YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Development of an Assessment and Implementation Framework for the Use of Recycled Materials in South Australian Road Network Project – Part 1 Knowledge Capture

ARRB Project No.: 016932

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Summary

The adaptation of a circular economy in South Australia for the use of recycled materials in road and transport infrastructure is a high priority – for both the state and local governments. Around 80% of Australian roads are currently managed by local councils. It is imperative to provide these councils with a clear pathway for enabling the use of recycled materials in their road and transport infrastructure. However, it is important that it is done in an environmentally safe and responsible way. This project aims to provide advice on the most sustainable options for use on road networks, whilst also considering longevity and not creating any legacy issues. This project has been undertaken with support and funding from Green Industries South Australia as well as in collaboration with the Institute of Public Works Engineering Australasia, City of Mitcham, City of Burnside, Port Pirie Regional Council, and the Adelaide Hills Council. The project is supervised by a project steering committee comprised of representatives from Green Industries SA (GISA), Department of Infrastructure and Transport SA (DIT SA), Environment Protection Authority SA (EPA SA), Local Government Association SA (LGA SA), and the Australian Road Research Board (ARRB).

The project has three main components: knowledge capture, a review of environmental implications and a life cycle assessment of SA roads containing recycled materials. This report is the first deliverable of the project, covering the 'knowledge capture' component. It provides a comprehensive review of the barriers and opportunities for SA councils with the aim to improve the confidence of councils in further incorporation of recycled materials. The report is focused on three priority waste streams, crumb rubber (CR), recycled crushed glass (RCG) and recycled plastics (RP).

The barriers and challenges for councils in the use of recycled materials have been identified through consultation with SA councils. Furthermore, the insights from primary stakeholders were recorded through a questionnaire. The questionnaire was designed to capture the understanding, awareness, and current confidence of councils in the use of recycled materials in road and transport infrastructure. ARRB has provided recommendations to overcome the raised issues and barriers. These recommendations support the bridging of gaps between councils, private industry, and government sectors.

Opportunities for councils are covered in the subsequent sections of the report. A holistic overview is also provided, highlighting the potential applications of recycled materials in road and transport infrastructure to support a thorough understanding of the options available for councils. The purpose is to provide a one-stop shop for the councils to select the appropriate recycled materials and for the right applications. Whether the recycled material products have already been implemented as common practice or are still under consideration, this report will be a single source of information for regional and metropolitan councils to confidently adopt applicable products.

A technical review on the use of recycled materials in pavement structures is a key section of this report. This section provides a summary of available standards and specifications, the current gaps in SA specifications and recommended testing, and evaluation criteria for roads containing recycled materials. This section also covers the methods to incorporate recycled material in different layers of the pavement structure and their incorporation rates.

Finally, the report discusses long-term performance monitoring and how it can provide confidence in recycled materials usage. This section covers two case studies that highlight the importance of long-term performance monitoring of local roads.

The report is a compendium for the use of CR, RCG and RP within road infrastructure, comprising of a literature review, survey responses, potential applications, and recommendations. A few components of this report will also form an integral part of the final report disseminated along with the findings from the environmental implications review and life cycle assessment deliverables of the project.

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List of Abbreviations

Abbreviation	Term
ABS	Acrylonitrile butadiene-styrene
ACD	Automatic Crack Detection
ACT	Australian Capital Territory
AfPA	Australian flexible pavements association
ARRB	Australian Road Research Board
AS	Australian Standards
C&D	Construction and demolition
C&I	Commercial and industrial
CDS	Container deposit schemes
CR	Crumb rubber
CRC	Crumb rubber concrete
CRM	Crumb rubber modified
DGA	Dense graded asphalt
DIT	Department for Infrastructure and Transport
DIPL	Department of Infrastructure, Planning and Logistics
DoT	Department of Transport
DSG	Department of State Growth
EfW	Energy from Waste
EPA SA	Environment Protection Authority South Australian
EPD	Environment product declaration
ESS	Extreme stress seals
EVA	Ethylene-vinyl acetate
FWD	Falling weight deflectometer
GGA	Gap graded asphalt
GISA	Green Industries South Australia
GHG	Greenhouse gas
GPR	Ground-penetrating radar
HDPE	High-density polyethylene
HSS	High-stress seals
LDPE	Low-density polyethylene
LG	Local government
LDPE	Linear low-density polyethylene
LTCRA	Low traffic crumb rubber asphalt
MRF	Materials recovery facility
MRWA	Main Roads Western Australia
MSW	Municipal solid waste
NAWMA	Northern Adelaide Waste Management Authority
NSW	New South Wales
NSV	Network survey vehicle
NT	Northern Territory
OGA	Open graded asphalt
OHS	Occupational health and Safety
PCP	Post-consumer plastics
PE	Polyethylene

