# Review: Health and Environmental Impacts of Used Tyre Crumb Rubber

## Report

**JBS&G 67800 | 165,029**

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JBS&G

**We acknowledge the Traditional Custodians of Country throughout Australia and their connections to land, sea and community.**

We pay respect to Elders past and present and in the spirit of reconciliation, we commit to working together for our shared future.

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# Abbreviations

| Term | Definition |
|---|---|
| Al | Aluminium |
| ATSDR | Agency for Toxic Substances and Disease Registry (USA) |
| AUSMAP | Australian Microplastic Assessment Project |
| BACT | Best available control technology |
| B[a]P | Benzo[a]pyrene |
| BHT | Butylated hydroxy toluene |
| BTZ | Benzotriazole |
| Ca | Calcium |
| Cd | Cadmium |
| CDC | Centers for Disease Control and Prevention (USA) |
| Co | Cobalt |
| Cr | Chromium |
| Cu | Copper |
| DCCEEW | Department of Climate Change, Energy, the Environment and Water |
| EC | European Commission |
| ECHA | European Chemicals Agency |
| EOL | End of life (tyres) |
| ETRA | European Tyre Recycling Association |
| Fe | Iron |
| HMMM | Hexa(methoxymethyl)melamine |
| IARC | International Agency for Research on Cancer (World Health Organisation) |
| K | Potassium |
| MBTZ | Methylbenzotriazole |
| Mg | Magnesium |
| µm | Micrometre |
| Ni | Nickel |
| nm | Nanometre |
| NSW | New South Wales |
| P | Phosphorus |
| PAH | Polycyclic aromatic hydrocarbon |
| Pb | Lead |
| 6PPD | N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine |
| 6PPD-Q | N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine quinone |
| S | Sulfur |
| Si | Silicon |
| TSCA | Toxic Substances Control Act (USA) |
| TPSS | Tyre Product Stewardship Scheme |
| TSA | Tyre Stewardship Australia |
| US EPA | United States Environmental Protection Agency |
| V | Vanadium |
| WHO | World Health Organisation |
| Zn | Zinc |

# Executive Summary

In September 2023, the European Commission implemented a ban on the sale of microplastics which are intentionally added to cosmetics, personal care products and detergents, as well as the use of (used) tyre crumb rubber as infill for synthetic turf sporting fields. The ban on intentional use of microplastics was primarily based on concerns about impacts to living organisms in the environment, including human health risks. The ban on crumb infill was initiated on the basis of health risks from exposure of users of the sporting fields to polycyclic aromatic hydrocarbons contained within the crumb rubber, with a particular focus on risks to children. An eight-year transition period was specified to phase out the sale of crumb as infill to accommodate the anticipated lifetime of synthetic turf sporting fields. Alternative infill products will be required for synthetic turf when the ban comes into force in 2031.

Used tyre crumb rubber is also used as infill for synthetic turf sporting fields in Australia. As such, a question arises as to whether the risks to users of those facilities are exposed to unacceptable health risks which may necessitate consideration and possible implementation of a ban on crumb rubber infill for synthetic turf installed in Australian sporting facilities. The impacts on the environment from infill that is unintentionally released from the turf and enters the environment may also present an unacceptable risk.

JBS&G has carried out a review of the more recent public domain literature on the health and environmental impacts from crumb rubber to identify if additional findings since the EC ban was implemented support a similar ban on crumb infill in Australia. This review is limited to information published since 2023 and as such, does not attempt to critique prior information and reports that informed assessments of risk for crumb infill. Government policy and initiatives for the beneficial use of used tyre products, guidance provided by regulatory agencies and published studies of health and environmental impacts from crumb rubber released into the environment have been considered, as well as the significance of tyre wear particles which are also released into the environment from the intended use of tyres. Furthermore, the review has examined an alternative approach to recovery of used tyre resources (pyrolysis), which presents different human health and environmental risks to the intentional use of crumb rubber as a beneficial use for used tyres.

The information reviewed has clearly demonstrated that crumb rubber is released from the fields and enters the environment, predominately via storm water run-off directly into nearby water courses and also via the stormwater systems. Other information has demonstrated specific toxic impacts from some of the chemicals within the rubber to various marine organisms. Evidence for impacts on human health are less compelling but are not contradictory to the studies that underpinned the EC ban. It is clear that more research is required to understand the risks in an Australian context.

As such, this review has concluded that a precautionary approach should be adopted by government and regulators to the use of crumb rubber infill for synthetic turf sporting fields. That precautionary approach could be extended to the use of crumb rubber for any application (such as playground mats, asphalt) where the crumb can, at some point in the lifetime of the application, be released into the environment. A precautionary approach could be in the form of new guidelines that require comprehensive environmental and human health risk assessments as part of the planning and approvals processes for new sporting facilities that will use synthetic turf, running tracks and playgrounds mats containing crumb rubber. The use of crumb rubber for asphalt manufacturing and road construction presents potential risks to the workers during construction, as well as longer term risks to the environment from road wear materials. That requirement could be extended to advice on alternatives to crumb rubber as infill or other purpose for the applications, or to consider alternative use for used tyre products such as pyrolysis.

Studies that include monitoring and assessments of impacts from existing synthetic sporting fields are required to inform the risk from an Australian context. The potential for long term adverse environmental and human health impacts from tyre crumb infill suggest other products should be utilised for synthetic turf infill in Australia, at least until additional studies are completed, and a low-risk outcome is demonstrated for crumb infill.

# 1. Introduction

Australia generates approximately 450,000 tonnes of used tyres per annum from approximately 563,000 tonnes of tyres purchased, which is the equivalent of 58 million passenger tyres (DCCEEW, 2024a). The use of landfill for management of end-of-life (EOL) tyres is no longer an acceptable approach, posing risk of adverse impacts to the environment arising from the long degradation times and release of chemical substances into the environment. Also, disposal via landfilling is a dead end for the materials EOL tyres comprise and doesn't allow realisation of the potential environmental and economic value of recovery of those resources. Used tyres can be considered as a resource if beneficial uses are identified for the tyre components (i.e., rubber, fabric and steel wire) which include as a fuel substitute for fossil fuels (coal, oil and gas) for energy production. Other beneficial uses have been identified for the rubber component in the form of tyre crumb rubber, which is generated from abrasive processing of the rubber. These uses include as an additive to asphalt for road construction, permeably urban paving, athletic tracks and playground matting, noise and acoustic barriers.[1] Thermal processing (pyrolysis) of tyre rubber enables recovery of oil and carbon char. These products have potential as an alternative source of gas, oil and carbon for a range of applications including fuels, chemicals and as a source of carbon black for re-use in rubber manufacturing.

The economic benefits of utilising used tyres as a resource can only be realised if the environmental impacts from the re-use of used tyre materials do not give rise to environmental harm to the ecosystem and human health. The use of tyre shred as a combustion fuel source has an economic benefit from substitution of a fossil fuel as well as diversion from landfill which mitigates the potential adverse impacts from breakdown of the rubber and release of toxic chemicals that may enter the environment. However, use as fuel is a dead end for most of the materials and the majority of the (non-biogenic) carbon in the rubber (and fabric) is oxidised to carbon dioxide which add to global greenhouse gas concentrations and consequent climate change issue. Also, other air emissions are generated from combustion of used tyre material which, in the absence of appropriate pollution controls, may have local adverse impacts on human health. This is of particular concern if EOL tyre shred[2] were exported from Australia and used for fuel purposes in jurisdictions that do not have stringent air quality regulations.

The use of tyre crumb rubber for the applications listed above (and others) presents a potential environmental risk from release of that material into the environment and subsequent physical and chemical degradation which may release toxic chemicals to a wider area than occurs from a landfill.

This review has been triggered by the ban implemented by the European Commission (EC) in September 2023 on the intentional placing on the market of microplastics, as a substance on their own or intentionally added to mixtures in greater than 0.01% by weight such as glitter, cosmetics, fertilisers, medical devices. Specifically described in the ban is the sale of tyre crumb for us as granular in-fill for synthetic sports surfaces, which is prohibited from 17 October 2031. In effect, the EC has determined that the human health and environmental impacts from in-fill crumb rubber are not acceptable and other approaches are required to dealing with EOL tyres.

Note that the ban specifically does not include the consequential release of tyre rubber into the environment from the normal use of tyres for road transport purposes. Tyre wear materials include tyre rubber but also include asphalt road surface wear materials. This raises the question as to whether the use of tyre crumb as an additive to asphalt for road construction is also undesirable from an environmental perspective, since that material will ultimately be released into the environment as the road surface wears.

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[1] See https://www.tyrestewardship.org.au/innovation/source-recycled-tyre-products/ for a list of recycled tyre products

[2] Tyre export is regulated under the Recycling and Waste Reduction Act 2020 and Recycling and Waste Reduction (Export-Waste Tyres) Rules 2021 and includes limiting export for tyre derived fuel to tyres that have been processed into shreds or crumb of not more than 150 millimetres https://www.dcceew.gov.au/environment/protection/waste/exports/tyres

As noted above, an alternative approach to the recovery of used tyres components as a resource involves pyrolysis to generate oil and carbon. This approach does not present the same potential for environmental risk from release of rubber microplastics from intentional use as infill materials. The toxic constituents (chemicals) in crumb rubber are either destroyed in the pyrolysis process or captured in those products where they can be managed in downstream processing for beneficial uses.

