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Best Practice Expert Advice on the Use of Recycled Materials in Road and Rail Infrastructure: Part A Technical Review and Assessment

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Executive Summary

This report (*Part A:Technical Review and Assessment*) is the first of two *Best Practice Expert Advice on the Use of Recycled Materials in Road and Rail Infrastructure* reports. Combined, these reports support the Australian Government's delivery of the *National Waste Policy Action Plan 2019* objective to increase the use of recycled content in road and rail infrastructure and inform government procurement requirements.

This report provides a review of **government policies and actions** that support the transition to a circular economy through the use of recycled materials in road and rail infrastructure. It also provides a **technical examination** of the application and uses of recycled materials; emerging opportunities; comparative performance to virgin materials; market maturity; supply; and estimated recycled content potential.

The following materials are considered:

1. Crushed Concrete and Brick
2. Recycled Crushed Glass (RCG)
3. Reclaimed Asphalt Pavement (RAP)
4. Crumb Rubber
5. Ground Granulated Blast Furnace Slag (GGBFS)
6. Fly Ash
7. Bottom Ash
8. Recycled Solid Organics
9. Recycled Ballast
10. Recycled Plastics.

Part B will provide further information on the environmental, economic and social impacts of using recycled materials in major infrastructure projects across the road and rail industries in Australia.

Key Findings

Australian governments have introduced a range of policies, strategies and plans to promote the reduction of waste, recycling and reuse of materials and drive the transition towards a circular economy.

The *National Waste Policy: Less waste, more resources 2018* provides the **national framework** for waste and resource recovery in Australia and has been endorsed by all levels of government. While the details of policies and plans vary from jurisdiction to jurisdiction, all are working towards the targets in the *National Waste Policy Action Plan*. This includes reducing total waste generated and an 80% average resource recovery rate from all waste streams.

Most state and territory policies and targets aim to turn Australia's major waste streams into valuable commodities, driving both the demand and supply of recycled materials and creating new market opportunities. This transformation will generate long-term economic benefits, lower carbon emissions and help deliver a circular economy. There are, however, few specific quantifiable targets to significantly increase the use of recycled content by governments and industry, as set out in the national policy.

As purchasers and managers of major road and rail infrastructure, governments drive market demand through their purchasing decisions. The Australian Government, as well as all states and territories have some form of **procurement guidance** that, at a minimum, supports value-for-money purchasing that delivers on environmental, social and economic goals. Most jurisdictions have a sustainable or green procurement policy or guidance that refers to purchasing considerations around the desirability of using recycled materials, recyclability and reuse of purchased products together with waste reduction.

The Commonwealth's *Sustainable Procurement Guide* recommends setting mandatory, minimum or desirable **requirements for use of recycled materials** when planning a project. Only Victoria and South

Australia have explicit guidance around establishing these. Other jurisdictions' guidance around recycled materials is presented as desirable procurement outcomes.

Industry, local and state governments have been gradually **increasing their use of recycled material** in road and rail infrastructure projects, and there is a keen interest across industry and government to improve sustainability outcomes. **Industry confidence** varies according to the extent the use of a material has been established. For example, there is lower confidence in newer and emerging applications, such as recycled plastics in pavements and rail sleepers. Conversely, there is higher confidence in the use of crumb rubber in sprayed seals, based on decades of use nationally.

Some of the **key barriers** to the growing use of recycled materials in infrastructure include a lack of awareness and education; a disconnection between market demand and supply; a lack of more enabling specifications, standards and guidelines; and lastly, a lack of evidence to guide long-term performance outcomes and sustainability benefits.

The Materials

In terms of **performance**, **cost** and **sustainability impact**, the following high-level findings can be inferred from the research undertaken:

- **Crushed Concrete and Brick**: the use of crushed concrete and brick as a supplementary material for virgin crushed rock is a well-established practice. Certain applications can enable use of up to 100% recycled crushed concrete, dependent on material properties and performance requirements. It is estimated that 8,000 tonnes of construction and demolition waste would be diverted from landfill per kilometre of road construction.
- **Recycled Crushed Glass (RCG)**: recycled crushed glass can be employed in the construction of embankments, structural and non-structural fill, retaining wall backfill and drainage, with several specifications in place to support its use. The use of glass in road pavements and as a replacement for virgin sand in some rail applications are several of the emerging opportunities.
- **Reclaimed Asphalt Pavement (RAP)**: reclaimed asphalt pavement, once milled from end-of-life pavements, can be recycled into new pavements or utilised as a granular material for unbound granular pavement. Up to 100% RAP can be used or supported through the incorporation of rejuvenators. The use of RAP is widely accepted across Australia, with several standards, guidelines and specifications outlining requirements for successful and beneficial use. This results in an efficient and cost-effective use of resources.
- **Crumb Rubber**: crumb rubber has been used in sprayed seal applications for decades, in small volumes. Additionally, there are several applications in asphalt pavements, with a variety of standards and specifications developed nationwide. Less prominent applications include the potential for use in rail ballast, or as tyre-derived aggregates. Performance-wise, crumb rubber has been found to positively affect pavements, including through reduced noise and risk of cracking. Crumb rubber is a relatively mature market, with over 20 recyclers and over 1,500 accredited retailers, and there is sufficient supply of end-of-life tyres to support more use of the material in road and rail.
- **Ground Granulated Blast Furnace Slag (GGBFS)**: GGBFS is typically used as a supplementary cementitious material or as a Portland cement replacement, offering a durability and strength increase compared to using Portland cement. This application is relatively mature, emerging in the 1960s. There is only one operational producer of the material in Australia, with some supplies imported.
- **Fly Ash**: some applications include fly ash as a supplementary cementitious material, a Portland cement replacement, or a filler in asphalt, with strong comparable performance to non-recycled materials. Several standards and specifications are in place for fly ash use across Australia. Recovery rates for generated fly ash are variable, with WA at 72% compared to Qld at 18% and NSW at 10%.
- **Bottom Ash**: bottom ash, a by-product from coal combustion or Waste to Energy plants, can be employed as a bound or unbound aggregate. Bottom ash from Waste to Energy plants is confidently used by industry globally, predominantly in Europe. There is no current market in Australia but given Waste to Energy is an emerging waste management practice in Australia and the abundance of coal-based plants, the material has potential to be commercially available in the near future.
- **Solid Organics**: solid organics, sourced from plant or animal waste, may be used in several applications within the transport industry, predominantly landscaping; erosion control; and biorientation and

biofiltration. Around 50% of solid organic waste presently enters landfill, with large stockpiles nationwide, indicating a real potential for the material to be recycled into higher value uses.
- **Ballast**: in-situ cleaning of rail ballast is a current practice across Australia and there is potential to increase the practice. Additionally, removal and ex-situ cleaning of ballast is an emerging practice with keen industry interest, however very few facilities possess the right processing capacity.
- **Recycled Plastics**: recycled plastics have the potential to be employed in a number of road and rail applications, including in asphalt, railway sleepers, pipes, bollards, supplementary aggregate material, noise walls and bike paths. Australia's recovery rate of recycled plastics is around 10%, indicating a significant available supply, yet the market maturity of recycled plastics applications in infrastructure is relatively low. Notably, however, there are many emerging initiatives to increase recycling programs nationally. Key challenges include environmental factors such as risk of microplastics and leachates, as well as validating performance to increase industry confidence.

Executive Summary Conclusion

This report shows that there are a lot of recycled materials that are widely used and that there is ample **opportunity** to increase their **percentages** within applications, or even the **frequency** that they are used, within their most suited application. There are also **emerging** recycled materials technologies that have significant opportunity for increased uptake. Improved **awareness** and **education** in how these materials are used, supported by policy and procurement **drivers**, new and improved **specifications** and more modern recycling **facilities** with increased capacity, can all contribute to increases in the use of recycled materials, sustainability outcomes and a more **circular economy**.

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Glossary

Term	Definition
Asphalt wearing course	An asphalt layer at the surface of the road. It provides a smooth surface for rideability whilst also providing surface friction characteristics.
Capping layer	A layer placed immediately above an expansive (high swell) subgrade material for the full formation width. The capping layer protects the formation from moisture variations in the subgrade material.
Dry method	Additives are incorporated during asphalt mixing as an aggregate and/or fines replacement.
Geopolymer binder	A binder containing greater than 80% of a material high in alumina and silica, such as fly ash, Ground Granulated Blast Furnace Slag (GGBF Slag), Amorphous Silica and/or metakaolin and up to 20% alkaline components, such as sodium hydroxide.
Los Angeles Abrasion Value (LAAV)	The Los Angeles Abrasion Test is a measure (value) of aggregate toughness and abrasion resistance such as crushing, degradation and disintegration.
Microsurfacing	A bituminous slurry, containing polymer, which is capable of being spread in variably thick layers for rut-filling and correction courses and for wearing course application where good surface texture is required to be maintained throughout the service life.
Organic waste	The component of soil that is composed of organic compounds that have come from the remains of organisms, such as plants and animals, including their waste products.
Processed solid organic waste	A pasteurised material from a processing site that does not include liquid organic waste, digestate from anaerobic digestion, or vermicast (refer to vermicast). In addition, it does not contain any chemical contaminant concentrations or non-organic physical contaminants exceeding the upper limits for that chemical contaminant parameters.
Re-cementation	Recycled crushed concrete can rebind under the action of residual unreacted cement content. It is important that this is managed, as a re-cemented layer is liable to cracking.
Recycled organics	A general term, used by industry, for products that are recycled from organic waste. This includes compost, soil conditioners, mulch and other products that can be applied to the land, for landscaping or soil treatment.
Wet method	Additives, such as crumb rubber or plastics, are incorporated in the bitumen in a mill at elevated temperatures.

List of Abbreviations

Abbreviation	Term
ABS	Acrylonitrile butadiene-styrene
ACT	Australian Capital Territory
ADAA	Ash Development Association of Australia
ARRB	Australian Road Research Board
AS	Australian Standards
ASA	Australasian Slag Association
BA	Bottom ash
BFS	Blast furnace slag
C-SPARC	Commonwealth Sustainable Procurement Advocacy and Resource Centre
CBR	California Bearing Ratio
CR	Crumb rubber
CRMA	Crumb rubber modified asphalt
CRMB	Crumb rubber modified bitumen
DAWE	Department of Agriculture, Water and the Environment
DGA	Dense graded asphalt
DIT	Department for Infrastructure and Transport South Australia
DIPL	Department of Infrastructure, Planning and Logistics Northern Territory
DoT	Department of Transport Victoria
DSG	Department of State Growth Tasmania
FA	Fly ash
GGA	Gap graded asphalt
GBF	Granulated blast furnace slag
GGBFS	Ground granulated blast furnace slag
GHG	Greenhouse gas
HDPE	High-density polyethylene
HSS	High stress seals
LAV	Los Angeles Value
LAAV	Los Angeles Abrasion Value
LDPE	Low-density polyethylene
MRF	Materials recovery facility
MRPV	Major Road Projects Victoria
MRWA	Main Roads Western Australia
NSW	New South Wales
NT	Northern Territory
OGA	Open graded asphalt
PA	Polyamide
PAFV	Polished aggregate friction value
PE	Polyethylene
PET	Polyethylene terephthalate
PMB	Polymer modified bitumen
PP	Polypropylene
PS	Polystyrene
PSD	Particle size distribution
PSV	Polished stone value

Abbreviation	Term
PU	Polyurethane
PVC	Polyvinyl chloride
Qld	Queensland
RAP	Reclaimed asphalt pavement
RCG	Recycled crushed glass
SA	South Australia
SAM	Strain alleviating membrane
SBS	Styrene-butadiene-styrene
SCM	Supplementary cementitious material
Tas	Tasmania
TCCS	Transport Canberra and City Services
TfNSW	Transport for New South Wales
TMR	Transport and Main Roads Queensland
UCS	Unconfined compressive strength
Vic	Victoria
XSS	Extreme stress seals
WA	Western Australia
WHS	Work health and safety

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1. Introduction

1.1 Background

National roads and railways form the backbone of the transport network in Australia. Over the next 10-years, $120 billion is being invested in infrastructure projects under the Australian Government's Infrastructure Investment Program. The infrastructure pipeline is driving substantial road and rail investment as well as unlocking the economic potential of many regions. Further, state and territory governments are delivering an unprecedented infrastructure investment program with a major focus on road and rail infrastructure.

While the investments will deliver economic and social benefits, the construction of transport infrastructure is resource intensive, requiring significant amounts of natural raw and engineered materials. The extraction, transportation and production of these materials produces waste, consumes energy and emits greenhouse gases. Significant benefits can be realised by using recycled materials that can be reused or recycled at the end of their useful lives as infrastructure assets are eventually upgraded or decommissioned.

The *National Waste Policy Action Plan* recognises the importance of incorporating recycled products in road and rail projects. Similarly, state and territory governments have established waste reduction, recycling and circular economy policies that are supported by sustainable procurement requirements to drive the use of recycled materials in funded projects. The concept of a circular economy is one in which waste is treated as a resource through the practice of reuse, recycling and repurposing. Figure 1.1 illustrates the conceptual stages within a circular economy.

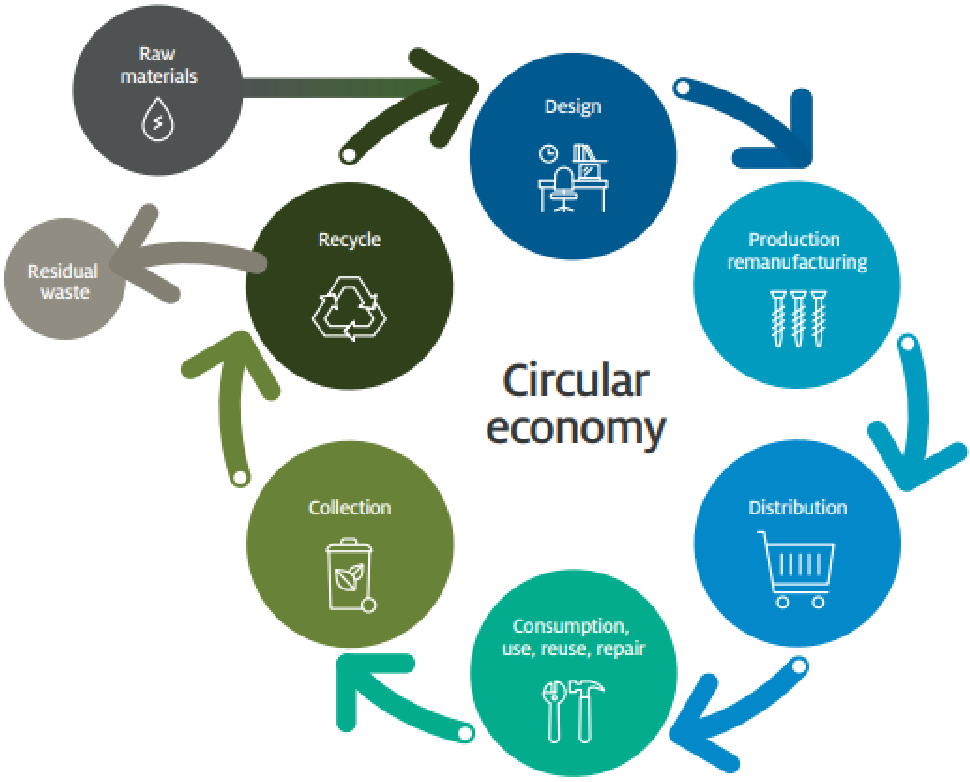
The increasing use of recycled materials in infrastructure projects is also being driven by industry with leadership from the Infrastructure Sustainability Council, its members and other private businesses that are aiming to reduce their environmental impacts. Similarly, waste-generating and waste-management businesses are increasingly exploring opportunities to make better use of their collected and stockpiled materials and industrial by-products.

Lastly, there is a strong driver from within the Australian community to do better in reusing and recycling household domestic and industrial waste, creating a circular economy and reducing the country's environmental footprint.

Recycled materials have a proven ability to play a strong role as alternatives to traditional materials – which are often depleting and increasingly costly – in road and rail infrastructure construction and maintenance. In some cases, recycled materials can also be used in combination to improve the properties of traditional materials. Recycled materials also make use of under-valued waste streams, giving a 'waste product' a second life and keeping it out of landfill.

Recycled materials have been used in roads and associated infrastructure for a long time as a cost-effective way to reduce waste and emissions to deliver safe, sustainable and reliable transport infrastructure. In recent years, demand for recycled products and industry capability to process and use the products has grown significantly – the beginnings of a major shift in the way transport infrastructure is built.

Figure 1.1: Stages in a circular economy



Source: Department of Agriculture, Water and the Environment (2021).

State road and transport agencies and local governments have been gradually introducing recycled materials into road construction to reduce economic and environmental costs. Meanwhile, recycled materials are also starting to make their way into rail infrastructure projects.

The incorporation of recycled materials into the construction, rehabilitation and maintenance of roads and rail infrastructure can provide comparative benefits, including:

- reducing the amount of waste sent to landfill
- reducing illegal dumping and littering
- reducing the greenhouse gas (GHG) emissions generated by the production of new materials and the disposal of waste materials
- reducing our reliance on non-renewable and imported resources
- developing a circular economy in which materials are continually reused in their highest and best usage
- creating new and enhancing existing markets and creating new jobs
- reducing whole-of-life infrastructure costs
- improving asset durability and performance.

However, the use of recycled materials as business-as-usual materials is progressing slowly due to the lack of awareness and education, the disconnection between market demand and supply, lack of specifications and guidelines and most importantly, the lack of consistent and scientific evidence to report on longer-term performance and sustainability benefits.

This project provides robust, evidence-based knowledge on how to optimise the uptake of recycled materials in infrastructure projects. It supports the *National Waste Policy Action Plan 2019* target to significantly increase the use of recycled content, prioritising road and rail, and establish procurement goals.

1.2 Project Partners

This research is funded by the Australian Government's Department of Agriculture, Water and the Environment (DAWE) and managed by the Commonwealth Sustainable Procurement Advocacy and Resource Centre within the Department. The research and best practice advice is provided by the Australian Road Research Board.

The **Commonwealth Sustainable Procurement Advocacy and Resource Centre (C-SPARC)** is a business group within the DAWE. C-SPARC is supporting the transition to a circular economy by generating demand for recycled content and promoting sustainable procurement.

C-SPARC works between government and industry to facilitate opportunities to significantly increase the use of recycled content in line with target four of the *National Waste Policy Action Plan*. C-SPARC runs an education and advocacy program to help Australian Government agencies to embed sustainable procurement practices in their purchases. C-SPARC is also working with industry partners to identify the potential to optimise the use of recycled content in infrastructure.

The **Australian Road Research Board (ARRB)** is a source of independent, expert transport knowledge, advising key decision makers on our nation's most important transport challenges. ARRB's collective knowledge, gained over more than 60 years, includes significant research in sustainable, innovative and creative solutions on low-carbon options for recycled and recovered materials in road, rail and transport infrastructure.

ARRB has a long history of working with Austroads and its member state road and transport agencies in developing value-added applied knowledge, including state-specific fact sheets, specifications and guidelines to address the engineering properties and environmental suitability issues. Recently, ARRB has increasingly been sharing knowledge and expertise with local governments and with the rail industry.

ARRB's work covers a broad range of recycled materials, applications, assessments, trials and implementation guidance for states and territories across Australia. It also actively delivers assessment methodologies, frameworks and tools to help asset managers understand and quantify the impacts associated with the applications of recycled materials. Along the journey, ARRB has identified sustainable benefits including reduced greenhouse gas emissions, captured value from waste materials, improved asset durability and lowered costs from feasible recycled materials.

2. Policies, Actions and Procurement Drivers for Recycled Material

Government policies and actions are important drivers for the transition to a circular economy. Policies, strategies and action plans define governments' intentions, provide direction for government agencies and certainty for industries and communities who engage with government. At the same time, governments can use their purchasing power to achieve sustainability and circular economy objectives supported by procurement requirements and guidance.

The section provides an overview of the national and state and territory policies, actions and procurement drivers that support the demand and supply of recycled materials for transport infrastructure projects.

These drivers and actions are complemented by increasing community expectations for better environmental and socially responsible outcomes as well as industry drivers such as potential commercial benefits, demonstration of leadership and innovation, product and waste stewardship, technological developments and sustainability ratings and recognition. This report acknowledges the importance of these non-government drivers but does not document them in detail.

2.1 Waste and Recycling Policies

Australian governments have introduced a range of policies, strategies and plans to promote the reduction of waste, recycling and reuse of materials and drive the transition towards a circular economy.

Table 2.1 outlines the primary and supporting waste and recycling policies, strategies and action plans in each Australian jurisdiction.

Table 2.1: Waste and recycling policies

Jurisdiction	Primary policy	Supporting policies, strategies and plans
National	*National Waste Policy: Less waste, more resources (Department of Aggriculture, Water and the Environment 2018)*	*National Waste Policy: Action Plan (Department of Agriculture, Water and the Environment 2019)*
Vic	*Recycling Victoria – A new economy (Department of Environment, Land, Water and Planning 2020)*	*Recycled First Policy* *State-wide Waste and Resource Recovery Infrastructure Plan (SWRRIP) (Sustainability Victoria 2018c)* *Recycling Industry Strategic Plan (Department of Environment, Land, Water and Planning 2018)*
NSW	*Waste and Sustainable Materials Strategy 2041 Stage 1: 2021–2027* (*Department of Planning, Industry and Environment 2021a)*	*NSW Plastics Action Plan* (*Department of Planning, Industry and Environment 2021b).* *NSW Waste and Sustainable Materials Strategy: A Guide to Future Infrastructure Needs (Department of Planning, Industry and Environment 2021c)* *Net Zero Plan Stage 1: 2020–2030 (Department of Planning, Industry and Environment 2020)*
Qld	*Waste Management and Resource Recovery Strategy* (Queensland Government 2019a)	*Queensland Resource Recovery Industries: 10-Year Roadmap and Action Plan (Queensland Government 2019b)* *The Resource Recovery Industry Development Programme* *Tackling Plastic Waste: Queensland's Plastic Pollution Reduction Plan (Queensland Government n.d.),*
WA	*Waste Avoidance and Resource Recovery Strategy 2030 (WA Waste Authority 2020)*	*Action Plan 2021–22: Waste Avoidance and Resource Recovery (WA Waste Authority 2021)* MRWA's *Sustainability Policy (MRWA 2016)* MRWA's *Environmental Policy (MRWA 2021a)*

Jurisdiction	Primary policy	Supporting policies, strategies and plans
SA	*South Australian Waste Strategy 2020–2025* (Green Industries SA 2020a)	Green Industries SA *Strategic Plan 2021–2025* (Green Industries SA 2021)
Tas	*Draft Waste Action Plan* (Department of Primary Industries, Parks, Water and Environment 2019)	
ACT	*ACT Waste Management Strategy: Towards a Sustainable Canberra 2011–2025* (Department of Environment and Sustainable Development 2011)	*ACT Waste-to-Energy Policy 2020–25* (ACT Government 2020)
NT	*Waste Management Strategy for the Northern Territory (2015–2022)* (NT EPA 2015)	*NT Circular Economy Strategy 2022–2027* (Northern Territory 2022)

2.1.1 The National Waste Policy and Action Plan

The *National Waste Policy: Less waste, more resources* provides the national framework for waste and resource recovery in Australia and has been endorsed by all levels of government. The policy applies principles of a circular economy to waste management and outlines the roles and responsibilities for businesses, governments, communities and individuals.

Five key waste-management principles that will enable the transition to a circular economy are defined as:

- Avoid waste.
- Improve resource recovery.
- Increase use of recycled material and build demand and markets for recycled products.
- Better manage material flows to benefit human health, the environment and the economy.
- Improve information to support innovation, guide investment and enable informed consumer decisions.

The *National Waste Action Plan* details actions to deliver on the seven national targets, including:

1. Ban the export of waste plastic, paper, glass and tyres (a phased approach from 1 January 2021).
2. Reduce total waste generated by 10% per person by 2030.
3. Recover 80% of all waste by 2030.
4. Significantly increase the use of recycled content by governments and industry.
5. Phase out problematic and unnecessary plastics by 2025.
6. Halve the amount of organic waste sent to landfill by 2030.
7. Provide data to support better decisions.

Actions contributing to targets 1, 2, 3, 5 and 6 will turn Australia's major waste streams into valuable commodities, driving the supply of recycled materials and creating new market opportunities. This transformation will generate long-term economic benefits, lower carbon emissions and help deliver a circular economy.

Actions contributing to targets 4 and 7 will aid the demand of such materials.

2.2 Sustainable Procurement Requirements

The Commonwealth, state and territory governments have committed to an unprecedented infrastructure investment program with a major focus on road and rail infrastructure. As major purchasers and managers of infrastructure, government agencies, both collectively and individually, have enormous purchasing power that can be used to drive demand for recycled content in infrastructure and significantly improve sustainable outcomes.

As a key principle of the National Waste Policy, all governments have now committed to use sustainable procurement to help build markets for recycled content.

Sustainable procurement involves planning for and assessing tenders that achieve value for money outcomes, considering financial and non-financial impacts, such as environmental and social impacts. It also involves using governments collective and individual purchasing power to create and support the development of new markets and job opportunities.

Sustainable procurement helps build a circular economy, aiming to reduce adverse social, environmental and economic impacts of purchased goods and services throughout their life. This includes considerations such as waste disposal and the cost of operations and maintenance over the life of the goods and services. Adoption of sustainable procurement can be a demand-side market force to influence producers and encourage the development of sustainable products and practice; and it can create a greater demand for recycled products.

2.2.1 Summary of Procurement Policies

The Australian Government, as well as all states and territories have some form of procurement guidance that, at a minimum, support value-for-money purchasing that delivers on environmental, social and economic goals. Most jurisdictions have a sustainable or green procurement policy or guidance that refers to purchasing considerations around the use of recycled materials, recyclability and reuse of purchased products and waste reductions.

A summary of the published national and state procurement policies and their inclusion of recycled content is shown below in Table 2.2.

Table 2.2: Summary of procurement policies

Jurisdiction	Policy and issuer	Year	Recycled content mention	Specified target or requirements for recycled content
National	*Commonwealth Procurement Rules* Department of Finance	2020	Entities are required to consider the Australian Government's Sustainable Procurement Guide where there is opportunity for sustainability or use of recycled content.	N/A
	Sustainable Procurement Guide Australian Government	2021	All levels of government and industry have committed to significantly increase their use of recycled content. The Australian Government has committed to using its purchasing power to help build demand and markets for products containing recycled content.	Recommends creating mandatory, minimum or desirable requirements for use of recycled material for projects when planning a project.
Vic	*Social Procurement – Victorian Government Approach* Victorian Government	2018	Where virgin materials can be substituted, or complemented using alternative or recycled materials, and the resulting product is fit-for-purpose, the Victorian Government strongly recommends the use of those materials.	An analysis on the opportunities for use of recycled content. Establish appropriate minimum targets for the use of recycled content. Suppliers to receive and provide detail on use of recycled content Require suppliers to commit to developing, implementing and reporting against an environmental management plan which includes a specific focus on the use of recycled content.
	Sustainable Procurement Guidelines VicRoads	2011	A sustainable product is made with minimum use of virgin materials and a maximum use of post-consumer materials.	Give preference to products that are reusable, recyclable and/or contain recycled content where such products fit the purpose, provide environmental benefits and are of comparable cost and quality to alternative products.
NSW	*Procurement Policy Framework* NSW Government	2021	Procurement should purchase construction materials with recycled content.	N/A
Qld	*Integrating Sustainability into*	2018	Key sustainability impacts to consider include the resource use and to consider recycled content of goods (reduces demand for virgin resources).	N/A

Jurisdiction	Policy and issuer	Year	Recycled content mention	Specified target or requirements for recycled content
	the Procurement Process Queensland Government			
WA	*Environmental Procurement Guide* WA Government	2021	Sustainable procurement requirements include resource use, including the use of non-renewable resources and recycled materials.	N/A
	The Western Australian Social Procurement Framework WA Government	2021	Community outcome of social procurement is increased use of recyclable materials.	N/A
SA	*Green Procurement Guideline* Government of South Australia	2021	Recycled content of goods (reduces demand for virgin resources) is an issue to consider.	Projects should include specific measurable requirements that can be desirable or minimum/maximum for objectives such as raw material content.
	Sustainability Manual Department of Infrastructure and Transport	2021	Ask suppliers to specify the percentage of post-consumer recycled content in products.	N/A
Tas	*Procurement – Better Practice Guidelines (Principles and Policies)* Department of Treasury and Finance (Tas)	2021	Agencies should consider: • recycled or recyclable goods with recycled composition or components, such as recycled tyre products and recycled plastic parks furniture etc. • reclaimed materials, for example crushed concrete aggregate, recycled building materials, recycled compost and mulch.	N/A
ACT	*Sustainable Procurement Policy* ACT Government	2015	Waste should be looked at as a resource opportunity where products can be re-introduced into another product life cycle (known as "cradle to cradle" approach) at disposal stage. This encourages the inclusion of recycled content in goods and reduces demand for virgin resources.	N/A
NT	*Procurement Rules* Northern Territory Government	2020	N/A	N/A

Summary based on published documents available in early 2022.

Appendix A provides a detailed summary of the procurement policies and guidance for the Commonwealth and each state and territory.

3. Use of Recycled Materials in Road and Rail Infrastructure

Australia's increased population and consequent increased use of natural resources and increased generation of waste highlights the need to investigate where waste can be recycled. Transport infrastructure is continuously growing, with the potential to absorb some of those impacts by replacing virgin materials with recycled ones. Waste products such as used tyres, glass, and slag aggregates from steel production, are already used with some success. For other types of waste, such as plastics, efforts are more recent (Angelone et al. 2016).

Specifications promoting the use of recycled materials in Australia started emerging in the last decade. The NSW Government put forward the first industry-wide specification providing advice for best practice for use of recycled materials in pavements, earthworks, and drainage (IPWEA 2010). TMR released a specification (*MRTS35 – Recycled Materials for Pavements*) in 2010 listing the requirements that suppliers must meet to replace crushed rock with recycled crushed glass and/or concrete. Similarly, WA developed an inspection criterion for using recycled crushed concrete to replace crushed rock (*Pavement Specification 501*). Tas' specifications, developed in 2011, include criteria that ensure no hazardous compounds appear in recycled materials used in road infrastructure. In Vic, recycled materials are incorporated in road construction provided they are of comparable quality, with specific guidelines (*Sustainable Procurement Guidelines*, VicRoads 2011). In NT and SA, however, specifications did not exist at the time of Newman et al. (2013)'s report.

While the above specifications and guidelines vary, it is generally the case that:

- Some recycled materials, such as crushed concrete/brick, RAP and crumb rubber (CR) spray seals, have been used for a long time.
- There has been a strong, recent drive to reduce waste's environmental impacts, create value from waste, and address problematic stockpiles exacerbated by the waste export ban and poorly regulated waste sector.
- There is now stronger leadership in the area from governments and industry.
- New materials and applications are fast emerging.

This report documents the state of play for the testing, trialling and uses of 10 key mature and emerging recycled materials in road and rail infrastructure as listed in Table 3.1. Note: reusing existing granular pavement materials back into granular road pavements, which may involve improving the granular materials' properties through mechanical or chemical stabilisation, is already common practice, so will not be explicitly covered in this report.

Table 3.1: Recycled materials applications

Material	Description	Usage options
Crushed concrete	Crushed material from construction and demolition	Crushed rock and cement-treated crushed rock replacement (pavement). Footpaths and kerbs Channels and culverts
Crushed brick	Crushed material from construction and demolition	Pavement

Material	Description	Usage options
Crushed glass	Crushed material from construction and demolition, manufacturing and household waste	Asphalt Crushed rock supplement, sand replacement Footpaths and kerbs Drainage Fences
Reclaimed asphalt pavement (RAP)	Recovered asphalt from maintenance rehabilitation of existing roads	Asphalt
Crumb rubber **(including tyre derived aggregate)**	Ground end-of-life tyres, typically truck tyres, though sources may include passenger tyres, off-road mining tyres or conveyor belts	Binder modifier Asphalt Lightweight embankments Retaining walls Drainage Beneath the sub-ballast (rail)
Ground granulated blast furnace slag **(and slag aggregates)**	Steel making by-products (and by-products from the manufacture of iron)	In-situ stabilisation (pavement) Concrete Aggregate additive
Fly ash	By-product of black coal combustion	In-situ stabilisation (pavement) Concrete
Bottom ash	By-product of black coal combustion and waste-to-energy facilities	Aggregate replacement Embankment fill Capping and subbase Backfill material
Recycled organics	Biodegradable organic waste from either a plant or animal	Landscaping Erosion control Bioretention/Biofiltration systems
Recycled ballast	Reconditioned fouled ballast	Ballast aggegrate replacement
Recycled plastics	Commercial, industrial and municipal waste	Binder modifier Asphalt Noise walls Bollards and wheel stops Drainage Bike paths, decking, boardwalks Roadside furniture, bins, drinking fountains, signage Garden edging, tree stakes, retaining walls, architectural screens Roadside art Sleepers (rail)

Pathways for implementing recycled materials

One major roadblock to adopting recycled materials is the lack of confidence around their long-term performance. In road and rail infrastructure, field trials assess this performance over a period of time, often years. Accelerating this is therefore desirable. In the case of road pavements, one key national resource for such testing is the Acclerated Loading facility (ALF) operated by ARRB (Figure 3.1). In many cases, accelerated pavement testing has provided the confidence to adopt innovative use of recycled materials as replacements for virgin resources. ALF performance testing can be undertaken in months, not years, presenting a sound approach to validating the use of recycled materials in transport infrastructure.