Abbreviation	Term
PET	Polyethylene terephthalate
PIC	Post-industrial plastics
PP	Polypropylene
PS	Polystyrene
PaSE	Pavement strength evaluation
PSD	Particle size distribution
PVC	Polyvinyl chloride
QLD	Queensland
RAP	Reclaimed asphalt pavement
RCG	Recycled crushed glass
RP	Recycled plastics
SA	South Australia
SAMI	Stress alleviating membrane interface
SBS	Styrene-butadiene-styrene
SCM	Supplementary cementitious material
SMA	Stone mastic asphalt
TAS	Tasmania
TCCS	Transport Canberra and City Services
TfNSW	Transport for New South Wales
TMR	Transport and Main Roads
TSA	Tyre Stewardship Australia
UV	Ultraviolet
VIC	Victoria
WA	Western Australia
WHS	Work health and safety

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1. Introduction

1.1 Background

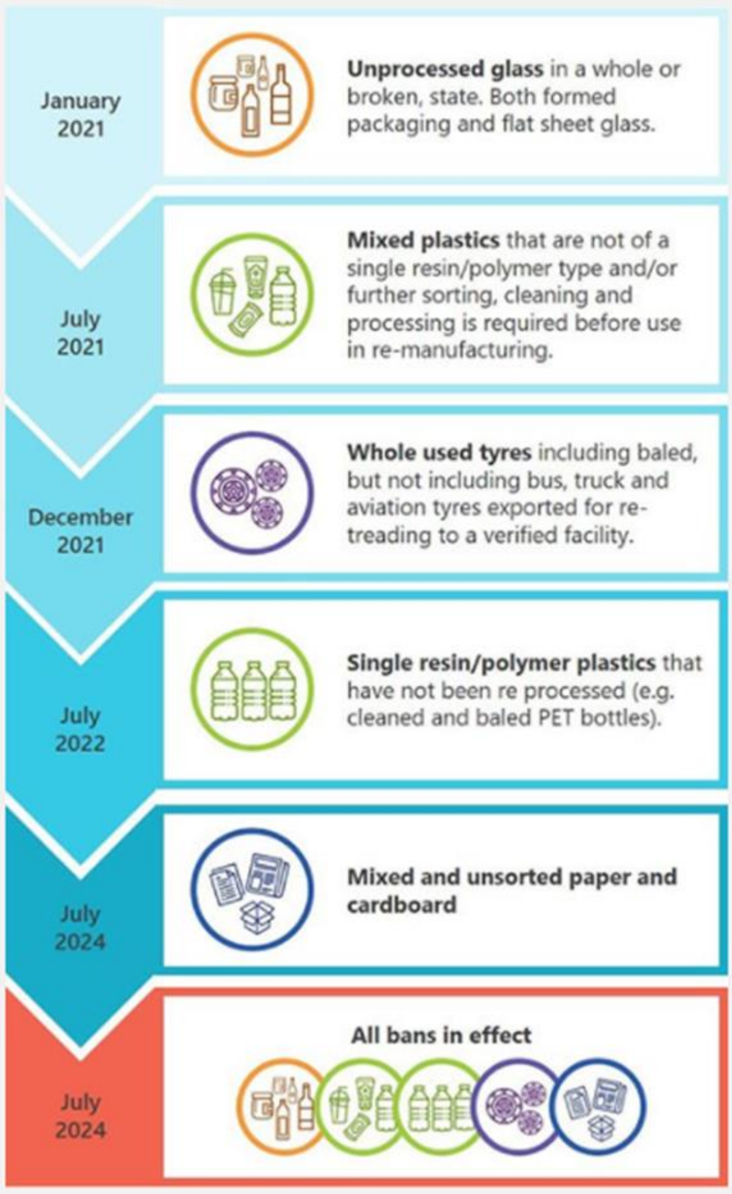
Sustainable road infrastructure is an essential consideration for the future of transport. This includes the incorporation of recycled materials and associated products. In Australia, the South Australian Government is leading the way in implementing circular economy business models across the state. In this context, Green Industries South Australia (GISA) has engaged the Australian Road Research Board (ARRB) to develop an assessment and implementation framework for the use of recycled materials in council road networks.

The Australian Government's National Waste Policy Action Plan (Department of Agriculture, Water and the Environment 2019) sets out targets and actions to implement the 2018 National Waste Policy. Key targets of the National Waste Policy Action Plan are:

1. Ban the export of waste plastic, paper, glass and tyres (commenced in the second half of 2020).
2. Reduce total waste generated in Australia by 10% per person by 2030.
3. 80% average resource recovery rate from all waste streams following the waste hierarchy 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. Make comprehensive, economy-wide and timely data publicly available to support better consumer, investment and policy decisions.