This review has therefore considered whether the use of tyre crumb rubber for sporting fields and related applications is appropriate from the health and environmental risk perspective, and whether thermal processing to recover valuable materials (oil and carbon) is a more appropriate strategy to deal with EOL tyres. The background to the EC ban has been examined in respect of the studies carried out that identified the environmental risks and informed an unacceptable risk outcome for the intentional use of microplastics and crumb rubber in particular. The reasons for the ban have been considered in respect of Australian initiatives for the use of crumb rubber and the potential environmental and human health impacts. Reports from studies conducted since the EC ban was implemented have been reviewed to identify current understanding of environmental and human health impacts. In effect, the risks identified for the use of tyre crumb rubber in Europe (and more recently the USA) have been considered in relation to their relevance to the Australian applications, and whether there is sufficient information available for government and regulators to consider a ban on use of crumb rubber for applications where the rubber can be released into the environment. The risks from the alternative approach to dealing with EOL tyres (that involves pyrolysis or similar) are discussed and considered for the potential applications for the valorisation products, such as the re-use of recovered carbon black from EOL pyrolysis for manufacturing of new tyres, and the use of pyrolysis derived oil as a feedstock for chemicals manufacturing or as an input into sustainable fuels production.

## 2. Current Australian Government Initiatives

EOL tyres have been included on the Federal Environment Minister's Priority List for 2022-2023 and again in 2023-2024 (DCCEEW, 2024a) to highlight a need for industry participation in the Tyre Product Stewardship Scheme (TPSS). TPSS has been implemented by Tyre Stewardship Australia (TSA) under an accreditation provided by the Department of Climate Change, Energy, the Environment and Water (DCCEEW) (2024b).

Two actions were indicated by the Minister in the 2023-2024 listing:

Actions

1. Manufacturers, importers, distributors and retailers must demonstrate improved and measurable product stewardship actions which could include any of the following: expanding and improving the industry-led product stewardship scheme (including through a significant decline in free riding); product design improvements and supply chain initiatives to increase durability, reparability, re-usability and/or recyclability; other supply chain initiatives that measurably support good product stewardship and circular economy progress. ***By November 2024***
2. To avoid government regulation, tyre importers not currently members of the Tyre Stewardship Scheme should commence formal participation. ***By November 2024***

Source: https://www.dcceew.gov.au/environment/protection/waste/product-stewardship/ministers-priority-list-23-24#tyres

The TPSS website describes the process behind the scheme, the benefits, funding arrangements and current practices for recycling and reuse of EOL tyres. A list of applications for tyre derived products and the goals for the scheme are described, as follows:

These tyre derived products can be used for purposes such as:

- crumbed rubber asphalt for improved road durability
- permeable urban paving to reduce run off and provide water to surrounding trees
- athletic tracks
- noise and acoustic barriers

Each year the scheme works towards these ambitious goals:

- increased use of Australian tyre derived products within Australia, including replacing imports of these products
- increased Australian capacity to manage end-of-life tyres in an environmentally sustainable manner
- growth in the number of organisations across the tyre industry participating in the scheme
- increased commercialisation of TSA's market development projects generating employment opportunities and new products utilising end-of-life tyres.

Source: https://www.dcceew.gov.au/environment/protection/waste/product-stewardship/ministers-priority-list-23-24#tyres

The DCCEEW has noted that the increase in industry participation since the initial listing has been minimal (DCCEEW 2024a), with reasons for that situation not discussed.

Data provided by the TSA for 2022-2023 shows approximately 320,000 tonnes per annum of EOL tyres were recovered with approximately 180,000 tonnes per annum disposed of in licenced landfills. The recovered tyres were utilised for re-treading or repaired, processed into tyre derived products (such as those listed in the TPSS), as a fuel (energy recovery) and for thermal processing. Approximately 70% of the recovered tyres were exported in 2022-2023 and 75% of the exports pre-processed (shredded) prior to shipping for use as a tyre derived fuel.

The TPSS goals include the increased use of tyre derived products within Australia, including replacing imported products with locally made products.

The applications listed by TPSS involve the use of crumb rubber, generated from mechanical grinding of tyre rubber after removal of the fabric (polyester) belt and steel wire components of a tyre. One of the applications listed in the Minister's Priority List is the use of crumb rubber for athletic tracks. Given the TPSS goals are to increase the use of tyre derived products then it is likely other types of sporting surfaces are prospects for the use of tyre derived products in their manufacturing.

One application in the sporting sector is the use of crumb as in-fill for artificial turf, which is specifically discussed in the EC ban. TSA provides a case study from 2016 on use of recycled tyre rubber granules for such applications as well as manufacturing of synthetic sporting fields and playground surfaces. The crumb rubber particles provide shock absorbing properties that are understood to reduce the risk of impact related injuries to participants.

However, the potential ecological and human health risks from the use of crumb rubber products in these and related applications must be considered to ensure no deleterious outcomes will arise. The TSA has considered these risks, with a literature review carried out and a report released in 2022 titled *Tyre Particle Health, Environment and Safety Report* (TSA, 2022).

# 3. TSA review of environmental and health risks from tyre road wear particles and tyre derived products

The TPSS list of applications focuses on re-use of the rubber component of EOL tyres and does not include thermal processing to recover raw materials for manufacturing of new tyres or other applications. The reason for the TSA focus on crumb re-use is unknown however it may be as a consequence of the applications provided by the TPSS.

With a focus on the re-use of crumb, the TSA review examined reports from 14 peer-reviewed scientific studies on tyre road wear particles and 10 studies on tyre derived products being rubber crumb (granules) utilised for artificial turf (TSA 2022). As indicated above, the review found that tyre derived products are safe materials to use in Australian markets with an overall minor risk to human health and the environment. TSA made a recommendation that precautionary measures are maintained to eliminate any potential hazards created by mismanagement practices or to identify knowledge gaps.

The review has specifically addressed tyre road wear particles and tyre derived products as separate risks. That approach was justified on the basis that tyre road wear particles tend to have smaller particle size distributions compared with tyre derived products. In particular, the size distribution of tyre road wear particles is reported (by TSA) as 0.005-0.25 mm whereas crumb rubber tyre derived products is 0.5-1.2 mm and rubber granules is 1-5 mm. From a microplastics perspective, tyre road wear particles can be considered as the finer size fraction of microplastics and the crumb and granule in the coarser size fraction.

The ecological and human health risks are likely to be influenced by particle size, so the approach adopted by TSA appears appropriate. An example is inhalation risk, where the size of inhaled particles is a key factor in uptake and elimination of particulate matter that can dictate human health impacts.

The TSA review has correctly noted that the composition of the tyre road wear particles and tyre derived products the volumes produced and whether the particles are bound or unbound, are key considerations for the risk assessment.

A summary of key findings from the TSA review is reproduced 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.

Source: TSA (2022)

The finding that tyre road wear particles provides a minor risk towards the environment is based on assessments of ecological risks primarily from toxic effects of leachable chemicals present in tyre rubber, with a smaller number of studies focused on physical impacts from ingestion of rubber particles. Studies of impacts of tyre road wear particles and tyre rubber particles on algae, crustaceans, frog embryos and larvae, zebra fish eggs, cyprinid (carp & minnow fish) and salmon were reviewed.

That review has included consideration of health risks from exposures to tyre and road wear particles and crumb rubber utilised for artificial turf, playground and running surfaces. The review concluded that:

- Tyre derived products are safe materials to use in Australian markets with an overall minor risk to human health and the above organisms, and
- It is recommended that precautionary measures are maintained to eliminate any potential hazards created by mismanagement practices or identify knowledge gaps.

As indicated above, that review was published in 2022. Since then, the stance on the suitability of tyre crumb rubber for those applications has been challenged by the European Commission ban on the bringing to market

of microplastics, or product mixtures containing microplastics, including the intentional use of tyre crumb . The European ban is discussed below in Section 4.

# 4. European Commission Initiatives

## 4.1 Microplastics Ban

As noted above, the EC ban is relevant to the intentional use of microplastic. Microplastics are defined by the World Health Organisation (WHO 2022) as:

> *A material consisting of solid polymer-containing particles, to which additives or other substances may have been added, and in which ≥ 1% w/w of particles have (i) all dimensions 1 nm ≤ x ≤ 5 mm, or (ii), for fibres, a length of 3 nm ≤ x ≤ 15 mm and a length to diameter ratio of > 3.*

The definition covers size ranges from 1 nanometre (1 nm) to 5 mm, with nano-plastics being a subset of microplastics (size range 1-1000 nm). The definition includes fibrous materials with an aspect ratio of > 3. Polymers that occur naturally and have not been chemically modified (other than by hydrolysis) or are biodegradable are not considered as microplastics from an environmental impact perspective.

The European Chemicals Agency (ECHA) defines microplastics as:

> *...small pieces (typically smaller than 5mm) of ... solid plastic particles composed of mixtures of polymers and functional additives. They may also contain residual impurities. Microplastics can be unintentionally formed when larger pieces of plastic, like car tyres or synthetic textiles, wear and tear. But they are also deliberately manufactured and added to products for specific purposes, such as exfoliating beads in facial or body scrubs.*

Tyre derived products (as crumb rubber) can thus be considered as a microplastic.

In regard to the European ban on the sale of microplastics, the European Commission (EC) adopted Regulation EU 2023/2055 in September 2023 "*that restricts synthetic polymer microparticles on their own or intentionally added to mixtures with the aim of reducing the emission of microplastics in everyday products in order to protect the environment*" (EU 2023). This restriction came into force immediately with transitional periods provided for the phasing out of the use of various types of microplastic materials. The Regulation has considered tyre derived crumb rubber as a microplastic, with the sale of granular in-fill (crumb rubber) for synthetic sports surfaces prohibited from 17 October 2031.

