, in particular children, to rubber materials from recycled tyres and the substances they contain has led to several international studies included in this assessment. The results from the studies that investigated the health and environmental effects of these surfaces produced no evidence to suggest an increased risk from exposure. As the studies pertained to a limited number of locations, additional studies in more widespread locations would provide a more conclusive assessment.

A selection of studies have been conducted to address whether the inclusion of crumb rubber modified asphalt in construction applications creates a greater risk of toxic emissions to personnel working onsite. The identified literature generally agrees that both conventional asphalt and crumb rubber modified asphalt produces toxic emissions in varying levels, but whether there is an increased health risk from asphalt containing crumb rubber requires more investigation. Importantly, the recent study in Victoria, Australia comparing crumb rubber-modified asphalt and conventional asphalt found the fumes and airborne particles are not above SafeWork Australia standards, are not carcinogenic and the inclusion of crumb rubber does not appear to increase negative symptoms for asphalt construction workers. One study also assessed the environmental risks of leachates from crumb rubber modified asphalt and agree that soil sorption and biodegradations readily remove toxic chemicals and prevent distribution in waterways.

A risk assessment based on these literature studies regarding TDP can be found in the Appendix (Table 4 and Table 5). The literature generally agrees there is a minor risk towards the environment and human health from using artificial turf fields. The literature studies on bound surfaces, such as playgrounds and sports tracks were assessed to have a minor risk towards the environment and human health. An assessment of crumb rubber modified asphalt studies suggests there is a minor risk to the surrounding environment and a moderate/minor fuming risk towards construction workers during asphalt construction, similar to conventional asphalt and depending on personal protective equipment usage.

Knowledge Gaps

5

A few knowledge gaps still exist regarding microplastic and TRWP pollution. There is limited evidence relating to TRWP production and concentration in the environment. There is also a lack of studies regarding TRWP and microplastic exposure pathways and the potential human health effects. To fully understand the negative effects of microplastics and TRWP, and create more accurate risk assessments and solutions, these knowledge gaps need to be addressed.

The European Tyre and Rubber Manufacturers Association (ETRMA) has launched a collaborative body, the European TRWP Platform, to share knowledge and develop potential solutions and methods to address concerns regarding TRWP. A recent action from the ETRMA was a released statement saying that the tyre industry intends to review the findings of study relating to the toxicity of 6PPD-quinone towards aquatic organisms. The Tire Industry Project is another initiative to provide a global forum to discuss tyre sustainability issues and includes TRWP as a key focus area. On a local scale, the Marine Biodiversity Hub, with a collaborative partnership with the Australian Government's National Environmental Science Program (NESP), have undertaken a research project to assess primary microplastics in the marine environment. A component of the project investigated TRWP, their sources, release and pathways into the environment, and potential options to address the TRWP contributions to microplastic pollution.

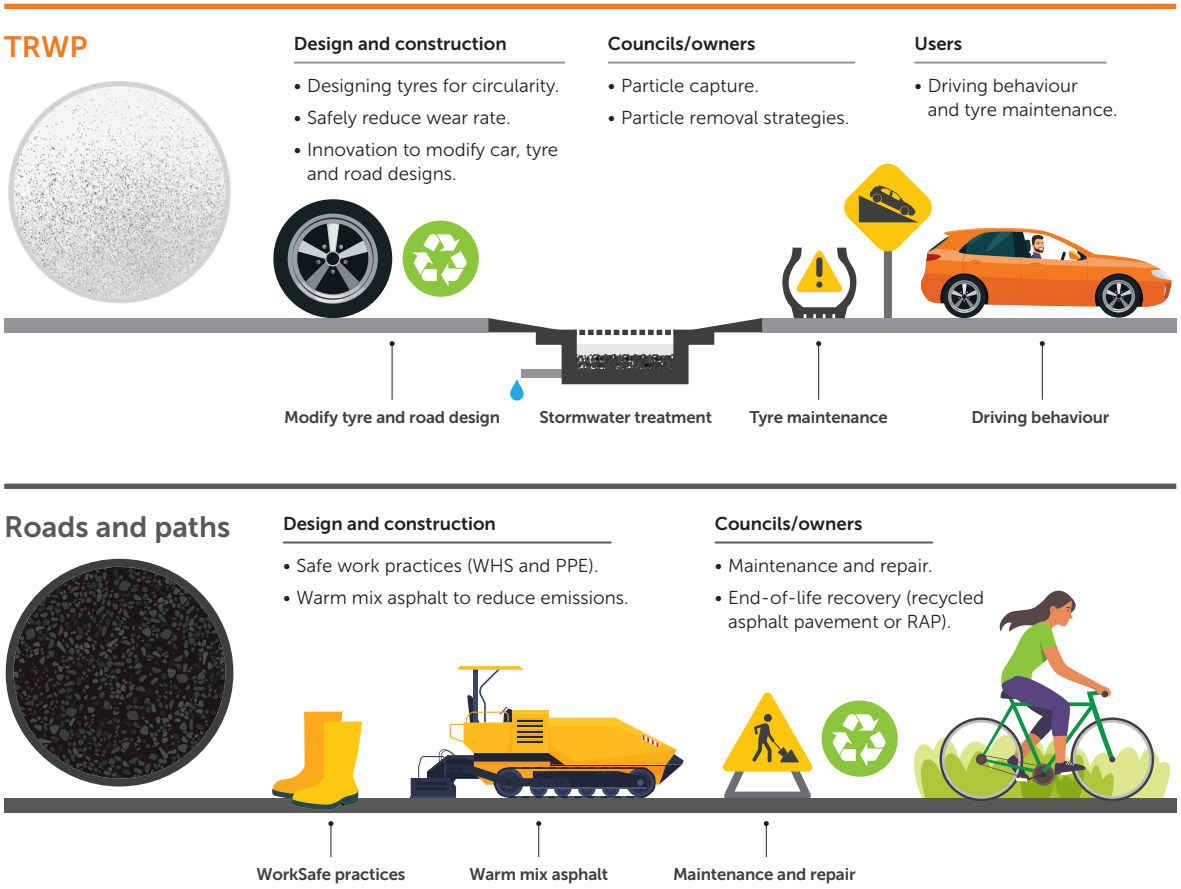
Whilst the above knowledge gaps remain, recommendations from studies, microplastics forums and organisations generally agree on adopting precautionary measures. Several strategies proposed to reduce TRWP are presented in Figure 3, including particle capture and removal systems, technology and innovation to modify car, tyre and road designs and driving behaviour education.