The Council of Australia Government (COAG) established a timetable to ban the export of waste plastic, paper, glass and tyres in August 2019. The definitions and timeframes for materials in scope of the export ban are summarised in Figure 1.1.

Figure 1.1: COAG waste export timetable



Source: Department of Agriculture, Water and the Environment (2019)

Road infrastructure presents an ideal opportunity for the local government (LG) to incorporate recyclables given the long asset life and the ability of some recycled materials to improve certain properties of the road structure. The last few years have seen an inclusion of recyclables such as plastics, rubber and glass in road pavements and asphalt surfacing in the South Australian local roads network. However, there has been no consistent approach and the use is still considered somewhat novel across the state.

The main challenge in adopting the use of recycled materials as business as usual in road infrastructure is the lack of confidence in recycled material products amongst council road and asset managers. The reason for this stems from the lack of structured and organised guidance on how to increase the uptake of recycled materials without compromising the quality of the asset.

The project has three major components: knowledge capture, review of environmental implications and a life cycle assessment. The findings will then be used to develop a systematic and customised (to SA local materials) assessment framework that will facilitate asset managers and contractors to incorporate products containing optimised amounts of recycled materials into roads without compromising on the quality of these roads.

1.2 Objective and Scope

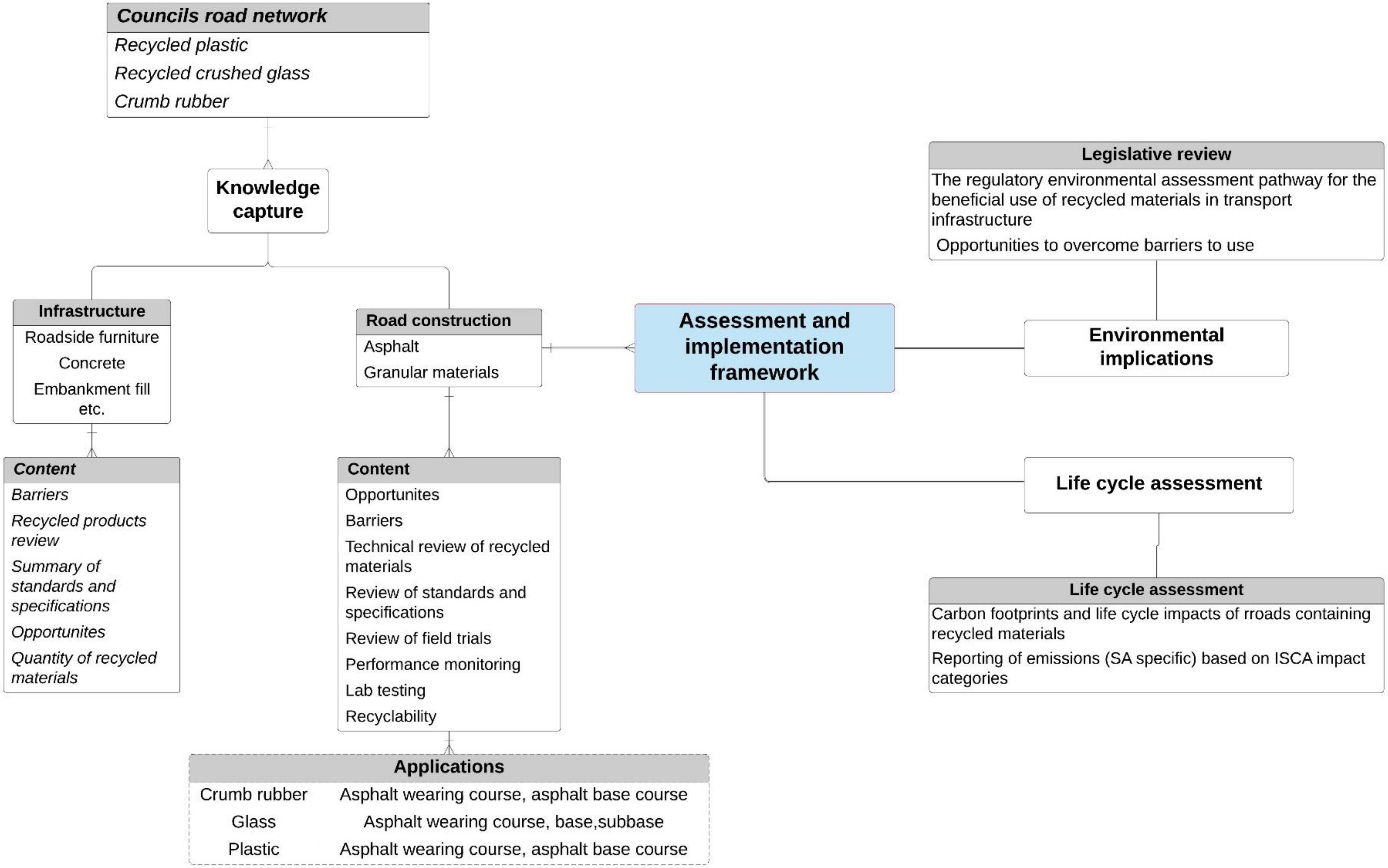
The scope of this project is outlined in Figure 1.2. This report addresses the first component of the project which is the knowledge capture of current applications, barriers and opportunities of glass, plastic and rubber in road and transport infrastructure.