This ban casts some doubt over the suitability of tyre derived products in the microplastic particle size for applications whereby those rubber particles can enter the environment and impact upon ecosystems as well as potentially give rise to human health exposure risks.

The restriction on the sale of granular in-fill appears to be based on findings from a ECHA study "*Investigation of concentration limit for eight PAHs in loose rubber granules and mulches used in children's playground and other domestic applications to conclude whether the limit values set in Entry 50 of REACH Annex XVII are protective for very young children*" (ECHA 2023). That study was commissioned by the EC to assess exposure risks for eight polycyclic aromatic hydrocarbons (PAHs) (known as REACH-8 PAHs) that are present in tyre rubber. A 20 mg PAH/kg rubber concentration limit (EC 2021) was adopted for tyre rubber for playground and sporting applications as being protective of children's health.

PAHs are known human carcinogens (cancer forming) and genotoxic (causes cell mutation) substances that can also give rise to non-cancer impacts such as obstructive lung diseases and cardiovascular diseases (WHO 2021). Limited epidemiological evidence from animal studies has suggested a link between early life exposures to airborne PAHs and cognitive and behavioural function issues that may manifest in children (WHO 2021). The 20mg/kg EC and ECHA limit on PAH content in tyre rubber has been applied to address those risks (EC 2021).

The EU ban on intentionally added microplastics was first initiated with a proposal by ECHA in January 2019. The TSA review into the ecological and human health risks from the use of crumb rubber products was concluded in 2022. As such, the TSA study was not party to the more recent deliberations of the EC that led to the microplastic ban on 23 September 2023, as well as more recent studies and assessments conducted by other jurisdictions (in particular the US EPA and NSW Government) and independent researchers. JBS&G has examined the information and studies considered by the EC in the risk assessment behind the decision to implement a ban. We have also examined the information and studies referenced by the TSA in its 2022 review and more recent published findings on environmental and human health risks from tyre derived microplastics. This paper describes the information reviewed and our findings in respect of those risks.

## 4.2 Tyre Wear Particles

The EC has proposed new Euro 7 standards that tighten up requirements for exhaust emissions from internal combustion engine vehicles but also tackles emissions from brakes and tyres (EC 2022). The proposed new standards are intended to augment the environmental benefits from decline in exhaust emissions from the vehicle fleet with the uptake of electric vehicles. The proposed regulation of (particulate) emissions from brakes and tyres is pertinent to all types of vehicles and will be the first regulatory instrument to address those sources of emissions.[3]

Operation of vehicles gives rise to non-exhaust particulate emissions including brake wear particles , tyre-road contact particles which are comprised of tyre wear particles , road wear particles and re-suspended road dust (Beji *et al* 2023). Of relevance to this review is tyre-road contact particles and its components (tyre wear particles and road wear particles).

Tyre wear particles are comprised of carbonaceous materials (rubber and additives), silicon (Si) zinc (Zn) and sulfur (S) (from vulcanising agents) (Wagner *et al* 2024). Other metals including cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and vanadium (V) were identified in tyre tread and thus are also expected in Tyre wear particles. Road wear particles are carbon rich (from the bitumen used in the asphalt) and contain various metals (as oxides) from the aggregate including calcium (Ca), iron (Fe), aluminium (Al), silicon (Si), magnesium (Mg), phosphorus (P) and potassium (K) (Beji *et al* 2023). Road wear particles derived from asphalt manufactured containing tyre crumb rubber will also present the additives associated with the tyre rubber. These include the elements listed above as well as vulcanising agents, plasticisers, antioxidants/ozonates (predominately 6PPD) [4] and oils.

The potential for human health impacts from exposures to the above metals and chemicals is determined based on the toxicological data and the extent and route of the exposure. The publications reviewed include description of the assessments of the risk of adverse health and environmental impacts from the release of crumb rubber (and associated chemicals constituents) into the environment. Metals known to be in tyre rubber, as listed above, include some with toxic impacts; a summary of those impacts provided in Table 4-1 to provide a reference for the discussions below.

[3] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495
[4] 6PPD is N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine

**Table 4-1: Toxicology of in tyre rubber metals**

| Chemicals in tyre rubber | Toxicology | Reference |
|---|---|---|
| Cadmium (Cd) | Human carcinogen, toxic impacts on kidneys, skeletal and respiratory systems | https://www.who.int/teams/environment-climate-change-and-health/chemical-safety-and-health/health-impacts/chemicals/cadmium |
| Chromium (Cr) | Hexavalent chromium is a known human carcinogen, whereas the trivalent form is of low toxicity. Cr in tyre rubber is likely to be present as the trivalent form. | https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=60&toxid=17 |
| Lead (Pb) | Cumulative toxicant, adverse impacts on neurologic, hematologic, gastrointestinal, cardiovascular, and renal systems. Children are particularly vulnerable to the neurotoxic effects of lead, and even relatively low levels of exposure can cause serious and in some cases irreversible neurological damage. | https://www.who.int/teams/environment-climate-change-and-health/chemical-safety-and-health/health-impacts/chemicals/lead |
| Nickel (Ni) | IARC Group 1 human carcinogen. | Genchi et al (2020) |
| Vanadium (V) | Possible humans carcinogen (IARC) | https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=274&toxid=50 |

Vulcanising agents and accelerators are sulfur based chemicals added to tyre rubber monomers (e.g., styrene-butadiene) to generate cross-linking in the polymerisation process that provides a structurally strong but flexible rubber matrix. Elemental sulfur is predominately used along with a large number of organosulfides, including thiazoles, sulfenamides, guanidines, thioureas, thiuarms and dithiocarbamates. The toxicology of some examples are listed below.

- Tetramethylthiuram disulfide – tumour initiating and promoting in mice (Shukla at al 1996)
- Dipentamethylenethiuramtetrasulfide – skin irritant[5]
- 2-Morpholinodithiobenzothiazole – animal toxicity studies have not found significant toxic impacts[6]
- Dithiomorpholine – corrosive (skin)[7]
- Caprolactam disulfide – toxic to aquatic organisms, human skin and eye irritant[8]
- Alkyl phenol disulfide – degradation products (alkyl phenols) are toxic to aquatic organisms[9]

Notwithstanding the similarities in chemical composition, the impacts from tyre wear particles and crumb infill that are released into the environment are unlikely to be similar due to differences in exposure mechanisms. Differences in physical properties, in particular particle size, will influence exposure mechanisms which may manifest as differences in risk. Of relevance is the large difference in tyre wear particles input to the environment compared with crumb infill. Authors of a 2017 review paper estimated total tyre wear in 13 countries for nominal 2013 and 2016 of 3.4 million tonnes, with the USA contributing 1.5 million tonnes/year, China 760,000 tonnes/year, India and Brazil 290,000 tonnes/year, Japan 230,000 tonnes/per year. Australia contributes 20,000 tonnes/year (Kole *et al*, 2017). Emissions per capita are dominated by the USA (4.7 kg per

[5] https://pubchem.ncbi.nlm.nih.gov/compound/Dipentamethylenethiuram-disulfide
[6] https://dra4.nihs.go.jp/mhlw_data/home/file/file95-32-9.html
[7] https://pubchem.ncbi.nlm.nih.gov/compound/Thiomorpholine#section=Safety-and-Hazards
[8] https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/72312
[9] https://pubmed.ncbi.nlm.nih.gov/8013351/#:~:text=The%20most%20potent%20of%20the,to%20these%20estrogenic%20alkylphenolic%20compounds.

person/year), with Australia fifth highest at 0.87 kg per person/year. Presumably the higher USA rates reflect a higher vehicle ownership per person and associated greater distance travelled by the vehicle fleet compared with other countries.

In contrast, the EC has estimated that crumb rubber infill emissions to the environment are 16,000 tonnes per year,[10] based on an average of 500 kg per full size sporting field (football/soccer pitch) and 32,000 pitches in Europe. That infill loss has been refuted by European Tyre Recycling Association (ETRA). In particular, the ETRA claim the estimated total infill loss equates to 30 g per person per year, whereas the adoption of risk management measures would give rise to 3 g per person per year.[11] That equates to 0.03% of the total tyre wear. The ETRA notes that the destination for the crumb infill release is '*turf surroundings*'. That is unlikely to be entirely true, since run off from synthetic turf playing fields could conceivably enter nearby water courses and stormwater systems, which in many locations discharge directly to rivers or the ocean, that could be well removed from the 'surroundings' of the playing field. The ETRA does not support its assertions with any evidence and, as such, a low weight is placed upon those assertions.

A key difference in the environmental and human health risks from the use of crumb infill versus tyre wear particles is the fact that release of the wear particles arises as a consequence of the intentional use of tyres, whereas the intended use of crumb infill is for the amenity of users of sporting fields. That amenity extends from enhanced playing performance from a superior surface to a reduction in injuries from the cushioning afforded by the rubber. It is not the intention for infill to be released from the sporting fields into the environment where it can give rise to adverse impacts, nor is it the intention to provide a material risk to the health of the users of the sporting fields made from synthetic turf. As such, it appears illogical to permit the use of crumb rubber where that material can be released into the environment.