Figure 3.1: The ARRB Accelerated Loading Facility (ALF) has been used extensively to assess the performance of recycled materials in road pavements

3.1 Crushed Concrete and Crushed Brick

3.1.1 Materials Overview

Crushed concrete and crushed brick derive primarily from buildings demolitions, from which over 6 billion tonnes of concrete is produced around the world (Figure 3.2). These mainly comprise aggregates and the cementitious adhesion medium used during construction (Nwakaire et al. 2020). Demolition waste accounts for approximately half the solid waste worldwide (Edge Environment 2011). Often, contaminants such as timber, steel and plastics, need removing and the materials need further crushing and screening before incorporatation in road infrastructure (Trochez et al. 2021).

Figure 3.2: Images of (a) reclaimed concrete, (b) crushed concrete , (c) stockpiled brick, and (d) crushed brick

Source: VicRoads (2019); Steffen (2021).

3.1.2 Market Maturity

The large volumes of crushed concrete and crushed brick produced in Australia have led to good market maturity, especially for concrete. They are also part of the waste resources with the largest volume of diversion from landfill (Beyer & Cooper 2020).

Maturity of supply and demand

In Vic, well-established recycling facilities located close to growing areas primarily receive construction waste, while demolition waste is often received by facilities near Melbourne's CBD and other urban areas (Sustainability Victoria 2014a). A study conducted in Melbourne showed notable cost benefits associated with the recycling of bricks when compared to disposing to landfill. For example, the cost of landfilling 1,000 tonnes of brick could reach $92,356, while recycling activities for the same quantity can cost $29,419 (Maqsood et al. 2019).

Construction and demolition waste recyclers in WA supply recovered aggregates for various applications including asphalt, road base, aggregates for drainage, structural fill and general mixed sand, bricks and pavers (Beyer & Cooper 2020). In WA, the demand for recycled construction and demolition waste was weak in the year 2017–18. Lack of awareness, fear of asbestos contamination, then-current government restrictions prohibiting the use of such materials in road base, suspended construction activity consequently affecting supply, and poor material performance, were responsible (Perryman & Green 2019). In 2019 however, WA published its *Waste Avoidance and Resource Recovery Strategy 2030* and introduced its Roads to Reuse program to encourage the use of recycled construction and demolition products in civil applications, such as road construction. Regardless, 35% of the crushed concrete processed by then had already found applications in roads and road shoulder work, driveways and carparks among other building construction-related applications (Beyer & Cooper 2020).

Barriers to supply and demand

Barriers to the broader adoption of recycled concrete aggregates exist. These include low supply and demand, lack of standards and specifications, lack of financial incentives, potentially poor quality of materials, and long haulage distances between the waste-generation site and the recycling facility (Maqsood et al. 2019). A major barrier for use of these materials in asphalt as aggregate replacement is the complex process of separating them. Despite the high costs, some success has been reported (Newman et al. 2013). Additionally, haulage costs often determine whether construction and demolition waste is landfilled or recovered (Sustainability Victoria 2014a).

Strategies for accelerating supply and demand

A number of strategies to remove said barriers and create a sustainable market for recycled brick have been proposed. Sustainability Victoria is developing educational materials for designers and builders to improve the onsite separation of brick from other construction and demolition waste, while it has intensified the promotion for the recycling of such materials in the construction of pavements. Organisations such as Cardno and Edge Environment note the need for increasing awareness and educating relevant bodies, as well as introducing further incentives to discourage waste generators towards solutions such as landfilling (Maqsood et al. 2019).

At the same time, research is being conducted in Qld on the use of crushed concrete in earthworks, backfill materials and drainage, as well as a partial aggregate replacement in non-structural concrete (TMR 2021).

3.1.3 Supply

The construction and demolition sector in Australia is accountable for approximately 40% of the 74.07 million tonnes of generated waste (Pickin et al. 2020). This includes approximately 1.3 million tonnes of demolition brick and 8.7 million tonnes of demolition concrete, which primarily end up in stockpiles that grow annually

(Arulrajah et al. 2013). In 2016–17, the majority (95%) of brick recycled in Australia was recycled in NSW and Vic. In SA, approximately 80% of the generated brick waste is recycled (Maqsood et al. 2019). In WA, approximately 85% of the waste generated is due to construction and demolition works; of this, 25% is concrete, of which up to 3% is brick (Beyer & Cooper 2020).

Concrete from demolition sites is collected and delivered to yards where excavators with hammer and pulveriser attachments break up large slabs and extract other materials, such as metals. The clean concrete is then fed into a crusher machine, which breaks up the waste concrete into 7–75 mm pieces or even dust. The processed concrete may then be delivered to work sites for recycling (Dold 2020). The process for brick recycling is simpler: it involves crushing the bricks either in source-separated streams or as mixed loads (Maqsood et al. 2019).

3.1.4 Standard Practices and Opportunities to Use Recycled Content

Recycled concrete and brick aggregates have been used to produce concrete, mortar, and brick tiles and are also suitable for pipe backfilling (Nwakaire et al. 2020). Additionally, they may be re-used as aggregates in concrete, replacing quarry rock. The presence of hydrated cement and gypsum on the surface of those aggregates prohibits their use as fine aggregate replacement but they have been successfull replacements for coarse aggregates (Tabsh & Abdelfatah 2009). Other applications may include fill in rock garden mulch or in slabs under temporary offices and water tanks (Dold 2020). Table 3.2 summarises these applications. Note: recycled concrete may also contain contaminants, the impacts of which are under ongoing investigation.

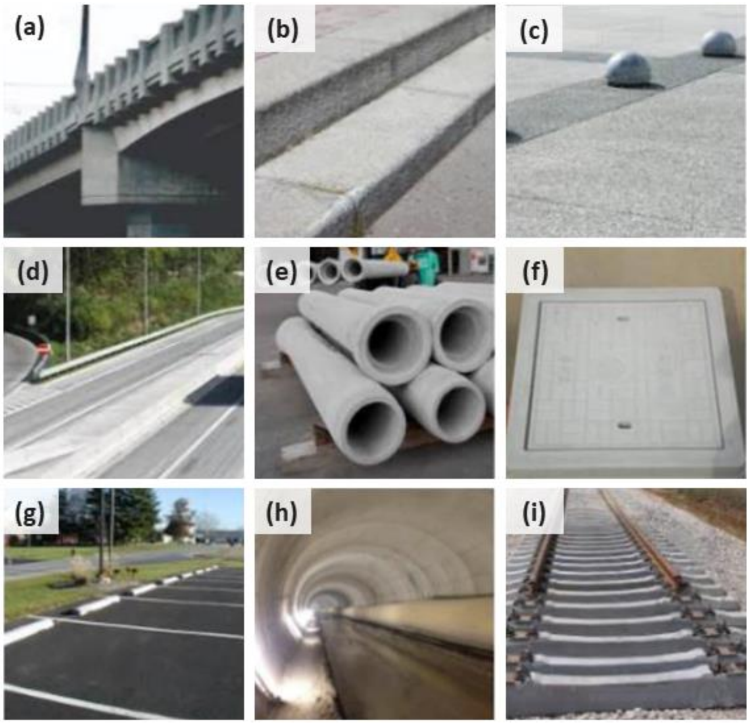
Table 3.2: Standard practices for the recycling of crushed concrete and crushed brick

Application	Virgin materials replaced
Tiles	Clay, sand
Concrete	Quarry rock
Rock garden mulch	Quarry rock
Slabs	Quarry rock

3.1.5 Opportunities for Use in Road and Rail Infrastructure

Concrete is used in a range of applications in road and rail infrastructure, which vary in requirements. Some are presented in Figure 3.3.

Figure 3.3: Applications of concrete in road and rail infrastructure. (a) bridge, (b) kerb, (c) footpath, (d) road pavement, (e) pipes, (f) drain covers, (g) parking lots, (h) tunnels, and (i) sleepers



Source: Adapted from Maqsood et al. (2019).

Replacing virgin, quarry-derived crushed rock with crushed concrete in road infrastructure was established in Vic in the 1990s, while crushed brick was introduced in 2009 as a supplementary material (VicRoads 2019). Crushed recycled concrete is primarily used as road base and may also find applications as aggregate replacement in asphalt (Austroads 2014a). The use of crushed concrete and crushed brick in unbound pavement subbase applications has also been investigated (Arulrajah et al. 2013).

Research is underway for using crushed brick and crushed concrete as replacement for natural capping materials in railway layers (Naeini et al. 2019). Crushed concrete may also find applications in gravel paths and driveways, wall cage fill, covers for drainage (Dold 2020), and geosynthetic reinforced segmental retaining walls (Bhuiyan et al. 2015). Table 3.3 summarises these.

Table 3.3: Rail and road infrastructure recycling opportunities for crushed brick and crushed concrete

Application	Virgin materials replaced
Road infrastructure	
Road base	Quarry rock
Asphalt	Quarry rock
Subbase	Quarry rock, sand
Geosynthetic reinforced segmental retaining walls	Quarry rock (limestone)
Rail infrastructure	
Capping in railways	Quarry rock

As this shows, there is ample opportunity to reduce the use of quarry rock through the incorporation of recycled crushed concrete and crushed brick in both road and rail infrastructure applications. This is especially beneficial when there are increases in quarried rock prices.

3.1.6 Specifications

States lacking specifications for concrete and brick as replacement materials in infrastructure projects will require testing of these materials for compliance in selected applications. Some of the relevant specification documents are listed in Table B.1 in Appendix B.

The appropriateness of recycled concrete and brick from demolition and construction waste for use in road pavements is defined by each state as shown in Table B.3 in Appendix B, where relevant performance requirements are listed. There are four types of unbound pavement materials that are categorised based on their physical and performance characteristics. These include:

- *Type 1*: High standard granular
- *Type 2*: Standard material
- *Type 3*: Standard material for use in relatively dry environments only
- *Type 4*: Non-standard materials (TMR 2021).

To provide uniform support for the pavement surface layers, unbound granular layers must meet specific engineering requirements, including resistance to permanent deformation, high permeability, adequate stiffness, and have a particle size distribution within a specific range (Ardalan et al. 2017).

Construction and demolition waste usually contains other contaminants that would deteriorate the performance of the recycled materials. For this reason, states and territories in Australia have posed upper limit restrictions. These restrictions are found in specifications listed in Table B.1. in Appendix B.

3.1.7 Comparative Performance

Road pavement

Research suggests that recycled concrete aggregates have generally satisfactory performance when compared to natural aggregates, but their functionality and durability need to be carefully assessed before their addition to pavements. The performance of concrete aggregates is dependent on that of the parent concrete, the presence of contaminants, as well as the process used to extract them (Nwakaire et al. 2020). When recycled crushed concrete and crushed brick are incorporated into infrastructure, the particle size distribution (PSD) and polished aggregate friction value (PAFV) or polished stone value (PSV) of aggregates are important factors affecting the selected application of the available aggregates. The available aggregates also depend on traffic and weather conditions among others factors (Austroads 2019c).

Compared to natural, quarry-derived aggregates, recycled crushed concrete aggregates have higher moisture absorption, lower impact resistance, lower density and lower abrasion resistance. Some of these properties, such as specific gravity, might even be below the allowable specifications. Their weaker properties have been attributed to the presence of mortar, heterogeneity and internal cracks. Despite this, 100% replacement of natural aggregates may be considered for hydraulically bound or unbound lower pavement layers. The incorporation of post-processing steps that include heat treatment, chemical treatment, and/or mechanical treatment, as well as the incorporation of additives like superplastisisers, or increasing the pavement mixture, might mitigate performance concerns and produce aggregates appropriate for pavement surfacing (Nwakaire et al. 2020).

On the other hand, recycled materials offer benefits. Crushed concrete has greater levels of stiffness and strength than conventional road construction materials for granular subbase applications (Arulrajah et al. 2013; Naeini et al. 2019). Crushed brick and crushed concrete also have comparatively low hydraulic conductivity (Arulrajah et al. 2013). Additionally, crushed brick may be incorporated in the subbase of road pavements only if it has a moisture ratio around 65% and often needs to be blended with other aggregates to improve its durability and other performance characteristics (Maqsood et al. 2019). A study involving the Alex Fraser Group found that the incorporation of recycled concrete may yield better performance in wet weather when compared with its virgin material counterparts (Maqsood et al. 2019). Consideration of the potential for re-cementation and shrinkage of recycled crushed concrete when used in unbound granular materials replacement applications is required (Chai et al. 2009). Hence, using recycled crushed concrete in subbase applications is preferred to limit the potential for reflective cracking. In addition, blending recycled crushed concrete with other recycled materials, such as recycled crushed glass, can help overcome the re-cementing. ARRB has conducted a study for the Canterbury Bankstown City Council on the use of recycled crushed concrete and recycled crushed glass in the subbase layer of a council's road. A blend of 70% recycled crushed concrete and 30% recycled crushed glass was found to perform well (Grenfell et al. 2021).

Recycled crushed concrete and crushed brick can be used to partially replace virgin granular materials for stabilisation applications. For example, TMR has a number of specifications that cover the use of these materials in stabilisation applications (TMR TN193 2020). Ongoing work between QTMR and ARRB through the National Asset Centre of Excellence (NACOE) innovation program is looking at optimisation of the allowable levels for different granular recycled materials components.

Capping layers in railways

Crushed concrete and crushed brick have comparable properties – including PSD, Los Angeles Abrasion Value (LAAV), water absorption and specific gravity – to conventional materials used for capping layers that meet the requirements set by Australian Standards (AS) (Naeini et al. 2019). Naeini et al. (2019) also found that crushed concrete had almost twice the stiffness and strength of natural capping materials and that crushed brick had comparable strength.

Retaining wall infill

Crushed concrete and brick may also be used as infill for retaining walls replacing natural aggregates, including limestone. When compared to limestone aggregates, crushed 30 grade concrete has a decreased alkalinity, while the alkalinity of 60 grade palm oil fuel ash concrete may be notably higher. Concrete that is 30 grade is a normal concrete, whereas 60 grade concrete is palm oil fuel ash concrete used in Malaysia. For geosynthetic reinforced segmental retaining walls applications, consideration should be given to interface shear capacity of the aggregate-filled blocks. The maximum shear stress of hollow blocks filled with natural limestone aggregate is slightly greater than that of recycled crushed concrete, possibly due to differences in angularity and the higher void content of the recycled aggregates (Bhuiyan et al 2015).

Summary

For the successful incorporation of recycled aggregates in road base and subbase, further testing of their critical properties is required even though preliminary results are promising. When such materials are investigated for capping material replacement in railways or as infill in geosynthetic reinforced retaining walls, their properties may be acceptable.

3.1.8 Estimated Recycled Content Percentages Based on Material Type and End Application

Road pavements

Approximately 8,000 tonnes of construction and demolition waste (including concrete, brick, and crushed glass, which is discussed in the next section) could be diverted from landfill for each kilometre of road constructed (TMR 2021). In Australia, there are 873,573 km of road, of which 145,928 km are urban roadways (CIA 2022).

There is great potential for using recycled concrete aggregates in flexible pavement applications when properties such as stability, resilient modulus, water susceptibility, indirect tensile strength and other volumetric properties, as well as results from wheel truck tests, are assessed. Adoption rates of 25–100% have been reported for such applications (Nwakaire et al. 2020). A mixture of 25% crushed concrete aggregate and 75% of virgin aggregate achieves comparable resilient response and permanent deformation properties as virgin quarry-derived dense graded aggregate base coarse as currently used in granular base and subbase pavement layers in New Jersey in the USA (Bennert et al. 2000).

In a specification developed with an initiative by the NSW Government, Savage (2010) summarised that up to 100% concrete may be used for road base or as bedding material. At the same time, other construction- and demolition-derived aggregates, including clay brick tiles, crushed rock and masonry, may be introduced in contents no higher than 20% for base course Class R1 and 30% for base course Class R2 (Savage 2010).

Capping material in railways

Early research shows that 100% crushed concrete, or crushed concrete combined with up to 20% crushed glass, are optimum mixtures for replacing capping layers. This may yield greater stiffness and strength than conventional materials, while comparable performance to that of conventional materials may be achieved through the use of 100% crushed brick or crushed concrete combined with up to 40% crushed glass (Naeini et al. 2019).

Retaining wall backfill

Research shows there is potential to replace virgin limestone aggregates with recycled crushed concrete as infill in I-Blocks used for geotechnical applications. The infill weight of each I-Block may vary between 88 and 95 kg, depending on the density of the aggregates (Bhuiyan et al. 2015).

Drainage

Recycled crushed concrete may be used as a drainage medium without additional virgin materials (Savage 2010).

Summary

Incorporating recycled concrete and brick from construction and demolition waste in road pavement applications is a potentially promising solution due to the extensive road network in Australia. However, there are great variances regarding the amount that can be absorbed. These are related to the specific performance requirements for roads in different climates or with varying traffic conditions, as well as the layer in which their incorporation is being considered.

Great potential has been realised for use of both crushed concrete and crushed brick as capping material in railways, replacing up to 100% of virgin materials. With more than 41,000 km of railway tracks spanning across Australia (Warwick & Cruse 2014), there is great potential for absorbing a large percentage of the waste generated.

In other applications, such as backfill for retaining walls and in drainage, the replacement of 100% of virgin materials appears to be simpler but primarily restricted by the pH of the recycled aggregates.

3.2 Crushed Glass

3.2.1 Material Overview

Recycled crushed glass (RCG) (see Figure 3.4(b)), which is generally processed to pass the 4.75 mm sieve, is a product of manufacturing and consumer mixed glass waste. It is sourced mainly from food and beverage glass containers and may be colourless or coloured, with different particle sizes depending on the method of production and chemical composition (Trochez et al. 2021).

There are different types of glass commonly found in the consumer market with varying chemical compositions. These include crystal and lead crystal glass, electric glass, soda-lime glass and borosilicate glass, all of which have different processing requirements for recycling (Mohajerani et al. 2017).

Glass waste may also derive from construction and demolition activities. Types of glass originating from that stream include float glass, shatterproof glass, laminated glass, extra clean glass, chromatic glass, tinted glass, glass blocks, glass wool, insulated glazed glass and toughened glass (Shooshtarian et al. 2019). These types have different characteristics that may complicate their recycling.

Figure 3.4: Images of (a) waste glass stockpile and (b) RCG

Source: VicRoads (2019).

Every tonne of glass recycled has the potential to save approximately 176 kg of soda ash, 560 kg of sand, 64 kg of feldspar and 176 kg of limestone (Mohajerani et al. 2017).

3.2.2 Market Maturity

The use of RCG in asphalt dates back to the 1970s and commercial products with up to 30% RCG are already available in the market (Newman et al. 2013).

Australia-wide, the supply of glass waste to recyclers remains above the demand for RCG, diverting thousands of tonnes of waste glass to stockpiles (Austroads 2022a).

In WA, the largest market for RCG is in construction but the lack of local recyclers and the high transportation costs for interstate delivery are barriers (Perryman & Green 2019).

In Vic, the demand for RCG in the market is high but limited by the processing capacity in the industry. Additionally, it fluctuates depending on price, and when prices are low, glass is stockpiled. With the current recycling systems in place, a number of barriers for market entry exist. These include:

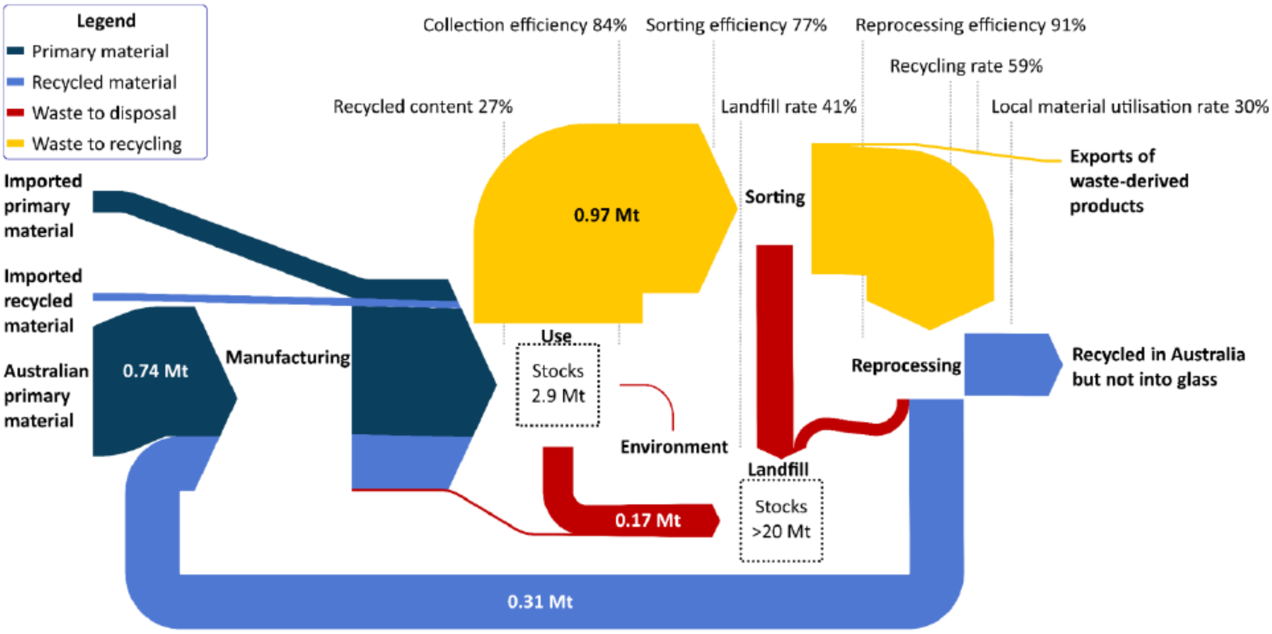
- *processes for collection systems*: kerbside collection of comingled waste leads to breakage of glass that then cannot be efficiently sorted.
- *contamination*: contaminants may affect the quality of the glass, which can affect the performance of the recycled product with severe implications such as end-user injuries (Sustainability Victoria 2014b).

Despite the challenges, opportunities for entering the market do exist and they involve the increasing consumer awareness, the establishment of separate glass recycling bins in large venues and workplaces, and the decrease in compaction rates (which can affect further cleaning and processing) in collection trucks among others (Sustainability Victoria 2014b). Increased use of glass fines as bedding sand and in concrete may also be realised, however when incorporating RCG in concrete it is important to be mindful of contamination level (Sustainability Victoria 2014b). Markets outside the recycling of glass back into glass containers are still underdeveloped and their full potential is yet to be realised (Austroads 2022a). Research is also underway in Qld to investigate the addition of recycled glass as partial sand replacement in concrete for non-structural applications and as drainage bedding media (TMR 2021).

3.2.3 Supply

RCG is primarily sourced from glass factories, demolition waste and recycled glass bottles (Newman et al. 2013). In 2017–18, total glass consumption in Australia was approximately 1.3 million tonnes, of which 46% was recovered (Allan 2019a). Great losses of glass for recycling are noticed during the collection and sorting process (Allan 2019b). The glass flows in Australia are presented in Figure 3.5.

Figure 3.5: Glass flows in Australia



Source: Pickin et al. (2020).

Commercial glass waste collected from the kerbside is often recycled back into packaging at plants in Brisbane, Sydney, Adelaide and Melbourne. Green glass, commonly used in wine bottles, is often in oversupply in Melbourne and Sydney and so is shipped to Adelaide where demand, due to extended wine production, is high. Facilities have not been established in NT and Tas, where kerbside waste is often shipped to either Melbourne or Adelaide. In WA, waste glass is almost entirely repurposed in infrastructure, such as for road base applications (Allan 2019a).

Waste crushed glass found unsuitable for recycling as packaging is increasingly finding applications as replacement for sand in road infrastructure. All Australian states, excluding Vic, have deposit schemes in place, where consumers may return eligible packaging for a 10-cent refund. In 2019, it was estimated that approximately 126,000 tonnes of glass were returned through such schemes Australia-wide (Allan 2019a). Vic is aiming to implement such a scheme by 2023. Table 3.4 summarises the amounts of glass generated and currently recovered in Australia as a whole and per state.

Table 3.4: Summary of glass waste generated and recovered per state and Australia-wide

State	Generated (tonnes)	Currently recovered (tonnes)
ACT	Data not publicly available	Data not publicly available
NSW	338,255 (Shooshtarian et al. 2019)	Data not publicly available
NT	Data not publicly available	Data not publicly available
Qld	240,753 (Shooshtarian et al. 2019)	104,548 (Queensland Government 2021a)
SA	Data not publicly available	74,000 (Green Industries SA 2020b)
Tas	Data not publicly available	Data not publicly available
Vic	212,253 (Shooshtarian et al. 2019)	55,000 (Sustainability Victoria 2014b)
WA	Data not publicly available	45,800 (Perryman and Green 2019)
Australia	1.16 million (Pickin et al. 2020)	688,000 (Pickin et al. 2020)

Table summarises publicly available data from different sources and different years. Numbers fluctuate and should be read as a general guide.

Waste glass deriveing from construction and demolition activities is generally put into landfill in all Australian states except NSW, where 100% of it is recycled. When other waste streams such as consumer waste are considered, the recycling of waste ranges from 37% in NT to 82% in SA (Shooshtarian et al. 2019).

3.2.4 Standard Practices and Opportunities to Use Recycled Content

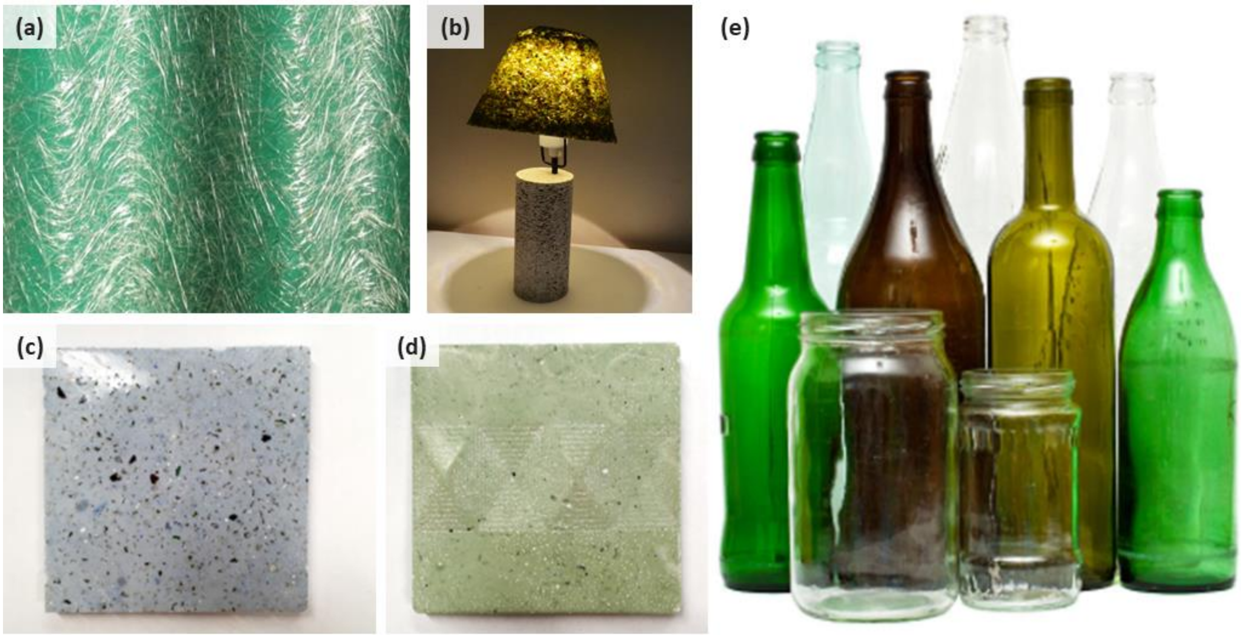
During the 19th and 20th centuries, commercial glass packaging was returned, washed and reused. While this was the most energy-efficient way to recycle those glass containers, consumer patterns changed towards the end of the 20th century and different materials for packaging were introduced. As a result, glass manufacturers started to produce containers from thinner glass, for recycling after crushing rather than for reuse (Allan 2019a).

Nowadays, commercial waste glass is collected from kerbsides and delivered to recycling depots where it is sorted and crushed. When properly sorted into clear, green and brown groupings, glass waste of the same colour may be melted and moulded back to jars and bottles for the consumer market. Often, however, glass is not appropriately sorted and the resulting colour of the recycled products is not attractive enough for the consumer market. This waste may be redirected and recycled in asphalt for playgrounds and roads (Walker 2007).

RCG may also be used as a silica-free abrasive alternative, replacing aluminium oxide and silicon carbide (Zulkarnain et al. 2021) in sandblasting and as a surface for sandpaper. Mixed glass may also be used to create fibreglass reinforced composites (Walker 2007). Additionally, it may find applications as filter media for water-quality projects (Allan 2019a) or as additive in fired brick, where it may improve mechanical performance (Maqsood et al. 2019). Some materialised applications of recycled glass are depicted in Figure 3.6.

RCG sand should be produced from food and beverage container glass or window glass, as other glasses contain more contaminants. The source material must be essentially free of glass derived from the following sources: cathode ray tubes; fluorescent and incandescent lights; glass recovered from electrical equipment; glass recovered from a laboratory source; porcelain products or cook tops; and glass from hazardous waste containers (Austroads 2022c).

Figure 3.6: Applications for recycled glass: (a) glass fibres, (b) consumer designer goods, (c) cement sample, (d) tile, and (e) bottles and jars



Source: Adapted from Flood et al. (2020).

Other glass waste, such as that from plates or windows, may be reprocessed for insulation, although this is not common practice and this glass often ends up in landfill instead (Sustainability Victoria 2014b). A summary of potential applications for waste glass is provided in Figure 3.7.

Figure 3.7: Summary of various potential applications for RCG

Construction materials and products	Consumer products	Artisanal purposes	Environmental uses
• Thermal insulation for prefabricated panes • Concrete aggregate • Cement replacement • Cementitious glass • Lightweight bricks • Building products made from glass foam	• Decorative objects • Tiles • Porcelain • Stoneware • Bricks • Glazes	• Marving • Fusing • Laminating	• Water filtration systems • Alternative to granitic sand and gravels for landscaping • Glass structures that support sea-bed erosion • Artificial reef structures • Feedstock for mycelium biocomposites

Source: Summarised from Flood et al. (2020).

Even though the most efficient and effective way to recycle glass is back into glass packaging, where up to 60% recycled material can be used, only up to 37% RCG is currently used (Allan 2019a).

3.2.5 Opportunities for RCG in Road and Rail Infrastructure

RCG is a granular material that can be used as a natural sand replacement in different infrastructure applications. Used for a number of years, its applications have been realised to the point that there are opportunities to utilise all existing stockpiles (see 4.2.6 Market Maturity and 4.2.7 Supply for details).

In road infrastructure, RCG may be used as a replacement for fine aggregates and sands in asphalt pavements, or as a foreign material component in road base and subbase (Newman et al. 2013). Additionally, it might be used as an aggregate supplement along with recycled concrete as a rail capping layer (Macken et al. 2021). MRWA (2021b) recognises that using recycled glass in road applications is not the most efficient and valuable recycling application. However, it provides a solution for absorbing waste glass, diverting it from landfill while conserving natural materials.

ARRB has also been involved in research activities investigating the use of waste glass in various road and rail infrastructure applications. The many opportunities this has identified include its aforementioned use in road base and subbase on sealed roads; as unsealed road wearing course; as fine aggregate for concrete and asphalt production; as fine aggregate for bituminous slurry emulsions; as bedding and backfilling material for underground pipes and/or cables and services; and as bedding material for block-paved pavements and footpaths (ARRB Group 2010).

Studies show that RCG can be used in the construction of embankments, structural and non-structural fill, retaining wall backfill and drainage (foundation and drainage blankets) (Grubb et al. 2006, Eberemu et al. 2013). Incorporation of RCG in clay has shown to improve the engineering properties of subgrade, such as permeability and resilient modulus (Davidović et al. 2012, Yaghoubi et al. 2021).

ARRB has prepared a technical report for Austroads (Austroads 2022a) for the use of RCG as a sand aggregate replacement. The report identifies the use of RCG in such landscaping applications as sand paths and mulch blends for garden beds.

The Austroads (2022a) report also states that RCG can be used as a partial fine aggregate sand replacement for concrete works, including concrete pavements, kerbs and channels, footpaths and shared paths, and footings and plinths for traffic signs and lights. There is concern that the high silica in RCG may lead to alkali-silica reactions in the presence of high alkaline materials in the concrete mix. These can initiatiate microcracks in concrete and, accordingly, loss of strength. Solutions to mitigate this include decreasing the size of the RCG by grinding, controlling the pH of the concrete to be less than 12, and adding other materials such as GGBFS and Fly Ash (Austroads 2022a).

Powdered RCG can also be used in foamed concrete, as a partial replacement for cement, which results in higher compressive strength and lower density and alkali-silica reactions (Khan et al. 2019).

Recent studies show that foamed glass, produced from RCG, can be used in drainage and filtration applications in the construction of bridges and roads, as well as in landscaping bricks and kerbs, due to its porous and lightweight nature (Flood et al. 2020). Due to this lightweight nature and potential of decreasing alkali-silica reactions in concrete, foamed glass can be used in foamed concrete too (Filshill 2018).

3.2.6 Specifications

RCG tends to be processed to a passing 4.75 mm product and can be used as a natural sand replacement. RCG can be used as an aggregate replacement in a number of different infrastructure applications. These can be summarised as follows:

- As a partial fine aggregate replacement within asphalt.
- As a partial fine aggregate replacement within unbound granular materials for use in road base and subbase applications.
- As a partial fine aggregate replacement within unbound granular materials for use in bedding and backfill, drainage applications, embankment fill and landscaping.
- As a partial fine aggregate replacement within concrete for use in non-structural applications such as kerb and channel and low risk pavement applications.