This report aimed to identify current applications, potential barriers and opportunities for local councils to increase the uptake of recycled materials in local road infrastructure. Road infrastructure includes road pavement and non-pavement applications. Road pavement applications include the layers of the road itself such as asphalt, sprayed seals and bound or unbound granular pavement layers. Non-pavement applications cover other road infrastructure within the road corridor such as roadside furniture, embankments, footpaths, accessories and aesthetics, fencing, noise walls etc. Overall, this project focuses on the use of recycled materials in pavement applications.

The term ‘recycled materials’ in this report refers to three recycled materials of interest; recycled crushed glass (RCG), recycled plastics (RP) and crumb rubber (CR). These materials have been chosen based on their potential to replace virgin materials without significantly compromising the durability of the final product.

This report is aimed at all levels of local government including elected members, executives, procurement teams, sustainability officers, asset managers and engineers to help them understand the recycled materials options available for inclusion in local roads and allow them to specify their use with greater confidence.

Figure 1.2: Project scope – the development of an assessment and implementation framework for recycled materials



1.3 Structure of the Report

This report is divided into the following five sections:

Section 1 – This section defines the project objectives, background, scope and structure of the report.

Section 2 – This section will shed light on the importance of circular economy principles and their implementation in council infrastructure. The section highlights the importance of the assessment and implementation framework that will assist councils in adopting circular economy principles within their procurement, construction and governance.

Section 3 – This section is further sub-divided into three sections addressing each recycled material independently. This section will provide a holistic overview of opportunities for councils that will assist them in decision making on the selection of applications. This section is a non-technical review of all the possible opportunities and barriers that will provide an overview to councils of where potential future investment opportunities lie.

Section 4 – This section will dig deeper into the technicalities of using recycled materials in asphalt, spray seals and granular materials. The incorporation of glass, plastic and rubber into roads is not a straightforward task and can pose technical challenges if not managed correctly in terms of durability and long-term performance. Therefore, it is important to understand the key technical issues for using recycled materials in road infrastructure to eliminate any doubts that hinder the use of these materials. This section will start with the general understanding of recycled materials in road construction. Following this, relevant specifications and standards will be reviewed and outlined to supplement South Australian specifications related to the use of recycled materials.

Finally, two case studies (Crumb rubber demonstration trial – East Boundary Road and Low traffic crumb rubber asphalt road – City of Greater Dandenong) are included to highlight the importance of performance monitoring for roads containing recycled materials.

Section 5 – This section includes the responses to the survey questionnaire to highlight the current barriers and challenges in the use of recycled materials in their road and transport infrastructure. Based on the identified gaps and barriers, recommendations are made to fill in those gaps.

1.4 Stakeholder Engagement

As part of the research methodology of this report, ARRB engaged with South Australian councils to identify the barriers and opportunities in the use of recycled materials in the local road network. The engagement was done via a survey. The survey was divided into four sections as follows:

- waste stream analysis
- specifications and standards
- environmental implications
- procurement and funding.

The survey questions were designed to capture the understanding, awareness and current confidence of councils in the use of recycled materials in their road and transport infrastructure. The following South Australian councils participated in the survey.

- City of Burnside
- City of Mitcham
- City of Adelaide
- City of Tea Tree Gully
- Town of Gawler
- City of Port Adelaide Enfield

- City of Salisbury.

Survey's responses have been documented and is presented in Section 5. Barriers and opportunities identified through surveys and consultations are discussed throughout the report whereas Section 3 and Section 4 address those key challenges and highlight opportunities to increase the uptake of recycled materials in road and transport infrastructure.