# 5. NSW Initiatives

## 5.1 EPA 2022 study

The NSW Office of the Chief Scientist and Engineer (OCSE) commissioned a review (NSW review) in November 2021 of the "*design, use and impacts of synthetic turf in public open spaces*" (NSW Government 2022). This is a comprehensive study that describes all aspects of environmental and health impacts from synthetic turf, which includes turf with crumb rubber infill. A conservative estimate was presented of approximately 181 synthetic turf sports fields in NSW with many featuring long synthetic blades supported by infill. Infill was cited as most commonly styrene butadiene rubber (SBR) crumb sourced from recycled tyres. The review was informed by extensive work conducted by technical specialists (reports presented in the review appendices). A detailed critique of the review is beyond the scope of this assessment; however some key findings are presented below that inform the potential risk from use of tyre crumb infill.

A key finding from the NSW review was that there is a lack of data on specific synthetic turf and infill used in NSW, with more data required to inform potential health and environmental impacts.

Human health impacts were considered from the use of crumb infill that include injuries and heat stress, with chemical, microplastic and microbiological exposures also examined. The health risk assessment considered risks for exposures to PAHs, metals, volatile organic chemicals, plasticisers and antioxidants as components of crumb rubber.

Inhalation and dermal exposures to PAHs and heavy metals in the rubber were noted as primary routes for health risk with the current understanding (at that time) that the risk is within acceptable limits. The NSW

[10] https://echa.europa.eu/hot-topics/microplastics
[11] https://etra-eu.org/index.php/news/is-the-infill-ban-the-scapegoat-to-divert-attention-from-most-dangerous-microplastics

review noted the EC's 20 mg/kg restriction on carcinogenic PAHs in crumb rubber infill for synthetic turf pitches, playgrounds and other sports applications (ECHA 2023).

The NSW review concluded that although health risks from chemicals in synthetic turf are likely to be very low, *"...progressive restrictive measures to limit potentially harmful chemicals in synthetic turf components may reduce unforeseen consequences to health"*.[12]

The NSW review found that risks from airborne pollutants released from crumb infill have not been well studied. Volatile organic compounds and semi-volatile organic compounds are released from the turf at higher temperatures, which provides an inhalation exposure risk. Longitudinal studies of adequate sample size are required to understand long term risks, in particular to children.

In respect of environmental impacts, the review discusses risks from storm water and run-off migration (water pollution) and impacts on soils in areas surrounding the sporting fields from the chemicals within the crumb and ingestion of crumb microplastics by fauna. Dispersal routes include "walk-off" on players footwear, clothing and skin, maintenance equipment, removal with leaves, splash from play, wind and runoff. The microplastic pollution may extend to wastewater from the players homes where clothes are washed.

Of note is the observations reported by the authors where "*significant quantities of infill and turf blades were regularly observed around and near fields...*".[13]

From examination of information from European studies, the independent review conducted by UNSW Water research Laboratory (Appendix 4 to the NSW review) concluded that 10 to 100 kg of infill is likely to be transported to the stormwater system or waterways from a synthetic turf field each year. The NSW review also noted that 100s of kg of synthetic turf fibres may also be lost along with the crumb infill material.

The overall amounts of tyre crumb infill lost will depend on total number of sporting fields, the type of synthetic turf used, the amount of infill and the management of surface water including any containment measures to prevent entry of the crumb into the environment. The age of the field may also impact on the rate of infill loss as the turf fibres deteriorate and the infill is more exposed to sporting participants and prevailing weather. Furthermore, sporting amenities are often located in low lying areas not suitable for other infrastructure, therefore the impact of flooding events should also be a consideration.

The substances examined for human health risks were also considered for an environmental risk assessment. Not discussed was the environmental risk for release of 6PPD and its oxidation product 6PPD-quinone from crumb rubber that reports to waterways and the marine environment. It is noted that recent detailed toxicological studies on 6PPD postdate the NSW review. 6PPD is an antioxidant/antiozonant substance added to tyre rubber to prevent oxidative degradation of the rubber. These substances are highly toxic to fish and other marine fauna (Ihenetu *et al*, 2024). The impacts from tyre wear material entering the marine environment are the subject of legal proceedings in the USA, and have been recently identified by US EPA for technical review (US EPA 2024a and 2024b) (see discussion in Section 6.2).

The Chief Scientist's review, which also considered heat island effect and bushfire risk, examined alternatives to crumb tyre rubber, including ethylene propylene diene monomer (EPDM) and thermoplastic elastomers, plant derived materials (cork, coconut husks) and bioplastics as well as the potential for fourth generation synthetic turf that eliminates a requirement for shock absorbing infill. The use of cork for infill, which is biodegradable and less flammable than tyre crumb, is commercialised, whereas the others may require more research and development. Successful implementation of these alternatives will eliminate the risk from crumb tyre rubber lost to the environment from synthetic turf playing fields.

[12] Page 43 of NSW 2022
[13] Page 51 of NSW 2022

Recommendations were made to reduce potential human health environmental impacts from synthetic turf (reproduced below):[14]

> ### 6.3 Recommendations
>
> Given longer-term climate and heat projections, attention should be given to mitigating environmental risk in existing and planned synthetic turf installations, implementing best practice natural turf management, advancing materials research into new alternative materials. A set of requirements for approval and funding of synthetic turf fields is needed to assist with the management of identified environmental issues, and the identified data gaps that currently limit decision-making and innovation.
>
> Specific recommendations have been developed to allow NSW to reduce potential human health and environmental impact of synthetic turf through planning, design, and mitigation measures. These focus initially on managing pollutant 'runoff' and 'walk-off' risks and exploring the potential of best-practice design and maintenance of natural turf fields to meet increasing use requirements.

Specific approval conditions for assessment of cumulative impacts related to heat, extent, light, soil and water health, containment measures and stormwater treatment as well as flood and fire risk.

Overall the recommendations suggest a precautionary approach should be applied to current and future use of synthetic turf, with an apparent preference for better managing natural turf facilities instead of using synthetic turf.

## 5.2 Department of Planning, Housing and Infrastructure guidelines

The NSW Department of Planning, Housing and Infrastructure has issued draft guidelines on *Synthetic Turf in Public Open Space* for public exhibition from 17 March to 29 April 2024 (DPHI, 2024). The guidelines are intended to inform decision makers of factors to be considered in deciding to utilise natural or synthetic turf for sporting fields. Environmental considerations are described that negative effects such as air and water pollution from rubber crumb, which are described as "*a key concern*"[15], waste disposal issues from end of life synthetic turf, and inferior greenhouse gas performance compared with natural turf. The guidelines also go on to note that "*Research has suggested that biological pathogens, toxic chemicals, and micro-plastic ingestion are all risks to human health that are associated with synthetic materials*".[15] The guidelines also describe positive attributes of synthetic turf, in particular reduced water usage.

The Guidelines discuss design considerations which makes reference to loss of infill material and risks from ingestion, lodgement, inhalation and skin contact. Infill loss via runoff is also discussed with a comment that the design must prevent loose material from being carried offsite and into surrounding waterways or stormwater systems.

## 5.3 Moore Park synthetic turf replacement

Consistent with the EPA 2022 study recommendations is the recent refurbishment of the Moore Park (Sydney) All-Weather Sporting Field (Robertson Rd, Moore Park), where the existing synthetic turf with crumb rubber infill has been replaced with synthetic turf with 'organic' infill (Centennial Parklands, 2024). The replacement has been required because of greater than expected aging of the turf. A recent news article advises that the 'organic' infill is a 'cork-based' material.[16] Cork is a layer of bark from the cork oak (predominately *Quercus sp*) which is comprised of naturally occurring organic polymers suberin, lignin, and polysaccharides, with

[14] Page 60 of NSW 2022
[15] Page 18 of DPHI, 2024
[16] https://www.news.com.au/lifestyle/health/health-problems/toxic-dark-reason-behind-moore-park-oval-removal/news-story/5afdf869134ecb76bcff016148a30776

monosaccharides (such as glucose) also present. In contrast to crumb rubber, cork is completely biodegradable and does not generate toxic chemicals in the environment.

The news article includes commentary from the Australian Microplastic Assessment Project (AUSMAP) Program Director Dr Michelle Blewitt regarding the environmental risks from crumb infill and AUSMAP's call for a 5-year moratorium on new approvals for synthetic turf playing fields. The news article also quotes the Greater Sydney Parklands spokesperson that *"The resurfacing has adopted modern standards and materials with an organic infill material being used to replace the old crumb rubber."*

A precautionary approach appears appropriate from consideration of the design guidelines, the NSW Chief Scientist's findings and the DPHI 2024 draft guidelines in respect of environmental risks from crumb rubber infill. The decision by the Greater Sydney Parklands to replace crumb with cork infill for the Moore Park refurbishment is consistent with a precautionary approach.

# 6. Recent US Litigation and US EPA Initiatives

The potential for environmental risks from release of tyre rubber into the environment is being legally tested via litigation initiated in the USA [17] and risk management 'rule-making' announced by US EPA (2024). The risks for consideration are from the release of 6PPD and it's degradation product 6PPD-quinone.