There is prevalent research regarding TDP and the risks towards the environment and human health, however, there are still a few knowledge gaps to be addressed. There are limited long-term environmental impact studies of TDP applications and few broader scale studies of TDP applications that conduct analysis at multiple locations. The risk assessment performed above was generalised to Australian applications, under the assumption that products use analogous tyre materials in similar applications, which would ideally be supported by future studies.

Future research should be directed at filling these knowledge gaps and adding to the current body of research. As more information and knowledge gaps are filled, the risk assessments from this review will need to be updated.

In many examples of TDP use, precautionary measures exist and are presented in Figure 3. For crumb rubber modified asphalt this includes ensuring work health and safety (WHS) practices and personal protective equipment (PPE) are used during road construction, regardless of asphalt types, to ensure the safety of workers. Risk management measures (RMMs), in the sporting industry, are aimed at reducing the loss of particles to the environment in surfacing applications.[45] This includes strategies such as drain filters, containment barriers, correct storage and installation practices, machine and boot cleaners, and regular maintenance and repair to damaged surfaces. These RMMs are particularly relevant with an upcoming decision to be made by the EU Commission on whether to ban rubber infill in artificial turf applications.[46] These best practice strategies can be extended to playgrounds and other non-slip rubber surfaces.

Figure 3: Examples of various actions and opportunities that exist to reduce tyre particle impacts during the entire lifecycle of materials. These include actions during the design, construction, maintenance, use and end-of-life of materials.



Conclusions

6

The information gathered and summarised in this report is a literature review conducted regarding TRWP and TDP health and environmental safety. The findings from various studies have been reviewed and contextualised for tyre particle safety in Australia. A general assessment of each tyre material was conducted, and a summary of the risks findings from the current research is outlined below:

- **TRWP -** A review of this literature was assessed in detail and deemed that at current concentrations, there is a minor risk towards the environment. Studies regarding the health effects of TRWP towards humans, in particular the inhalation of particles, was also deemed to be a minor risk.

- **Artificial turf -** Has been studied in great depth and despite ongoing contention related to environmental transport of particles from the EU commissions microplastics initiative, the literature generally agrees there is a minor risk towards the environment and human health.

- **Playgrounds and running tracks -** Has been examined by researchers internationally across a number of surfaces and assessed to have a minor risk towards the environment and human health.

- **Crumb rubber-modified asphalt -** An assessment of these studies suggests there is a minor risk to the surrounding environment and a minor/moderate fuming risk towards construction workers during asphalt construction. Importantly, recent studies comparing crumb rubber-modified asphalt and conventional asphalt have found the fumes and airborne particles are not above SafeWork Australia standards, are not carcinogenic and the inclusion of crumb rubber does not appear to increase negative symptoms for asphalt construction workers.