ARRB also engaged with local waste recovery facilities, peak bodies and industry suppliers including:

- REDcycle
- Close the Loop
- North Adelaide Waste Management Authority (NAWMA)
- Tyre Stewardship Australia.

The information provided by these stakeholders is discussed throughout the report.

2. Circular Economy

2.1 What is a Circular Economy?

A generalised definition of a circular economy that encapsulates the essence of the concept is given below:

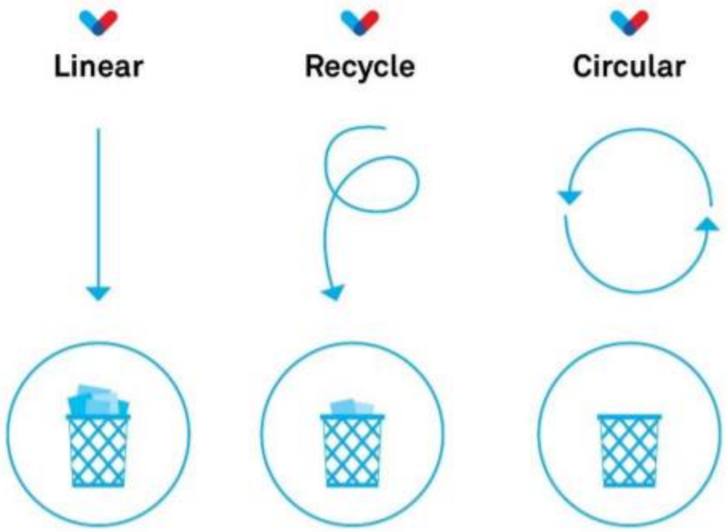
> A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. Ellen Macarthur Foundation (2013)

The circular economy of materials which is the focus of this report can be defined as follows:

> A circular economy is an economic system of closed loops in which raw materials, components and products lose their value as little as possible, renewable energy sources are used and systems thinking is at the core. Het Groene Brein (n.d.)

There is a common misconception that a circular economy means recycling. However, both systems differ in the way waste is ultimately handled. Circular economy system emphasises the 'designing out' waste concept, which means waste does not exist. The recycling system repeatedly recycles materials until it cannot be recycled further and eventually produces waste. However, recycling is a crucial part of realising a circular economy, which has a different end goal. Figure 2.1 describes these three concepts to highlight the differentiation of a circular economy.

Figure 2.1: A schematic of the elements of a circular economy



Source: Lim et al. (2020).

2.2 Circular Economy in South Australia

The circular economy is a prominent focus for GISA. The Green Industries SA Act 2004 incorporates the concept of circular economy as a guiding principle. The objectives of the Act are to:

- promote waste management practices that, as far as possible, eliminate waste or its consignment to landfill
- promote innovation and business activity in the waste management, resource recovery and green industry sectors, recognising these areas present valuable opportunities to contribute to the state's economic growth.

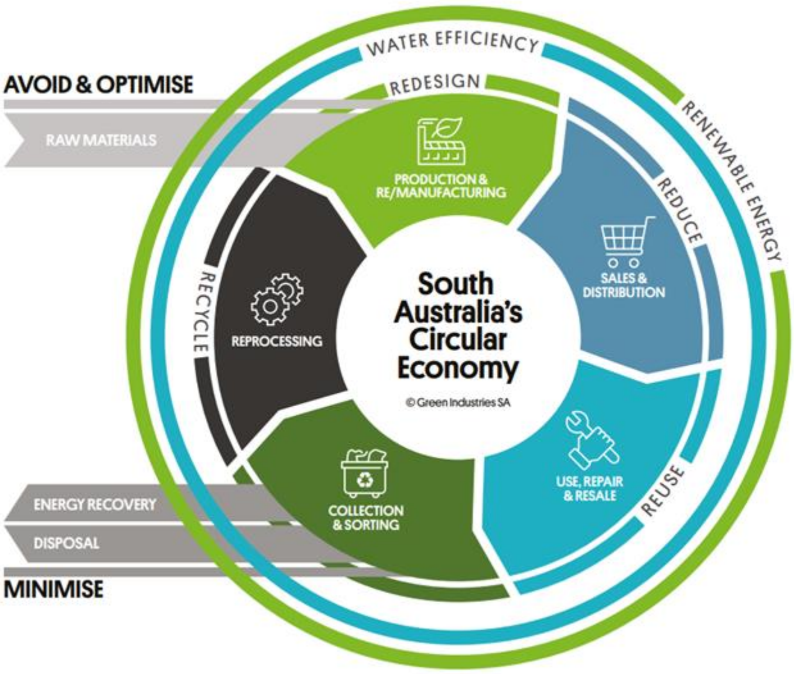
These two objectives are addressed in South Australia's Waste Strategy for 2020–2025 (Green Industries SA 2020). A transition to a circular economy is a priority and guiding focus in this strategy. This strategy forms a framework of policies, strategies, and plans meeting South Australia's priorities for economic growth.