## 6.1 Litigation

An environmental law firm Earthjustice has commenced litigation in the US District Court (Northern District of California) against US tyre manufacturers including Goodyear, Bridgestone and Continental, seeking declaratory and injunctive relief from the use of 6PPD in the manufacturing of tyres (Case No. 3:23-cv-5748, filed 8 November 2023).[17] The plaintiffs in the matter are the Institute for Fisheries Resources (IFR) and the Pacific Coast Federation of Fishermen's Associations (PCFFA). They allege devastating impacts on endangered and protected salmon and steelhead fish species under the US Endangered Species Act (ESA) from exposure to 6PPD degradation product 6PPD-quinone (6PPD-Q), which is formed from oxidative breakdown of 6PPD entering the environment from tyre wear material. The chemical structures of 6PPD and the quinone are shown in Figure 6.1

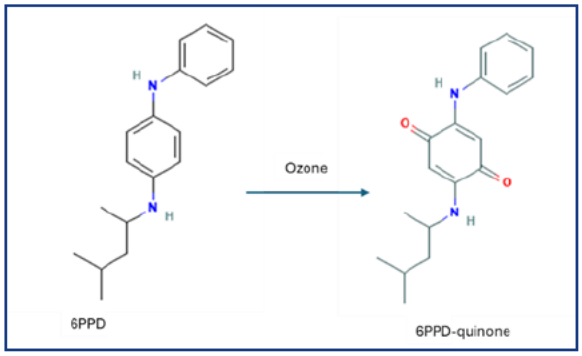


**Figure 6.1: Structures of 6PPD and 6PPD-quinone**

The legal matter is not directed specifically at crumb rubber as the source of 6PPD and 6PPD-Q but is looking at all sources of tyre rubber that enters the environment, in particular tyre wear particles. The Defendants in the matter sought a stay from the proceedings which was rejected by the Court. [18] Timing for a hearing is not known.

[17] https://www.reuters.com/legal/government/tire-makers-say-lawsuit-over-fish-killing-chemical-sidesteps-epa-2024-03-11/
[18] https://casetext.com/case/inst-for-fisheries-res-v-contl-tire-the-ams

## 6.2 US EPA Initiatives

Separate to the legal action, the Yurok, the Port Gamble S'Klallam and the Puyallup Tribes of Indians submitted a petition to the US EPA to establish regulations prohibiting the manufacturing, processing, use and distribution of 6PPD in tyres (Earthjustice, 2023). The US EPA subsequently granted that petition to address the use of 6PPD in tyres to help protect the allegedly affected fish species (salmon) (US EPA, 2023). The agency agreed with petitioners that it was "*necessary to initiate risk management rulemaking under the Toxic Substances Control Act to address risk to the environment from 6PPD-quinone, a degradant of 6PPD.*" The US EPA noted that "*concentrations of 6PPD-quinone in stormwater in the Pacific Northwest were found to be lethal to coho salmon after only a few hours of exposure.*"

The US EPA released advance notice of proposed rulemaking on 6PPD on 19 November 2024 (USEPA 2024a) and more recently finalised a rule under Section 8 of the Toxic Substances Control Act (TSCA) that requires manufacturers (including importers) of 6PPD to report (to US EPA) copies of unpublished health and safety studies on 6PPD and 6PPD-quinone (US EPA, 2024b).

It appears from the information provided by US EPA that the December 2024 rule requiring reporting of unpublished health and safety studies is intended to ensure the agency is fully informed of risks from 6PPD prior to making a determination on prohibiting this chemical in tyres. The implications of this initiative for Australia in respect of risk to fish species (and any other water fauna) from ingress of 6PPD into marine and freshwater environments from the use of tyres are unknown at this time. The known lethality of 6PPD and 6PPD-quinone for North American salmon suggests studies should be carried out as a priority to establish the ecotoxicity for fish and other water fauna of this chemical and the quinone in Australian waters. However, until such studies are carried out, it prudent that a precautionary approach be adopted in Australia, where the intentional introduction of tyre rubber (i.e., crumb) is not permitted. The wider issue of environmental harm from tyre wear particle derived 6PPD entering the environment will require a change in the formulation of tyre rubber to substitute 6PPD for another antioxidant/antiozonant substance that is not toxic to the environment. Such as change is unlikely to occur in the near future and the legacy risk from the pre-existing tyre fleet will remain until the new formulation is fully established in the tyre manufacturing process.

Until then (and as indicated above), a precautionary approach is advocated to follow the lead from EC and prohibit the use of crumb for infill or any application where that material can enter the environment.

## 6.3 US EPA/CDC/ATSDR study

The US EPA , Centers for Disease Control and Prevention (CDC) and Agency for Toxic Substances and Disease Registry (ATSDR) have released a series of reports on a joint long term study into the health impacts from tyre crumb infill on synthetic sporting fields.[19] Of direct relevance is the report on the exposure characterisation. (US EPA/CDC/ATSDER 2024). Key findings from the study are:

- Relatively small amounts of volatile organics are released from crumb to air, however ambient concentrations of some volatiles were elevated compared with background levels.
- Only small fractions of metals are released from crumb into biological fluids, with those concentrations in the study cohort similar to the general population.
- No differences in PAH metabolites were observed in the study cohort using synthetic turf sporting fields compared with those using grass fields.

The study did not constitute a formal health risk assessment and was only intended to determine the exposure risks. The environmental impacts from release of tyre crumb infill were outside the scope of the study.

[19] https://www.epa.gov/chemical-research/tire-crumb-research-public-and-stakeholder-engagement-resources

The results provide a baseline for further studies into the health impacts and risk associated with the use of crumb as infill for sporting fields. No conclusions were made in respect of those risks.

# 7. Other studies on environmental impacts of tyre crumb

As noted above, the EC ban was implemented in late 2023. A review of more recent public domain literature has been carried out to identify more up-to-date understandings of tyre crumb environmental and human health impacts and risks. Some earlier publications that examined tyre crumb risks were also reviewed. Findings from some publications of relevance are described below. Note that this review is not exhaustive and not all publications of relevance have been examined.

## 7.1 Zuccaro *et al*, 2024

Zuccaro and colleagues recently published an opinion piece (Zuccaro *et al*, 2024) which considered the basis and significance of the EC 2023 ban on microplastics that includes crumb rubber infill. The paper concluded that the bans implemented by other countries (other than the USA) on microplastics in personal care and detergent products, which constitute on 2% of the total microplastic environmental burden in Europe, will not make a significant (beneficial) impact on the environment. Nonetheless, the paper opines that '*it is time for the U.S. Environmental Protection Agency (EPA) and the regulatory bodies of other countries to follow the EU in reining in microplastic pollution*', with tyre crumb infill included in such initiatives.

## 7.2 Ihenetu *et al*, 2024

Ihenetu and colleagues (2024) have published a review of the environmental fate of 6PPD and 6PPD-Q, the antioxidant and degradation product from tyre rubber. The review included a comparison of thermal processing techniques that can be used for conversion of waste rubber into valuable products.

The authors found that these substances can accumulate in aquatic organisms and transfer through the feed chain, with the toxicity of these substances presenting "*significant ecological and human health challenges.*" Reference studies cited by the authors indicate that pyrolysis or similar thermal processes provided a mitigation strategy for impacts caused by release of 6PPD and 6PPD-Q into the environment.

## 7.3 Rauert *et al*, 2022

Researchers from the University of Queensland (UQ) and Department of Environment Science and Innovation (DESI) published two papers in 2022 on their findings from measurements of microplastics that include tyre wear particles in surface waters from Brisbane and four regional urban areas in Queensland. The first paper (published January 2021) reported the detection and distribution of 6PPD-Q and a range of tyre rubber additives including vulcanising accelerators, antioxidants and tyre bonding agents in the Cubberla Creek, a south-western tributary of the Brisbane River (Rauert *et al* 2022a). The collection site was 160 m downstream of the M5 Western Freeway and 1.8 km from a major highway (Moggill Rd).

The Rauert study demonstrated that tyre wear particles do report to the nearby waterways and leach chemicals from the rubber, with the known toxic 6PPD-Q ubiquitous in the samples. The authors noted that similar traffic counts were reported for the Western Freeway as for the Highway 509 in Washington, nearby to Miller Creek sampling site where the coho salmon mortality was observed. This suggests a potential for similar adverse impacts to vulnerable fish species in the Brisbane waterways. However the authors found that the measured concentrations of tyre wear particles derived substances normalised for population densities were 2-15 times lower than those reported for surface waters in Toronto and Seattle. They hypothesised that the lower tyre wear particles concentrations reflected the use of all-season tyres in Australia which have lower tyre wear particles rates compared with the summer and winter tyres used in the northern states of the USA.

The second publication extended the study to four regional urban centres along the Queensland coast (Rauert *et al* 2022b). Similar profiles of tyre wear particle derived chemicals were measured in surface waters at those locations, but with lower concentrations. The authors concluded the measured levels constituted baseflow or baseline concentrations that will assist to identify changes from future increases in traffic volumes.

Overall, the UQ/DESI studies have clearly demonstrated that the environment is already challenged by chemicals in tyre rubber.

These findings suggest that the intentional use of crumb rubber for applications where the crumb is can be inadvertently released into the environment constitutes a risk that should be avoided, with measures implemented to prevent such releases, including a requirement to use alternative materials for infill.

## 7.4 Graça *et al* 2022

These authors reported findings from measurements of metals in EOL tyre crumb rubber collected from artificial turf fields in multiple countries (Graça *et al* 2022). A wide range of concentrations were observed for the most abundant metals (Zn, Fe, Mg, Al). The levels were mostly above safe limits from EC Directives for soils and toy materials. However, a multi-pathway human exposure study showed non-carcinogenic and carcinogenic risks from accidental crumb ingestion were above acceptable values for all but adult bystanders at sporting fields, with a higher significance for younger participants. Those risks were driven by chromium (Cr) and lead (Pb) levels in the rubber (see Table 4-1 above for more details on toxicology of these metals).