Table C.1 in Appendix C lists the current specifications across Australia that enable the use of RCG in various applications.

High proportions of waste glass can be utilised in bedding or backfill applications. However, it is likely larger volumes can be utilised in granular subbase and base applications due to higher overall materials quantities being used. Despite only 5% RCG being permitted in asphalt wearing courses, as this component of a bound structure is most frequently replaced, it still represents a significant opportunity to reutilise waste glass.

3.2.7 Comparative Performance

Road pavements

RCG has the potential to be used in both asphalt and unbound granular pavement structures as a partial aggregate replacement. RCG tends to be processed to a passing 4.75 mm product and is used as a partial sand-size fraction of graded aggregates, as there are limits on how much can be used in certain applications. It has a similar density and strength to that of the aggregates it is used to replace (Austroads 2014a). It may have a lower specific surface area than the aggregates it replaces, which has the potential to impact slightly on aggregate interlock and the moisture susceptibility of asphalt mixtures.

RCG can be used as a partial aggregate replacement in asphalt base and intermediate asphalt courses. Within these layers it can be incorporated by up to 10% by mass of the total asphalt mixture. Historically, it has been less widely used in asphalt wearing course, however with the improved processing of recent years it is often accepted by up to 5% by mass of mixture.

Using RCG can bring both benefits and negatives. For example, in unbound granular applications, it has been found that fine (4.75 mm) and medium (9.50 mm) glass can be ‘well graded’ yet its inability to absorb water and retain water results in compaction curves comparable to typically poorly graded sand (Disfani et al. 2011). Converserly, RCG’s compaction curves present as flatter than those of the natural aggregates, indicating that RCG is not susceptible to variations in moisture in the environment. Additionally, RCG has been found to have hydraulic conductivity within the typical range for natural aggregates with the same gradation (Wartman et al. 2004).

Concrete

In concrete, replacing fine sands with RCG is generally reported to result in an increase in compressive strength. The extent of increase varies, depending on the morphology and size of RCG, and some studies have even reported a decrease in the compressive strength. Typically, in concrete paving applications, up to 20% RCG can be used as a fine aggregate replacement. Great care needs to be taken, however, to avoid reactions between alkali in concrete with the silica of the aggregates, which result in notable strength decrease due to the formation of microcracking (Austroads 2022a). The reports on the workability of the concrete have been found to vary (Mohajerani et al. 2017).

When crushed glass (10% by volume), together with recycled waste plastics (10% by volume), were used in a concrete footpath, it was found to yield average splitting tensile stress above that specified by ASTM C496/496M-17 and compressive stress greater than 25 MPa, which is more than the compressive strength required for footpath in Vic. They were, however, found to have greater water absorption when compared with the controlled concrete footpath. Larger water absorption is an indication of larger sorptivity of the concrete, which could be an indication of lower durability of concrete (Wong et al. 2020).

Other applications

The thermal conductivity of recycled glass is reported to be comparable to that of natural aggregates, suggesting that it could be used in utility trench applications where heat transfer properties are of concern. However, further assessment is required to build confidence (Austroads 2022a).

Summary

Overall, RCG has similar performance to that of the natural sand it would be replacing (Austroads 2009b), but care needs to be taken when incorporated in concrete to avoid akali aggregate reactions.

3.2.8 Estimated Recycled Content Percentages Based on Material Type and End Application

Road pavements

Unbound granular applications

RCG can be used up to 20% by mass in granular bases and up to 50% in granular subbase (see Table C.2)

Bound granular applications

Up to 10% of RCG can be used in asphalt bases (see Table C.2).

Asphalt applications

RCG can be used in asphalt base and intermediate courses at up to 10% and asphalt wearing courses at up to 5% respectively (see Table C.2).

Capping material in railways

Up to 40% RCG may be used with recycled concrete aggregates in rail substructures (Naeini et al. 2019). This was found to meet Victorian rail authority requirements (Macken et al. 2021).

Bedding and drainage

As bedding for drainage works and as a drainage medium, RCG can be used at a 100% content (see Table C.2).

Concrete

A field study in Vic showed that up to 10 vol.% RCG combined with 10 vol.% of waste plastic may be successfully incorporated in concrete footpaths (Wong et al. 2020) and a study in the early 2000s in Australia reported that up to 20% RCG can be incorporated in non-structural concrete (Sagoe-Crentsil et al. 2001).

3.3 Reclaimed Asphalt Pavement

3.3.1 Material Overview

Reclaimed asphalt pavement (RAP) (Figure 3.8) is obtained from the excavation of road pavements or from the milling of existing asphalt surfaces (Austroads 2014a). RAP usually has high moisture content and consists of high-quality and well-graded aggregates coated with bitumen (Milad et al. 2020).

Figure 3.8: Reclaimed asphalt pavement

Source: Trochez et al. (2021).

3.3.2 Market Maturity

RAP has effectively been used in asphalt since 1917, but its potential was truly realised in the 1970s, when oil prices surged. Greater quantities of RAP were further introduced in 2006 and 2013, when the cost of asphalt binders increased and the aggregate supply experienced a shortage (Milad et al. 2020).

In Australia, approximately 50% of the asphalt removed from road pavements is re-used as RAP in hot mix asphalt applications making it the most popular recycling route. The remaining 50% is used in cold recycling in small amounts, or as a fill in base and subbase materials (Austroads 2009b).

3.3.3 Supply

At present, there are no figures available for RAP generation, recovery rates or stockpiles in Australia. This is something that the Australian Flexible Pavement Association (AfPA) are looking into in more detail. They are in the process of engaging with industry to generate annual figures on RAP usage in asphalt by state. It is expected that more accurate figures will be available later in the year[1].

In Qld, even though there is constant encouragement to increase the amount of RAP currently incorporated in new roads, there is not enough supply of waste material, which could hypothetically lead to inconsistencies in the composition of roads across the network in the future (Trochez et al. 2021).

In NSW and Vic, shortages of virgin quarry materials have increased their prices by up to 70%, primarily because of the increased haulage distances (Sustainability Victoria 2015).

3.3.4 Standard Practices and Opportunities for Recycled Content

Asphalt pavements are fully recyclable. At the end of their lives, they are milled to create RAP, which consists of aggregate (approximately 96%) coated with residual bituminous binder (approximately 4%). This material can be reused within new asphalt (Lamb 2011). The binder is heavily aged but is blended with virgin binder during the mixing process, which balances its properties. RAP has the potential to minimise, if not eliminate, the amount of virgin aggregate and bituminous binder required in new asphalt mixes. This not only reduces our reliance on virgin materials, it also allows for the cost of fresh asphalt to be decreased. RAP can also be incorporated with granular materials for unbound granular pavements. Cold in-place recycling

[1] Personal communication between Dr James Grenfell and Anna D'Angelo that took place on 2 February 2022.

processes, such as foamed bitumen stabilisation, can be used to rehabilitate end-of-life pavements. Research conducted by ARRB for Austroads has shown that foamed bitumen stabilisation can incorporate up to 50% RAP with acceptable performance in both permanent deformation and fatigue (Austroads 2019a, Austroads 2022b). There now exists the technology to mill asphalt pavements and treat them with foamed bitumen to create a foamed bitumen stabilised pavement consisting of up to 100% RAP. These types of rehabilitated pavements are being implemented for local government authority roads (Wirtgen Group n.d.).

3.3.5 Opportunities for Recycled Content in Road and Rail Infrastructure

As mentioned above, RAP can be introduced back into the asphalt mix as an aggregate and partial bitumen replacement (Newman et al. 2013). Generally, RAP is stockpiled and then introduced back into new asphalt at the asphalt plant to make new hot mix asphalt. When incorporating higher RAP contents, a recycling agent or rejuvenator may be used (Milad et al. 2020). This tends to be the case where the RAP content exceeds 30%, and to ensure the resultant asphalt has similar properties to virgin asphalt, softer binders or rejuvenators are required to adjust the stiffness of the blended RAP binder. It can also be incorporated in-situ using either cold or hot processes or during the cold plant mixing (Austroads 2014a). RAP stockpile management is a key consideration in developing RAP asphalt mixes, particularly as the proportion of RAP increases and the consistency of the RAP properties becomes more important.

RAP may also be used as fill or unbound pavements to minimise costs and greenhouse gas emissions (TMR 2020). Cold plant-recycled asphalt can replace up to 100% of virgin aggregates for applications such as asphalt pavement patching, shoulder surfacing, pavement shape correction prior to surfacing, and intermediate or basecourse in deep lift pavements (Austroads 2009a).

RAP has also been investigated for use in base and subbase pavement applications as a partial or full replacement of aggregates, where some reports suggest that up to 100% of RAP may be used (Arshad & Ahmed 2017). In the form of asphalt planings or crushed slab asphalt, RAP has been used as a low-dust surfacing for unsealed roads and as unbound granular base course and subbase material on rural and country town roads. When combined with bitumen emulsion, RAP can be used to manufacture a bound base course or subbase in cycle tracks, full depth bituminous residential streets, industrial surfacings, and as part replacement of intermediate layers in deep lift asphalt pavements (Austroads 2009b).

A number of benefits may be realised by incorporating RAP into pavements, such as a reduction in costs, the amount of non-renewable material used, and the amount of waste sent to landfill, all without compromising performance when compared to traditional materials (TMR 2020). Great benefits have been realised through the cold in-place recycling of RAP with foamed bitumen, a process that limits further degradation of the recycled materials (Kar et al. 2018).

3.3.6 Specifications

The use of RAP in road pavement applications is widely accepted throughout Australia. There are various specifications that define its use for each of the states and territories, depending on the application. Specifications for the use of RAP within asphalt and within granular pavements are detailed in Table D.1 (see Appendix D). Overall, its use is allowed in asphalt up to 25% by mass in wearing courses and up to 40% in layers other than wearing courses.

RAP may also to be used in granular layers, including unbound and bound base and subbase layers, at contents up to 50% by mass. States including Vic, SA and Tas allow for the highest rates of incorporation of RAP in their roads (up to 50%), followed closely by Qld (up to 45%) and NSW (up to 40%), while NT and WA allow only up to 15% of RAP dependent on application and layer. Further details are discussed in Appendix D. Table D.2 and Table D.3 provide a summary of the allowable limits for asphalt and granular layers respectively, depending on the application as per each Australian state and territory.

3.3.7 Comparative Performance

When compared to virgin asphalt, mixes containing RAP may show an increase in stiffness, depending on the amount added. They have also been found to be comparable in tensile strength, while their fatigue life may be negatively affected depending on temperature (Milad et al. 2020). Addition of 15 to 20% RAP is expected to have little impact in properties such as ravelling, fatigue cracking, rutting and weathering (Austroads 2009a). Studies in the USA have shown that the long-term performance of pavements containing up to 30% RAP is equivalent to those comprising virgin materials. Their performance is primarily affected by the increase in stiffness of aged bitumen contained in RAP, representing a risk for fatigue that needs to be managed. An increase in RAP content has also been found to increase resilient modulus and permeability, which reduces the risk of permanent deformation, but may cause a decrease in shear strength in asphalt and reduce the material's bearing capacity, which increases the risk of fatigue, when compared to virgin aggregates. Additionally, the strength of base layers containing only virgin aggregates has been reported to be lower than that of base layers containing RAP (Milad et al. 2020).

Arshad & Ahmed (2017) summarised studies investigating the effect of RAP content in base and subbase applications. They expressed that RAP is generally finer than quarry-derived natural aggregates, especially when using the milling process. Dry density and California Bearing Ratio (CBR) were found to decrease, and the resilient modulus and residual strain were found to increase regardless of the amount of RAP content, while properties such as permeability and moisture content were found to be dependent on the amount of RAP added (Arshad & Ahmed 2017). Arulrajah et al. (2013) suggested that RAP cannot be used to replace 100% of virgin granular materials in subbase applications due to its high LA abrasion value and relatively large change in the gradation curves of a modified compaction test.

Overall, the content of RAP, the application and the climate are significant factors to consider for the successful incorporation of RAP in asphalt. For use in base and subbase applications, the LAV and CBR have been found to be restricting in the amounts of recycled material that might be added, but RAP stabilised with cement is more promising. Additionally, the amount of binder present in RAP needs to be carefully considered when it is used in base and subbase applications because too high content might hinder drainage, which will in turn be detrimental to the function of the base and subbase layers of the pavement (Arshad & Ahmed 2017).

RAP up to 50% by mass of the host material that is to be stabilised has performed well in foamed bitumen stabilised pavement bases in both permanent deformation and fatigue (Austroads 2019a, Austroads 2022b).

3.3.8 Estimated Recycled Content Percentages Based on Material Type and End Application

Road pavements

New asphalt pavements can be incorporated with up to 100% RAP with the help of rejuvenators to bring the binder grade of the RAP binder back to equivalent viscosity of fresh bituminous binder. Very high RAP contents are already being implemented in Europe and North America (Zaumanis et al. 2016). However, in Australia the road network is different. Around 95% of the road network is made from granular materials. These granular pavements are either unsealed (63%) or sealed with a sprayed seal (32%). This means only 5% of the pavement structures in Australia are surfaced with asphalt (ARRB 2020). Asphalt in Australia is not so prevalent as in North America and Europe. Incorporating 25% RAP in all new asphalt mixtures would utilise all the RAP generated in Australia.

Adding up to 15% RAP is not expected to affect the properties of a dense graded asphalt (DGA) when conventional bitumen binders are used. When adding greater amounts, adjustments in the bitumen grade to compensate for the increased stiffness observed in aged binders is required. The asphalt manufacturing method significantly affects the amount of RAP that may be added. Using the batch mixing process, up to 30% RAP may be added but depending on the temperature and duration of the process, slightly larger amounts may be considered. When a counterflow drum mixer is available, up to 50% RAP can be used, while a theoretical 60% could be added with a double drum mixer (Austroads 2014a). Worldwide, particularly in Europe and North America, the asphalt industry is developing capabilities towards producing 100% RAP containing asphalt mixes. It is possible that the industry in Australia would follow suit, dependent on the availability of high levels of RAP.

Fulton Hogan has developed a proprietary product, called RAPBASE, to be used as bitumen-treated base course and subbase layers. This is a granular base material that uses an anionic bitumen emulsion as a binder and which has the capacity to absorb nearly 100% RAP (Jones 2020b).

For absorbing RAP in hot-mix asphalt, Austroads (2009b) specifies that the practical limit is up to 50%. However, if processed in special plants that use a microwave technology or similar indirect methods of heating, potentially up to 100% RAP may be incorporated. These plants have higher energy costs though (Austroads 2009b), so an overall cost-benefit analysis should be conducted.

RAP can also be utilised in unbound granular pavements, but this does not take advantage of the residual RAP binder, so is not the optimum end usage for RAP. In a specification developed with an initiative by the NSW Government, Savage (2010) summarised that up to 40% RAP may be used for road base (Class R1 and Class R2), 50% for select fill (Class S), 20% for bedding material (Class B), while 5% may be acceptable as drainage medium (Class D75, D20, and D10). RAP can also be included within the host material for foamed bitumen stabilisation. This can be at levels of up to 50%, even for heavily trafficked foamed bitumen stabilised based (Austroads 2019a, Austroads 2022b).

Summary

Overall, the use of RAP in asphalt is an efficient and cost-effective use of resources, with the potential to divert nearly 100% of waste asphalt from landfill. The amount added into the manufacturing of new asphalt pavements depends on the equipment available at each site or manufacturing facility. Additionally, careful consideration needs to be given to the composition of the bitumen that is contained with RAP, especially with the increased incorporation of polymers that have found applications in heavily trafficked roads. Better control and care during the crushing and screening process may promote the reuse of RAP in value-add applications, such as incorporation back into asphalt, where its residual binder content can be used to offset the amount of virgin bitumen required.

Other applications for RAP exist, such as in granular materials like those discussed by Savage (2010). However, they may not be considered as the highest and best end-use for RAP, as it does not take advantage of the residual RAP binder, as it does in asphalt.

Although new technologies in which polymers and other additives are incorporated in asphalt mixes present certain performance benefits, they appear to negatively affect the rates of RAP reuse back into asphalt.

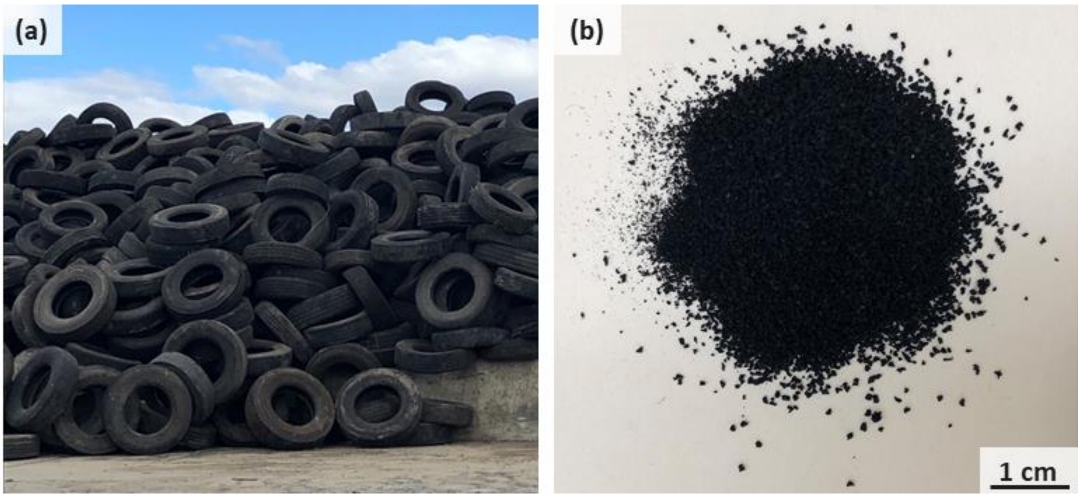
3.4 Crumb Rubber

3.4.1 Material Overview

Tyres comprise several materials, such as elastomer compounds, textile fibres, carbon black, steel cord and various other inorganic and organic components (Landi et al. 2018). Tyres made for different purposes, including passenger car tyres, truck tyres and off-road tyres, differ in composition. A key difference between truck and passenger tyres is the content of natural rubber, with that of the passenger vehicle tyres being 35% and that of truck tyres around 70%. Additionally, truck and off-road tyres do not contain fabrics, which are hard to recycle and for which there is currently no market, and so are preferred for recycling (O'Farrell 2019b).

Rubber from end-of-life tyres can be processed into a number of different size fractions, including crumb rubber and larger sizes such as rubber shreds (known as tyre shreds). The main focus of this section is crumb rubber but it there can be useful applications for larger rubber size fractions within granular materials, particularly as lightweight fill in embankment applications. Crumb rubber derives from the recycling of those feedstock tyres at the end of their life, which are collected and then ground to crumb rubber (Trochez et al. 2021).

Figure 3.9: (a) End-of-life tyre (ELT) stockpile and (b) crumb rubber



Source: ARRB.

3.4.2 Market Maturity

Crumb rubber has been utilised in road construction since the early 1970s. Crumb rubber obtained from the recycling of truck tyres has been used with considerable success in sprayed seal road applications in Vic, WA, NSW, and SA for decades (Austroads 2019c, Austroads 2021b). As a result, S45R, S15RF, and S18RF, which are three crumb rubber binder grades, are included in the national specifications for polymer modified binders (Austroads 2021b). While its incorporation in asphalt is established across the globe, in Australia it is yet to be widely adopted. However, the potential has been recognised and hence there are reports for an Australia-wide effort to assess the feasibility of incorporating crumb rubber into asphalt. These include:

- the development of national specifications for crumb rubber binders in asphalt and sprayed seals
- the optimisation of the use of crumb rubber modified bitumen (CRMB) in asphalt and spray seals and transferring that technology to Qld
- using crumb rubber in gap graded asphalt in Qld
- increasing the use of CRMB in OGA and transfer that technology to WA
- investigation of new mixes in crumb rubber modified asphalt (CRMA) in SA (funded by the Tyre Stewardship Australia)
- developing a specification for light traffic CRMA in Vic (Harrison et al. 2021).

In Australia, 1,591 accredited retailers and 22 recyclers, which includes the addition of three new recyclers in one year, exist as of the end of the 2020–21 financial year (Tyre Stewardship Australia 2021a). By the end of 2021, another plant was added in NSW with the capacity to process tens of thousands of tyres previously sent overseas (Scott 2021). While the incorporation of crumb rubber in asphalt is widely accepted by the industry in principle, the recovery process is energy intensive and consequently costly (Newman et al. 2013).

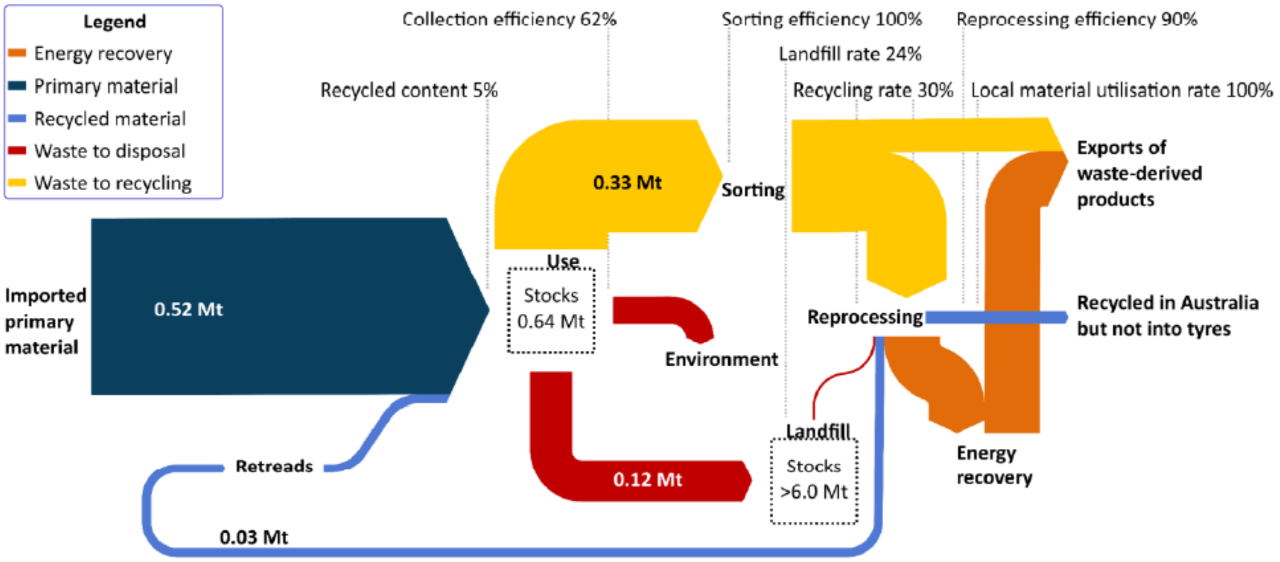
Figure 3.14 shows that the supply of crumb rubber and road construction costs can hinder the wide adoption of the technology. For the benefits of crumb rubber to be realised by road infrastructure, high quality crumb rubber needs to be supplied. Currently, there are only some facilities with the capacity to produce such product in Vic, Qld, and NSW, but transportation costs restrict its adoption by Tas and NT. Relevant changes need also to be made in the road construction plants, which are also costly. Additionally, should crumb rubber be processed in the plants, operational costs would also increase, due to the increased content of binder in use for both sprayed seal and asphalt applications and the higher temperatures required during processing (Austroads 2021b). Additional barriers for greater recycled tyre adoption by the industry in WA include the lack of consumer awareness, lack of government guidelines for sustainable procurement, and the remote location of stockpiling which increases transportation costs (Perryman & Green 2019). Changes are being made however, even if small in scope: in an effort to increase the usage of crumb rubber in asphalt in WA, MRWA has mandated its use in OGA mixtures, a small part of the asphalt market (MRWA 2021b).

More recent technology developments allow for the incorporation of greater amounts of crumb rubber in applications such as footpaths, tree protection zones, bike paths, parking lots and driveways. One example is Porous Lane, which creates a permeable surface for better rainwater management (Tyre Stewardship Australia 2021b).

3.4.3 Supply

In Australia alone, approximately 56 million tyres are disposed of every year, of which only 10% are currently recycled into applications where they may add value, while the vast majority becomes landfill (Harrison et al. 2021). Of these, 117,595 tonnes are offroad tyres (Randell et al. 2020), the majority of which are buried in mine sites and pits or simply left on site (Tyre Stewardship Australia 2021a); 189,921 tonnes of which were passenger tyres; and 157,702 tonnes were truck tyres (Randell et al. 2020). Tyre consumption in Australia is projected to increase by 1.5 %/year until 2025 (Randell et al. 2020). In 2018–19 in Australia, 69% of the 466,000 tonnes of used tyres were recovered for reuse, processed into tyre derived products, or thermally processed. There is a long way to go though, as the remainder is still either stockpiled or disposed to landfill (Tyre Stewardship Australia 2020). The tyre flows in Australia are depicted in Figure 3.10.

Figure 3.10: Tyre flows in Australia



Source: Pickin et al. (2020).

The largest amounts of end-of-life tyres in 2018–19 were generated by NSW, followed by Vic and Qld. Significantly lower amounts were generated by WA, SA and Tas, while ACT and NT produced the least amounts (Department of Agriculture, Water and the Environment 2020). Approximate numbers for the year are listed in Table 3.5. Of these, 208,000 tonnes remained in Australia and were distributed among casings and seconds (6%), civil engineering applications (1%), and crumb rubber, granules and buffetings (7%); whilst notable amounts were landfilled (7%), stockpiled (ceased due to EPA regulations), dumped (2%), or disposed of on-site (20%); and 56% were exported (Randell et al. 2020).

Table 3.5: Summary of end-of-life tyres generated, recovered and remaining per state and Australia-wide

State	Generated (tonnes)	Currently recovered (tonnes)
ACT	5,000(1)	Data not publicly available
NSW	135,000(1)	Data not publicly available
NT	5,000(1)	Data not publicly available

Qld	102,000(1)	51,676(3)
SA	30,000(1)	18,600(4)
Tas	11,000(1)	Data not publicly available
Vic	114,000(1)	Data not publicly available
WA	61,000(1)	18,100(5)
Australia	465,218(2)	Data not publicly available

Data in table are summarised from different sources and include information from different years. Numbers fluctuate and should be read as a general guide and not as absolute

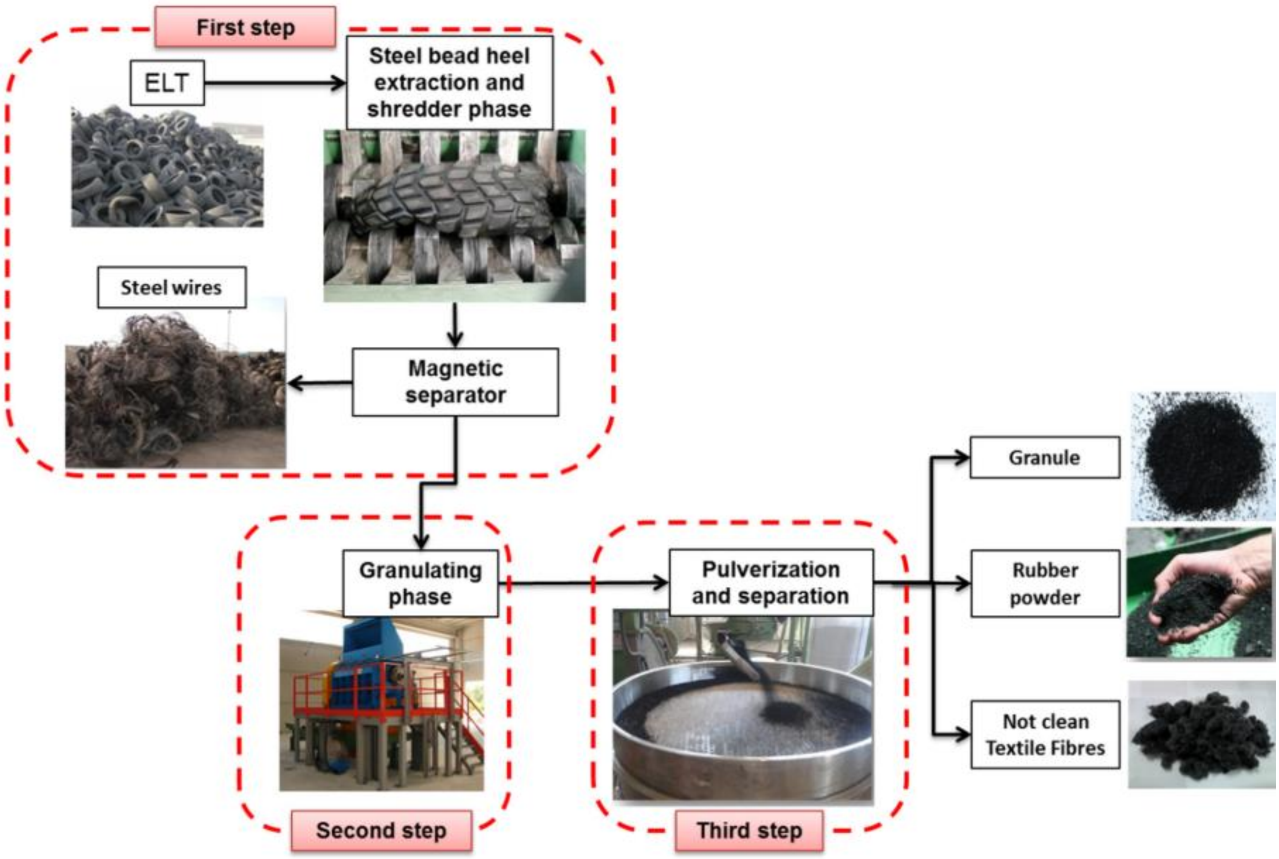
Sources:

1. O'Farrell (2019b).
2. Randell et al. (2020).
3. Queensland Government (2021a).
4. Green Industries SA (2020b).
5. Perryman and Green (2019).

3.4.4 Standard Practices and Opportunities to Use Recycled Content

The recycling of tyres is primarily achieved through granulation. This may involve a variety of techniques such as complex mechanochemical or thermal treatments, or simpler mechanical methods (Newman et al. 2013). Figure 3.11 illustrates the established ambient process for recycling end-of-life tyres, while other methods, such as a cryogenic method, where liquid nitrogen is used to freeze and in turn shatter the tyres into crumb rubber, could also be used (Bekhiti et al. 2014).

Figure 3.11: End-of-life tyre (ELT) processing



Source: Landi et al. (2018).

End-of-life tyres may be repurposed through destructive methods, such as in: foundries; cement works; for urban heating or steelworks; or they may be recovered as crumb rubber (Bekhiti et al. 2014; Clauzade et al. 2010). The steel recovered from end-of-life tyres is of high quality and is already being used by the steel industry for the production of virgin steel, while the textile fibres have not found such a high rate of adoption

(Landi et al. 2018). Crumb rubber may find applications in playgrounds, as filling for artificial turf football fields, for modification of concrete properties, floor slabs, or even as decorative mulch (EcoGreen 2018). Some of those are illustrated in Figure 3.12. While fuming and smell do occur, they are not hazardous and all methods, both destructive and recovery, have an overall positive environmental impact (Clauzade et al. 2010).

Figure 3.12: Applications for recycled crumb rubber: (a) playgrounds, (b) filling for artificial turf fields, (c) concrete and (d) flooring

Sources: ArtificialTurf (2015); Ganjian et al. (2009); MEETALL Sports (2020); Tyre Crumb (2021).

3.4.5 Opportunities for Recycled Content in Road and Rail Infrastructure

The main opportunities including crumb rubber into transport infrastructure are through the wet process as a modifier for bitumen for use in asphalt and sprayed seals, or as an additive for asphalt incorporated via the dry process. During the wet process, bitumen is heated to typically 180 °C and then the crumb rubber is added and blended in with a shearing process. Rubber can be added to bitumen from 5–20% by mass depending on the end application or requirements. Crumb rubber modified bitumen is then used as a binder in crumb rubber modified asphalt and sprayed seals or as a crack sealant or stress alleviating membrane interface between bound pavement layers. In the dry process, the rubber is added as a partial replacement of the fine aggregate.

Crumb rubber can find applications in several areas in road and rail infrastructure. It can be used to manufacture road speed reducers, in cycling tracks, or in bitumen as an additive. It can also be used as vibration absorption systems for railway structures (EcoGreen 2018). There are two main drivers for incorporation of crumb rubber in asphalt. First, the obvious redirection of end-of-life tyres from landfill; and second, the expectation that the elastic properties of the rubber might benefit the performance of the roads (Santagata et al. 2013).

One challenge is the presence of textile fibres, which form bundles and cannot uniformly mix with bitumen. Processing of end-of-life tyres is advanced in Australia and very consistent contaminant-free products, with fine particle gradings, are available. Through the development of specific treatments, bituminous blends with improved mechanical performance may be produced (Landi et al. 2018). Its use in asphalt is often as an additive, either in bitumen as a modifier (wet process) or as an aggregate replacement (dry process) (Newman et al. 2013). Crumb rubber is generally ground in an ambient environment; however, it can also be processed via other techniques such as cryogenic grinding or water jet separation. Care needs to be taken to not introduce contaminants or moisture and for the crumb produced to have appropriate particle size distribution to conform with roads applications. It is currently used in both asphalt and sprayed seal applications (Trochez et al. 2021).