The National Waste Policy Action Plan circular economy principles for waste are:

1. Avoid waste
   - Prioritise waste avoidance, encourage efficient use, reuse, and repair.
   - Design products so waste is minimised, they are made to last and material are easily recoverable.
2. Improve resource recovery
   - Improve material collections systems and processes for recycling.
   - Improve the quality of recycled material produced.
3. Increase the use of recycled materials and build demand and markets for recycled products.
4. Better manage material flow to benefit human health, the environment and economy.
5. Improve information to support innovation, guide investment and enable informed consumer decisions.

The key components of SA's circular economy are summarised in Figure 2.2.

Figure 2.2: South Australia's circular economy



Source: Green Industries SA (2020)

Green Industries SA has developed a strategic plan to advance South Australia's circular economy over the next five years (Green Industries SA 2021a). The plan outlines how SA can ensure a sustainable future while maintaining a thriving economy. Five strategic priorities will be focused on:

1. **Circular products and services:** Designing out waste to keep resources circulating in the economy and enabling sustainable procurement
2. **Circular consumption:** Reducing wasteful consumption by sustaining products through repair and reuse, avoiding waste, and improving recycling and recovery
3. **Circular resource recovery:** Investing in state-of-the-art infrastructure to unlock the value of materials that would otherwise be sent to landfill
4. **Circular sectors**: Creating economic growth and job opportunities by making targeted industry sectors resource efficient and carbon-neutral
5. **Circular capacity:** Capacity building through investment in training, education, innovation and research and development to nurture the next generation.

2.3 Circular Economy and Road Infrastructure

Key opportunities for South Australian councils to adopt a circular economy practice lie within their road and transport infrastructure. To enable this, the following six elements of circular economy outlined by Schandl et al. (2020) should be adopted at each step of incorporating recycled materials into roads and transport infrastructure:

1. Retain material through use and collection – Use of reclaimed asphalt pavement (RAP) within asphalt, use of RP in noise walls or use of RCG as an aggregate replacement are a few examples to tick off the first key element of the circular economy.
2. Upscale and innovative recycling technologies – Improved recycling, reprocessing, and sorting facilities can assist in overcoming the barriers related to the quality and consistency of recycled materials products. Furthermore, innovative technologies for the manufacturing of RP and CR containing asphalt can help to reduce the production cost, improve storage stability, and minimise OHS implications.
3. Innovate and collaborate in design and manufacture – CR in sprayed seals is already a business-as-usual material for many councils. However, the unresolved need is the design of a more robust and resilient process that minimises cost, increases durability and lessens the environmental impact.
4. Develop markets for secondary materials and the products that use them – This is an opportunity for government and sustainable corporations to develop the market for secondary materials and implement streamlined standards that assist in the use of recycled materials as a valuable resource. Moreover, financial incentives can encourage the use of recycled products.
5. Streamline nationally consistent governance – The advantages of using RP, RCG and CR within road construction have been widely accepted and appreciated. However, there is no streamlined approach currently adopted for the use of these materials. This is an opportunity to work together to adopt streamlined guidelines when using recycled materials in road infrastructure. Councils need nationally consistent standards for materials use, collection, and evaluation to ensure long-term benefits and asset integrity.
6. Secure a national zero-waste culture – Circular economy targets can only be achieved by transforming from a take-make-waste culture. Every individual should support a circular economy vision and endeavour to change mindsets and guide behaviours both at home and at work. Councils should adopt these principles at their core and facilitate circular economy practices as part of their business as usual.

3. Recycled Materials in South Australian Local Government – an Overview

EPA SA defines recycled materials as materials recovered and manufactured into products (EPA SA 2019). It was noted during the stakeholder consultations that SA is already using recycled materials in several applications on the road network. These are highlighted in Table 3.1.

Table 3.1: Current examples of applications in use by SA local councils

Council name	Applications
City of Port Adelaide Enfield	• Plastics in asphalt, bollards, wheel stops & street furniture • In bitumen works alone for 2020–21, Council used 10.5 million plastic bags, 307,600 printer cartridges & 8,157 tonnes of recycled asphalt
City of Burnside	• Asphalt (10% RAP) • Sand (100% recycled product made from crushed concrete) as a granular material
City of Mitcham	• Recycled screenings in permeable footpaths • Recycled plastic bollards • Pedestrian bridge decking – recycled plastic • RAP in asphalt – 10–30% • Re-use backfill for footpath/kerb
City of Tea Tree Gully	• RAP both in the road base and in asphalt • Various other products use such as Modwood bollards etc. on street furniture
City of Adelaide	• RAP material in road resurfacing and base course rehabilitation • Recycled plastic for parkland footbridges

This review covers three recycled materials of interest: recycled crushed glass (RCG), recycled plastics (RP) and crumb rubber (CR). These recycled materials have been chosen based on their potential to replace virgin materials without significantly compromising the durability of the final product.