The results are somewhat contradictory to other studies carried out prior to this study, with the authors noting "*these results bring a different perspective regarding most of the studies reporting low risks related with exposure to metals in crumb rubber*".

The uncertainties provided from contradictory studies provide support for a finding that a precautionary approach may be prudent for approval of crumb rubber infill for synthetic turf sporting fields.

## 7.5 Armada *et al* 2024

Armada and colleagues have reported findings from a study of bio-accessibility[20] of a range of chemicals in tyre rubber including eighteen PAHs, 6PPD, 6PPD-Q, the cross-linking agent HMMM, [21] and vulcanisers BTZ and MBTZ.[22] The study was the first that demonstrated the bio-accessibility of the above listed substances from tyre crumb rubber, as employed for infill.

As discussed above in Section 4.1, PAHs are known human carcinogens and genotoxic substances that can also give rise to non-cancer impacts such as obstructive lung diseases and cardiovascular diseases (WHO 2021). More specifically , one of the PAHs identified in tyre rubber (benzo[a]pyrene) by Armada and colleagues is classified by the IARC as a Group 1 known human carcinogen,[23] with others classified as Group 2A probable human carcinogens and Group 2B possible human carcinogens. Nine of the listed PAHs have not been classified because of limited or inadequate experimental evidence.[23] A list of PAHs found in tyre rubber and their carcinogenic classifications is shown in Table 7-1.

The Armada study found that the more volatile PAHs achieved the highest bio-accessibilities, with benzo[a]pyrene detected in 75% of samples of bio-accessible fractions.

Assessments of carcinogenic impacts from PAHs are typically carried out using the combined potency of the individual PAH substances (ATSDR 2022a). Potency equivalence factors (PEFs) have been developed for individual PAHs which are referenced to the potency of benzo[a]pyrene (PEF of 1.0). The concentrations or

[20] Bio-accessiblity is the fraction of the total amount of a substance that is potentially available for absorption in target organisms, seehttps://dtsc.ca.gov/wp-content/uploads/sites/31/2021/03/Bioaccessibility-Def-A.pdf
[21] HMMM = Hexa(methoxymethyl)melamine
[22] BTZ = benzotriazole, MBTZ = methyl benzotriazole
[23] See https://www.ncbi.nlm.nih.gov/books/NBK570325/ for carcinogenic classifications of PAHs.

dose rates of individual PAHs are factored by their respective PEFs and the total of the individual PEF weighted concentrations or dose rates added to generate a single B[a]P equivalent concentration. The PEFs for the individual PAHs are included in Table 7-1.[24] One of the PAHs listed (dibenzo[ah]anthracene) is a 2.4 times more potent carcinogen that B[a]P, others are less potent which is reflected in the IARC classifications.

**Table 7-1: Tyre rubber PAHs and IARC carcinogenic classifications**

| PAH | Abbreviation | IARC group | Classification | PEF |
|---|---|---|---|---|
| Naphthalene | NAP | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Acenaphthylene | ACY | N/A | not classified | 0.001 |
| Acenaphthene | ACE | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Fluorene | FLU | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Phenanthrene | PHN | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Anthracene | ANC | 3 | not classifiable as to their carcinogenicity to humans | 0.01 |
| Fluoranthene | FLA | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Pyrene | PYR | 3 | not classifiable as to their carcinogenicity to humans | 0.001 |
| Benzo[a]anthracene | B[a]A | 2B | possibly carcinogenic to humans | 0.1 |
| Chrysene | CHY | 2B | possibly carcinogenic to humans | 0.01 |
| Benzo[b]fluoranthene | B[b]F | 2B | possibly carcinogenic to humans | 0.1 |
| Benzo[j]fluoranthene | B[j]F | 2B | possibly carcinogenic to humans | 0.1 |
| Benzo[k]fluoranthene | B[k]F | 2B | possibly carcinogenic to humans | 0.1 |
| Benzo[e]pyrene | B[e]P | 3 | not classifiable as to their carcinogenicity to humans | N/A |
| Benzo[a]pyrene | B[a]P | 1 | carcinogenic to humans | 1.0 |
| Indeno[1,2,3-cd]pyrene | IND | 2B | possibly carcinogenic to humans | 0.1 |
| Dibenzo[ah]anthracene | D[ah]A | 2A | probably carcinogenic to humans | 2.4 |
| Benzo[ghi]perylene | B[ghi]P | 3 | not classifiable as to their carcinogenicity to humans | 0.01 |

The EC limit of 20 mg PAH/kg crumb rubber is based on oral and dermal exposures of various amounts of rubber per kg of body weight, with inhalation exposures assessed as B[a]P equivalents (B[a]P µg/m$^3$). An excess risk rating of 1.17 x $10^{-6}$ was determined for this PAH limit, which exceeds the 'point of departure' threshold of $10^{-6}$ (NHMRC 2010).[25]

The Armada study included a risk assessment for exposure to PAHs by children from a number of age groups. The assessment found PAH exposures for a child of 3-6 years were below the US EPA proposed oral reference dose for B[a]P but that did not consider the cumulative risk from contributions of other PAHs and the other substances tested.

In regards to the toxicity of other chemicals identified by Armada and colleagues, the ecotoxicity of 6PPD, 6PPD-Q has been reported in Ihenetu *et al* (2024) (as discussed above in Section 7.2) and Rauert *et al* (2022a and 2022b) (as discussed above in Section7.3), with a legal determination on the ecotoxicity status of these chemicals potentially forthcoming from the legal action launched by Institute of Fisheries Resources (IFR) and the Pacific Coast Federation of Fishermen's Associations (PCFFA) (as discussed above in Section 6.1.)

[24] PEFs sourced from ATSDR (2022a), Samburova et al (2017). PEFs are available for other PAHs not identified in tyre rubber.
[25] Page 18 of NHMRC (2010).

HMMM is listed by the ECHA under the Classification, Labelling and Packaging regulations as an acute toxicant class 4 (harmful if swallowed), mutagenic class 2 (suspected of causing genetic defects) and carcinogenic class1B (suspected of causing cancer).[26]

BTZ and MBTZ have been shown as toxic to aquatic organisms (Pillard *et al* 2001).

Overall, the findings suggest that avoidance of exposures to those chemicals (and in particular PAHs) is advisable to minimise the risk of the indicated adverse impacts to the environment and humans. In respect of exposures to these chemicals in tyre crumb rubber infill, that avoidance could entail either a reduction in participation in sporting activities on synthetic turf with crumb infill, or substituting non-hazardous infill material for crumb infill .

## 7.6 Chibwe *et al* 2022

The results from a comprehensive study of ecological impacts from tyre wear particles on fathead minnow embryos have been reported by Chibwe and colleagues (2022) Simulated tyre wear particles were prepared from cryogrinding of samples of tread from a Michelin Energy-Saving all season tyre, with particle size distribution ranging from 1.7 µm to 1.7 mm, well within the size distribution of crumb rubber utilised for sporting fields. Those tyre wear particles were incubated with purified water in an environmental chamber at 34 °C to generate leachates that was considered to simulate worst case surface water temperatures from roads and surfaces where tyre wear particles can accumulate. The minnow eggs and hatched embryos were exposed to the leachates for varying times, with various measurements made of hatch rates, physical changes to the embryos and physiological impacts such as impaired heart rates.

The organic chemical composition of the leachates were determined from various analytical measurements, and the relationships between the chemical constituents in the leachates and the toxicity responses were determined from multivariate statistical analyses.

Significant adverse physical and physiological impacts were observed in the study. These are illustrated from photographs shown in the report, reproduced below in Figure 7.1.