E-Pave technology, patented in 2003, involves the design of a permeable road construction system to improve the strength of subbase in areas with poor soil properties. This technology is constructed using one or two layers of tyres filled with crushed rock and/or sand (Newman et al. 2013). Permeable pavement carpark materials have been trialled made from 50% used tyres. A trial of the permeable asphalt surface in a car park in the City of Mitcham, SA, incorporated approximately four tonnes of recycled tyre rubber, the equivalent of 500 used passenger tyres, and is capable of soaking away on site up to a 100-year storm (Water Sensitive SA 2019).

Crumb rubber has also been combined with plastic to wrap a concrete inner structure for sleepers in rail applications, with promising preliminary results (Macken et al. 2021). Figure 3.13 summarises the different possible applications where waste crumb rubber may be absorbed.

Figure 3.13: Summary of crumb rubber applications in road and rail infrastructure

Applications of crumb rubber in road and rail infrastructure

- Aggregate replacement in asphalt
- Additive in bitumen
- Road speed reducers
- Cycling tracks
- Railway sleepers
- In ballast in railways

3.4.6 Specifications

Road pavements

Crumb rubber has found applications in both road and rail infrastructure. Most road agencies have specifications for crumb rubber modified asphalt. There are also Austroads specifications for crumb rubber modified binders for use in asphalt and sprayed seals applications. These are summarised in Table E.1 in Appendix E.

For Victoria, VicRoads (2017) specifies that highly modified bitumen containing crumb rubber (S45R) may be used in extreme stress seals (XSS) or strain alleviating membrane (SAM) seals, allowing contents of up to 15 wt.% of the binder for the latter. In NSW, crumb rubber can be added for sprayed seal applications provided that unmodified bitumen is used as the base and in asphalt via the dry process (QA Specification R118 2020). In WA, rubber granules may be added in geotextile reinforced seals, asphalt, and sprayed seals (Specification 503 2018, MRWA 2021b), while research projects are underway to transfer the technology throughout WA to adopt the incorporation of crumb rubber in bitumen in both open graded asphalt (OGA) and gap graded asphalt (GGA) mixes (WARRIP 2021).

Railways

Crumb rubber may be used in combination with ballast in railway applications to improve its elastic properties and consequently decrease degradation rates. Different methods for doing so have been investigated, including the use of a resilient epoxy adhesive to bind together a mixture of standard ballast aggregates and crumb rubber (‘Resiliently Bound Ballast’), bonding small particles of crumb rubber with the standard ballast aggregates, and the addition of unbound crumb rubber particles in the gaps formed by the standard ballast aggregates (Sol-Sánchez et al. 2015). In Australia, standard AS 2758.7 sets the requirements for the quality of the rock to be used in ballast (Cement Concrete & Aggregates Australia 2009). However, crumb rubber is not to be used as aggregate replacement in this application, rather as an extra material with the potential to increase the lifespan of ballast (Sol-Sánchez et al. 2015).

3.4.7 Comparative Performance

Road pavements

Typically, the addition of rubber may positively affect mechanical performance, noise, weight, environmental sustainability and durability (Landi et al. 2018). However, some improvements in performance could also come through increased total binder content, as the rubber acts as a binder extender. Furthermore, even though some positive results have been reported when crumb rubber was incorporated into bitumen through the wet method, the results obtained when the dry method was used have not been as promising, with homogeneity and compaction challenges being reported. These may be overcome through the pre-treatment of crumb rubber using function-specific catalysts (Santagata et al. 2013). The advantages and challenges associated with incorporating crumb rubber in road construction are summarised in Figure 3.14.

Figure 3.14: Benefits and impediments of using crumb rubber in road construction

Environmental benefits	Performance benefits in asphalt	Performance benefits in sprayed seals	Impediments
•Traffic noise reduction •Reduction in energy and greenhouse emissions •Repurposing of end-of-life tyres	•Resistance to cracking (indirect) •Aging and oxidation resistance (indirect) •Rutting resistance •Durability •Lower maintenance costs (frequency)	•Crack resistance •Productivity •Oxidation resistance •Aggregate retention on heavily trafficked roads	•Crumb rubber/ binder segregation and degradation •Road construction costs •Emissions

Source: Adapted from Austroads (2021b).

It has been reported that introducing crumb rubber instead of polymers to modify bitumen in DGA may achieve comparable rutting and fatigue resistance. Additionally, it has the capacity to increase flexibility and provide resistance to reflective cracking, while it assists to avoid bleeding and instability when high contents of binder are used (Harrison et al. 2021). When compared to unmodified bitumen, crumb rubber modified bitumen (CRMB) has been found to increase durability and enhance elasticity (Grobler et al. 2017).
Table 3.6 summarises those findings.

Table 3.6: Effects of incorporating crumb rubber through the dry or wet process in DGA and GGA

Application	Rutting performance	Fatigue resistance	Moisture sensitivity	Thermal cracking resistance
Crumb rubber in DGA	Increase rutting resistance	Increase fatigue life	Increase moisture sensitivity	Increase thermal cracking resistance
Crumb rubber in GGA	Increase rutting resistance	Increase fatigue life	Decrease moisture sensitivity	Increase thermal cracking resistance
Crumb rubber in GGA versus polymer modified bitumen (PMB) in GGA	No improvement	Increase fatigue life	Decrease moisture sensitivity	No improvement

Source: Adapted from Austroads (2021b).

Crumb rubber modified binder may provide some enhancement in properties over conventional bitumen. When CRMB is used in the manufacture of asphalt, it is expected to have improved fatigue resistance over conventional asphalt; however, as mentioned above, this could also be through increased total binder content as the rubber acts as a binder extender. Potentially similar property enhancements can be made through the dry process, albeit with higher rubber content.

Railways

In railways ballast, the addition of unbound crumb rubber has been found to decrease ballast breakage and vertical stiffness and increase energy dissipation. However, if too high, the quantities of crumb rubber (> 20 vol.%) result in an increase in ballast settlement and excessive vertical deflection, negatively affecting fatigue life (Sol-Sánchez et al. 2015).

Additionally, railway sleepers fabricated with pre-stressed concrete have become widely accepted. More recently, inspired by the benefits found using rubber under sleeper pads, pre-stressed concrete sleepers wrapped with crumb rubber (powder) and recycled plastics are being investigated (Dolci et al. 2020). They provide a reduction in maintenance costs through the increase in service life and a reduction in noise and vibration levels when compared to conventional designs (Mackenet al. 2021).

3.4.8 Estimate Recycled Content Percentages Based on Material Type and End Application

It is unlikely that transport infrastructure applications can utilise all end-of-life tyre stockpiles, so other applications and industries need to be involved. However, various applications within transport infrastructure can benefit from the incorporation of crumb rubber as follows.

Asphalt and sprayed seals (aggregate replacement or additive in bitumen)

Crumb rubber is typically incorporated at between 5–18% by total mass of binder for sprayed seal applications. Around 900,000 tonnes of bitumen is used in Australia each year. This is split pretty evenly between sprayed seal applications and asphalt. This means there is the potential to use as much as 65,000 tonnes of crumb rubber in sprayed seal applications in Australia annually. However, crumb rubber modified sprayed seals make up only a proportion of sprayed seals constructed/maintained in each state and their use varies among states (Austroads 2016a). They are used extensively in Vic, WA, NSW and SA, and their use in Qld has increased considerably over recent years. Crumb rubber binders are not currently used for sprayed seal applications in Tas and NT (Austroads 2021b).

An asphalt mixture made by the incorporation of a crumb rubber binder could include up to about 1% rubber by mass of mixture (considering 20% crumb rubber by total mass of binder). Through this process, storage stability of the modified binder needs to be ensured. Binder/crumb rubber segregation is typically controlled through the incorporation of augers or paddles in the storage tanks (Austroads 2021b). Through the dry process, around 2% by mass of the asphalt mixture could contain rubber.

In Australia, it is estimated that between 3,000 and 6,000 tonnes of crumb rubber could potentially be absorbed each year, based on the road construction rates (Jones 2020a).

Road speed reducers

Speed humps can be made using 100% recycled crumb rubber and they are becoming the material of choice over steel or polymer speed humps, due to the realised environmental benefits as well as their lower price (Image Extra 2021).

Cycle paths

Cycle paths could potentially be constructed from tiles made from 100% crumb rubber. These would probably be used only in specialist applications, as their construction is likely to be considerably more expensive than using conventional techniques.

Railways

Crumb rubber may be combined with recycled plastics, a polymer-based additive, and magnesium hydroxide-based flame retardant to manufacture the outer shell of railway sleepers. Approximately 67 wt.% of that shell may comprise recycled materials (rubber and plastics), while the rest might take up the remaining weight of the shell. For a 0.154 m^3 sleeper, this may translate to 18.2 kg of crumb rubber powder and recycled plastics (Polyethylene (PE) and Polypropylene (PP)) (Dolci et al. 2020).

Sol-Sánchez et al. (2015) discussed that based on the volume of voids present among the standards ballast aggregates, up to 30 vol.% crumb rubber may be added. However, taking into consideration various performance characteristics, they concluded that up to 10 vol.% of crumb rubber may be optimal (Sol-Sánchez et al. 2015).

Summary

Using crumb rubber in asphalt and sprayed seal applications is seen as its most effective use within infrastructure applications. In this application, crumb rubber provides performance enhancements over conventional unmodified bitumen and asphalt. The use of crumb rubber in sprayed sealed applications is already mature in Australia and as specifications are developed for its use in modified binders for asphalt usage and asphalt itself, its uptake is likely to increase significantly.

The use of crumb rubber in road pavement applications has been considered by most states where relevant specifications have already been developed. Research, however, is still underway to increase the allowable content. Additionally, the specifications vary across the states in the allowable limits and applications.

Crumb rubber generated from truck tyres is currently more than enough to cover all bitumen and asphalt applications. It is also possible to utilise car tyre rubber in these applications. However, the lower yields of crumb rubber from end-of-life car tyres, and their greater synthetic rubber content, make this source of crumb rubber in asphalt less desirable than truck tyre rubber. There is no driver to incorporate car tyre crumb rubber into asphalt applications until truck tyre rubber is fully utilised.

To have more impact on the end-of-life tyre waste stream, more applications would need to be considered in parallel to bitumen and asphalt applications. This report has identified additional technologies and applications that are worth considering. Some of these applications incorporate much higher percentages of crumb rubber as a function of the structure; however, the volume usages of these applications are likely to be much lower than that of asphalt and sprayed seals. At the present time, these applications are fairly specialised and not widely adopted.

The absorption of end-of-life tyre waste in the fabrication of speed humps, cycle paths and footpaths appears to be rather promising and possibly warrants the technology adoption for other similar applications.

3.5 Ground Granulated Blast Furnace Slag

3.5.1 Material Overview

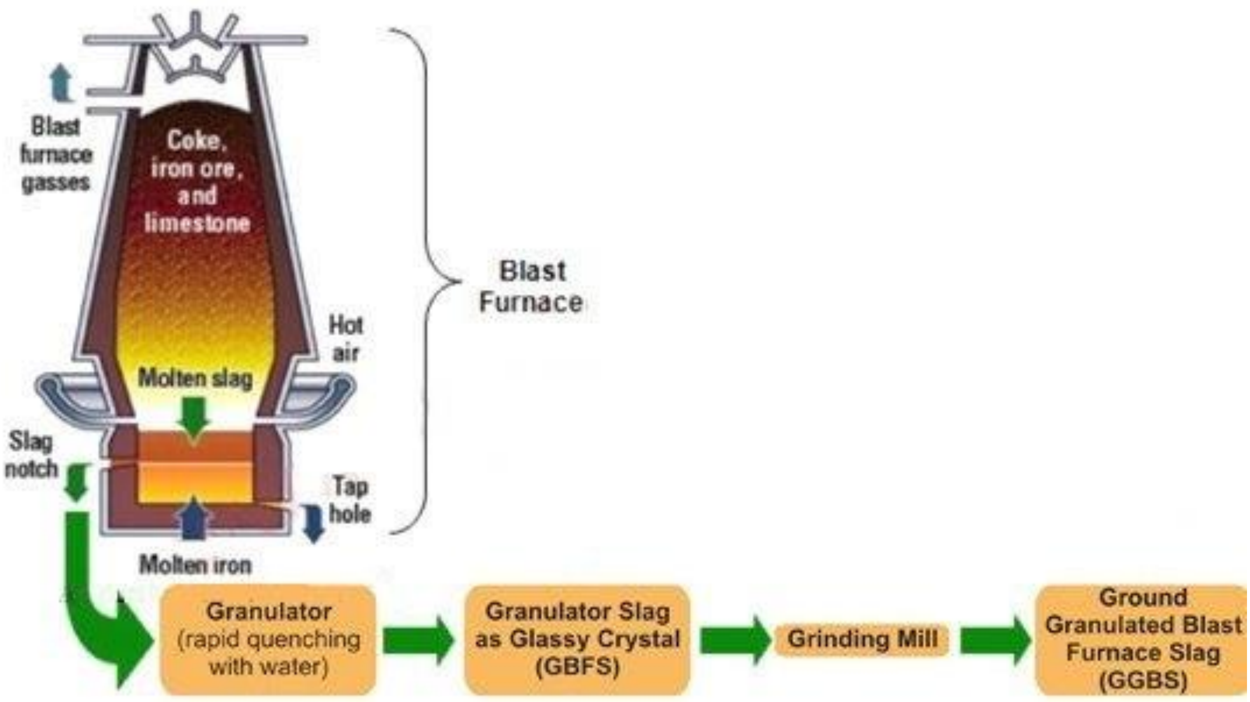
Blast furnace slag (BFS) is a by-product of steel and iron manufacturing. When the molten BFS is rapidly quenched with water, the slag becomes granulated. The granulated blast furnace slag (GBFS) is then ground to form the ground granulated blast furnace slag (GGBFS), which is a white powder (Figure 3.15).

Figure 3.15: Ground granulated blast furnace slag

Source: Australasian Slag Association (2022).

Figure 3.16 demonstrates the manufacturing process of GGBFS. GGBFS is a latent-hydraulic material, which means it can react with water, under ambient temperature, in the presence of a calcium-rich solution (Australasian Slag Association 2020b). Calcium oxide, known as quick lime, (CaO), silica (SiO_2) and alumina (Al_2O_3) dominate the chemical composition of GGBFS (Yaghoubi et al. 2019).

Figure 3.16: Manufacture process of GGBFS



Source: Adapted from Mo Civil Engineering (n.d.).

3.5.2 Market Maturity

GGBFS has been used as a supplementary cementitious material (SCM) since 1960s in Australia and, currently, it is the most widely used SCM. GGBFS is commercially available currently, and with the future decline in the fly ash production (due to the reduction of coal-combustion-based electricity), it is considered as a reliable SCM for the foreseeable future (Cement Concrete & Aggregates Australia 2018). Various iron and steel slag stakeholders, i.e. producers, processors, marketers, customers and suppliers, have formed the Australasian (iron & steel) Slag Association (ASA) in Australia. The objectives of ASA members are to research, provide information and increase the uptake of GGBFS in various applications (Australasian Slag Association 2022).

3.5.3 Supply

In 2020, about 530 tonnes of GBFS were produced in Australia with a further 1,270 tonnes being imported. Of this total 1,800 tonnes, about 1,660 tonnes (~92%) were turned into GGBFS and used in the manufacture of cementitious materials (Australasian Slag Association 2020a). Previously (since the 1960s), GGBFS was produced in Port Kembla (NSW), Newcastle (NSW) and Kwinana (WA). The only current operational producer in Australia is in Port Kembla (Cement Concrete & Aggregates Australia 2018).

3.5.4 Standard Practices and Opportunities to Use Recycled Content

GGBFS can be used as the only/main binder or as a supplementary cementitious material (SCM) in combination with Portland cement and/or other materials such as lime or Fly Ash. The content of GGBFS to be used depends on the application and specific requirements (Cement Concrete & Aggregates Australia 2018). Different allowable contents of GGBFS for use in various applications are presented in Table F.1. When used as a precursor for geopolymeric binder in soil stabilisation, it is reported that mixing GGBFS with soil and then adding and mixing the alkaline activator results in higher compressive strengths compared to when mixing GGBFS with the alkaline activator and then mixing with soil (Yaghoubi et al. 2019).

GGBFS is considered more environmentally friendly compared to Portland cement, as cement production requires natural materials (i.e. soil and aggregate) and energy and also generates a significant amount of CO_2 (estimated at 1 tonne CO_2 per tonne of cement) (Cement Concrete & Aggregates Australia 2018, Yaghoubi et al. 2019). This is while GBFS is a by-product and the only extra process to obtain GGBFS is milling, using similar mills as those used for Portland cement (Cement Concrete & Aggregates Australia 2018).

3.5.5 Opportunities for Use in Road and Rail Infrastructure

GGBFS is usually used as a supplementary cementitious material and/or a replacement for Portland cement. As such, GGBFS is used in stabilisation of granular pavement materials and in-situ stabilisation of soft soils; manufacture of concrete and mortar/grout; and more recently, in producing geopolymeric binders, due to the high presence of SiO_2 and Al_2O_3 in its chemical composition (Yaghoubi et al. 2019, Australasian Slag Association 2022). Figure 3.17 shows the use of GGBFS in concrete works, including geopolymer concrete in Salmon Street Bridge in Melbourne (Figure 3.17 (b)).

Figure 3.17: Use of GGBFS in concrete works

a) Concrete containing GGBFS

Source: Young and Prado (n.d.).

b) Geopolymer concrete containing GGBFS

Source: Zeobond (2022).

3.5.6 Specifications

The AS/NZS 3582.2-2016 *Supplementary cementitious materials: Part 2: Ground granulated blast-furnace* specifies the requirements for GGBFS to be used as a cementitious material.

Different road agencies across Australia have allowed the use of GGBFS in various infrastructure applications and have specified requirements. Based on the specifications, GGBFS can be used as a binder or an SCM in concrete, both common (up to 90% of the binder) and geopolymer (up to 100% of the precursor) concretes, and stabilisation works (up to 90% of the binder).The detailed applications and the relevant limits are presented in Table F.1.

3.5.7 Comparative Performance

Stabilising soils/subgrades using GGBFS as a cementitious binder and geopolymer binder has resulted in a higher strength and durability compared to using Portland cement. Combining GGBFS with fly ash in geopolymeric binders has resulted in further improvements (Yaghoubi et al. 2018, Yaghoubi et al. 2019, Abdila et al. 2022). Using GGBFS as a partial replacement for Portland cement increases the durability of concrete due to higher sulfate attack resistance, lower chloride ion penetration, lower concrete drying shrinkage (Cement Concrete & Aggregates Australia 2018). While the 28-day strength of concretes containing GGBFS as an SCM meets the standard requirements, longer curing times for these concretes result in higher compressive strengths compared to when only Portland cement is used (Cement Concrete & Aggregates Australia 2018). In addition, using GGBFS as an SCM can help mitigate the alkali-silica reaction that reduces the durability of concrete (Tapas et al. 2019).

3.5.8 Estimate Recycled Content Percentages Based on Material Type and End Application

As the performance of GGBFS as a binder and SCM has been shown to be equal to, or better in some instances than, Portland cement (see Market Maturity above), GGBFS can be used in a variety of transport infrastructure applications. According to Table F.1, the GGBFS content to be used depends on the application as follows:

Stabilisation

- If used as an SCM for stabilisation, up to 90% of the binder can be GGBFS.
- If used as a geopolymeric binder, up to 100% of the binder can be GGBFS.

Note: the total binder content used for stabilisation works depends on a variety of factors such as the soil/aggregate properties (e.g. bearing capacity of subgrade).

Concrete

- If used as an SCM in concrete for structural applications, such as bridges, up to 70% of the cementitious material can be GGBFS.
- If used as a precursor for geopolymer concrete, up to 100% of the cementitious material can be GGBFS.

Note: the total content of cementitious material in the concrete depends on the mix design, which is based on various factors such as the required compressive strength of concrete (e.g. 25 MPa or 40 MPa).

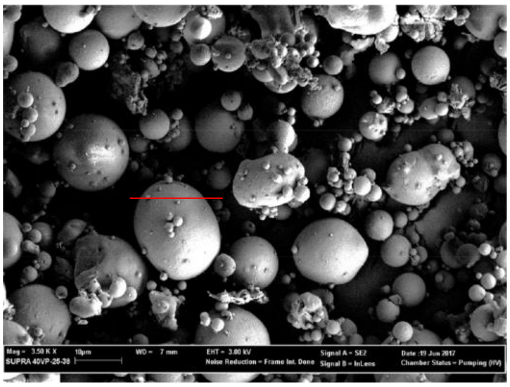
3.6 Fly Ash

3.6.1 Material Overview

Fly ash (FA) is a by-product of combusting coal in power plants. When pulverised coal is combusted in the furnace, ash with different particle sizes is generated. The lightweight ash that is collected by electrostatic precipitators is called FA and constitutes about 90% of the total generated ash. The type of coal and mode of operation does impact the particle size distribution of fly ash and to meet the Australian Standard AS/NZS 3582.1-2016, fly ash must have 75% particles passing the 45 µm. FA can be generated through other sources such as waste-to-energy incineration facilities (at about 10–30% of total generated ash), although that is on a much smaller scale currently (Pickin et al. 2020). FA is usually grey in colour and has spherical particles. Figure 3.18 shows a) FA and b) magnified (3.50K x) spherical particles of FA.

Figure 3.18: Fly ash

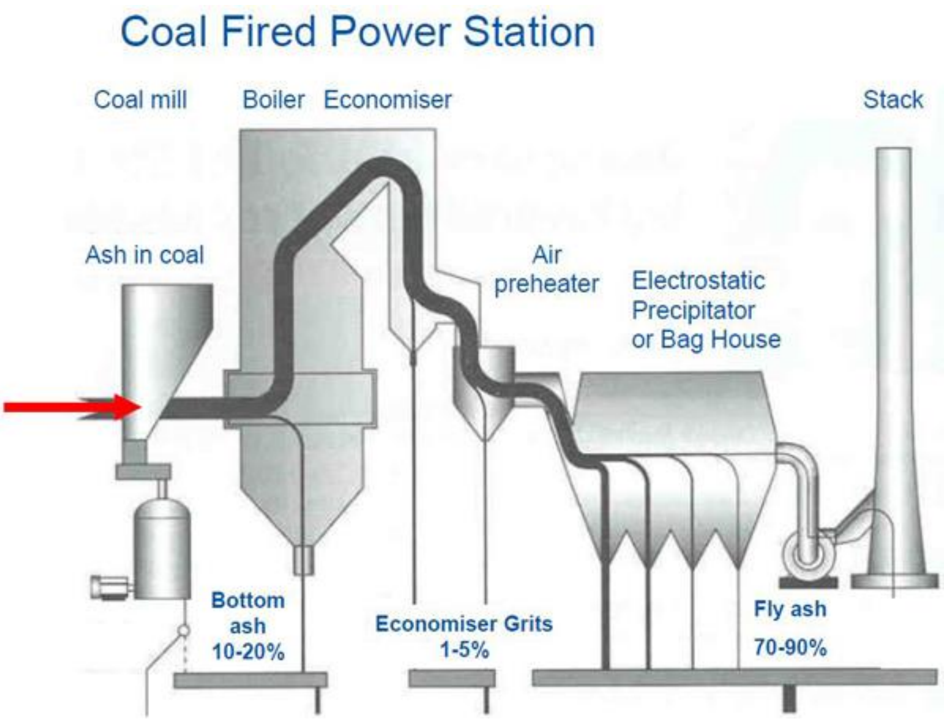
a) Photo by Mohammadjavad Yaghoubi



b) Source: Yaghoubi et al. (2019)

Figure 3.19 illustrates the process of FA generation in a power station. The pozzolanic properties of FA allow it to form cementitious compounds when reacted with lime (Flyash Australia 2021). The main compounds of FA are typically SiO_2, Al_2O_3 and Fe_2O_3, with the first two dominating the composition (Yaghoubi et al. 2019). According to the AS/NZS 3582.1-2016 requirements, the minimum total content of these three compounds must be 70% in the chemical composition of FA.

Figure 3.19: Fly ash generation process



Source: Flyash Australia (2021).

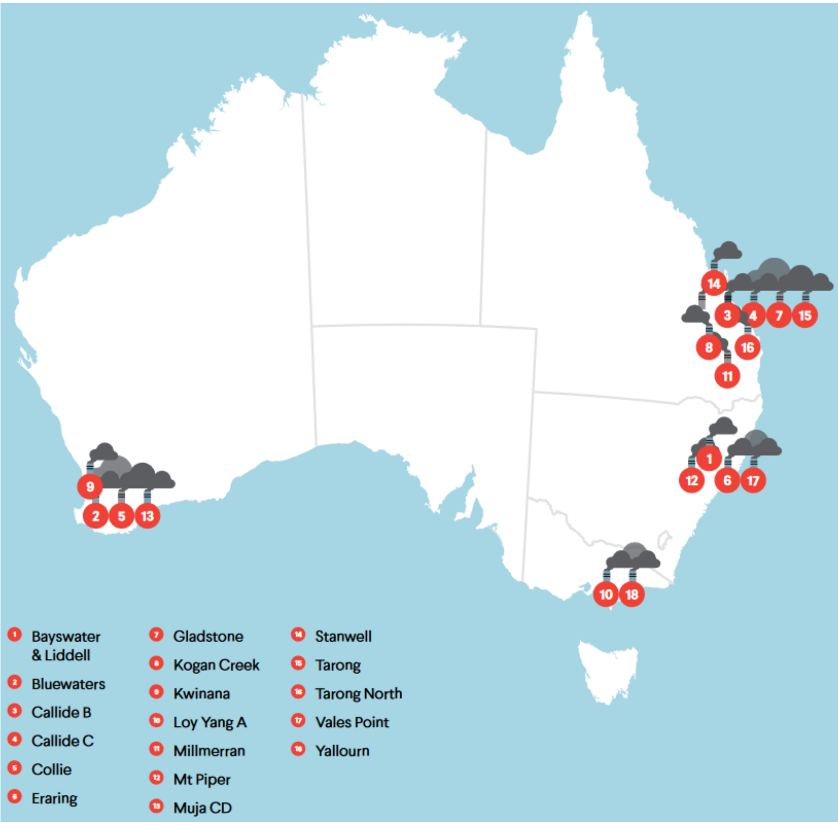
3.6.2 Market Maturity

In Australia, FA has been used in various applications including concrete manufacture and as a cementitious binder since 1975 (ADAA 2018). FA is currently supplied in the market and major coal ash producers have formed the Ash Development Association of Australia (ADAA) to explore opportunities and promote its use in various applications, including construction projects.

3.6.3 Supply

In 2018–19, 56% of Australia's electricity was generated by coal combustion. This generated 12.5 Mt of ash, about 90% of which was FA (Pickin et al. 2020). The major deposits of FA in Australia are in Qld, NSW, WA, and Vic. Figure 3.20 presents the location of current ash dumps in Australia (Environmental Justice Australia (EJA) 2019).

Figure 3.20: Fly ash dump locations in Australia



Source: EJA (2019).

In Qld, around 4.90 Mt of FA was generated during 2019–20 and around 0.88 Mt was recovered, an 18% recovery rate (Queensland Government 2021a). In NSW, around 4.3 Mt of FA is generated annually, with a 10% recovery rate. The total accumulated ash in NSW is estimated to be around 260 Mt, 90% of which is FA (Hunter Community Environment Centre (HCEC) 2020). The recycling rate for WA sat at around 72% in 2018–19, with a 1.0 Mt FA generation rate (Pickin et al. 2020). Pickin et al. (2020) reported a 0.86 Mt generation rate of coal ash (both FA and Bottom Ash) in Vic for 2019, although the recovery rate was not clear. In Australia, about 50,000 tonnes and 4,409 tonnes of FA was used respectively in road base/subbase and controlled low-strength material as flowable fills in 2018 (ADAA 2018).

3.6.4 Standard Practices and Opportunities to Use Recycled Content

Using FA as a cementitious material, such as within cementitious binders, to replace Portland cement and lime, has economic and environmental benefits. Aside from saving natural resources and energy from the production of Portland cement, significant amounts of CO_2 emissions are reduced. Around 1 tonne CO_2 per tonne of Portland cement production is generated (Yaghoubi et al. 2019).

3.6.5 Opportunities for Recycled Content in Road and Rail Infrastructure

Fly ash can be used:

- to replace Portland cement in concrete manufacturing for pavement layers, as well as structural and non-structural concrete works (Ambrus et al. 2019, EJA 2019, Lim et al. 2020)
- as a binder or SCM for stabilisation (both pavement layers and subgrade) (Ambrus et al. 2019)
- as a precursor (source of alumina and silica) in geopolymeric binders for stabilisation and geopolymer concrete (Ambrus et al. 2019, Yaghoubi et al. 2019, Lim et al. 2020)
- in flowable fill, such as low strength control material (American Coal Ash Association (ACAA) 2003)
- as an additional SCM in foamed bitumen stabilisation (Trochez et al. 2021)
- as a filler in asphalt, replacing natural mineral fillers (Lim et al. 2020).

Figure 3.21 shows examples FA usage in transport infrastructure.

Figure 3.21: Fly ash uses

		
Fly ash in soil stabilisation Source: ACAA (2003).	Geopolymer concrete pavement Source: City of Sydney (2019).	Fly ash in flowable fill for bridge abutment Source: ACAA (2003).

3.6.6 Specifications

The AS/NZS 3582.1-2016 *Supplementary Cementitious Materials: Part 1: Fly Ash* specifies the requirements for FA to be used as a cementitious material.

Different states and territories in Australia have specified the use of FA in various applications including:

- supplementary cementitious material (SCM) in blended cements for stabilisation and concrete works
- cementitious binders for stabilisation
- cementitious material for grout
- filler in asphalt.

The limits for FA contents vary with applications. In addition, while the use of FA has been allowed for a variety of applications, limits are not specified for all applications. In general, in stabilisation of pavement materials and subgrade, FA contents of up to 3% and 5% (by mass), respectively, are allowed. In concrete works, FA content can be up to 8% by mass of the total mix; in asphalt, FA can be used as filler up to 1.2%. For more details refer to Table G.1, which presents the limits of using FA in different applications specified by various road agencies.

3.6.7 Comparative Performance

The benefits of replacing virgin materials with FA are listed in Table 3.7, based on application.

Table 3.7: Benefits of replacing virgin materials with fly ash benefits of replacing virgin materials with fly ash

Application	Virgin Material	Benefits	Source
Binder for concrete	Portland cement	• Increased durability, strength, workability and setting time • Conserving resources • Avoids mercury and greenhouse gas emissions (from cement production) • Reduced leachability of chemicals and segregation • Reduction of alkali-silica reaction	EJA (2019), (Lim et al. 2020)
Stabilisation of fine-grained soils	Portland cement, lime	• Decrease in swelling shrinkage and plasticity potential • Improved compressive and tensile strength • Good performance on durability tests • Decreased permeability	Ambrus et al. (2019)
Lightweight aggregate for concrete	Sand	• Increased strength/weight ratio • Improved thermal and sound insulation • Improved fire resistance	Ambrus et al. (2019)
Geopolymer (concrete and binder)	N/A*	• Good mechanical strength • Acid and fire resistance • Environmental sensitivity • Low price and permeability in comparison with Portland cement • Higher rate of carbonation	Ambrus et al. (2019) Austroads (2016b)
Filler in asphalt	Natural mineral fillers	• Higher rut resistance • Reduction in asphalt stripping • Reduction in cost • Improved stability and resistance to moisture	(Lim et al. 2020) ACAA (2003) Mirković et al. (2019)

* Geopolymer, in which industrial by-products such as FA are used, is a replacement for Portland cement-based concrete and binder.

3.6.8 Estimated Recycled Content Percentages Based on Material Type and End Application

Accumulation of residual ash is becoming a critical environmental concern in Australia. Of the total generated ash in 2018–19 in Australia (12.5 Mt), only 47% was recycled, which is much lower than the ash recycling rates of other countries including Japan, China and the UK at rates of 97%, 70% and 70%, respectively (Pickin et al. 2020).

Depending on the application, the amount of FA being used could be varied. The estimates of FA content used in different applications are listed below:

Stabilisation

a. Pavement (base and subbase) stabilisation

   Austroads AGPT04D-19 (Austroads 2019b) defines three levels of pavement stabilisation, using cementitious materials, based on the 'indicative laboratory strength after stabilisation' being unconfined compressive strength (UCS). The UCS is a function of the content of cementitious material added for stabilisation. According to AGPT04D-19, the three categories are:

   – modified materials (UCS < 1 MPa)
   – lightly bound cemented materials (1 ≤ UCS ≤ 2 MPa)
   – bound cemented materials (UCS > 2 MPa).

   The content of cementitious material to be used, hence the content of FA as a replacement, is very much dependent on the pavement aggregate and specific design requirements. For instance, AGPT04D-19 states that typical cementitious binder contents for lightly bound cemented materials and bound cemented materials are less than 3% (by mass of dry materials) and 3% or more, respectively.

b. Subgrade stabilisation

Austroads AGPT04D-19 (Austroads 2019b) states that for earthwork/subgrade stabilisation, a UCS value of 1 ≤ UCS ≤ 2 MPa is typically targeted, and a cementitious material content of 2–5% is stated as the typical range for this. Based on this, FA up to 5% (by mass), if used as the main cementitious binder, can be used in subgrade stabilisation works, although cementitious binder contents of up to 30% have been reported to be used for ground improvement (stabilisation) projects in field (Yaghoubi et al. 2019).

Concrete

Dissimilar to stabilisation, FA cannot be used as a single cementitious material in concrete (except in geopolymer concrete) and needs to be blended with other cementitious materials such as Portland cement and lime. However, since the cementitious binder content in concrete is generally higher than that used in stabilisation, there is a higher opportunity of FA usage in concrete. Different states and territories have specified the FA content in a blended cement depending on the application (See Table G.1). The content of FA to be used in concrete, hence, depends mainly on the following two factors:

- the type of concrete, including concrete for structures, such as bridges, and concrete for pavement layers (base and subbase), which determines the strength requirements for concrete and accordingly the binder content (mix design)
- the portion of FA in the blended binder.