3.1 Crumb Rubber

3.1.1 What is Crumb Rubber?

CR is recycled rubber produced from end-of-life truck and car tyres. According to the South Australia EPA Guideline 183/10 *Waste Tyres*, end-of-life tyres while structurally intact (not mechanically broken down or otherwise retaining their shape) can cause issues in landfills due to their relatively low-density ratio when stacked EPA SA (2019). They may occupy large amounts of space with a relatively low mass while also causing issues with compaction and retarding the overall volumetric breakdown of general waste within landfills. When stored in large quantities, tyres pose a significant fire hazard. As tyres are approximately 60% hydrocarbons and are relatively energy-dense, they have the potential to release high levels of pollutants into the atmosphere upon ignition. Additionally, tyre stockpiles have been identified as housing vermin and insects.

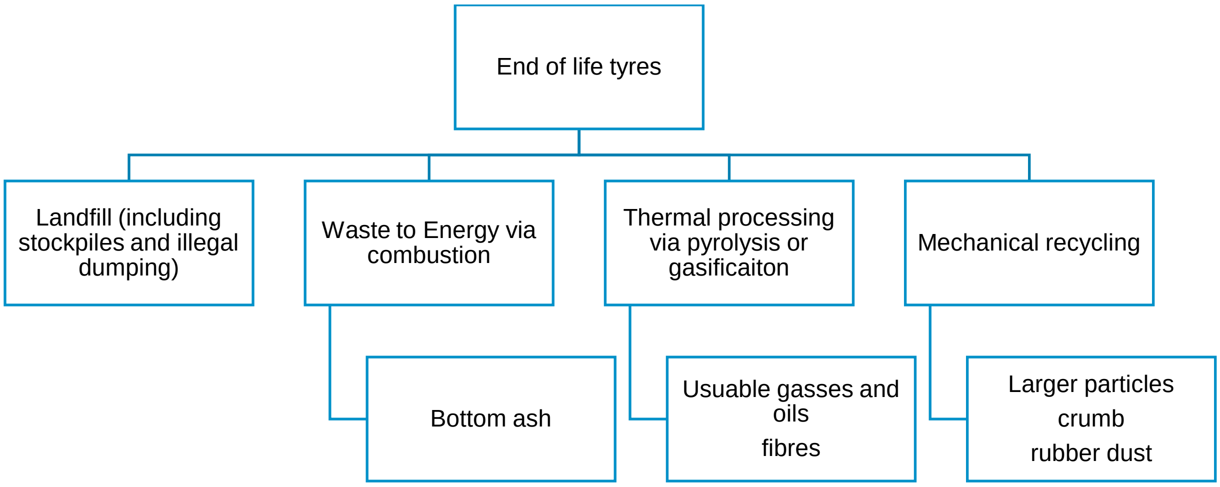
Figure 3.1 represents the recycling options for end-of-life tyres. During the recycling process of end-of-life tyres, steel and textiles are removed and the rubber crumb is formed by a series of mechanical grinding or chemical cryogenic cracking. The particle size of the CR can be adjusted depending on its end application.

Recycling end-of-life tyres can also be completed through energy recovery through combustion and gasification processes (also known as energy-from-waste, EfW). The by-products of this EfW process can also be recovered and re-purposed.

According to Lapkovskis et al. (2020), recycling tyres into usable high-value waste materials is difficult due to the complex composition within the tyre structure. Aside from synthetic and organic rubber, tyres contain varying quantities of textiles, carbon black, reinforcing metal fibres and other additives that are difficult to reduce into usable components. To overcome this obstacle, mechanical processing has become the preferred process to reduce tyres into shredded or granulated particles of varying gradations.

Due to the chemical and physical properties of the rubber material within tyres, they have been identified as a source of high-value waste products which can be used (and reused) within the context of circular economies. A major benefit of mechanical processing is the retention of the elastomer properties as the polymers within the particles remain largely intact.