The recycling of rubber from EOLT has great environmental benefits due to the repurposing of an otherwise waste product, as well as additional benefits due to the improved performance features of many tyre-derived materials. However, TSA also acknowledges that any utilisation of recycled tyre material must be done so in a manner that is safe to the community and environment. The purpose of this research was to better understand and characterise these risks. The risk assessments conducted in this report are only a guide. They rely on the most current research and will require updating when new information and research is published. It is recommended that precautionary measures are maintained to eliminate any potential hazards created by mismanagement practices or identified knowledge gaps. As such, TSA will continue to remain vigilant in monitoring new information and research as it becomes available. TSA will also undertake research where appropriate and beneficial.

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Appendix

Figure 1: Risk Matrix and Risk Assessment

Consequences		
	Human Health	**Environment**
Severe	- Fatality due to injury or illness caused by exposure	- Irreversible environmental damage - Remediation clean-up for more than 1 year - Local community outrage
Large	- Permanent disabling injury or illness caused by exposure	- Long-term environmental damage or pollution - Clean up and rehabilitation more than 1 year
Medium	- Medical treatment required, loss of work time, illness caused by exposure	- Medium-term environmental harm or pollution - Clean up and rehabilitation requires less than 1 year
Small	- No long-term health effects, exposure may require first aid treatment	- Short term environmental harm or pollution - Clean up and rehabilitation requires less than 1 month
Insignificant	- No short or long-term health effects	- Minor environmental harm and pollution - Clean up requires less than 1 day

Likelihood	
Very High	- Almost certain to occur in identified situations with no controls in place - A trend in incidents, with near certainty it will occur again
High	- Likely to occur in identified situations without any controls - A trend in incidents but without certainty
Medium	- May occur in identified situations with no controls in place - Infrequent incidents
Low	- Could occur in identified situations with no controls in place - Small number of recorded incidents
Very Low	- Very unlikely to occur in identified situations with no controls in place - No evidence of incidents

Risk Matrix		**Consequences**				
		Insignificant	**Small**	**Medium**	**Large**	**Severe**
Likelihood	Very High					
	High					
	Medium					
	Low					
	Very Low					

Risk Rating: Negligible Minor Moderate Significant Critical

Table 4: Risk assessment of tyre particle sources towards the environment

Source	Potential Hazards	Potential Consequences	Risk rating		
			Magnitude	Likelihood	Risk Rating
Tyre and Road Wear Particles*	Ingestion of particles by organisms	Toxic effects on survival, growth and feeding	Medium	Low	Minor
	Chemical leaching causing toxicity in organisms	Zinc accumulation leading to mortality, developmental delays, immobility	Medium	Low	Minor
Artificial Turf Fields*	Ingestion of particles by organisms	Toxic effects on survival, growth and feeding	Medium	Very Low/Low (depending on RMMs)	Negligible Minor
	Chemical leaching causing toxicity in organisms	Zinc accumulation leading to mortality, developmental delays, immobility	Medium	Low	Minor
Playgrounds and Running Tracks**	Chemical leaching causing toxicity in organisms	Zinc accumulation leading to mortality, developmental delays, immobility	Medium	Low	Minor
Crumb Rubber-Modified Asphalt**	Chemical leaching causing toxicity in organisms	Zinc accumulation leading to mortality, developmental delays, immobility	Medium	Low	Minor

*Assumption: TRWP and artificial turf are loose rubber particles, and the environmental transport of both the physical particles and the chemical leachate present was considered during the assessment.

**Assumption: Playgrounds and running tracks and crumb rubber-modified asphalt products are a polymer bound product, with no loose rubber particles, and only the environmental transport of chemical leachate was considered during the assessment.

Table 5: Risk assessment of different tyre particles towards the human health

Source	Potential Hazards	Potential Consequences	Risk rating		
			Magnitude	Likelihood	Risk Rating
Tyre and Road Wear Particles	Inhalation of particles	Respiratory symptoms, inflammation, lung diseases	Medium	Low	Minor
Artificial Turf Fields (acute and lifelong exposure)	Inhalation of toxic fumes	Respiratory symptoms, inflammation, lung diseases	Insignificant	Low	Negligible
	Inhalation/ ingestion of particles	Respiratory symptoms, inflammation, cancer risks	Insignificant	Very Low	Negligible
	Dermal contact with particles	Inflammation, physical damage, cancer risks	Small	Medium	Minor
Playgrounds and Running Tracks (acute and lifelong exposure)	Ingestion of particles	Inflammation, physical damage, cancer risks	Insignificant	Low	Negligible
	Dermal contact with particles	Inflammation, physical damage, cancer risks	Insignificant	Medium	Minor
Crumb Rubber-Modified Asphalt (acute and lifelong exposure)	Inhalation of toxic fumes	Respiratory symptoms, inflammation, lung diseases, cancer risk	Medium	Medium (Low if PPE in place)	Moderate Minor if PPE in place
	Inhalation of particles	Respiratory symptoms, inflammation, lung diseases	Medium	Low	Minor