For instance, a base concrete has a total binder content of 15% (by mass of the total mix), of which 3% can be FA (Austroads 2017a), while in concrete road and bridge structures, up to 20% of the total mix can be binder of which 8% can be FA (TMR MRTS70 2018). FA can be used in geopolymer concrete as a sole precursor; however, the setting time under ambient temperature is prolonged. In such a situation, a combination of FA and GGBFS, as precursor, is recommended (Austroads 2016b).

Added Filler

Filler, in an asphalt mix, is the fine aggregate (smaller than 75 µm) portion and is typically 0.6–1.2% (by mass) of the total asphalt mix. Filler can be the fine particles resulted from crushing the aggregate or can be as an added material. FA can be used as a common added filler (Austroads 2014a). Therefore, if asphalt aggregates do not have smaller than 75 µm particles, i.e. filler, so potentially up to 1.2% FA can be used.

3.7 Bottom Ash

3.7.1 Material Overview

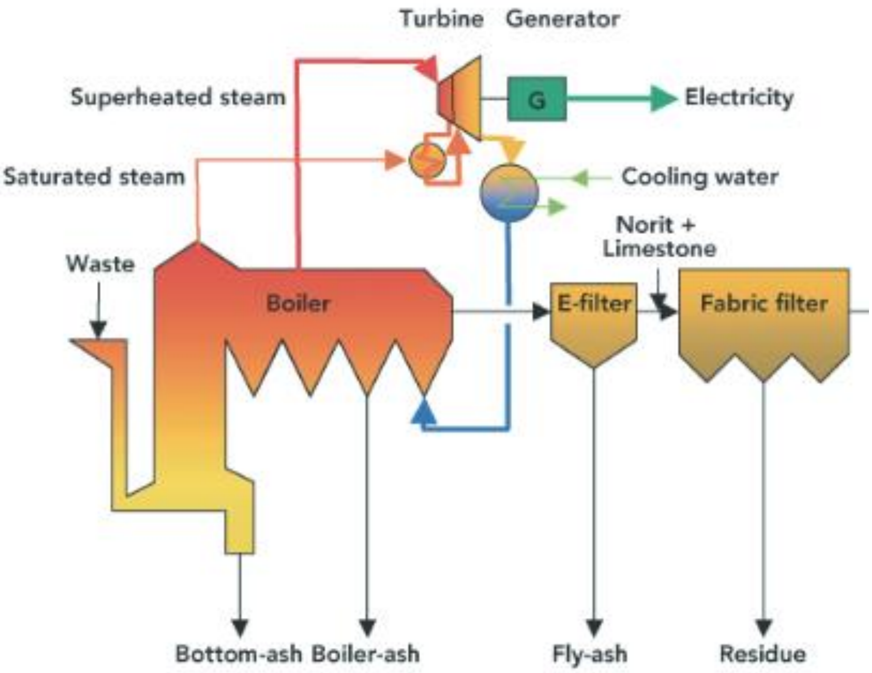
Bottom ash (BA) is another by-product of coal combustion in power plants (See Figure 3.19). Ash with different particle sizes is generated when pulverised coal is combusted in the furnace. The coarse particles that fall to the bottom of the furnace are called BA and constitute about 10% of the total generated ash. Other sources of BA generation include energy-to-waste incineration facilities (with BA constituting 70–90% of total generated ash), which is currently on a much smaller scale in Australia (Pickin et al. 2020). Several waste-to-energy facilities are in the planning and/or approval process. The Kwinana facility, in WA, is the most progressed facility currently, and is in its final stages of becoming operational. BA is presented in Figure 3.22.

Figure 3.22: Bottom ash

Source: Kim and Lee (2015).

Figure 3.19 presents the BA generation process in a coal combustion power plant and Figure 3.23 illustrates the process in an waste-to-energy facility. The source of BA, whether coal or waste, is the main driver for its chemical composition. In a coal-based BA, silicon dioxide, aluminium oxide and iron dioxide are the dominant compounds (Kim & Lee 2015). In BA generated in waste-to-energy facilities, silicon dioxide, calcium oxide and aluminium oxide are the main compounds, although the composition varies with the feedstock, i.e. source of waste (Lynn et al. 2017).

Figure 3.23: Bottom ash generation process in an waste-to-energy facility



Source: IEA Bioenergy (2013).

3.7.2 Market Maturity

BA does not have a current market in Australia, but given:

a. the increase in interest in its use in transport infrastructure (John Holland 2019, TMR 2021,
b. abundant coal-based power plants in Australia, and
c. several waste-to-energy facilities planned for construction and operation (Australia Renewable Energy Agency (ARENA) 2022),

BA has the potential to be commercially available in the near future.

ARRB conducted a market study for Sustainability Victoria on the use of BA generated by energy-from-waste facilities (Gurrie et al. 2020). The study included three stages of reviewing international practices, material flow analysis across Australia, and analysis of market development barriers and opportunities. According to this study, reusing BA in road applications would be the best practice approach in BA management.

3.7.3 Supply

In 2018, around 1.34 Mt of BA was generated in Australia and 0.64 Mt was recycled, giving a recycling rate of about 47.6%, although there is no indication of where and how this amount was recycled (Department of Aggriculture, Water and the Environment 2019). It is estimated that in 2018, about 20 tonnes and 243 tonnes of BA were used in structural fills/embankments and in road base/subbase respectively (ADAA 2018). There is not much data on the breakdown of these volumes for each state though. In Qld, around 0.71 Mt of BA was generated during 2019–20, and around 0.09 Mt was recovered, resulting in an 12.45% recovery rate (Queensland Government 2021a).

Currently, there is not much use of BA in Australia. However, the stored BA from coal-based power plants can be used for potential applications. In addition, with the commencement of operation of waste-to-energy facilities, the supply of BA will be ongoing.

3.7.4 Standard Practices and Opportunities to Use Recycled Content

BA is a reliable granular material for replacing natural aggregates, including gravelly and sandy soils. Using BA as a total or partial replacement will result in environmental benefits, due to lower consumption and processing of natural aggregates and saving of valuable landfill spaces, and economic benefits. In a project in regional NSW, 85,000 tonnes of BA were used in the construction of a fleet maintenance facility and a 15% reduction in cost was achieved, compared to the use of quarried material (John Holland 2019). Since BA has potential pozzolanic reactivity, it can be further processed (crushed) for use as a cementitious material and replace Portland cement, in soil stabilisation for instance. The economic and environmental aspects need to be considered though, because of the additional processing (Kim & Lee 2015, Lynn et al. 2017).

3.7.5 Opportunities for Recycled Content in Road and Rail Infrastructure

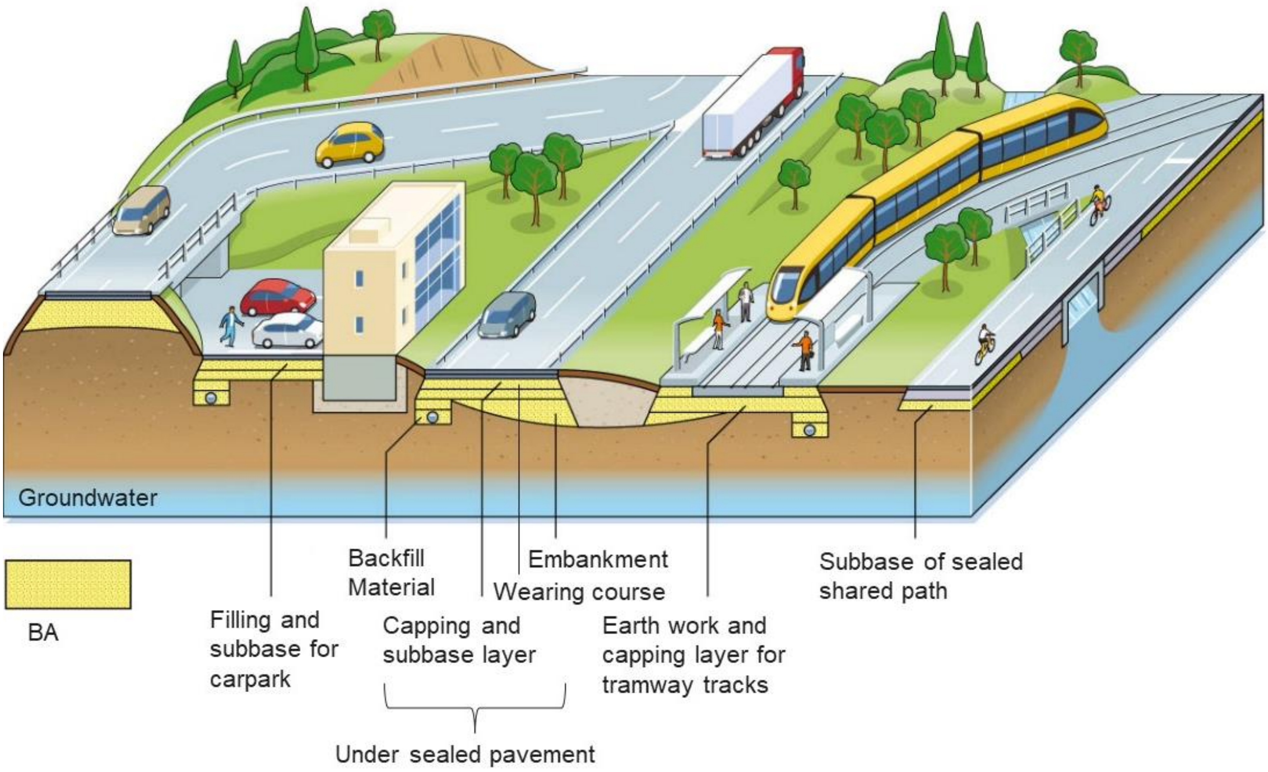
BA has beneficial uses as both unbound and bound aggregate. BA can be used as unbound aggregate in embankment fill and subbase layer or as an unbound aggregate in the capping layer of pavements over expansive soils (Lynn et al. 2017). Moreover, BA has been used as abutment fill for heavy vehicle access and rail bridges to replace quarried materials (John Holland 2019). In combination with Portland cement, or other binders such as lime and fly ash, BA can be used in stabilised subbase and base layers of roads. Another application for BA is as an aggregate for concrete works. BA can also be used in bituminous bound road base and wearing courses as an aggregate (Lynn et al. 2017, Astrup et al. 2016, Austroads 2019b). Using BA as a cementitious material, which requires further processing of BA such as sieving or crushing, has also been reported; however, due to lower amounts of amorphous silica and alumina in BA compared to fly ash, BA is probably not a preferred option (Astrup et al. 2016). Figure 3.24 shows the use of BA for the construction of road base in France (Cerema 2016), while various applications of BA in transport infrastructure are illustrated in Figure 3.25.

Figure 3.24: Bottom ash in road base

a. Granular BA | b. Cement-treated BA

Source: Cerema (2016).

Figure 3.25: Uses of bottom ash



Source: Adapted from: Cerema (2016).

3.7.6 Specifications

There are currently few standards, specifications or requirements in Australia for the use of BA. The only road agency to have any is TfNSW, which allows 10% by mass of BA to be used in base and subbase as granular material (TfNSW D&C 3051 2020) in NSW. TfNSW also allows using BA in public road related activities (road construction and maintenance; installation of road infrastructure facilities) but does not specify any limits or requirements (TfNSW QA R44 2020). However, while TMR in Qld does not specify any requirements for the use of BA in road infrastructure, research is being conducted by ARRB and TMR to investigate the use of BA in earthworks, drainage and concrete applications, and potentially updating the relevant specifications (TMR 2022). Previously, in a collaborative study and through reviewing national and international literature, ARRB and TMR identified BA as a suitable material for earthworks and drainage in road infrastructure (Nguyen et al. 2021).

3.7.7 Comparative Performance

BA has a well-graded PSD ranging from gravel (40 mm) down to silt and clay (smaller than 75 µm). BA has a lower density (at about 0.7–1.6 t/m^3) compared to that of general fill material and similar-sized sand and gravel (at about 1.6–2.0 t/m^3) (Muhunthan et al. 2004, Kim & Lee 2015, John Holland 2019). This lower bulk density, as well as the drainage capacity of BA (at 10^{-2}–10^{-5} m/s), makes it ideal as a lightweight fill on soft soils. BA has been reported to be a suitable replacement for aggregates in subbase and embankment fills due to its adequate bearing capacity (CBR values of 36–110%) (Kim & Lee 2015). This allows BA to be used in a cement stabilised road base layer too (Lynn et al. 2017).

Compared to sand and gravel, BA is reported as having higher shear strengths and a suitable material for road base; however, due to its lower abrasion resistance, it is recommended not to replace 100% natural aggregates with BA in a base layer (Xie et al. 2017). The porous structure of BA particles (5–13% porosity) leads to more water demand, in compaction, compared to that of natural materials (< 4%). Optimum moisture contents of 12–20% are reported for coal BA as compared with that of gravel and sand at 9–11%. This porous structure may result in higher binder demand too (Kim & Lee 2015, Lynn et al. 2017). Addition of BA to the wearing course results in an increase in the skid resistance, potentially due to higher shear strength of BA compared to similar-size sands and gravels (Kim & Lee 2015, Lynn et al. 2017). Although there are concerns over rushing, i.e. aggregate strength, of BA when used at 100% content in asphalt layers. Field trials show that up to 50% BA can be used in asphalt wearing courses (Lynn et al. 2017).

3.7.8 Estimated Recycled Content Percentages Based on Material Type and End Application

BA has not been used much in Australia and there is little guidance on its use in transport infrastructure from road agencies. Based on international studies though, the recommended content of BA to be used in the construction of transport infrastructure can be as follows:

- as a granular fill or embankment material, up to 100% of natural aggregates can be replaced with BA (Muhunthan et al. 2004, USA)
- in lower layers of roads, such as subbase, up to 100% of natural aggregates can be replaced with BA. In base layer, lower contents should be used (Xie et al. 2017, China)
- road base course containing up to 60% BA and stabilised with bitumen have been reported to perform well in terms of indirect tensile stiffness modulus and durability (Hassan & Khalid 2009, UK)
- studies have shown that BA can replace up to 80% of natural aggregates in asphalt mixes (Astrup et al. 2016, Europe (Denmark, Italy, Belgium); Luo et al. 2017, Taiwan).

3.8 Recycled Solid Organics

3.8.1 Material Overview

Recycled solid organic material is a general term used by industry for products recycled from organic waste. This includes compost, soil conditioners, mulch and other products that can be applied to the land for landscaping or soil treatment.

Organic waste, otherwise known as *biowaste*, is any material that is biodegradable, coming from either a plant or an animal. This includes green waste, food waste, food-soiled paper, nonhazardous wood waste, timber and pruning waste. Biodegradable waste is organic material that can be broken into carbon dioxide, methane or simple organic molecules. Examples of solid organic waste material are shown in Figure 3.26.

Figure 3.26: Types of organic waste

Source: City of Signal Hill (n.d.).

Recycled solid organic material is more formally known as *processed solid organic waste*. This term refers to a pasteurised material from a processing site that does not include liquid organic waste, digestate from anaerobic digestion or vermicast. It does not contain any chemical contaminant concentrations or non-organic physical contaminants exceeding the upper limits for that chemical contaminant parameters. An example of recycled organic material is shown in Figure 3.27.

Figure 3.27: Recycled organic material

Organic waste is a priority waste stream in Vic (priority waste is a subset of industrial waste, such as processed food waste and liquid organic wastes). This type of waste has greater regulatory controls and duties because it: is prone to mismanagement; is hazardous to human health or the environment; and has potential for reuse or recycling opportunities (EPA Victoria 2021).

In 2018–19, across Australia, 14,602,871 tonnes of organic waste was generated. With the recycling rate of this material being only 51.5%, leaving 48.5% going to landfill. The National Waste Policy aims to halve the amount sent to landfill by 2030. Further to this, research has shown that the organic waste industry is capable of processing 82% of organic waste materials given the physical capacity of their existing operations. However, the demand for this processed material needs to grow.

By recycling organic waste, the industry can contribute to the conservation of natural resources and to reducing greenhouse gas emissions. When organic waste is dumped in landfills, it undergoes anaerobic decomposition (due to the lack of oxygen) and produces methane. When released into the atmosphere, methane is 20 times more potent a greenhouse gas than carbon dioxide. In fact, organic matter decaying in landfills is responsible for approximately 2% of Australia's greenhouse gas emissions (Department of Agriculture, Water and the Environment 2018). When recycling instead of landfilling, the process is aerobic and only CO_2 is generated, the amount of which varies according to the feedstock and process.

The general process for recycling solid organic material is described in Figure 3.28.

Figure 3.28: Solid organic waste recycling process

Source: Veolia (n.d.).

Several sources of organic waste material can be used as either raw or processed products. Organic waste sources, raw products, processing methods and processed products are summarised in Table 3.8.

Table 3.8: Organic waste

Organic waste	Processing of organic waste	Product (processed)	Products (unprocessed)
• Green waste (biomass) • Food-soiled paper • Non-hazardous wood • Waste timber • Landscape waste • Paper and cardboards • Animal waste • Agriculture waste • Municipal waste	• Composting • Vermicomposting • Dehydration	• Compost • Matured compost • Pasteurised compost	• Mulch • Animal feed
	Energy recovery, aka bioenergy • Anerobic digestion • Incineration • Gasification • Pyrolysis	• Digestate • Biogas • Bio oil • Chemicals • Biochar	

Sources: Adapted from Risse and Faucette (2017), RedCorn et al. (2018), KPMG (2020), Jain et al. (2018).

As seen in Table 3.8, the three key processing methodologies for organic waste are composting, vermicasting and dehydration. There are further detailed in Table 3.9.

Table 3.9: Processing types for organic waste

Processing method	Description	Products	Applications	Benefits
Composting	Composting is an aerobic method (meaning it requires air) of decomposing organic solid wastes. It can therefore be used to recycle organic material.	Composts, mature compost, pasteurized compost.	Landscaping: fertilisers, soil conditioning, soil amendment, turfing etc.	• Gives the soil organic material. • Helps roots grow healthy and strong. • Makes it easier for water to drain through the soil. • Gives sandy grounds density, allowing for better humidity retention. • Improves the soil's pH (acidity). • Helps control soil erosion. • Reduces stress in plants during droughts or cold temperatures.
Vermicomposting	Vermicomposting is the process by which worms are used to convert organic materials (usually wastes) into a humus-like material known as vermincompost. Vermicompost is better than compost due to its higher nitrogen, phosphorus and potassium content, and its ability to improve the soil structure, and to increase its water-holding capacity.	Composts, mature compost, pasteurized compost.	Landscaping: fertilisers, soil conditioning, soil amendment, turfing etc.	• Provides nutrients to the soil. • Increases the soil's ability to hold nutrients in a plant-available form. • Improves the soil structure. • Improves the aeration and internal drainage of heavy clay soils. • Increases the water-holding ability of sandy soils. • Provides numerous beneficial bacteria.
Dehydrating	Rapidly decomposed or dehydrated food waste is the output produced by machines that process food waste in a short period, usually less than 24 hours, by actively heating and mixing the waste in the presence of air. This is done with or without the addition of microbes.	Dried organic products (not compost)	Soil amendments, animal feed, fertilizer	• Converts waste into an easily manageable material with the potential for many uses. • Requires very little space and maintenance. • Produces distilled water that is evaporated from the food waste and can be used for irrigation, cleaning, or can be safely disposed of down the drain.

Source: Adapted from Risse and Faucette (2017), RedCorn et al. (2018), KPMG (2020), Jain et al. (2018).

3.8.2 Market Maturity

The primary established end-market for composts, mulch and other soil improvers is the urban amenity market, including landscaping, parks, commercial projects and home gardens. Horticulture, viticulture and broad-acre farming are emerging markets with good potential, based on the sheer land area dedicated to these primary industries. To date, these markets have been largely constrained in their use of recovered organics by transport costs, from the point of most production (metropolitan fringe areas) to agricultural markets, as well as concerns over product quality assurance. Land rehabilitation and bioremediation provide limited, low-value markets for low-quality products and are unlikely to take up significant volumes of material (Sustainability Victoria 2018a).

The potential market sectors, defined by Sustainability Victoria (2018a), for recycled organics are:

- Urban amenity (current market size 73%): This market consists of home garden supplies/retail nurseries, recreational surface establishment and maintenance, commercial landscaping projects and local and

state government projects, including landscaping works of road projects. It is typically strong for blended soil/compost mixes and clean fine mulches.
- Intensive agriculture and extensive agriculture (current market size 9%): Not related to transport infrastructure.
- Land rehabilitation and bioremediation (current market size 10%): Landfill and mine site rehabilitation and erosion stabilisation, including sideroad areas such as embankment slopes. This is a low-value market with low-quality expectations and limited willingness to pay and is often an outlet for excess product rather than a viable market. Bioremediation for contaminated sites and biofiltration are a niche market that uses limited quantities, so it is not generally sustainable.
- Other (current market size 8%): Unidentified markets.

3.8.3 Supply

There is currently a large stockpile of organics in Australia. In fact, organic waste is the second-largest waste category in Australia, the majority of which is being sent to landfill (Department of Agriculture, Water and the Environment 2018).

Further to this, across Australia, there is currently greater potential for organics recycling. This means there is no shortage in supply of this material. However, this enormous economic and environmental benefit is not only contingent upon the right policy settings but also industry's capacity and capability to take up the opportunity. To achieve a 95% recycling rate, the industry would need to increase its output by 6.4 million tonnes from its current 7.5 million tonnes to 13.9 million tonnes each year. Currently, SA and ACT are the only jurisdictions capable of meeting the targeted capacity for each of the 70%, 80%, 90% and 95% recycling rates. NSW is capable of meeting the target recycling rate of 80% but is not positioned to meet either a 90% or 95% recycling rate. All other states and territories have shortfalls for meeting required capacity for 80%, 90% and 95% recycling rates (Australian Economic Advocacy Solutions 2021).

3.8.4 Standard Practices and Opportunities to Use Recycled Content

Recycled solid organic material can be used in any application where organic matter is often implemented, as long as the recycled solid organic material is compliant with relevant standards, specifications and regulations.

3.8.5 Opportunities for Recycled Content in Road and Rail Infrastructure

There are three main applications of the use of recycled solid organic material in road infrastructure applications. These include: for landscaping; for erosion control; and within bioretention/biofiltration systems.

Landscaping

Landscaping refers to the materials and treatments used to stabilise soil surfaces, re-establish vegetation and to provide vegetation cover suited to the location. Landscaping can enhance the visual amenity and environmental values of the road reserve.

Soil amelioration

Soil amelioration is the process of modifying the physical and chemical properties of soils to improve the quality, primarily improving the air and water balance in the soil.

Turfing and planting

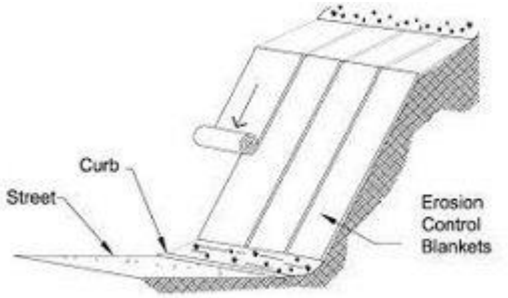
Planting refers to the establishment of vegetation; turfing refers to the establishment of grass as turf.

Erosion control

Compost blanket

A compost blanket is a layer of loosely applied composted material placed on the soil to reduce stormwater runoff and erosion and provide a seed bed to assist germination (Figure 3.29 and Figure 3.30). The compost blanket fills in small voids to limit channelised flow, as well as providing a more permeable surface to facilitate stormwater infiltration, promoting revegetation. A compost blanket often contains select plant seed and fertiliser. The compost is usually applied using blowers (Figure 3.31). The attributes of compost blankets are best realised on steep slopes where there is little or no existing topsoil, or where in-situ topsoil cannot be reused (e.g. due to quality or weed issues) (International Erosion Control Association 2010).

Figure 3.29: Compost blanket diagram



Source: City of Denton (2014).

Figure 3.30: Compost blanket on slope

Source: Full Circle Mushroom Compost (n.d.).

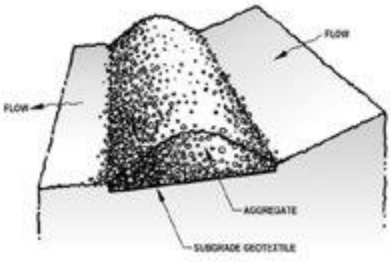
Figure 3.31: Compost blanket application

Source: Integrated Soxx Australia (2021).

Filter berm and filter sock

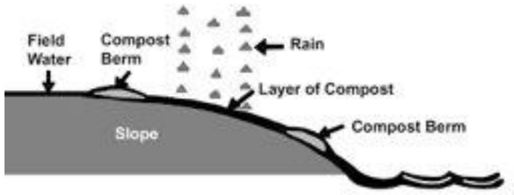
A filter berm (Figure 3.32), trapezoidal in cross section, is a dike of compost or mulch product placed perpendicular to sheet-flow runoff to control erosion in disturbed areas and retain sediment. It can be used in place of a traditional control tool such as silt fences or compost filter socks. Vegetated compost filter berms are generally placed along the perimeter of a site, or at intervals along a slope (Figure 3.33). A filter berm also can be used as a check dam in low-slope, small drainage ditches (Stormwater Services 2008).

Figure 3.32: Filter berm diagram



Source: Minnesota Pollution Control Agency (2022).

Figure 3.33: Filter berm diagram on slope



Source: Risse and Faucette (2009).

A filter sock (Figure 3.34) is a type of contained compost filter berm (refer filter berm), where a tube is filled with composted organic material and is placed perpendicular to sheet-flow runoff, to control erosion and retain sediment.

Figure 3.34: Filter sock

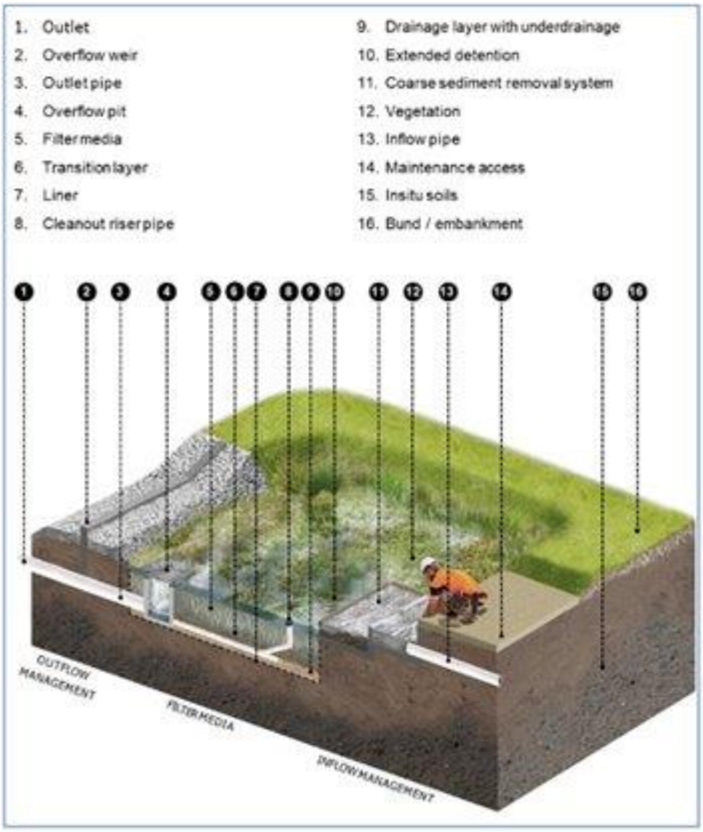
Source: Caltrans (2022).

Bioretention and biofiltration

Biofiltration systems and bioretention systems are low-energy treatment technologies. Their main function is improving stormwater quality through filtration of fine sediment, phosphorus, nitrogen, metals and hydrocarbons. Biofiltration systems are similar to bioretention systems. However, while biofiltration systems remove stormwater via infiltration into the surrounding soils, bioretention systems attenuate runoff with flow-regulating underdrains.

Organic matter can be used in the Filter Media of these systems. Filter Media is the portion of a filtering (or biofiltration) system that separates out the unwanted particles from the substance being filtered and typically provides a rooting media for plants (Figure 3.35). This application could be used for filtering surface runoff on the side of roads. Melbourne Water have a *Biofiltration Systems in Development Services Schemes: Guideline*.

Figure 3.35: Biofiltration system



Source: Melbourne Water (2020).

3.8.6 Specifications

There are currently no developed standards or specifications for the use of recycled solid organic material. However, there are relevant standards and specifications for the use of organic material that can be adapted to the use of recycled solid organic material.

The voluntary industry standard Australian Standard for *Composts, Soil Conditioners and Mulches* (AS 4454-2012) sets out measures for a minimum level of quality assurance for producers of certified recycled organics including compost, soil conditioner and mulch products. The aim is for products to be of a consistent quality, uncontaminated by heavy metals, and free from plant and animal pathogens and plant propagules (Sustainability Victoria 2018a).

In addition, EPA guidelines need to be followed, where relevant for the jurisdiction in which the material is being used.

Major Road Projects Victoria (MRPV) is currently developing a Specification for *Processed Solid Organic Waste for Road Infrastructure Applications.* This is likely to be published in 2022.

3.8.7 Comparative Performance

As recycled solid organic material needs to meet the same standards as virgin organic material, it will have the same performance outcomes. Recycled solid organic material can be used where it meets the maturity level to be defined as raw mulch, pasturised product, composted product and mature compost. In addition, recycled solid organic material can be used where it meets the characteristics and particle size for soil conditioner, fine mulch and coarse mulch, relevant to its intended use. Limits of pathogens and contaminations, both physical (e.g. plastic) and chemical (e.g. heavy metals), as well as physical (e.g. particle size) and chemical properties (e.g. pH level) of recycled organics, must be checked against the limits specified for virgin organics in AS 4454-2012 and EPA guidelines in each jurisdiction.

3.8.8 Estimate Recycled Content Percentages Based on Material Type and End Application

Where recycled organic material aligns with the intended use of the product, and where it is compliant with Australian Standards and relevant guidelines, it can be used as a 100% replacement for virgin material.

3.9 Recycled Ballast

This section investigates the potential for reusing and recycling ballast in road and rail infrastructure.

3.9.1 Material Overview

Ballast is the granular material that forms the base for railways sleepers (Figure 3.36), comprising coarse-sized crushed rock (Cement Concrete & Aggregates Australia 2015). It is a volume waste product in the rail industry, with, for example, Melbourne's Metro track renewal projects in 2019 generating 30,000 tonnes of ballast waste. It acts primarliy as a level, load-bearing platform, providing drainage and limiting vegetation growth around tracks. Generally, ballast has a nominal size of 53 mm or 63 mm. Ballast can be readily purchased as a virgin aggregate material.

Figure 3.36: Ballast

Source: Hanson Heidelberg Cement Group (2022).

3.9.2 Market Maturity

Ballast cleaning in-situ has been practiced in Australia for close to three decades (Mirzababaei et al. 2019) but ex-situ cleaning is an emerging market, with few processing capabilities across Australia. The size of Australia's rail network is a major challenge to being financially viable and environmentally sustainable.

Repurpose It is the only company within Vic processing ballast ex-situ, and with market support from VicTrack, MTM, V-Line and Yarra Valley Rail, industry is clearly supporting it. However, metropolitan Melbourne, where Repurpose It is located, presents a more viable environment for managing a cleaning process than, for example, rural Qld. Geographical factors may therefore determine financial and environmental viability.

3.9.3 Supply

Repurpose It currently treat used ballast ex-situ to create recycled ballast on demand and as required. The market is seemingly driving processing and supply at the present time.

3.9.4 Standard Practices and Opportunities to Use Recycled Content

Typically, ballast removed from the track has been reused in low-grade applications, such as road subbase in access tracks. Mirzababaei et al. (2019) used discarded ballast fines (< 26 mm) to construct access roads in Qld, finding the recycled ballast performed well and concluding it could confidently be used for this application. Several SA examples include using recycled ballast in structural pavement layers, embankments and general earthworks (Department of Planning, Transport and Infrastructure 2015). Rail ballast can also be recycled in other uses, such as concrete production (Jogi et al. 2020).

There is an emerging market for reclaimed ballast suitable for reuse once again as ballast. Facilities such as that operated by Repurpose It, in Vic, offer ex-situ washed and scrubbed reclaimed ballast products suitable for reuse in high-value applications (Repurpose It 2022). Repurpose It has received support and interest from VicTrack, MTM, V-Line and Yarra Valley Rail for the reuse of ballast and is providing the washed ballast product, when it can demonstrate it meets specification. The ideal goal is to reuse ballast in its most valuable form – as ballast. However, as the material may not always meet specifications there is potential to reuse it as ballast on haul roads or as a drainage material (Repurpose It 2022).

Recylced ballast may also be reused as a 100% mix or in combination with a mixture of fresh ballast (Jia et al. 2019).

Other sustainability practices include using other recycled materials, such as rubber, plastics, brick and concrete, to enhance or replace virgin ballast. Sol-Sánchez et al. (2015) and Fathali et al. (2019) demonstrated that 10% tyre-derived aggregate (of 5–50 mm size) was optimal in reducing ballast degradation, supporting energy dissipation and reducing stiffness.