[26] https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/50601

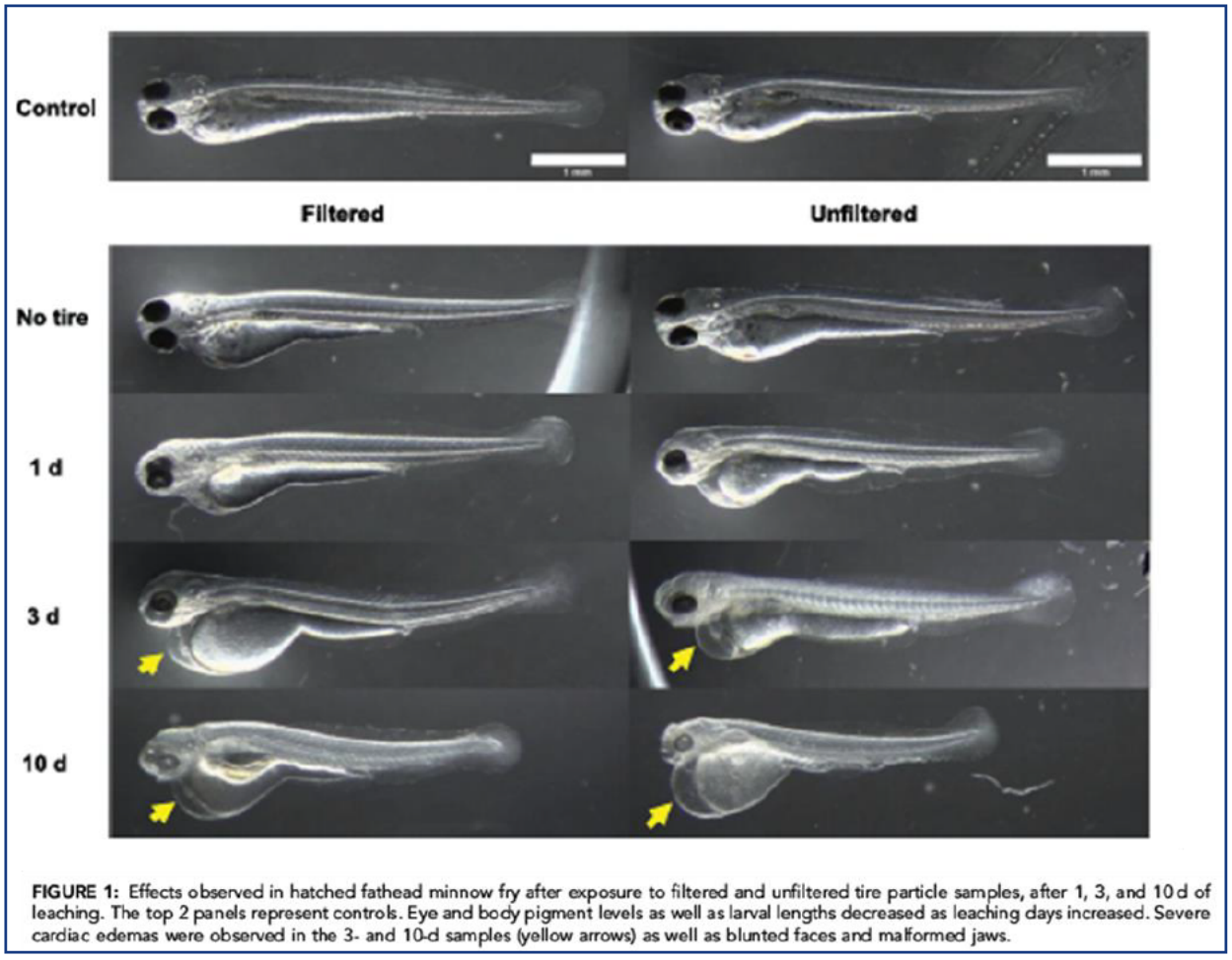


FIGURE 1: Effects observed in hatched fathead minnow fry after exposure to filtered and unfiltered tire particle samples, after 1, 3, and 10 d of leaching. The top 2 panels represent controls. Eye and body pigment levels as well as larval lengths decreased as leaching days increased. Severe cardiac edemas were observed in the 3- and 10-d samples (yellow arrows) as well as blunted faces and malformed jaws.

**Figure 7.1: Observed impacts in hatched fathead minnow from exposure to tyre wear particle leachate (Figure 1 from Chibwe *et al* 2022)**

A suite of chemicals were detected in the tyre wear particle leachates including benzotriazoles, benzothiazoles, HMMM, benzoquinoline, dihydrotrimethylquinoline and benzo[c]acridine. The toxicity of benzotriazoles has been discussed in Section 7.5. Benzothiazole is reported to exert acute toxicity and is a respiratory irritant and dermal sensitiser to humans (Ginsberg e*t al* 2011). Methylbenzothiazole is a rodent carcinogen and has been associated with human bladder cancer (Ginsberg e*t al* 2011). Benzoquinolines are reported to reduce filtration rates of zebra mussels (*Dreissena polymopha*) (Kraak *et al* 1997). IARC reports only limited evidence for carcinogenic impacts from benzo[c]acridine.[27]

In addition to the chemicals identified in the study, another 29 chemicals were detected but not identified in one type of analysis positive ion mass spectrometry) and 44 chemicals were detected but not identified in another type of analysis (negative ion mass spectrometry). Some of these unknown chemicals were found to contribute to the observed toxicological impacts.

This study has demonstrated that adverse impacts can occur from environmental exposures to tyre wear particles, mindful that the exposure rates that could occur in the environment were not discussed in the study to provide 'real life' context to the observed impacts. Of note is that adverse impacts were determined from the leachates which contained many tens of chemicals that could not be identified in the analyses. Also, the study did not include impacts from metals that are present in tyre rubber. Ecotoxicological studies are

[27] https://www.inchem.org/documents/iarc/vol32/benz[c]acridine.html

required to identify actual environmental risks, however such studies are complex and costly, and as such typically target a small number of organisms. Although the findings from this study provide a basis for new studies, the identified uncertainties support the adoption of a precautionary approach for the use of tyre derived products (including crumb rubber) where those products can be released into the environment.

## 7.7 Halsband *et al* 2020

An earlier study from Halsband and colleagues (2020) examined the sea water leachates from pristine and weathered crumb rubber, to ascertain the leaching properties for a range of organic chemicals and metals, and the impacts of the leachates on marine life (copepods). The authors found a 'cocktail of organic additives and metals' readily leached into seawater, with the rate of leaching of organics stabilising within days whereas metals continued to leach out over the 30-day experimental program.

The organics identified in the seawater leachates included PAHs (pyrene and phenanthrene), benzothiazoles (benzothiazole, 2-mercaptobenzothiazole), phenols (4-tert-octylphenol, 3-tert-butylphenol), methyl stearate, quinolines and amines (6PPD and diphenylamine). Metals identified included Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Sb and Pb. The toxicity of PAHs has been discussed in Section 7.5, benzothiazoles in Section 7.6, , phenols below (Section 7.8), the quinolines in Section 6.2 and metals in Section 4.2. Diphenylamine is not likely to be a human carcinogen but is moderately toxic to fish and aquatic invertebrates.[28] Methyl stearate is not toxic to humans[29] and i toxic effects are not observed in *Daphnia* ( a small planktonic crustacean species) and algae.[30]

High mortality rates were observed for high leachate concentrations, with a dose-response relationship observed, i.e., less impact at lower doses. Impacts at the lowest doses were less than the controls and the authors suggest that reflects an adaptive response of the organism to the counter the toxic impacts of the chemicals in the leachate. As noted for the Chibwe study, the study did not consider the actual concentrations of the tyre chemicals that result from leaching from crumb rubber in a marine environment.

Nonetheless, the findings from this study are consistent with others that have demonstrated the potential for adverse effects from tyre crumb or tyre wear particles on the marine environment.[31]

## 7.8 Gomes *et al* 2021

A review of harmful chemicals in crumb rubber (as used for synthetic turf pitches) was carried out by Gomes and colleagues (2021). This review examined a wide range of chemicals including metals, PAHs, volatile organic chemicals, plasticisers, semi-volatile organic compounds, antioxidants and various additives. Some of these substances have known toxic impacts to the environmental and humans (see Table 4-1 above for information on metals and Table 7-1 for information on PAHs).

Volatile organic compounds found in tyre rubber arise from solvents used for manufacturing process, with the levels in crumb rubber considered insufficient to present a human health hazard when released from infill in outdoor sporting fields. Higher concentrations were observed from indoor sporting facilities, which were found to exceed occupational exposure standards (Gomes *et al* 2021).

Plasticisers found in tyre crumb were largely phthalate esters and bisphenol A (BPA). One phthalate ester (di-2-ethylhexyl phthalate) is considered 'reasonably anticipated to be a human carcinogen' on the basis for formation of liver tumours in rats and mice[32], albeit that the ATSDR notes 'human epidemiology studies evaluating potential adverse effects from exposure to phthalates (including DEHP) are insufficient to draw firm conclusions regarding cause and effect or dose-response for individual phthalate esters' (ATSDR, 2022).

[28] https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-038501_10-Apr-98.pdf
[29] https://pubchem.ncbi.nlm.nih.gov/compound/Methyl-Stearate#section=Other-Safety-Information
[30] https://echa.europa.eu/registration-dossier/-/registered-dossier/14837/6/2/1
[31] https://echa.europa.eu/registration-dossier/-/registered-dossier/14598/6/2/1
[32] https://www.ncbi.nlm.nih.gov/books/NBK590781/

BPA is an endocrine disruptor that adversely affects the reproductive, immune and neuroendocrine systems.[33]

Antioxidants and additives identified in tyre rubber include benzothiazoles (previously discussed above), 4-t-octylphenol, isononylphenol, BHT (butylated hydroxy toluene). 4-t-octylphenol and isononylphenol are endocrine disruptors (Tran *et al* 2020 and Soares *et al* 2008, respectively). BHT is widely used in the cosmetics industry with a 2023 review from the European Commission Scientific Committee on Consumer Safety concluding it safe for such applications (Granum *et al*, 2023).

The Gomes study did not draw any conclusions in respect of the actual environmental impacts of the chemicals examined. Instead it provided additional knowledge on the chemicals that can be considered for further research into those impacts.

## 7.9 Cunningham *et al* 2024

The chronic and generational toxicity impacts of tyre derived rubber micro- and nano--plastic particles on the reproduction of *Daphnia magna* (planktonic crustacean species) was studied by researchers from Oregon State University (USA) with a report published in 2024 (Cunningham *et al*, 2024). The study found that adverse impacts on reproductive function including delaying, decreasing and eliminating reproduction from exposures to both micro and nanoparticle fractions, with the more severe impacts within a generation were observed for the microparticles whereas intergenerational impacts were only observed for the nanoparticles. Significant intragenerational impacts from microparticles were attributed to nutrient dilution caused by the physical presence of those particles in the gut of the animal.

These findings suggest that sublethal impacts from exposures to crumb rubber particles may occur which may impact upon the ability of the organism to reproduce and therefore decrease the viability of the organism in a particular location that is impacted by microplastic crumb rubber particles. The study authors noted that further research is required to identify the chemicals released from tyre rubber that cause the detrimental impacts on the *Daphnia* crustacean species.

The authors concluded that reproductive impacts from chronic exposures to rubber particles could have 'devastating impacts on populations of *Daphnia*'.