Recycled content can be used in subballast/capping layers (i.e. the track formation layer below ballast), including recycled plastic blended with construction and demolition waste (Naeini et al. 2021, Mohammadinia et al. 2020, Imteaz et al. 2021). Studies have shown that plastics blended with brick and concrete have a slight decrease in performance compared to virgin materials; however, they have also been deemed suitable overall as sustainable materials for use in rail capping layers. Such blends have the potential to then be re-recycled as granular material. Research also notes that recycled materials in capping layers can offer cost benefits and CO_2 emission savings (Imteaz et al. 2021). Additionally, Imteaz et al. (2021) undertook an environmental sustainability assessment with respect to using recycled plastic in place of virgin aggregate, finding all leachates, except lead, to be within EPA Victoria's limits.

3.9.5 Opportunities for Recycled Content in Road and Rail Infrastructure

Overtime the ballast bed will undergo a degree of fouling, including from materials rising from the subsoil, aggregate breakage and external environmental influences (Plasser Australia 2017). Ballast must interlock to provide stability and enable load transfer, so it needs periodic replacement or cleaning to ensure it forms an effective structure for the track (Cement Concrete & Aggregates Australia 2015). There are ballast cleaning processes undertaken across Australia, whereby ballast is cleaned in situ. This can be done without dismantling the track and as such is an economical option, saving on transportation, track disruption and consumption of virgin materials.

Aurizon, Australia's largest freight rail operator with approximately 2,670 km of heavy haul track through Qld, annually renews or cleans a proportion of their track. With 30% rejected in the process this can equate to up to 230,000 m^3 of ballast being discarded annually. Ballast removed from the track can be reused in low-grade applications such as road subbase in access tracks (Mirzababaei et al. 2019). This can reduce the need to haul the material elsewhere for disposal.

Other uses include structural pavement layers; embankments; general earthworks (Department of Planning, Transport and Infrastructure 2011); drainage (Quarry 2019); or in concrete production (Jogi et al. 2020).

3.9.6 Specifications

The various Australian rail network owners and industry bodies have various specifications in place, as listed in Table H.1 in Appendix H. The Australian Standard specification for the supply of railways ballast is AS 2758.7, which outlines density, dimensional and durability requirements. Aggregate materials that meet the requirements are applicable for use as ballast. Cement Concrete & Aggregates Australia (2015) highlights that rock, gravel, metallurgical slag, or synthetic materials may be used, provided the aggregate criteria is met.

Explicit reference to recycled ballast is not widely found across Australian ballast standards and specifications; however, it can be found in select documents.

3.9.7 Comparative Performance

Recycled ballast, once suitably cleaned and processed to meet ballast specifications, can be used again as ballast. If it cannot be returned to a suitable level, it can be reused in lower graded applications (Quarry 2019). Key specification requirements include size, durability, density and contamination levels. State/operator-based specifications may require other factors to be met for ballast reuse, such as meeting environmental agency contamination requirements, using only below the depth specified for free draining ballast, or approval from the lead engineer on site (Department of Planning, Transport and Infrastructure 2015, MTM 2021).

3.9.8 Estimated Recycled Content Based on Material Type and End Application

Up to 100% recycled ballast can be used provided it has been cleaned to a suitable extent to meet relevant aggregate specifications (Repurpose It 2022), including ballast that would previously have been rejected (e.g. as is the case with Aurizon).

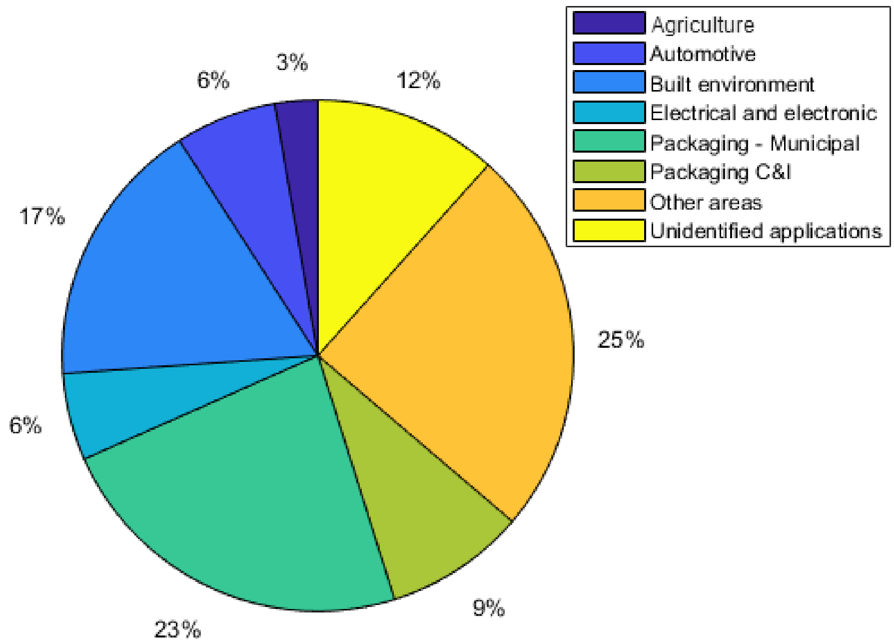
3.10 Recycled Plastics

3.10.1 Material Overview

Plastics are organic materials, typically the product of refined crude oil, with relatively high melting and degradation temperatures (White & Reid 2019). In this report, the term plastics is used to describe polymeric materials derived as waste from commercial and industrial uses. This segregation between plastics and polymers is made because the properties of plastics may differ to those of their pure polymer grade counterparts, as they may contain pigments and other contaminants. In addition, ageing effects might also have taken place due to their processing history (Pandelidi et al. 2021b). Polymers may be separated in two major categories: thermoplastics and thermosets. The plastics discussed here are thermoplastics, as thermoset polymers cannot generally be recycled (Shieh et al. 2020). Thermoplastic polymers may be processed through a variety of manufacturing methods. These include injection moulding, extrusion, blow moulding (National Research Council 1994) and, more recently, additive manufacturing (Pandelidi et al. 2021a and Pandelidi et al. 2021b).

In Australia, most of the plastic waste comes from packaging and some from built environment, automotive industry, and electrical and electronics applications (O'Farrell 2019a). These applications, along with the most common polymers used in Australia, are summarised in Figure 3.37.

Figure 3.37: Common applications of polymers in Australia



Source: Data sourced by O'Farrell (2019a).

The most common polymers found in these applications are high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyurethane (PU), polyamide (PA) and some bioplastics. Some of the commonly recyclable plastics are depicted in Figure 3.38. The majority of those used to be exported for recycling once they became waste, while a comparatively small amount, predominantly PET, HDPE, LDPE, PA, and PP, was locally reprocessed and repurposed (O'Farrell 2019a). However, with the recent import bans on waste imposed by some Southeast Asian countries and China (Ellis-Petersen 2019) and Australia's waste export bans (Council of Australian Governments 2020), Australia has to find other outlets primarily focussing on locally repurposing those waste stockpiles and diverting them from landfill (CSIRO 2021).

Figure 3.38: Common recyclable plastics

Source: Adapted from Austroads (2019e).

3.10.2 Market Maturity

In 2017, a total of 76 reprocessing facilities for waste plastics were counted in Australia. Of those, 20 were in NSW, two in NT, 12 in Qld, 12 in SA, 24 in Vic, two in Tas, and four in WA (Austroads 2019e). There are four main businesses focussing on the recycling of waste in Australia. These include Visy, Suez, Cleanaway and ResourceCo. In the years leading to 2017, the prices of recycled commodity plastics were in decline, a price change felt by the recyclers (Senate Standing Committees on Environment and Communications 2018). More recent reports, however, explain that an increase has been observed (Envisage Works, IndustryEdge & Sustainable Resource Use 2021). There has, therefore, been a push from both government agencies and industry to find ways to add value to the generated plastic waste, with the expectation that positive economic and environmental impacts will be realised.

Based on Figure 3.39, the recycling market is increasing and even though recycled plastics suppliers hold a position of strength during transactions, a shift may be expected due to the recent increase in the number of suppliers. Current developed regulations and increasing demand for environmentally conscious practices are some of the key market drivers, while the need for more efficient recycling practises is recognised as a major challenge (Locock et al. 2017).

Various projects demonstrating the use of recycled plastics in asphalt are being undertaken by contractors in conjunction with local government authorities in various Australian states. Examples are listed in Appendix I.4. It is recognised, however, that the amount of waste plastics that can be recycled in asphalt might be restricted due to performance requirements. Other applications might have the capacity to absorb larger amounts of that waste.

Figure 3.39: Five forces analysis for the plastic recycling industry

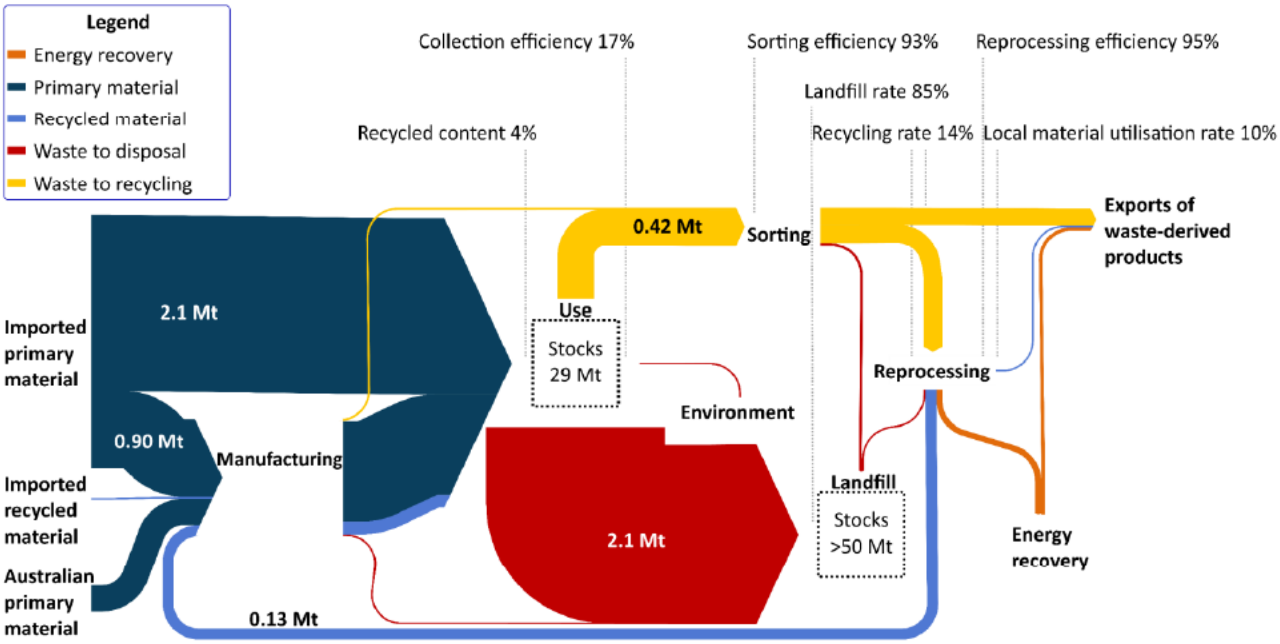
Source: Locock et al. (2017).

3.10.3 Supply

Post-consumer plastics are those deriving directly from consumers. These are often contaminated and hence complex to recycle. Additionally, various thin plastics, including cling wrap, are not typically considered for recycling. Post-industrial waste is generally easier to recycle as it does not include as many contaminants and the polymer grades are often clearly grouped. Despite this, the market uptake of recycled plastics does not meet the supply, primarily due to the comparative cost of recycled plastics to their virgin counterparts (Austroads 2021c). In Australia, 2.5 Mt of plastic were generated in 2018–19 (Pickin et al. 2020). While plastics consumption saw a 10% increase, recycling rates saw a 2% decrease (Austroads 2021c). It is recognised that the Australian recyclables market cannot absorb all that is collected as waste and with the import bans from China (Senate Standing Committees on Environment and Communications 2018) as well as the announcement of export bans released by the Council of Australian

Governments in 2020 (Pickin et al. 2020), innovative solutions are needed. Figure 3.40 shows the flow of plastics in Australia.

Figure 3.40: Plastics flows in Australia



Source: Pickin et al. (2020).

The recycling program for plastics in Australia includes kerbside collection taking consumer recyclables to materials recovery facilities (MRFs), contractors collecting industrial waste from workplaces, container deposit schemes in SA, NT, Qld, NSW and WA, and collection points for soft plastics to be returned to stores (Grenfell 2020).

Currently, there are a few limitations that inhibit the smooth transition of the discussed plastics from kerbside waste to recycled products. PET is often found to be contaminated with PVC, which can result in the release of hydrochloric acid if not processed accordingly. Additionally, it is often found in multilayered packaging and contains pigments that may need to be removed. HDPE needs to be carefully sorted as it has been used in food and non-food containers that leave residual odour. Similar challenges apply for PP as well. The two are also often mingled and need to be separated. PVC may be sourced from both domestic and industrial waste and streams, so it needs to be therefore carefully sorted. It often contains additives that need to be considered when recycled, as some companies might have policies to avoid phthalates and lead. The main challenge with LDPE is that it has a high cost of collection, sorting and processing due to its low density. PS also has a high cost of collection due to its low weight, and it is often rejected from recycling plants because it comes with food contamination (Locock et al. 2017).

Table 3.10: Plastics consumed, and waste plastic generated and recovered per state and Australia-wide

State	Plastics consumed (tonnes)	Currently recovered (tonnes)
Australia	3,435,200	393,800
ACT	58,000	4,600
NSW	1,099,000	149,000
NT	34,000	1,000
Qld	688,800	40,300
SA	236,000	32,300
Tas	71,800	4,200
Vic	893,100	142,500
WA	354,500	20,000

Data in table summarised from different sources and include information from different years. These numbers fluctuate and should be read as a general guide and not as absolute.

Source: O'Farrell (2020).

Care needs to be taken when referencing the figures in Table 3.10, as great variance among sources can be observed. Measuring the actual waste generated is challenging while understanding the consumption and recovery numbers is more achievable. At the same time, different sources report different values. Overall, it is evident that even though not all plastics consumed are disposed of, the recovery numbers are still relatively low and, therefore, further opportunities for recycling need to be developed.

3.10.4 Standard Practices and Opportunities to Use Recycled Content

Co-mingled waste plastics are collected from kerbside and delivered to a materials recovery facility (MRF), where they get sorted (Austroads 2019e). In Australia, the national recovery rate for plastics was just 11.5% in 2018–19 (Macken et al. 2021); however, calculations for the recovery rate tend to be based on annual plastic consumption, as definitive masses of plastic waste do not exist. Table 3.11 lists the most common recyclable plastic waste materials along with their common repurposing applications. Most are re-processed through extrusion or injection moulding (O'Farrell 2019a).

Table 3.11: Major and minor uses of recycled plastics in Australia

Polymer	Major uses	Minor uses
PET	Beverage bottles	Fence posts
		Geosynthetics
		Pallets
		Bottles for detergents
HDPE	Films	Cable covers
	Pallets	Shopping and garbage bags
	Wheelie bins	Drip sheets for water
	Irrigation hoses	Fence posts
	Irrigation pipes	Bollards
		Kerbing
		Outdoor furniture
PVC	Pipes	Hoses and fittings
	Floor coverings	Electrical conduit
		Clothing
		Bags
		Shoes
	Film	Vineyard cover
	Concrete lining	Pallets

Polymer	Major uses	Minor uses
4 LDPE	Freight packaging	Shrink wrap
	Garbage and shopping bags	Roto-moulding
		Slip sheets
		Irrigation tubes
		Cable covers
5 PP	Milk crates	Electrical cable covers
	Plant pots	Building panels
	Boxes	Furniture
		Irrigation fittings
		Agricultural and garden pipe
		Drainage products
		Builders' film
		Kerbing
		Bollards
6 PS	Industrial spools	Industrial packing trays
		Wire spools
		Automotive components
7 ABS	Agricultural piping	Laminate edging
		Drainage covers
		Mattresses
7 PU	Carpet underlay	Furniture fittings
7 PA		Garden stakes
		Castors

Source: Adapted from O'Farrell (2019a).

In general, recycled plastics are used in applications as described in Table 3.11, replacing their virgin counterparts or other virgin materials, such as wood. Waste plastics have also found uses in construction in masonry products, such as brick and concrete (White & Reid 2019).

3.10.5 Opportunities for Recycled Content in Road and Rail Infrastructure

When utilising plastics in transport infrastructure, the potential to generate microplastics will always need to be considered. The use of recycled plastics in various applications in this section needs to be done responsibly. When incorporating recycled plastics into bitumen and asphalt, which will then be subject to traffic loading, it is important to understand whether there is potential to generate microplastics that could be of concern to the environment. Ongoing work is investigating this in more detail.

There are three main ways to incorporate recycled plastics into transport infrastructure. The first is to manufacture plastic ancillary components. These include drainage covers, roadside furniture, bollards, road cones, safety barriers, boardwalks, signage, tree stakes, decking, noise walls, pipes, railway sleepers and modular cycle paths and walkways. In some cases, it may be possible to manufacture components from

100% recycled plastics. Others may need a certain percentage of virgin materials to meet performance or colour requirements (Chaudhry et al. in press; Maharaj et al. 2018; White & Reid 2018).

The second way to incorporate recycled plastics is into geosynthetics such as geogrids and geotextiles. These are then incorporated in the road and rail structures. Geogrids are polymeric meshes with relatively large openings and are used mainly as reinforcement elements. Geotextiles are fibrous polimeruc products that can be woven (polymeric fibres interlaced as filaments) or non-woven (polymeric fibers randomly oriented and bonded), and are used for applications such as filtration and separation of pavement layers.

Geosynthetics can be separated into two categories – structural and non-structural – and have a number of applications in transport infrastructure. These include geogrids to support granular materials (ballast in the rail structure or unbound granular base or subbase in the road structure); or layers between bound pavement layers. Geotextiles also find uses in geotechnical applications, helping with drainage and supporting sprayed seals on granular pavements. Due to the performance requirements of such structural products, however, their manufacture using purely recycled plastics is challenging. Although it may be feasible, it requires a higher level of waste plastics processing, or an increase in the design thickness, to meet performance requirements. This can mean that they are no longer cost competitive compared to virgin equivalents, although for non-structural applications such as drainage and filtration, higher contents of recycled plastics might be used (Williams et al. in press).

The third way is to incorporate recycled plastics into asphalt, providing modification to the bituminous binder or acting as a partial fine aggregate replacement (Airey 2003; Ameri et al. 2013; Dong et al. 2014). This option has recently attracted a lot of attention and so, even before a discussion on material compatibility and performance even begins, environmental and occupational health and safety concerns need to be addressed. State road authorities and Austroads (Austroads 2021d) have recognised this need and so investigations into the emission of fumes and the potential release of microplastics are already underway.

Specialty polymers, such as ethylene vinyl acetate (EVA) and styrene-butadiene-styrene (SBS), are already used with success. These are, however, quite cost intensive and hence their replacement by plastics otherwise destined for landfill could offer benefits in both levels. Low melting point plastics, such as LDPE and HDPE, can be blended with bitumen to modify its properties. As most recycled plastics tend to be plastomeric in nature, they tend to stiffen bitumen, which can improve its resistance to permanent deformation but can be detrimental to its fatigue properties. High melting point plastics, such as PET, can be used as a partial fine aggregate replacement. However, the recycled plastics are unlikely to be as strong as the aggregates they are replacing, so it is important that incorporation levels are not detrimental to the mechanical performance of the resultant asphalt.

Figure 3.41 illustrates some of the potential applications for recycled plastics in road and rail infrastructure.

Figure 3.41: Various applications of recycled plastics in road and rail infrastructure: (a) asphalt, (b) railway sleepers, (c) bike paths, (d) plastic furniture, (e) noise wall, (f) pipes, (g) bollards and (h) lumber

Source: Collected from Crick (2019); Integrated Recycling (2022); External Works (2022); Moodie (2014); RPM pipes (n.d.); PlasticRoad (2020); Replas(2019).

Specifics regarding examples where such plastics have found applications in road and rail infrastructure are provided in Appendix H.

3.10.6 Specifications

Most specifications for infrastructure-related plastic products tend to be performance based. This means that although they do not specifically allow the use of recycled materials, there are no limits to the amount of recycled material that can be incorporated into a product provided it still meets performance requirements. Dependent on the end application and its performance requirements, up to 100% recycled plastic products can be manufactured.

ARRB is currently working with MRPV to develop specifications for the use of recycled plastics in certain road infrastructure applications, such as pipes and noise walls. The pipes specification covers flexible plastic pipes, including behind kerb and under pavement. The requirements for recycled plastic pipes are expected to be the same as for those made with virgin materials, however evidence of durability and performance must be provided. For noise walls, besides structural considerations, the main functional requirement is to provide sufficient airborne sound insulation. The specification developed for recycled plastic noise walls is therefore expected to meet the requirement of a non-porous structure (VicRoads 2018). Some specifications on these topics are listed in Appendix I.2.

Modified binders and asphalt

Australian specifications for polymer modified binders are based on blends of virgin polymers and bitumen. These have a number of property requirements for either asphalt or sprayed seal applications. These specifications are ingredient blind and do not specifically preclude the incorporation of recycled plastics.

Australian asphalt specifications are mainly performance based but contain some prescriptive requirements around grading of aggregates, as well as some of the components in the asphalt mix. These specifications do not specifically preclude the use of recycled plastics in asphalt.

Local governments tend to follow state road agency specifications as it gives them confidence in the performance of materials. However, as they have no requirement to do so, there is opportunity to incorporate recycled plastics more readily into asphalt mixtures. In addition to meeting performance requirements, recycled plastic modified asphalt should be tested to ensure that does not cause any work health and safety (WHS) concerns for workers or the general public. Furthermore, it needs to be shown that there is no concern for environmental harm in the long term, such as through the generation of microplastics. There is a lot of current research in this area, with questions that have not yet fully answered.

Overall, it can be assumed that recycled plastics can replace virgin materials for applications in road and rail infrastructure, as discussed above, as long as performance requirements are met.

3.10.7 Comparative Performance

Ancillary devices

The performance of ancillary devices that incorporate recycled plastics is expected to be similar to that of the virgin equivalents. Most of these applications have performance requirements, which any product incorporating recycled content is also required to meet. For example, while concerns regarding the durability of recycled HDPE pipes under loading exist, preliminary studies suggest they could remain crack-free for over 100 years, which is comparable to virgin HDPE. However, in some cases, recycled content is limited in order to meet those performance requirements.

Geosynthetics

Due to the specifications around the performance of geosynthetics, any product that contains recycled content is required to meet the same performance characteristics as the virgin equivalents. As in ancillary devices, it is possible that to achieve those requirements, the recycled content could be limited. However, the biggest limitation is the supply of processed recycled plastics that meet the input requirements for manufacturing the end product.

Modified Binders and Asphalt

When using recycled plastics to modify bitumen or asphalt, such as in the wet or hybrid process, their plastomeric nature is likely to lead to a stiffer binder, which can also be brittler, similar to an EVA modified bitumen such as A35P (White & Reid 2018). A35P is a plastomeric polymer modified binder grade that tends to be much stiffer than conventional bitumen but does not offer the same enhancements in crack resistance as elastomeric polymer modified binders containing styrene-butadiene-styrene (SBS) or styrene-butadiene rubber (SBR). A35P grade binders are used to maximise rut resistance in heavy vehicle turning areas, race-track surfaces and container terminals (Austroads 2017b). In the dry process, where higher melting point plastics are used as a partial fine aggregate replacement, the method is likely to produce asphalt that is less stiff and durable than conventional asphalt, as the recycled plastics are not as strong as the aggregates they are replacing.

Different test protocols have been found to relate to different properties of interest where asphalt is considered (White & Reid 2019). It should be noted, however, that the base materials' (bitumen) properties need to be taken into consideration when their results are interpreted. Additionally, it has been highlighted that despite all efforts to predict the behaviour of road performance, field performance cannot be substituted (White & Reid 2018). Some performance effects with the incorporation of plastics into bitumen and asphalt are reported in Appendix I.3.

Railway applications

Combining recycled plastic with construction and demolition waste has been investigated as a granular material for capping. When plastic was combined with brick and concrete it was found to create a suitable energy-absorbing compound for rail capping layers, with an increase in plastic content resulting in an increase in energy dissipation. At the same time, a decrease in stiffness and a lower or equivalent permanent strain when compared to conventional materials was found (Macken et al. 2021).

Additionally, recycled plastic sleepers, as manufactured by Duratrack, have a 50-year design life, which is approximately four times that of timber. They also provide other benefits such as termite, UV and rot resistance. Other sleepers manufactured by Axion Inc. Ecotrax, comprise waste HDPE and PP and have been found to have improved toughness and durability (Macken et al. 2021).

3.10.8 Estimated Recycled Content Percentages Based on Material Type and End Application

Ancillary applications

A number of ancillary applications currently manufactured from plastics have been identified as opportunities for using increased amounts of recycled plastics. These include drainage covers, roadside furniture, bollards, road cones, safety barriers, boardwalks, signage, tree stakes, decking, noise walls, pipes, railway sleepers and modular cycle paths and walkways. Many of these have the potential to incorporate up to 100% recycled plastics. Some, however, are limited by performance requirements. For example, it is possible to make railway sleepers from 100% recycled plastics; however, due to their properties, they may only be suitable for certain parts of the railway network. Waste plastics, including PE and PP, may be incorporated with crumb rubber among other materials to fabricate covers for railway sleepers (Dolci et al. 2020). In Australia, patented technology named Duratrack has seen the development of 100% recycled plastic sleepers. It is estimated that with the use of this technology, approximately 90 tonnes of waste plastics may be recycled for every kilometre of standard gauge (Integrated Recycling 2022). Noise walls can be made from recycled plastics, however, to ensure they meet the performance specifications, currently around 75% of the component can be made from recycled materials. That is not to say the recycled component could not be increased in the future (Macken et al. 2021). Items for temporary traffic management such as road cones present a different issue. The base component, which is usually black in colour, can be made from 100% recycled plastics. However, the stem of the component, which has certain colour requirements, needs to be made from virgin plastics. For non-pressure applications, plastic pipes comprise three layers in a sandwich formation. The layer in the middle may be manufactured using 100% consumer recycled materials while for the inner and outer layers, virgin or post-industrial recycled plastics may be used. Sandwich pipes have been found to have service lives comparable to those of pipes made of 100% virgin materials.

Geosynthetics

Geogrids

There are geogrid products available that contain up to 100% recycled plastics. These tend to use highly processed PET yarn. At the present time, these recycled products are manufactured overseas using foreign recycled plastic. There is potential for manufacture in Australia but this is likely to be dependent on significant market demand for the product and improved recycling infrastructure. Most geogrid manufacturers are not incorporating recycled plastic content at the present time as they have concerns as to whether they can meet long-term performance requirements.

Geotextiles

Geotextiles can be produced with recycled plastics but are competing with other higher-end uses for the feedstock. Presently there are geotextile products that contain 10–20% recycled plastics, but to increase this content is at present not cost effective due to the lack of economical feedstock.

Asphalt

There are three ways to incorporate recycled plastics into asphalt: the wet method; the dry method; and the hybrid method.

For the wet method, lower melting temperature plastics, such as LDPE and HDPE, are blended with bitumen to make a recycled plastic modified bituminous binder. This is done in much the same way as for an EVA or SBS modified binder. Typically, recycled plastics would be added to bitumen by around 6 wt.%. This equates to only around 0.3 wt.% of the total asphalt mixture. The plastics that are blended with bitumen need to be storage stable to create a usable modified binder. A storage stable binder is one that has an even distribution of polymer or modifier throughout. If the modifier is not storage stable within the binder, there will be big discrepancies in the properties of the binder between the top of the storage tank and the bottom. It is important that the binder is homogeneous to create a homogeneous asphalt mixture. If the mixture is not homogeneous there will be big differences in the properties of different sections of the asphalt, with some having high levels of waste plastic modification and therefore potentially being overly stiff and brittle; and some areas with minimal modification, which would be overly soft. This will lead to poor performance of the resultant asphalt road. Storage stability of waste plastic modified binders is expected to be an issue. This would have to be overcome by continuous agitation or by adding a compatibility agent. Alternative incorporation methods could also be considered (see the hybrid method, below).

For the dry method, higher melting temperature plastics, such as PET, are added in with the aggregates in the asphalt plant as a partial fine aggregate replacement. This incorporation method could be expected to allow higher content of recycled plastics, up to 2 or 3 wt.% of the total asphalt mixture. However, this method is likely to produce asphalt that is less stiff and durable than conventional asphalt, as the recycled plastics are not as strong as the aggregates they are replacing.

For the hybrid method, lower melting temperature plastics, such as LDPE and HDPE, are added in with the aggregates in the asphalt plant, where they are expected to melt and be combined with the bitumen during the mixing process. This is done to allow the recycled plastic to modify the bitumen whilst overcoming the storage stability issues associated with the wet method. This methodology can be expected to give some performance enhancement to the asphalt but is again likely to make it stiffer and potentially more brittle. It is also possible that slightly more recycled plastics can be incorporated via this method than the wet method, potentially up to 0.6% by mass of the total asphalt mixture.

While the use of plastics in road infrastructure, such as in bitumen or as an aggregate replacement, might be limited to low quantities, even if only 5 wt.% absorption of recycled plastics is considered (via the wet method), up to 55,000 tonnes of plastics might be redirected from landfill. If the incorporation of those plastics in asphalt is considered via the dry method, this figure might even increase to 175,000–870,000 tonnes per year (Austroads 2021d). It should be recognised here that the amount of waste plastics with the potential to be recycled in asphalt is insignificant, totalling less than 1% of the total plastic waste generated in the country, and so it should be considered in combination with other applications (Trochez et al. 2021) proposed in this report.

Summary

Given the current knowledge and the large amounts of waste plastics generated in Australia, recycling of waste plastics into structures such as noise wall, bollards, furniture and drainage pipes, which that can absorb large quantities, would be desirable. Research relating to the incorporation of those plastics into bitumen, however, is still at embryotic stages and even though the quantities that may be absorbed through that avenue are not notable, there might be specific cost benefits associated with the replacement of expensive, purpose-specific, manufactured polymers.

4. Conclusions

Australian governments have introduced a range of policies, strategies and plans to promote the reduction of waste, recycling and reuse of materials and drive the transition towards a circular economy.

The *National Waste Policy: Less waste, more resources 2018* provides the national framework for waste and resource recovery in Australia and has been endorsed by all levels of government. While the details of policies and plans vary from jurisdiction to jurisdiction, there are some shared actions across jurisdictions, including and these include:

- All jurisdictions are subject to the national export ban on waste plastics, paper, glass and tyres.
- All jurisdictions are committed to reducing total waste generated.
- Most jurisdictions have committed to recover at least 80% of all waste by 2030.

Procurement policy within different states is also rapidly developing to help support the implementation of recycled materials. Vic's Recycle First policy is one of the best examples of this. This policy has seen significant uptake of novel recycled materials and components made with the inclusion of recycled materials. In delivering on the policy's objectives, Major Road Projects Victoria has developed new performance-based specifications to encourage the use of recycled materials. Performance-based specifications encourage industry to innovate and try to incorporate recycled materials within their products and applications without constraining designs and material choices.

Supply of suitable recycled materials can still be an issue and there can be significant variation when considering different geographic locations. For some materials, such as crushed glass, crushed concrete, RAP and crumb rubber processing practices are standardised, however there can be a lack of processing facilities in some geographic locations, especially in more remote regions of Australia.

The processing and suitable supply of other materials is evolving. For example, some recycled materials, such as recycled ballast and recycled organics, suffer from a lack of available processing facilities or technologies. Processing plastics is also very complex as there are many plastic types, product streams have varying levels of contamination and they require very complex processing to make them reusable for given applications.

Often the demand for the recycled materials drives the supply chain to develop processing infrastructure. However, when there is a lack of understanding or confidence in recycled products, there is no encouragement to develop new processing plants to facilitate their implementation.

4.1 Use of Recycled Materials in Transport Infrastructure

There are many specifications that allow for the use of recycled materials in transport infrastructure. Specifications are much more prevalent for the use of recycled materials in the road sector than the rail sector.

The use of some recycled materials, such as crushed concrete, RAP, fly ash, slag and crumb rubber, within transport infrastructure, is very mature. Some of these materials have many potential applications, whereas some are more limited in where or how they can be used. However, there are also some materials, such as plastics and organics, that are less widely used in infrastructure or are at present developing in terms of processing or protocols to allow their implementation.

4.1.1 Recycled Plastics

The use of recycled plastics has many potential applications. These range from standalone ancillary products, such as roadside furniture and temporary traffic management devices. Many of these applications could potentially incorporate up to 100% recycled plastic. They can be incorporated into geosynthetics such as geogrids or geotextiles, which can be used to provide support as part of a larger structure. Within geosynthetics there is the possibility to incorporate significant percentages of recycled plastics; however, they need to be highly processed to be able to meet performance requirements. This can affect their cost compared to virgin plastic equivalents or mean that they could be manufactured abroad as the Australian plastics recycling industry is at present unable to meet processing requirements. Plastics can also be used within asphalt as a modifier for bitumen or even as a partial fine aggregate replacement. This final application is still undergoing investigation, as the short-term WHS and longer-term environmental impacts of their incorporation into bitumen and asphalt are not widely understood. When used in asphalt, recycled plastics can only be incorporated at relatively low proportions of the total asphalt mix, however significant tonnages of asphalt are used each year.

4.1.2 Crumb Rubber, Recycled Crushed Glass, Crushed Concrete and Crushed Brick, RAP, Fly Ash and GGBFS

Other recycled materials that are widely used are crumb rubber, recycled crushed glass, crushed concrete and crushed brick, RAP and fly ash. Some of these have multiple end-use applications, such as fly ash, which can be used as complete or partial cementitious binder in concretes, materials stabilisation or even as a filler additive to asphalt. However, each of these applications uses relatively small percentages of fly ash as a function of the total mass of the structure. Crumb rubber is mainly used as a modifier to bitumen or within asphalt. In this application, it can provide performance enhancement but, again, the percentages of crumb rubber used within the structure are limited. Other applications for use of crumb rubber exist but are less mature or less widely used.

RAP has been used for many years and can be used in high volumes. Its main application is for reuse within asphalt. Asphalt is a success story of recycling as it is fully recyclable. RAP can also be used within granular materials applications. Some recycled materials only act as aggregate replacements or partial aggregate replacements, such as crushed concrete, crushed brick and recycled crushed glass. These materials can be incorporated in very high proportions within their end applications, even up to 100%.

The use of GGBFS is relatively mature but is mainly limited to being a partial cement replacement within cementitious binders.

4.1.3 Bottom Ash, Recycled Organics and Recycled Ballast

Other recycled materials such as bottom ash, recycled organics and recycled ballast, are less mature and less widely used. They are, however, seen as emerging materials and have the potential to be used in large volumes. Each of these materials has one main application. The main application for bottom ash is within granular materials. Recycled organics can be used within landscaping or, potentially, water filtration applications. The main use for recycled ballast is as a replacement for virgin ballast within rail infrastructure. However, due to the conservatism within the rail industry, it is not widely used at present.

4.1.4 Conclusion Summary

This report shows that there are a lot of recycled materials that are widely used and that there is ample opportunity to increase their percentages within applications, or even the frequency that they are used, within their most suited application. There are also emerging recycled materials technologies that have significant opportunity for increased uptake. Improved awareness and education in how these materials are used, supported by policy and procurement drivers, new and improved specifications and more modern recycling facilities with increased capacity, can all contribute to increases in the use of recycled materials, sustainability outcomes and a more circular economy.

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MRTS103 2017, *Fillers for asphalt*.

PSTS112 2019, *Crumb rubber modified asphalt*.

Technical note TN183 2019, *Use of high percentages of reclaimed asphalt pavement (RAP) material in dense graded asphalt*.

Technical note TN193 2020, *Use of recycled materials in road construction*.

Transport Canberra and City Services (TCCS) Municipal Infrastructure Technical Specifications

MITS 02C 2019, *Stabilisation.*

MITS 04 2019, *Flexible pavements.*

MITS 10 2019, *Concrete works*.

Transport for NSW (TfNSW)

Design & Construct Specification D&C R116 2021, *Heavy duty dense graded asphalt.*

Design & Construct Specification D&C R117 2020, *Light duty dense graded asphalt.*

Design & Construct Specification D&C R121 2020, *Stone mastic asphalt.*

Design & Construct Specification D&C 3051 2020, *Granular pavement base and subbase materials.*

Design & Construct Specification D&C 3211 *Cements, binders and fillers.*

Design & Construct Specification D&C 3256 2020, *Crumb rubber.*

QA Specification R44 2020, *Earthworks.*

QA Specification 3201 2021, *Concrete supply for pavement maintenance.*

QA Specification 3252 2020, *Polymer modified binder for pavements.*

QA Specification R118 2020, *Crumb rubber asphalt.*

QA Specification 3051 2020, *Granular pavement base and subbase materials.*

Transport Assets Standard T HR TR 00192 ST 2018, *Ballast*.

Metro Trains Melbourne (MTM)

L1-CHE-SPE-178 2020, *Earthworks & formation specification*.

L1-CHE-SPE-313 2018, *Recycled glass sand specification*.

L1-CHE-SPE-064 2021, *Technical specification for ballast supply*.

L1 CHE STD 029 2020, *Earthworks & formation standard*.

Appendix A Commonwealth, State and Territory Procurement Polices and Guidance

A.1 Commonwealth

The *Commonwealth Procurement Rules* (2020) set out the rules that Commonwealth officials must comply with when they procure goods and services. Section 4 sets out the core rule on achieving value for money. The rule states that price is not the sole factor when assessing value for money. When conducting a procurement, an official *must* consider the relevant financial and non-financial costs and benefits including, but not limited to the:

a. quality of the goods and services
b. fitness for purpose of the proposal
c. potential supplier's relevant experience and performance history
d. flexibility of the proposal (including innovation and adaptability over the life cycle of the procurement)
e. environmental sustainability of the proposed goods and services (such as energy efficiency, environmental impact and **the use of recycled products**):
   - recognising the Australian Government's commitment to sustainable procurement practices, entities are required to consider the Australian Government's *Sustainable Procurement Guide* where there is **opportunity for sustainability or use of recycled content**
   - the *Sustainable Procurement Guide* is available from the Department of Agriculture, Water and the Environment's website
f. whole-of-life costs.

Each of the above procurement considerations are important for understanding and evaluating recycled material opportunities. This report provides best practice information to help inform these considerations.

The Australian Government's *Sustainable Procurement Guide* is a practical resource to help agencies. This guide provides step-by-step guidance on how to consider sustainability in the different stages of the procurement process.

The guidance includes identifying the benefits of buying recycled content for different parties (as shown in Figure A.1), case studies and examples of the incorporation of recycled materials such as recycled glass, crumb rubber and recycled plastic in new and innovative uses in infrastructure.

Figure A.1: Benefits of buying recycled content

Party	Benefit
Purchaser (Government)	Savings as recycled materials require less water and energy to produce. Long-term value for money by reusing public resources made from recycled content. Public recognition for purchasing and using products and/or services with recycled content. Demonstrating social and environmental leadership.
Market	Increased demand for products using recycled content, promoting market growth and development. Increased market opportunities for local businesses. Support for businesses that innovate. Encouraging industry to operate in a clean, green economy. Reputational benefits for early adopters and market leaders.
Society and the environment	New jobs and skills in the recycling industry support local communities. Fewer natural resources used. Less waste directed to landfill. Encouraging the development of Australia's waste circular economy. Lower consumption of water and energy. Reduced greenhouse gas emissions which will lower air and water pollution.

Source: Department of Agriculture, Water and the Environment (2021).

A.2 Victoria

Vic's *Social Procurement Framework* (SPF) (State Government of Victoria 2018) aims to ensure value-for-money that is not solely focused on price but encompasses social and sustainable outcomes alongside financial considerations. The SPF imposes mandatory individual procurement activity requirements on government buyers to incorporate this framework into regular procurement planning or prepare a Social Procurement Plan (for which templates are provided) and consider opportunities to deliver sustainable outcomes in all procurement activities.

The SPF is to be applied to procurement of all goods, services and construction projects. Figure A.2 shows that procurement activity requirements for government buyers increase as the contract value increases.

Figure A.2: Procurement activity requirements for government buyers

Victoria's Social Procurement Framework Individual procurement activity requirements				
	Below threshold Regional under $1 million Metro or State-wide under $3 million	**Lower band** Regional $1 to $20 million Metro or State-wide $3 to $20 million	**Middle band** $20 to $50 million	**Upper band** Over $50 million
Planning requirement for government buyers	Incorporate SPF objectives and outcomes into regular procurement planning		Complete a Social Procurement Plan during procurement planning	
Described approach	**Encouraged** Seek opportunities where available to directly or indirectly procure from social enterprises, ADEs or Aboriginal businesses	**Proportionate** Use evaluation criteria (5 to 10 per cent weighting) to favour businesses whose practices support social and sustainable procurement objectives	**Targeted** Include performance standards and contract requirements that pursue social and sustainable procurement objectives	**Strategic** Include targets and contract requirements that pursue social and sustainable procurement objectives

Source: State Government of Victoria (2018).

Projects valued below the financial thresholds, (i.e. those valued under $1 million regional projections and under $3 million in metro or state-wide projects), the SPF requires that government buyers ask suppliers to demonstrate environmentally sustainable business practices, which are assessed against a weighted framework criteria. Projects valued $20 million and above must include additional requirements, such as the inclusion of recycled content.

This SPF directly encourages the use of recycled materials to meet sustainable goals. Likewise, the Victorian Government recommends using recycled content 'where virgin materials can be substituted or complemented using alternative or recycled materials' (State Government of Victoria 2018). The SPF requires government buyers to:

- analyse opportunities for use of recycled content, in consultation with a suitably qualified professional, prior to going to market
- establish appropriate minimum targets for the use of recycled content
- prepare information for suppliers on opportunities for using recycled content and specify suppliers to provide detailed proposals for sourcing and using recycled content in the project
- require suppliers to commit to developing, implementing and reporting against an environmental management plan, including a specific focus on the use of recycled content.

The SPF incorporates sustainable procurement practices, noting that the Victorian Government is committed to achieving positive environmental outcomes in addition to the social outcomes. In relation to this project, sustainable procurement practices may include maximising recyclable/recovered content, minimising waste and providing non-toxic solutions.

Sustainability Victoria has a webpage to provide an overview of sustainable procurement, listing the common tools and measures for assessing the environmental impacts and the likely outcomes of sustainable procurement (https://www.sustainability.vic.gov.au/recycling-and-reducing-waste/sustainable-procurement). The webpage also links to the Victorian Social Procurement Framework and lists the requirements of this framework (including maximising the use of recycled content). Furthermore, Sustainability Victoria provides a *Buy Recycled Directory* that lists local product options containing recycled content and materials, providing easy access to suppliers (https://directories.sustainability.vic.gov.au/buy-recycled).

In 2011, VicRoads (now the Department of Transport (DoT)) released the *Sustainable Procurement Guidelines* for road projects (Vicroads 2011). These guidelines broadened the definition of procurement to include the environmental consequences of procurement decisions and define a sustainable product as 'made with minimum use of virgin materials and a maximum use of post-consumer materials'. The guidelines' sustainability objective is 'to give preference to products that are reusable, recyclable and/or contain recycled content where such products fit the purpose, provide environmental benefits and are of comparable cost and quality to alternative products'. The guidelines outline a procurement strategy for critical purchases, such as construction projects, including:

- mandatory sustainability criteria
- incentives to promote sustainability outcomes
- standard specifications with existing sustainability requirements, e.g.:
  - use of shredded tyres as a drainage layer in landscaping works or whole tyre engineered walls as reinforced soil structures (VicRoads Section 204 2015)
  - the use of recycled asphalt product and glass (VicRoads Section 407 2021) and the use of warm mix asphalt (Section 409 2012)
  - the use of granular crumb rubber in the asphalt mix (VicRoads Section 421 2021)
  - the use of fly ash and slag as part of cement (VicRoads Section 610 2020)
- decision making around acceptance of a cost premium for sustainability outcomes
- benchmarking and use of sustainability rating schemes.

A.3 New South Wales

The NSW *Procurement Policy Framework* (NSW Government 2021) provides a consolidated view of government procurement objectives and requirements. The Framework identifies that sustainable procurement focuses on spending public money efficiently, economically and ethically to deliver value for money on a whole of life basis. It explains that sustainable procurement extends the assessment of value for money beyond the sourcing process, considering benefits and risks to the organisation, the community, the economy and impacts on the environment. Sustainable procurement also seeks innovative solutions to address sustainability throughout the supply chain and buys only what is needed or seeks sustainable alternatives.

The consolidated framework references the Resource efficiency and waste reduction directions under the *NSW Government Resource Efficiency Policy* (NSW Government 2019) and the *NSW Circular Economy Policy Statement: Too Good to Waste* (NSW EPA 2019), whereby government buyers:

- '…**should** purchase construction materials with recycled content' (NSW Government 2019) and;
- '…**should** consider the product lifecycle when conducting needs analysis and developing product specifications, including taking account of circular economy principles, so that use of recycled materials and disposal or repurposing of goods or assets is planned into the procurement process' (NSW EPA 2019).

Transport for NSW have a procurement policy (TfNSW 2016a) and a sustainable procurement policy (TfNSW 2016b), however neither mention recycled content and waste management or resource efficiency.

A.4 Queensland

The *Queensland Procurement Policy* (Queensland Government 2021b) provides principles, targets, commitments and actions. One action as part of its Leaders in Procurement Practice principle states that 'Procurement and business areas will proactively engage with each other to… manage demand and reduce waste, and manage consumption of valuable resources.'

The 2018 *Integrating sustainability into the procurement process* guidance document provides further guidance 'to assist procurement officers to integrate sustainability considerations into the procurement process' (DHPW 2018). The guidance provides examples of desirable social, environmental and economic outcomes or benefits, including:

- reduced waste and by-products (e.g. recycling and waste prevention)
- end-of-life options (e.g. recyclability, resource recovery)
- job creation (e.g. green technologies, use of local suppliers, creating markets for recycled products, back to work schemes).

It also identifies sustainability impacts for consideration, including:

- reusability and/or recyclability
- product efficiency and longevity: options for reuse, repair, upgrade or modification to increase product life
- recycled content of goods (reduces demand for virgin resources).

Finally, the guidance emphasises that contract specifications and invitation-to-offer documents ensure that they do not contain unnecessary obstacles to sustainable procurement, including phrases such as 'virgin paper only' or 'no recycled material'.

A.5 Western Australia

The Western Australian Procurement Rules (Government of WA 2021b) state agencies must seek the best value-for-money outcome for procurements considering the government's social, economic and environmental priorities, objectives and strategies. The rules, however, do not provide details or examples of the environmental prioritises as they relate to procurement.

The WA Government also has an *Environmental Procurement Guide* (Government of WA, 2021a), providing additional information on the environmental objectives of procurement. Key environmental considerations include:

- resource use, including the use of non-renewable resources and use of recycled materials
- volume and type of waste generated
- end-of-life options, e.g. reuse, recyclability and resource recovery.

A noted desirable benefit of environmental procurement is reduced waste and by-products (e.g. waste avoidance, reuse, use of recycled products or products with recycled content, recycling and resource recovery).

The WA Social Procurement Framework (Government of WA 2021c) contextualises the value for money principle regarding social procurement and brings together all relevant WA Government social procurement policies and priorities into one place. The *Social Procurement Framework* identifies the increased use of recyclable materials and locally produced recycled materials as key community outcomes for a sustainable WA.

The *Premier's Circular: Reducing the Use of Disposable Plastic* (Government of WA 2021d) requires agencies to choose sustainable options and increase the use of recycled products. This is specific to the use of disposable plastics and demonstrates a raising awareness of recycled products and this being promoted by procurement policies.

A.6 South Australia

The South Australian Government's *Green Procurement Guidelines* (Government of SA 2021) promotes procurement outcomes and encourages public authorities and suppliers to improve practices that balance procurement priorities, achieve value for money and minimise the impacts on the environment.

The guidelines identify a number of procurement considerations to minimise environmental impacts including:

- the use of recycled materials and recycled content of goods (reduces demand for virgin resources)
- reusability and/or product recyclability (reducing landfill waste).

The guidelines suggest that contract specifications should be used to outline minimum or desirable requirements and describe what is required from a supplier and how performance against these requirements will be assessed. Conversely, simply stating that products are to be 'environmentally preferable" or have a "lower environmental impact' is insufficient.

They also provide examples of contractor specification requirements, such as the following example for the procurement of paper with a recycled material content:

> Require suppliers to specify % of recycled and virgin fibre content, product source and manufacture with respect to responsibly managed forests, water use, labour, packaging and transportation. E.g. require evidence verifying legality and sustainability of paper pulp fibres via forestry custody certification (e.g. Forest Stewardship Council, Australian Forest Certification).

The South Australian DIT's *Sustainability Manual* (DIT 2021) suggests that similar conditions can be applied in transport infrastructure procurements in prequalification, specifications and evaluations. Specifically, it provides possible questions that can be given to suppliers to plan for sustainable material opportunities and risks, such as to specify the % of post-consumer recycled content in their products.

A.7 Tasmania

The Tasmanian Government's *Better Practice Guidelines* (Department of Treasury and Finance 2016) set out procurement principles and policies that apply to the government procurement framework in Tas and is also used for the procurement process for the DSG and other government bodies in Tas. Environmental considerations for products are included, however, as long as 'they represent value for money, are of appropriate quality and functionality, and there are no technical reasons for not doing so'. These considerations include the inclusions of recycled or recyclable goods with recycled composition or components to the product and reclaimed materials, for example, crushed concrete aggregate, recycled building materials and recycled compost and mulch.

A.8 Australian Captial Territory

The ACT's *Sustainable Procurement Policy* (ACT Government 2015) aims to use procurement to require social and environmental standards, encourage suppliers to adopt socially responsible and ethical practices and support innovation in the market and achieve value for money on a whole-of-life basis.

The policy states that 'waste should be looked at as a resource opportunity where products can be re-introduced into another product life cycle (known as "cradle to cradle" approach) at disposal stage'. Further, it lists desirable outcomes of sustainable procurement including:

- reduced demand of raw materials and natural resources (e.g. sustainable forestry and biodiversity)
- reduced waste and by-products (e.g. recycling and waste prevention).

The Appendix to the policy details sustainability impacts and issues to consider including the recycled content of goods (which reduces demand for virgin resources).

A.9 Northern Territory

The Northern Territory Government's *Procurement Governance Policy* (Northern Territory Government 2019) describes the Procurement Framework, which includes the Procurement Principles, Procurement Life-cycle approach, Procurement Governance Model and terminology that governs and guides procurement activities. The *Procurement Rules* (Northern Territory Government 2020) outline the mandatory requirements, exceptions, exemptions, and process options for all Northern Territory Government agencies and their personnel when undertaking procurement activities.

As outlined in these complementary documents, the Northern Territory Government commits to a principle of environmental protection in all procurement activities. This is defined by promoting the protection of the environment through harm minimisation and sustainable practices. The NT procurement documents do not mention the use of recycled materials or products, recycling, recyclability, waste reduction or the circular economy.

Appendix B Crushed Concrete and Crushed Brick

B.1 Specifications

VicRoads (2017) specifies that only fired brick may be used as an aggregate replacement and that non-fired brick or mud brick should not be used. Their strength properties may be assessed through the Los Angeles (LA) abrasion test, the wet to dry strength variation test, the wet/dry strength test, and/or the unconfined compressive strength (UCS) test (Austroads 2009b).

Table B.1: Specifications for the Use of Recycled Aggregates in Road and Rail Infrastructure (including Aggregates other than Concrete and Brick)

Specification/Standards	Agency/Institution	Application
Australia		
AS 2758.1-2014 *Aggregates and rock for engineering purposes*	Australian standards	
HB 155-2002 *Guide to the use of recycled concrete and masonry materials* (Sagoe-Crentsil 2002)	CSIRO	
EME2 *Model specification (AfPA 2018b)*	AfPA	Asphalt
Guide to pavement technology: Part 4E (Austroads 2009b)	Austroads	
ACT		
TCCS MITS 04 *Flexible pavements*		
NSW		
Specification for Supply of Recycled Material for Pavements, Earthworks, and Drainage (IPWEA 2010)	IPWEA	
TfNSW Specification D&C 3051 *Granular Pavement Base and Subbase Materials*	TfNSW	Base and subbase
NT		
Standard Specification for Roadworks v4.2	DIPL	
Standard Specification for Road Maintenance	DIPL	
Materials Testing Manual	DIPL	

Specification/Standards	Agency/Institution	Application
Qld		
MRTS05 *Unbound Pavements*	TMR	Unbound pavement materials
MRTS07B *In-situ Stabilised Pavements using Cementitious Blends*		Stabilised pavements
MRTS07C *In-situ Stabilised Pavements using Foamed Bitumen*		
MRTS08 *Plant-mixed Heavily Bound (Cemented) Pavements*		
MRTS09 *Plant-mixed Foamed Bitumen Stabilised Pavements*		
MRTS10 *Plant-mixed Lightly Bound Pavements*		
MRTS30 *Asphalt Pavements*		Asphalt
MTRS35 *Recycled Material Blends for Pavements*		
MRTS101 *Aggregates for Asphalt*		
SA		
RD-PV-S1-2020 *Supply of Pavement Materials*	DIT	
Environmental Instruction 21.6 ***Recycled Fill Materials for Transport Infrastructure*** (DPTI 2015)	DIT	
SA EPA (2013) ***Standard for the Production and Use of Waste Derived Fill***	EPA	
Tas		
Section 306 *Cementitious Treated Pavement Subbase*	DSG	Cementitious subbase
Section 812 *Production of Crushed Rock for Pavement Base and Subbase*	DSG	Base and subbase
Section 304 *Unbound Flexible Pavement Construction*	DSG	
Vic		
Section 407 *Dense Graded Asphalt*	DoT	Asphalt
Section 423 *Lean Mix Asphalt*		
Section 802 *Bituminous Cold and Warm Mixes*		
Section 703 *General Concrete Paving*		Footpaths
Section 801 *Material Sources for the Production of Crushed Rock and Aggregates*		
Section 812 *Production of Crushed Rock for Pavement Base and Subbase*		Base and subbase
Section 820 *Crushed Concrete for Pavement Subbase and Light Duty Base*		
Section 821 *Cementitious Treated Crushed Concrete for Pavement Subbase*		
Code of Practice RC 500.02 *Registration of Crushed Rock Mixes*		
Code of Practice RC 500.20 *Assignment of CBR and Percent Swell to Earthworks Fill and Pavement Materials*		
Section 175 Referenced Documents for Standard Specifications for Roadworks and Bridgeworks		
TN 107 *Use of Recycled Materials in Road Pavements*		
WA		
Specification for the Supply of Recycled Road Base (IPWEA & WALGA 2019)	Institute of Public Works Engineering Australasia/ Western Australia Incorporated and Western Australia Local Government Association	Base
Recycled Road Base and Recycled Drainage Rock (Waste Authoridy 2021)	Waste Authority	Base and drainage
Specification 501 *Pavements*	MRWA	

Table B.2: Strength parameters for recycled materials

Organisation	Parameters adopted by organisations for granular products			
Resource NSW	Wet strength 70 kN (min)	Dry strength 1.7 MPa (min)	Wet/dry variation 35 kN (max)	UCS 1.5 MPa (max)
MRWA	LA value 45 % (max)	Soaked CBR 50 (min)		
NZTA	Crushing resistance 130 kN (min)	Soaked CBR 80 (min)		
DTEI SA	Resilient modulus 300 MPa (min)	Deformation 10^{-8} %/ cycle (max)	LA value 30 % (max)	

Source: Adapted by Austroads (2009b).

Table B.3: Allowable limits for content of contaminants in recycled concrete; quantities in % maximum allowable content

	Resource NSW	MR WA	NZTA	DTEI SA
Supplementary materials (brick, crushed stone, tiles, masonry, glass)	3 – 30	5	3	20
Friable materials (plaster, clay lumps)	0.2	2	1	1
Foreign materials (rubber, plastic, paper, cloth, paint, wood, vegetable matter)	0.1	0.5	0.5 (includes bitumen)	0.5
Bituminous materials (asphalt, seals)	0.1	0	0	1 (bitumen content)
Asbestos	0	0	0	0

Source: Adapted by Austroads (2009b).

It is also recognised that recycled concrete may contain contaminants. The upper allowable content limit for those contaminants for Class 1A and Class 1B aggregate classification are listed in Table B.4.

Table B.4: Recommended content for contaminants and desired properties for reclaimed concrete aggregates

	Class 1A	Class 1B	Test method
Brick content (max [%])	0.5	30	
Stony material (max [%])	1	5	
Friable material (max [%])	0.1	0.1	
Particle shape (2:1 ratio [%])	35	35	AS 1141.14
Particle density (SSD min [t/m^3])	2.1	1.8	AS 1141.6
Bulk density (min [t/m^3])	1.2	1.0	AS 1141.4
Water absorption (max [%])	6	8	AS 1141.6
Aggregate crushing value (max [%])	30	30	AS 1141.21
Total impurity level (max [%])	1	2	
Loss on ignition (max [%])	5	5	
Lost substance on washing (max [%])	1	1	AS 1141.24
Soundness loss (max [%])	9	-	

Source: Adapted by Austroads (2009b).

Appendix C Crushed Glass

C.1 Specifications

Table C.1: Specifications and standards available per state and Australia-wide

Specification/Standard	Agency/Institution	Application
	Australia	
ATS 3050 *Supply of Recycled Crushed Glass* (Austroads 2022c)	Austroads	Granular material, including: • bedding, haunching, side fill and backfill of pipes and conduits • bedding and joint filling in block paving • drainage medium applications • embankment fill and earthworks applications • landscaping applications • partial aggregate replacement (mechanical stabilisation) for granular base and subbase material
		Partial aggregate replacement in asphalt
		Partial fine aggregate replacement in concrete for: • general works • concrete pavement applications
	ACT	
TCCS MITS 04 *Flexible Pavements*	TCCS	Granular base and subbase
	NSW	
TfNSW D&C R116 *Heavy Duty Dense Graded Asphalt*	TfNSW	Asphalt
TfNSW D&C R117 *Light Duty Dense Graded Asphalt*		
TfNSW D&C R121 *Stone Mastic Asphalt*		
TfNSW QA Specification R3051 *Granular Pavement Base and Subbase Materials*		Granular base and subbase
TfNSW QA Specification 3201 *Concrete Supply for Pavement Maintenance*		Slab replacement work for concrete pavements
Engineering Construction Guidelines (Lake Macquarie City Council 2018)	Lake Macquarie City Council	Asphaltic concrete (Roadways)
		Plain and reinforced concrete base
		Lean mix concrete subbase
Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage (IPWEA 2010)	Institute of Public Works Engineering Australia	Select fill (Class S)
		Bedding material (Class B)
		Drainage medium (Class D75 & D20)
		Drainage medium (Class D10)
		Road base & subbase (Class R1 & R2)
	NT	
Standard Specification for Roadworks v4.2	DIPL	Bedding for drainage works
	Qld	

Specification/Standard	Agency/Institution	Application
MRTS30 *Asphalt Pavements*	TMR	Dense-graded asphalt layers (other than surfacings) and dense-graded asphalt surfacings
TN193 *Use of Recycled Materials in Road Construction*		Unbound pavements (subtypes 2.3, 2.4 and 2.5)
MRTS05 *Unbound Pavements*		
MRTS04 *General Earthworks*		Bedding and backfill material
MTRS36 *Recycled Glass Aggregate*		Unbound pavements and asphalt
SA		
RD-LM-S1 *Materials for Pavement Marking*	DIT	Anti-skid mixtures for pavement markings
Tas & Vic		
Section 407 *Dense Graded Asphalt*	DoT	Intermediate and base course layers in dense-graded asphalt
TN 107 *Use of Recycled Materials for Road Pavements*		Granular base and subbase
RC 500.02 *Registration of crushed rock mixes* (Vicroads 2017)		
Section 702 *Subsurface Drainage*		Subsurface drainage – granular filter material
Section 204 *Earthworks*		Type A, B and C fill
MTM L1-CHE-SPE-313 *Recycled Glass Sand Specification*	Metro Trains Melbourne	Replacement for quarried sand as bedding and embedment materials
WA		
Specification 302 *Earthworks*	MRWA	Imported fill for embankment construction

Table C.2 presents a summary of the allowable limits for RCG in various road and rail applications as specified by standards and specifications across Australian states.

Table C.2: Allowable limits for RCG in road and rail infrastructure

State/Road agency	Application	Maximum allowable limit (% of mass)
ACT/TCCS	Granular base and subbase	10
NSW/TfNSW	Granular base and subbase	10
	Asphalt (wearing coarse)	2.5
	Asphalt (other than wearing coarse)	10
	Slab replacement work for concrete pavements	15
NSW/Lake Macquarie City Council	Asphaltic concrete (Roadways)	30
	Lean mix concrete subbase	30
	Plain and reinforced concrete base	30
NSW/IPWEA	Select fill (Class S)	10
	Bedding material (Class B)	50
	Drainage medium (Class D75 & D20)	50
	Drainage medium (Class D10)	100
	Road Base and subbase (Class R1 & R2)	10
NT/DIPL	Bedding for drainage works	100
Qld/TMR	Dense graded asphalt layers (other than surfacings)	10
	Dense graded asphalt surfacings	2.5
	Unbound pavements (subtypes 2.3, 2.4 and 2.5)	20
	Bedding and backfill material	100
SA	Anti-skid mixtures for pavement markings	30
Tas	Aligned with DoT	
Vic/DoT	Granular base	5–10
	Granular subbase	15–50
	Subsurface drainage – granular filter material	100
	Intermediate and base course layers in dense-graded asphalt	100 (of total natural sand)
	Dense-graded asphalt (wearing coarse)	5
WA/MRWA	Imported fill for embankment construction	20

In NSW, up to 2.5 wt.% granulated glass aggregate may be used in asphalt wearing course, while for asphalt layers (other than wearing course) as well as unbound, modified and bound base courses, up to 10 wt.% may be used (TfNSW D&C R116 2021, TfNSW D&C R117 2020, TfNSW QA Specification R118 2020 and TfNSW D&C R121 2020).

The TMR (TMR TN193 2020) specifies that up to 20% RCG may be used in unbound pavements and up to 10% in DGA layers excluding surfacings where up to 2.5% may be used. Specifications for the use of recycled aggregates are listed in Table C.1.

The only use of RCG in SA is in a blend of 70% glass beads and 30% crushed glass in anti-skid mixtures for pavement markings allowed by RD-LM-S1 Materials for Pavement Marking specification though DITSA (2019).

DoT Victoria allows the use of up to 100% RCG as filter media materials in subsurface drainage applications (VicRoads Section 702 2019). DoT also allows up to 10% RCG to be incorporated in in granular base and up to 50% RCG in granular subbase (VicRoads TN 107 2019). Recently, DoT has allowed the use of RCG up to 5% (by mass) in the wearing course of dense-graded asphalt (Types L and N) and as a natural sand replacement in intermediate and base course layers in dense-graded asphalt (Type SI, SS and SF) (VicRoads Section 407 2021). The use of RCG as a replacement for quarried sand for bedding and embedment materials has been allowed by Metro Trains Melbourne (MTM), although no specific limit is stated (MTM L1-CHE-SPE-313 2018).

Further specifications have been outlined by MRWA (2021b) (Specification 302 *Earthworks (302.10.1))*, where the use of RCG is permitted in fill material up to 20%.

Appendix D Reclaimed Asphalt Pavement

D.1 Specifications

RAP can be received as slab asphalt, asphalt planings, and/or granular asphalt planings. The latter is stockpiled as is and used without further processing, while the first two are crushed and screened and so occasionally meet specifications to that of virgin crushed rock. It is specified that asphalt planings that are milled and directly incorporated into unsealed wearing surfaces should approximate the grading of Class 2 granular material containing enough fine materials (Austroads 2009b). The Australian Asphalt Pavement Association (2018b) specifies than up to 15% RAP may be added in EME2 mix designs as long as it is free from other contaminants and 100% passing the 14 mm sieve. In hot asphalt mixing designs, when more than 20% RAP is incorporated, the grade of bitumen should be selected to compensate for the increased stiffness of the aged binder in the RAP. Additionally, such activities should preferably take place in mixing plants with the capacity to process the materials with optimised heat transfer and reduced emissions (Austroads 2009b).

It is explained that up to 20% RAP may be used in dense graded surfacing courses, up to 40% in DGA in other applications, and up to 15% in high modulus asphalt while its use in open graded and stone mastic is not permitted (TMR MRTS30 2022). TMR allows for up to 15% RAP to be incorporated into asphalt mixes, but they recommend that for the incorporation of greater amounts, the requirements as described in Technical Note 183 (TMR 2019a) should be consulted. Additionally, if asphalt includes other materials, such as polymers or crumb rubber, RAP cannot be re-used (TMR 2020). In cases where more than 15% of RAP is included in the asphalt mix, the binder content needs to be 4.1 ± 0.5 wt.% of the RAP (TMR PSTS112 2019).

In WA, a maximum of 10% of RAP is allowed in road base applications for Class 1 and up to 15% for Class 2 materials (IPWEA & WALGA 2019).