## 7.10 Perkins *et al* 2019

The carcinogenic potential of chemical constituents of crumb rubber infill was examined via a computational toxicology assessment conducted by a research team lead by Professor Perkins from the Yale Scheool of Public Health (Perkins *et al* 2019). The study utilised US EPA and ECHA classifications to identify 306 chemical constituents in crumb rubber, with 197 satisfying the *a priori* carcinogenicity criteria and 52 of those 197 chemicals classified as known, presumed or suspected human carcinogens. A large number of chemicals were not listed in the US EPA and ECHA databases which the authors concluded to be due to absence of evaluation data or insufficient information on carcinogenic classifications.

The authors concluded a computational toxicological assessment approach provides a means to prioritise hazardous chemicals for exposure monitoring studies for users of synthetic turf fields using crumb infill.

The above findings suggest further work is required to obtain a complete understanding of the carcinogenic risk from exposure to crumb rubber infill. The literature reviewed since this study was reported indicates that such an understanding has not been developed. That finding and the other that many hundreds of chemicals found in crumb rubber are not listed in carcinogen databases suggests a precautionary approach is prudent to the use of crumb rubber infill

[33] https://pubmed.ncbi.nlm.nih.gov/31299621/

## 7.11 Summary of crumb rubber chemicals and human health and environmental impacts

The literature reviewed has provided evidence that some of the chemicals found in tyre rubber are hazardous and may give rise to adverse impacts on human health and organisms in the environment from release of rubber products, including rubber crumb. The risks of adverse impacts are determined from the extent of exposures, i.e., the amounts of chemicals in the exposure, as well as the frequency and duration of exposures. The EC ban on crumb rubber infill reflects a finding that the risk from human exposures to PAHs (which includes a known human carcinogen B[a]P) is not acceptable and that risk is best mitigated by avoiding the exposure via the ban.

Several of the studies reviewed have noted that more work is required to better understand the exposures and associated human health and environmental risks from the release of tyre rubber chemicals into the environment. The chemicals discussed above are a small subset of the thousands of chemicals purported to be used in tyre manufacturing (Mayer *et al* 2024). An argument can be made that until such studies are concluded and the risks fully understood that a precautionary approach should be adopted where tyre derived rubber products are not utilised for applications where those products can degrade and release rubber (and associated chemicals) into the environment. Furthermore, the environmental toxicology of some chemicals (in particular 6PPD) suggests these chemicals should no longer be used for tyre manufacturing and alternative chemicals (in this case antioxidants/antiozonants) of low toxicity should be utilised. Such measures will reduce risks from tyre wear particles, which will continue to be released into the environment from the intended use of tyres for road transport purposes. Until such toxic chemicals can be replaced with less toxic substitutes in tyre manufacturing then risks from use of crumb rubber for applications where the crumb is released into the environment are arguably best mitigated by utilising other materials for those applications and using EOL tyre rubber for resource recovery via a process that does not release those chemicals into the environment. A discussion of such an approach (thermal processing – pyrolysis) is provided in the following sections.

# 8. End-of-life tyre pyrolysis

## 8.1 TSA review of tyre pyrolysis

TSA has recently published a review of technologies and product opportunities for EOL tyre pyrolysis (TSA 2024), as part of the initiatives being implemented under the TPSS. The review considered the different technologies currently available for commercial pyrolysis that generates tyre derived products being tyre pyrolysis oil, tyre pyrolysis carbon and steel wire. Key findings and conclusions from the review are:

- Pyrolysis provides an energy-efficient means to recover valuable materials from EOL tyres.
- Only a small number of pyrolysis plants are operating in Australia with some others under construction. A range of technologies have been utilised for those facilities and no particular technology appears to be favoured.
- Local markets for tyre pyrolysis oil and tyre pyrolysis carbon have been difficult to secure with further development required for new applications for these products. Upgrading may be required to meet quality and performance specifications for some markets.
- Globally, the tyre industry has been providing significant investment in tyre pyrolysis and upgrading of tyre pyrolysis oil and tyre pyrolysis carbon for beneficial uses. In particular, initiatives and investment has been made in Europe into recovered carbon black which is a refined version of tyre pyrolysis carbon that is being evaluated as a substitute for virgin carbon black utilised in tyre rubber manufacturing.

- These initiatives present a high value use for tyre pyrolysis carbon that supports a move towards a circular economy for tyre manufacturing and resource recovery.

The TSA review notes a requirement for the tyre pyrolysis industry to adhere to high safety and environmental standards. The safety aspects are managed by existing regulations for thermal treatment processes. Local environmental (which includes human health) impacts are managed by the respective state environmental agencies,[34] with environmental licences or approvals, with conditions on emissions and discharges, required to operate a pyrolysis plant. As discussed above, air emissions are produced from the pyrolysis process , in particular the products from combustion of recycled synthesis gas in the pyrolysis heating chamber/kiln. Those emissions are mitigated through the use of best available control technologies (BACT) that are required by the regulators.

In addition to the TSA review, the TSA Market Development Fund has provided a grant in December 2023 to researchers at Monash University for a thermal processing project to:

> *"develop two innovative technologies based on the use of end-of-life tyre char. In particular, the char derived from passenger and mining tyres will be part of this focus. This is due to the need to create natural demand for these types of end-of-life tyres as well as upgrading the plastics-derived oil and the desulfurisation of end-of-life tyre oil"*[35]

The intent of the project is to develop value-added applications for products from advanced co-pyrolysis of plastics and scrap tyre.

Other grants related to pyrolysis projects were provided to an unknown organisation in 2016 for the *Assessment of liquid fuel chemicals and porous material production from end of life tyres*,[36] and another unknown organisation in 2015 to develop graphene supercomposite from tyre pyrolysis products (*"... the utilisation of chemicals from the pyrolysis of tyres to create graphene composite materials for high value applications such as metal coating for light weight cars and planes"*).[37]

The status of those projects has not been advised by TSA with reports not available on the TSA website.

Nonetheless, it is clear from the TSA review and funding (for pyrolysis projects) that the utilisation of pyrolysis in Australia to recover value materials from EOL tyres has a high potential to support a circular economy for the tyre industry which delivers significant commercial and environmental benefits, once suitable markets are realised for the products.

## 8.2 Management of pyrolysis plant environmental and human health impacts

As noted above, the environmental impacts from pyrolysis plants are managed via established regulatory and planning processes and the use of best available control technology. This extends to the use of tyre pyrolysis oil and tyre pyrolysis carbon or upgraded products from those materials for various applications which are also managed by planning and environmental regulations and approvals for those applications. The regulation of tyre pyrolysis and uses for pyrolysis products is in contrast to the apparent absence of regulatory management for use of crumb rubber in applications where that material can enter the environment. More specifically, the use of crumb as infill is not regulated and as such the environmental and human health risks are unlikely to be adequately managed. This supports the application of a precautionary approach to the utilisation of crumb rubber to ensure a low risk of harm to the environment and human health.

[34] EPAs in NSW, Victoria, Tasmania, SA and NT; the Department of Environment, Tourism, Science and Innovation in Queensland, and the Department of Water and Environmental Regulation in WA.
[35] https://www.tyrestewardship.org.au/project/valorisation-of-scrap-tyres-pyrolysis-derived-products/
[36] https://www.tyrestewardship.org.au/project/assessment-of-liquid-fuel-chemicals-and-porous-material-production-from-end-of-life-tyres/
[37] https://www.tyrestewardship.org.au/project/check-project/

# 9. Conclusions and recommendations

Key findings from this review are as follows:

- The 2023 EC ban on microplastics, which includes tyre crumb rubber infill in sporting fields, appears appropriate on the basis of the information available at time, and is largely supported by findings from more recent studies and regulatory initiatives (e.g. US EPA).
- Additional research is required to better understand the human health and environmental risks from crumb infill, since those risks as identified for overseas locations may not be consistent for Australian locations depending on the nature of the receiving environments.
    - An example is the risks to the Great Barrier Reef from crumb rubber released from locations along the Queensland coast, which will be different to risks to the different marine environment that exists off-shore from Sydney.
- The contribution of tyre wear particles to environmental impacts to the overall environmental burden from toxic chemicals within crumb rubber is considerably greater than that from the use of crumb as infill.
- However, that does not provide justification for favouring the intentional use of crumb for applications where the crumb can be released into the environment.
- Risks from known toxic substances (e.g. 6PPD) in tyre rubber may be mitigated through substitution with alternative additives, however, that requires research and development by tyre manufacturers and will not be a near-term solution to reduce the environmental risk from use of crumb rubber infill and other applications.
- Risks from the use of crumb rubber infill for synthetic turf applications can be mitigated by replacement of crumb with alternative materials (such as cork) which are environmentally benign and do not pose a human health risk.
- Alternative solutions including pyrolysis are indicated for dealing with EOL tyres, where beneficial products can be produced with low environmental and human health risk that are managed with existing regulatory processes and the availability of best available technologies.

Overall, this review has found that a precautionary approach is indicated for the use of crumb rubber as infill or other applications where the rubber can pose a human exposure risk and/or enter and potentially adversely impact on the environment. That precautionary approach could include consideration by the Australian government and relevant regulatory agencies to implement a ban on the use of crumb in Australia where the human health and environmental risks have not been fully assessed. At the very least, controls could be required via the planning and development approvals processes where products and materials that contain crumb rubber are to be utilised for a development or project, to ensure the crumb is not released into the environment. Risk assessments would be required for each application to demonstrate the suitability and efficacy of the proposed controls to mitigate risks to the environment.

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