Table D.1: Specifications for the use of recycled aggregates in road and rail infrastructure (including aggregates other than concrete and brick)

Specification/Standards	Agency/ Institution	Application
Australia		
EME2 Model Specification (AfPA 2018b)	AfPA	Asphalt
Guide to Pavement Technology: Part 4E (Austroads 2009b)	Austroads	
ACT		
TCCS MITS 04 *Flexible Pavements*	TCCS	
NSW		
Specification for Supply of Recycled Material for Pavements, Earthworks, and Drainage (IPWEA 2010)		
TfNSW Specification D&C 3051 *Granular Pavement Base and Subbase Materials*	TfNSW	Base and subbase
NT		
Standard Specification for Roadworks v4.2	DIPL	
Standard Specification for Road Maintenance	DIPL	
Materials Testing Manual	DIPL	

Specification/Standards	Agency/ Institution	Application
Qld		
MRTS05 *Unbound Pavements*	TMR	Unbound pavement materials
MRTS07B *In-situ Stabilised Pavements using Cementitious Blends*		Stabilised pavements
MRTS07C *In-situ Stabilised Pavements using Foamed Bitumen*		
MRTS09 *Plant-mixed Foamed Bitumen Stabilised Pavements*		
MRTS10 *Plant-mixed Lightly Bound Pavements*		
MRTS30 *Asphalt Pavements*		Asphalt
MRTS32 *High Modulus Asphalt*		
MRTS101 *Aggregates for Asphalt*		
MTRS102 *Reclaimed Asphalt Pavement Material*		
SA		
RD-PV-S1-2020 *Supply of Pavement Materials*	DIT	
Environmental Instruction 21.6: Recycled Fill Materials for Transport Infrastructure (DPTI 2015)	DIT	
SA EPA *Standard for the Production and Use of Waste Derived Fil* (EPA SA 2013)l	EPA	
Tas		
Section 812 *Production of Crushed Rock for Pavement Base and Subbase*		Base and subbase
Vic		
Section 407 *Dense Graded Asphalt*	DoT	
Section 405 *Regulation Gap Graded Asphalt*		
Section 423 *Lean Mix Asphalt*		
Section 802 *Bituminous Cold and Warm Mixes*		
Section 801 *Material Sources for the Production of Crushed Rock and Aggregates*		
Section 812 *Production of Crushed Rock for Pavement Base and Subbase*		Base and subbase
Section 821 *Cementitious Treated Crushed Concrete for Pavement Subbase*		
Code of Practice RC 500.02 *Registration of Crushed Rock Mixes*		
Code of Practice RC 500.20 *Assignment of CBR and Percent Swell to Earthworks Fill and Pavement Materials*		
Code of Practice RC 500.01 *Registration of Bituminous Mix Designs*		Class 1-4 crushed rock (as supplementary material)
TN 107 *Use of Recycled Materials in Road Pavements*		
WA		
Specification for the Supply of Recycled Road Base (IPWEA & WALGA 2019)	Institute of Public Works Engineering Australasia/ Western Australia Incorporated and Western Australia Local Government Association	Base
Recycled Road Base and Recycled Drainage Rock (Waste Authority 2021)	Waste Authority	Base and drainage

Table D.2: Allowable contents of RAP in asphalt layers for each state and territory in Australia

RAP content limit		
NSW		
Surface	Up to 20% in wearing course and up to 40% for other than wearing course in heavy duty dense graded asphalt	TfNSW QA R116
	Up to 25% by mass in wearing course and up to 40% by mass for other than wearing course in light duty dense graded asphalt	TfNSW QA R117
Mix type	RAP is not allowed in CRA, SMA or OGA mixes. For PMB mixes, up to 10% RAP could be used	
NT		
Surface	In dense graded asphalts, up to 10% by mass in the wearing course, and up to 15% by mass in base layers	*Standard Specification for Roadworks v4.2*
Qld		
Surface	In dense graded asphalt, up to 20% by mas RAP is allowed in surfacing course. Maximum allowable limit is 15% if the dense graded asphalt contains PMB and multigrade bitumen In dense graded asphalts, up to 40% (by mass) RAP is allowed in base, intermediate and corrector courses	MRTS30
	The maximum allowable RAP in EME2 is 15% by mass	MRTS32
Mix type	RAP is not allowed in SMA and OGA mixes	
SA		
Surface	RAP is allowed to be used for wearing courses up to 10% (by mass) in coarse dense mix asphalt and up to 20% in fine dense mix asphalt Up to 50% (by mass) RAP is allowed in asphalt pavement layers (other than wearing course). In asphalt mixes containing PMB, the maximum allowable is 20%	RD-BP-S2
Mix type	RAP is not allowed in SMA and OGA mixes	RD-BP-S2
Tas		
Surface	Aligned with Vic	
Mix type		
Vic*		
Surface	Up to 40% (by mass) RAP content is allowed for dense graded asphalt depending on traffic volume. (Maximum 25% for RAP Level 1 and maximum 40% for RAP Level 2)	Section 407 Code of Practice RC 500.01
	Up to 10% (by mass) RAP in Regulation Gap Graded Asphalt	Section 405
Mix type	RAP is not allowed in SMA, OGA and high binder crumb rubber asphalt (HBCRA) mixes and mixes containing PMBs or EME2 binders	
WA		
Surface	The use of RAP for surface layers is not allowed	Specification 504
	The use up to 10% RAP in asphalt intermediate course layers is allowed	Specification 510
Mix type	RAP is not allowed in SMA, OGA, or PMB mixes	

* In further detail available in Table D.4.

Table D.3: Allowable contents of RAP in granular layers for each state and territory in Australia

RAP content limit		
NSW		
Base and subbase	Up to 40% by mass in unbound, modified and bound base and subbase	TfNSW QA 3051
NT		
Base and subbase	Not specified	
Qld		

RAP content limit		
Base and subbase	Up to 20% RAP is allowed in base and subbase of unbound pavements. In lower subbase and subgrade (Subtype 2.5 unbound pavement), up to 45% by mass is allowed	MRTS05
SA		
Base and subbase	Up to 20% (by mass) RAP is allowed in granular pavement materials	RD-PV-S1
Tas		
Base	Aligned with Vic	
Vic*		
Base and subbase	Up to 15% for unbound base (Class 3), and up to 40% for unbound and bound subbase (Class 4)	Code of Practice RC 500.02
	Up to 20% in lower trafficked base and up to 50% in lower trafficked subbase	Section 813
WA		
Base and subbase	The use up to 10% (by volume) RAP in stabilised base and subbase layers is allowed	Specification 515
	Up to 15% (by mass of the material larger than 4.75mm) of pavement materials can be RAP	Specification 501

* In further detail available in Table D.4.

The Vic specifications in Table D.1 above allow for the use of RAP in crushed rock and asphalt at the percentages shown in Table D.4. This table shows the level of complexity of allowable RAP levels by asphalt type and granular material class for one jurisdiction. Different states and territories have different naming conventions for each asphalt type and granular materials class. The information shown in Table D.4 can be used as an indicator of allowable levels for different pavement materials and functions.

Table D.4: Permitted RAP content in asphalt and crushed rock in Vic

Application	RAP (% by mass)
L	Level 1: 25 max
N, Light Traffic Crumb Rubber Asphalt	Level 1: 10 max (using C320 binder), 25 max (using C170 binder)
H	Level 1: 15 max Level 2: 16 to 20
SI, SS	Level 1: 15 max Level 2: 16 to 30
V	Level 1: 10 max Level 2: 11 to 15
SF	Level 1: 15 max Level 2: 16 to 40
Regulation Gap Graded	10 max
Class 1 Crushed Rock (as supplementary material)	5 max
Class 2 Crushed Rock (as supplementary material)	10 max
Class 3 Crushed Rock (as supplementary material)	15 max
Class 4 Crushed Rock (as supplementary material)	50 max

Sources: Code of Practice RC 500.01 *Registration of Bituminous Mix Designs*, Section 405 *Regulation Gap Graded Asphalt*, Section 407 *Dense Graded Asphalt*, Section 422 *Light Traffic Crumb Rubber Asphalt*, Technical Note 107 *Use of Recycled Materials in Road Pavements*.

Appendix E Crumb Rubber

E.1 Specifications

Table E.1: Australian Specifications Documents

Specification/ Standard	Agency/ Institution
Technical Specification ATS 3110 *Supply of Polymer Modified Binders* (Austroads 2020a)	Austroads
Crumb Rubber Modified Open Graded and Gap Graded Asphalt (AfPA 2018a)	Australian Flexible Pavement Association (AfPA)
QA specification R118 *Crumb Rubber Asphalt*	Transport for New South Wales (TfNSW)
QA specification 3252 *Polymer Modified Binder for Pavements*	
D&C Specification 3256 *Crumb Rubber*	
MRTS11 *Sprayed Bituminous Treatments (Excluding Emulsion)*	Queensland Department of Transport and Main Roads (TMR)
MRTS18 *Polymer Modified Binder (Including Crumb Rubber)*	
PSTS112 *Crumb Rubber Modified Asphalt*	
Master Specification RD-BP-S1 *Supply of Bituminous Materials*	Department for Infrastructure and Transport (DIT)
Section 408 *Sprayed Bituminous Surfacing*	Department of Transport Victoria (DoT Vic)
Section 421 *High Binder Crumb Rubber Asphalt*	
Section 422 *Light Traffic Crumb Rubber Asphalt*	
Specification 503 *Bituminous Surfacing*	Main Roads Western Australia (MRWA)
Specification 511 *Materials for Bituminous Treatments*	
Specification 516 *Crumb Rubber Open Graded Asphalt*	

Source: Adapted from Austroads (2021b).

In Victoria, Section 422 allows for the inclusion of crumb rubber through the wet mixing process with the provision that it complies with AGPT/T190 (Austroads 2019d) excluding the use of devulcanised or uncured rubber. Additionally, recognising the problem that the incorporation of crumb rubber in roads is trying to solve, it specifies that only end-of-life truck tyres generated in Australia and processed by a Tyre Stewardship Australia-accredited supplier are to be used (VicRoads Section 422 2019). Section 421 further specifies that when crumb rubber is added in asphalt with the purpose of improving elastic and flexural recovery properties and/or delay reflective cracking, RAP may not be used (VicRoads Section 421 2021).

In NSW, Transport for NSW (QA Specification 3252 2020) recommends that only unmodified bitumen is to be used to produce crumb rubber modified binders with 15% and 20% nominal crumb rubber concentration for S15RF and S20RF, respectively. When the wet method is used, it is recommended that the mixing time is increased when compared to unmodified asphalt mixes. The minimum amount of crumb rubber to be added in asphalt via the dry mixing process is 2 wt.% of the total mix (QA Specification R118 2020).

In WA, 5 wt.% of rubber granules may be added in C170 bitumen when used in a geotextile reinforced seal, as long as the requirements of Specification 511 are met (Specification 503 2018). In Specification 511, the supply and use of asphalt and sprayed bituminous surfacing materials is described (Specification 511 2021). Specific care needs to be taken for the binder mix to be uniform and remain so up to the point of application (Specification 503 2018). In asphalt, a minimum of 18 wt.% of the binder may comprise crumb rubber with the rest being bitumen of Class 170 and the mix should be designed to meet requirements listed in Specification 516, where a warm mix additive is excluded (Specification 516 2020).

TMR and allowed for up to 18 wt.% crumb rubber combined with C170 bitumen in sprayed seals while the DoT in Vic allows for up to 9 wt.% in high stress seals (HSS). MRWA also allows for 5 wt.% to be used with C170 for geotextile reinforced seals (GRS). In SA, trials performed contained 15 wt.% crumb rubber incorporated in bitumen through the wet process (Austroads 2021b). With the current rates of incorporation of crumb rubber in bitumen surfacing, only 10,000 tonnes of the 450,000 tonnes of available in Australia are being used (Waste Management Review 2019).

Testing conducted by ARRB following PSTS112 specifications, showed that up to 22 wt.% of crumb rubber may be used in the wet process. However, it was found that not all laboratory trials were repeatable when tests were replicated by other laboratories and so it was concluded that further research is required (Austroads 2021b).

The allowable limits for use of crumb rubber in bitumen as a modifier are defined by the performance of the derived binder. Some of these specific requirements are summarised in Table E.2.

Table E.2: Specified requirements for crumb rubber binders

Property	Test method	Requirements					
		PSTS112, 2017		AfPA	PSTS112, 2019	MRWA, 2018	MRWA, 2020
		CR1	CR2				
Viscosity at 175°C [Pa·s]	ASTM D2196	Report	Report	–	–	–	–
Viscosity at 175°C [Pa·s]	AGPT/T111	–	–	–	–	–	Report
Viscosity at 175°C [Pa·s]	ASTM D7741/ D7741M	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0
Torsional recovery at 25°C [%]	AGPT/T122 / ATM 122	Report	Report	Report	Report	Report	Report
Resilience at 25°C [%]	ASTM D5329	25 min	20 min	20 min	20 min	20 min	20 min
Softening point [°C]	AGPT/T131	57 min	55 min	55 min	55 min	55 min	55 min
Consistency 6% at 60°C [Pa·s]	AGPT/T121	–	–	–	Report	–	Report
Penetration at 4°C, 200 g, 60 s (0.1mm)	AS 2341.12	10 min	15 min	12 min	15 min	15 min	15 min
Penetration at 25°C (0.1mm)	AS 2341.12	–	–	Report	–	Report	–
Compressive limit at 70°C, 2kg [mm]	AGPT/T132	–	–	–	–	–	0.2 min
Flash point [°C]	AGPT/T112	250 min	250 min	250 min	250 min	250 min	–
Loss on heating [% mass]	AGPT/T103	0.6 max	0.6 max	0.6 max	0.6 max	0.6 max	0.6 max

Appendix F Ground Granulated Blast Furnace Slag

Table F.1: Specified limits for Ground Granulated Blast Furnace Slag (GGBFS) by road agency

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
NSW	TfNSW	Concrete work for bridges Shotcrete work Shotcrete work without steel fibres Lean-mix concrete subbase Concrete for general works No fines concrete subbase	SCM in binary blended cement[1]	70	TfNSW D&C 3211
			SCM in ternary blended cement[2]	50	
		Concrete pavement base	SCM in binary and ternary blended cement	65	
		Stabilisation of earthworks Construction of unbound and modified pavement course Construction of plant mixed heavily bound pavement course Insitu pavement stabilisation using slow setting binders Roller compacted concrete subbase Roller compacted concrete	SCM in binary and ternary blended cement	Not specified	
		Heavy duty dense graded asphalt Light duty dense graded asphalt Crumb rubber asphalt Open graded asphalt Stone mastic asphalt Thin open graded asphalt surfacing High modulus asphalt (EME2)	Binder	Not specified	
Qld	TMR	Insitu stabilisation	Binder (stabilising agent)	Not specified	MRTS07B
		Plant-mixed heavily bound (cemented) pavements			MRTS08
		Plant-mixed lightly bound pavements			MRTS10
		Lean mix concrete sub-base for pavements	SCM in blended cement	Not specified	MRTS39
		Concrete pavement base		65	MRTS40
		Concrete road and bridge structures	SCM in binary blended cement	40	MRTS70
			SCM in ternary blended cement	25	
WA	MRWA	Stabilisation of subgrade	SCM in blended cement	Not specified	Specification 302
		Low strength infill for the backfilling of redundant or abandoned pipes, culverts and other buried structures		Not specified	Specification 410
		Insitu stabilisation of granular pavement layers		Not specified	Specification 515

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
		High performance concrete for structures		65	Specification 820
		Concrete for general non-structural works		Not specified	Specification 901
Vic	DoT	Cementitious treated pavement subbase	SCM in blended cement	50	Section 306, Section 815
			Cementitious binder in a slag-lime blend	90	Section 815
		In situ stabilisation of pavements	SCM in blended cement	50	Section 307
			Cementitious binder in a slag-lime blend	90	
		Dense graded asphalt	Added filler	Not specified	Section 407
		Structural concrete	SCM in blended cement	40	Section 610
		Concrete for paving (including geopolymer concrete)		Not specified	Section 703
		Geopolymer binder		100	Section 703
		Concrete for drainage pits and covers (including geopolymer concrete)		Not specified	Section 705
Tas	DSG	Aligned with DoT			
SA	DIT	Controlled low strength material	SCM	Not specified	RD-EW-C4
		Stabilisation	SCM in binder	80[3]	RD-PV-S1
		Stabilised pavement	SCM in blended cement	Not specified	RD-PV-S2
NT	DIPL	Stabilisation Miscellaneous concrete works Drainage work structures (e.g. culverts)	SCM in blended cement	Not specified	*Standard Specification for Roadworks v4.2*
ACT	TCCS	Subgrade stabilisation	Binder (stabilising agent)	Not specified	MITS 02C
	Austroads	Concrete pavements	SCM in blended cement	Not specified	AGPT04C-17
		Geopolymer concrete	Binder	Not specified	ATS-5330-20
		Stabilisation (pavement and earthworks)	Binder (in cement-GGBFS blends)	60	AGPT4L-09
			Binder (in lime- GGBFS blends)	70	
			Binder (in lime-fly ash-GGBFS blends)	50	
			Binder (in cement-fly ash-GGBFS blends)	40	

1. Blended cements containing cement and one SCM.
2. Blended cements containing cement and two SCMs.
3. The total binder content is 5%, consisting of 4% GGBFS and 1% lime.

Appendix G Fly Ash

Table G.1: Specified limits for fly ash by different road agencies

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
NSW	TfNSW	Concrete work for bridges Shotcrete work Shotcrete work without steel fibres Concrete for general works No fines concrete subbase	SCM in binary blended cement(1)	40	TfNSW D&C 3211
			SCM in ternary blended cement(2)	30	
		Lean-mix concrete subbase	SCM in binary and ternary blended cement	75	
		Concrete pavement base	SCM in binary and ternary blended cement	40	
		Stabilisation of earthworks Construction of unbound and modified pavement course Construction of plant mixed heavily bound pavement course Insitu pavement stabilisation using slow setting binders Roller compacted concrete subbase Roller compacted concrete	Binder	Not specified	
		Heavy duty dense graded asphalt Light duty dense graded asphalt Crumb rubber asphalt Open graded asphalt Stone mastic asphalt Thin open graded asphalt surfacing High Modulus Asphalt (EME2)	Added filler	Not specified	
Qld	TMR	Insitu stabilisation	Binder (stabilising agent)	Not specified	MRTS07B
		Plant-mixed heavily bound (cemented) pavements			MRTS08
		Plant-mixed foamed bitumen stabilised pavements			MRTS09
		Plant-mixed lightly bound pavements			MRTS10
		Lean mix concrete sub-base for pavements	SCM in blended cement	Not specified(3)	MRTS39
		Concrete pavement base		40	MRTS40
		Concrete road and bridge structures	SCM in binary blended cement	40	MRTS70
			SCM in ternary blended cement	32	
		Asphalt	Added filler	Not specified	MRTS103

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
WA	MRWA	Stabilisation of subgrade	SCM in blended cement	Not specified	Specification 302
		Concrete for culvert		25	Specification 404
		Low strength infill for the backfilling of redundant or abandoned pipes, culverts and other buried structures		Not specified	Specification 410
		Insitu stabilisation of granular pavement layers		Not specified	Specification 515
		High performance concrete for structures		25	Specification 820
		Microsurfacing	Mineral filler	Not specified	Specification 507
Vic	DoT	Cementitious treated pavement subbase	SCM in blended cement	30	Section 306, Section 815
		In situ stabilisation of pavements		30	Section 307
		Dense graded asphalt	Added filler	Not specified	Section 407
		Concrete pavement courses	Fine aggregate	Not specified	Section 520
			SCM in blended cement	20	
		Structural concrete	SCM in blended cement	25	Section 610
		Concrete for paving (including geopolymer concrete)		Not specified	Section 703
		Geopolymer binder		100	Section 703
		Concrete for drainage pits and covers (including geopolymer concrete)		Not specified	Section 705
Tas	DSG	Aligned with DoT			
SA	DIT	Controlled low strength material	SCM	Not specified	RD-EW-C4
		Stabilisation	SCM in binder	67[4]	RD-PV-S1
		Stabilised pavement	SCM in blended cement	Not specified	RD-PV-S2
		Geopolymer concrete (for structures)	Binder	Not specified	ST-SC-S2
NT	DIPL	Stabilisation Miscellaneous concrete works Drainage work structures (e.g. culverts)	SCM in blended cement	Not specified	*Standard Specification for Roadworks v4.2*
ACT[5]	TCCS	Subgrade stabilisation	Binder (stabilising agent)	Not specified	MITS 02C
		Base and subbase	Filler and/or binder	Not specified	MITS 04
		Grout for concrete works	Grout material	Not specified	MITS 10

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
	Austroads	Lean-mix concrete subbase	SCM in binder	60(6)	AGPT04C-17
		Base concrete		20(7)	
		Geopolymer concrete	Binder	Not specified	ATS-5330-20
		Microsurfacing	Mineral filler	Not specified	ATS 3450
		Asphalt		Not specified	AGPT04B-14
		Stabilisation (pavement and earthworks)	Binder SCM	Not specified	AGPT04D-19
			Binder (in cement-FA blends)	50	AGPT4L-09
			Binder (in lime-FA blends)	75	
			Binder (in lime-slag-FA blends)	50	
			Binder (in cement-slag-FA blends)	40	

1. Blended cements containing cement and one SCM.
2. Blended cements containing cement and two SCMs.
3. Minimum 40% by mass of total cementitious material.
4. The total binder content is 3% consisting of 2% fly ash and 1% lime.
5. ACT has the Municipal Infrastructure Technical Specifications (MITS) in place. ACT follows the TfNSW specifications for its trunk road infrastructure under Trunk Road Infrastructure Technical Specifications (TRITS).
6. The total binder content is 10%, consisting of 6% fly ash and 4% cement.
7. The total binder content is 15%, consisting of 3% fly ash and 12% cement.

Appendix H Recycled Ballast

H.1 Specifications

Table H.1: Specifications for ballast in road and rail infrastructure

Agency	Specification
NSW	
Transport for New South Wales (TfNSW)	T HR TR 00192 ST *Ballast*
SA	
Department for Infrastructure and Transport (DIT)	*Environmental Instructure 21.6 Recycled Fill Materials for Transport Infrastructure*
Vic	
Metro Trains Melbourne (MTM)	L1-CHE-SPE-064 *Technical Specification for Ballast Supply*

In Vic, Metro Trains Melbourne has recently introduced changes to the ballast recycling requirements. Clause 4.4.5. *Recycling of Ballast Material* outlines the following processes for recycling of ballast material:

a. Recycled ballast material shall be tested for contamination. The determination of its reusability shall be dependent on the assessment and categorisation of contamination levels as prescribed in EPA Environment Protection Regulations.
b. Contaminated ballast material may require cleaning in order to ensure it is suitable for reuse and recycling and to ensure compliance with EPA Environment Protection Regulations and AS 4482.1.
c. The use of recycled ballast material is permitted if one of the following conditions is met:
   - Ballast material meets the Manufacture Requirements of Section 4.2 and the Sampling and Testing Requirements of Section 4.3.
   - The ballast material is only to be used below the depth specified for free draining ballast (i.e. to be used as part of earthworks / formation, drainage blanket, etc.) and the ballast material complies with MTM Earthworks and Formation Standard (L1-CHE-STD-029 2020) and MTM Earthworks and Formation Specification (L1-CHE-SPE-178 2020).
   - Approval is granted by the Chief Engineer following review of non-compliances to this Specification, with consideration for the proposed application in track and the Whole of Life Cost implications.

Note: Recycled ballast material that does not meet the requirements of sections 4.2 and section 4.3 may be suitable for low-risk applications like sidings or for completing 'top up' shoulder ballasting during maintenance. Whole of life cycle cost implications shall consider the ballast fouling index with respect to the remaining expected asset life of the application (low fouling index = longer life application).

The fouling index shall be assessed in accordance with the following method:

Fouling Index = % Passing 13.2 mm Sieve + % Passing 0.075 mm Sieve.

TfNSW outlines the following requirements for recycled ballast, in Clause. 10.2:

Recycled ballast shall be tested for contamination. The determination of its reusability shall be dependent on the level of contamination as prescribed in the relevant environmental legislation.

Contaminated ballast may require cleaning and remediation in order to meet the contamination threshold levels that make it suitable for reuse and recycling, and to ensure compliance with Section 6 of this standard and AS 4482.1 Guide to investigation and sampling of sites with potentially contaminated soil, Part 1: Non-volatile and semi-volatile compounds.

The use of recycled ballast is permitted if, as a minimum, one of the following conditions is met:

- *the reuse is approved by the Lead Track Engineer, ASA and the ballast is cleaned to remove fines and contaminants*
- *ballast material meets the testing requirements of Section 9.1 to Section 9.9*
- *the ballast is only to be used below the depth specified for free draining ballast*

Department for Infrastructure and Transport outlines the following requirements for ballast reuse:

Re-use within the same project site:

Provided that a suitably qualified contamination consultant has verified that re-use is in accordance with the EPAs Guidelines for Environmental management of on-site Remediation, ballast may be re-used within the same project site without the need for auditor involvement. Note that if the ballast exceeds NEPM HIL-F criteria, remediation may be required.

Re-use on other project sites:

Ballast is often sought as a waste derived fill in road construction products, for its compressive strength properties. However, reuse within DIT projects will depend on the classification of the material:

- B*allast material up to Waste Fill classification may be re-used as WDF within DIT road and rail corridors, without limitations on its placement within the corridor.*
- *Material exceeding Waste Fill classification but not exceeding Intermediate Waste classification may (subject to Auditor and EPA approval) be transferred off-site and used as WDF within DIT road and rail corridors, with some restrictions on its placement within the corridor. Suitable locations for WDF up to Intermediate Waste classification are described in Section 10.3.2.*

This EI does not cover the re-use of this material outside of DIT road and rail corridors. In these circumstances, the requirements in the WDF Standard should be adhered to.

Appendix I Recycled Plastics

I.1 Opportunities for Recycled Content in Road and Rail Infrastructure

Efforts are already being made in Australia to repurpose recycled plastics in infrastructure. In asphalt, the bituminous binder used can be modified by the addition of polymer. These are specially developed polymers, such as styrene-butadiene-styrene (SBS). However, TMR allows for the use of alternative materials as long as the binder complies with MTRS17. This creates a unique opportunity for recycled plastics that may provide similar advantages as those recognised through the use of specialty polymers. The evaluation of the use of recycled plastics in bitumen and asphalt is already underway, but there is yet a clear need for specific guidelines before they get confidently adopted by the industry (Austroads 2021c). Several councils throughout Australia are investigating the incorporation of recycled plastics in asphalt through field trials with the participation of various international and local companies, such as Fulton Hogan, Downer, Boral, and Alex Fraser (Austroads 2019e).

In asphalt, plastics can be incorporated as an additive in bitumen (wet method), as a partial replacement to fine aggregates (dry method), or in a hybrid process where lower melting point plastics are added in an asphalt plant with the aggregates, but with a view they will melt and combine with the bituminous binder. During the wet method, bitumen is typically processed at temperatures around 180 °C and so when the addition of plastics is being considered, it needs to be ensured that their melt temperature is compatible. It has been previously stated that polymers like PET have too high melt temperatures, 260 °C to be incorporated through the wet method and so might be better suited as aggregate replacement (White & Reid 2019).

HDPE may also find applications in drainage and culvert pipes in the rail industry. Other than the environmental benefits associated with absorbing waste HDPE in such applications, preliminary studies indicate no performance drawbacks in their use (Macken et al. 2021).

Recycled plastics can be used in the manufacturing of geosynthetics. Geosynthetics are products, mainly made of polymers, that are used in civil engineering applications. The main functions of geosynthetics are filtration (in rail track formation for instance), separation (of pavement layers for instance), reinforcement (of soil/embankment for instance), drainage and protection (through cushioning for loads applied to the lower layers). Geotextiles, geogrids, geonets and geocomposites are various types of geosynthetics, each of which is used for one or more of the abovementioned functions. Geosynthetics need to have specific requirements, such as strength and UV resistance, and as such the quality of recycled plastic to be used for the manufacturing is important (Austroads 2009c). Currently, recycled PET plastic is being used for the production of geotextiles, geogrids and geonets. Recycled HDPE plastics are being used in the production of geocomposites for drainage too, in a less extent compared to PET (though personal communications with geosynthetic suppliers between 24 and 26 November 2021).

I.2 Noise wall specifications

ARRB has been helping MRPV to develop a performance-based specification for plastic noise walls. This has been designed to facilitate the use of recycled plastics in these structures. MRPV has been utilising noise walls that incorporate up to 75% recycled plastics in their construction of the Mordialloc bypass. It is hoped that the developed specification will encourage further use of recycled plastics in noise wall structures in future construction projects.

The design of noise wall should follow specific standards as summarised in Table I.1.

Table I.1: Noise wall standards

Standard	Title
Australia	
AS 5100	*Bridge Design: Part 1: Scope and General Principles*
AS/NZS ISO 717.1	*Acoustics: Rating of Sound Insulation in Buildings and of Building Elements: Airborne Sound Insulation*
AS 1191	*Acoustics: Method for Laboratory Measurement of Airborne Sound Insulation of Building Elements*
ISO 10140-2	*Acoustics: Laboratory Measurement of Sound Insulation of Building Elements: Part 2: Measurement of Airborne Sound Insulation*
Vic	
Section 765	*Noise Attenuation Walls*
Section 685	*Anti-graffiti Protection and Graffiti Removal*
Section 204	*Earthworks*

Source: Summarised from (VicRoads 2018).

I.3 Comparative Performance

Table I.2 Comparative performance

Recycled plastic	Method	Additive content (%)	Penetration 25 °C (d.mm)	Softening point (°C)	Elastic recovery (%)	Force ductility (J/cm²)	Reference
PE	Wet	2	18	63	7	–	Angelone et al. (2016)
	Wet	3	17	68	6	–	
MR 6*	Wet	6	90	51	–	0.69	White and Reid (2019)
MR 10*	Wet	6	94	47	–	2.35	

* MR6 and MR10 are UK-specifically developed plastic pellets comprised of recycled plastic with proprietary composition.

White and Reid (2019) found an increase in deformation resistance when MR 6 and MR 10 plastics were added to the bitumen mixture and notably an increase in crack resistance, where in the case of MR 10 modified binders was comparable to SBS modified binders. MR 10 was found to produce binders with comparable strain to that of SBS modified A10E, but minimal recovery and MR 6 was found to produce binders with comparable response to EVA modified A35P[2] (White & Reid 2019).

The use of specially produced plastics has been found to have the capacity to improve the mechanical performance of the asphalt mixture which, with the increase in heavy vehicles traffic around the world, has become a requirement (Costa et al. 2013). Although recycling waste in an effort to minimise or even eliminate the use of raw materials is the environmentally conscious route, other benefits need to be clearly identified for the practice to be deemed sustainable. It needs to be proven, for example, that the selected recycled materials can directly substitute their virgin counterparts and that there is mechanical performance, health, and/ or economic advantages in using them. Additionally, their compatibility with the manufacturing processes already in use needs to be considered (Austroads 2019e).

[2] A10E and A35P are common elastomeric and plastomeric polymer matrix bitumen for high-performance applications in asphalt production in Australia (White & Reid 2018).

I.4 Market Maturity

Table I.3: Opportunities for recycled plastics waste in road infrastructure: Australian case studies

Company	State/ Territory	Description	Reference
Downer, Close the Loop	ACT	Trials conducted on a Gungahlin roundabout on Gundaroo Drive and in Casey, ACT, are stated to utilise 800 plastic bags, 300 glass bottles, 18 printer toner cartridges and 250 kg RAP per tonne of asphalt	(Roberts 2019)
	Vic	Trial in Craigieburn, Vic, used 4,500 printer cartridges, 50 tonnes RAP, glass and LDPE recycled plastic bags	(Sustainability Victoria 2018b)
	ACT, Vic, SA and NSW	Downer have undertaken recycled materials trials in multiple local governments across ACT, Vic, NSW and SA	(Downer 2018)
Alex Fraser, Suncoast Asphalt	Qld	The Moreton Bay Regional Council worked with leading recycler Alex Fraser and Suncoast Asphalt to resurface six Caboolture streets with Green Roads PolyPave™; an innovative, high-performance asphalt product containing reclaimed plastics (recycled plastic milk and shampoo bottles).	(Green Roads 2019)
Fulton Hogan	Qld	The City of Gold Coast, 410 metre section of KP McGrath Drive in Elanora was constructed that incorporated 3.5 tonnes of recycled plastic, 200 tonnes of crushed glass and 300 tonnes of recycled asphalt pavement.	(Echo 2019)
Alex Fraser, Suncoast Asphalt	Qld	Redlands City Council, Princess Street, Cleveland. PolyPave. The trial claims to incorporate 90,000 plastic bottles (HDPE), or equivalent of nine months of kerbside collection from the local street involved into the 1 km project.	(Redland City Council 2019)
MacRebur	Qld	Brisbane City Council, Allan St, Kedron. One truck load (approx. 20 tonnes) of each mix: MacRebur products MR6 & MR10 were used for the trials.	(Austroads 2019e)
Alex Fraser	Vic	Maribyrnong City Council worked with Alex Fraser to resurface Harriet Street in Seddon with Green Roads PolyPaveTM Recycled materials contained 3,100 two-litre plastic bottles and 23,400 glass bottles.	(Green Roads 2020)
		Stanley and Margaret Street in Richmond repaved with PolyPave™, containing recycled glass, asphalt, and HDPE plastic (hard plastic/bottles) amounting to almost 100 tonnes of recycled waste.	(Green Roads 2018)
Fulton Hogan	SA	Castle Road in Glanville was resurfaced with PlastiPhalt®, a proprietary asphalt product developed and manufactured by Fulton Hogan. Approximately 110 tonnes of PlastiPhalt® was laid using waste plastic. Furthermore, the addition of 20% Recycle Asphalt Pavement (RAP) was included in the asphalt mix.	(Fulton Hogan 2018)
Boral	SA	Boral resurfaced Carlisle Road in Westbourne Park for the City of Mitcham in April 2020 with a mix containing about 150 tonnes of recycled asphalt pavement and the equivalent of about 450,000 600ml plastic bottles, which laid end-to-end these bottles would stretch 60 kilometres. The project's sustainability credentials were enhanced with the inclusion of recycled aggregate in the concrete used to build new kerbing.	(Boral 2020)
	Vic	Recycled plastic, local recycled crushed glass, and recycled asphalt pavement (RAP) were included in the paving of the entrance of the City of Greater Bendigo's landfill in Eaglehawk in March 2020. The sustainable products included the equivalent of 586,000 600 ml plastic bottles and 303,000 330 ml glass bottles. The project was Boral's first asphalt contract containing glass, plastic, and RAP in Vic.	
	WA	Boral paved Arlington Way, Willetton for the City of Canning with the equivalent of 58,000 600 ml plastic water bottles, 316 tyres and 37,500 330 ml glass bottles. The project was the first time Boral had integrated four products in a single mix in Australia. Boral again used the same combination to pave Mofflin Avenue in Claremont with a mix containing the equivalent of 48,000 600 ml plastic water bottles, 250 car tyres and 31,000 330 ml glass bottles. The 250-metre-long project was done for the Town of Claremont in March 2020.	
	NSW	Boral developed an asphalt mix containing recycled plastic for the wearing course layer in Hereford Street, Stockton, during partial removal and replacement and deep patching rehabilitation works for the City of Newcastle in February 2019.	

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