Figure 3.1: Recycling options for end-of-life tyres



3.1.2 Crumb Rubber in Numbers

A Tyre Stewardship Australia report, *Used Tyres Supply Chain and Fate Analysis* by Randell Environmental Consulting (2020) indicates that in 2018–19 543,000 tonnes of new tyres manufactured overseas were imported into Australia, while an estimated 465,218 tonnes reached their end of life. According to this report, 260,000 tonnes of end-of-life tyres were exported taking the lion's share of disposal routes. Historically tyre waste mainly ends up in landfills or is diverted to waste to energy facilities such as incinerators or pyrolysis chambers (Lapkovskis et al. 2020; Lim et al. 2020). Tyres have also been stockpiled by private entities throughout Australia, however, with the introduction of EPA SA stockpiling regulations (as per Environment Protection (Waste to Resources) Policy 2010) this practice has been restricted (Randell Environmental Consulting 2020). Recent regulations have restricted disposing of end-of-life tyres into landfills which may lead to unlawful dumping or stockpiling. Such unlawful measures pose a significant environmental risk which is costly and time-consuming to rectify.

A relatively small share of the waste stream of end-of-life tyres have seen use in Australian road infrastructure since the early 1970s. Throughout the 2018–19 an estimated 32,900 tonnes of tyre waste was processed into crumb and granules, and it is estimated only 3,100 tonnes were used directly in civil engineering applications (Randell Environmental Consulting 2020). A dramatic expansion is required to increase this market share as the nation moves towards reducing and eventually banning export waste are enforced. There is room for improvement within the civil engineering and pavement space to have a greater impact on the 465,218 tonnes of tyre waste produced annually.

Within South Australia

The *Recycling Activity in South Australia 2019–20* report (Green Industries SA 2021b) indicates that 18,000 to 21,000 tonnes of rubber waste, predominantly from end-of-life tyres, was processed for resource recovery annually from 2013 to 2020 within South Australia. It was noted that of the recovered end-of-life tyres, 57% was processed in South Australia and 20% was sent interstate for processing with the remainder (23%) being sent overseas.

3.1.3 Applications of Crumb Rubber in Road and Transport Infrastructure

Table 3.2 summarises potential applications for crumb rubber within road infrastructure. Some applications are more established than others.

Table 3.2: Overview of potential applications of crumb rubber in road and transport infrastructure

Applications	Description	Market readiness	Reference
Asphalt and spray seals	Crumb rubber has seen international use within asphalt materials as both an aggregate replacement and a supplement to the bitumen binder.	Spray seals – Matured(1) Asphalt – matured overseas being implemented(2) in Australia	Lo Presti (2013)
Embankment fill	Bulk earthworks typically require large volumes of material to be imported or won from local quarries, however, even small percentage incorporation of crumbed or shredded tyres can drastically reduce the overall virgin material required.	Research phase(3)	EPA USA (2010)
Slope stabilisation	Crumb rubber has seen successful use in aiding slope stability for bulk fill material.	Research phase	(Moghadam et al. 2018)
Stabilisation of expansive soils	Investigation into crumbed or shredded rubber products in conjunction with lime or cement has shown promise in the stabilisation of poor subgrade materials	Research and feasibility phase(4)	EPA USA (2010)
Crumb rubber concrete (CRC)	Considerable research has been done into the use of crumbed rubber as a partial aggregate replacement in concrete for low risk/non-structural applications. Benefits include a lower density mix and improved thermal and sound insulation	Research phase	Mills et al. (2018)
Drainage backfill material	High levels of control over the shredding/crumbing process allow for a highly permeable material for use in drainage applications such as trenches and retaining wall backfill.	Implementation phase	
Footpaths, tree protection zones, car parks, driveways	Crumb rubber has successfully been used in children's playground surfacing and similar porous products have been used in footpaths such as Thompson Road in the City of Fremantle. Similar products have been used in tree protection zones for trees planted along footpaths in urban environments to allow for protection and safety for pedestrians while promoting free-flowing drainage into the root system.	Implementation phase Matured use in children's playgrounds	Porous Lane (2021)
Ports, riverbank and coastal stabilisation	Unprocessed whole tyres have seen use in ports and river/coastal stabilisation such as submerged and tidal retaining walls and anti-scour mattresses in riverbeds	Matured	HR Wallingford (2005)
As a means of absorbing seismic waves and for slope stabilisation	Studies have indicated that crumb rubber modified soils surrounding structural footings may act as an effective seismic isolation material to mitigate the loading actions imposed by earthquakes.	Research phase	Chiaro et al. (2019)

1. Matured: established application.
2. Implementation phase: transition from research to the commercialisation phase.
3. Research phase: laboratory testing at small scale to establish a proof of concept.
4. Feasibility phase: transition from research to implementation phase requiring socioeconomic analysis and life cycle assessment.

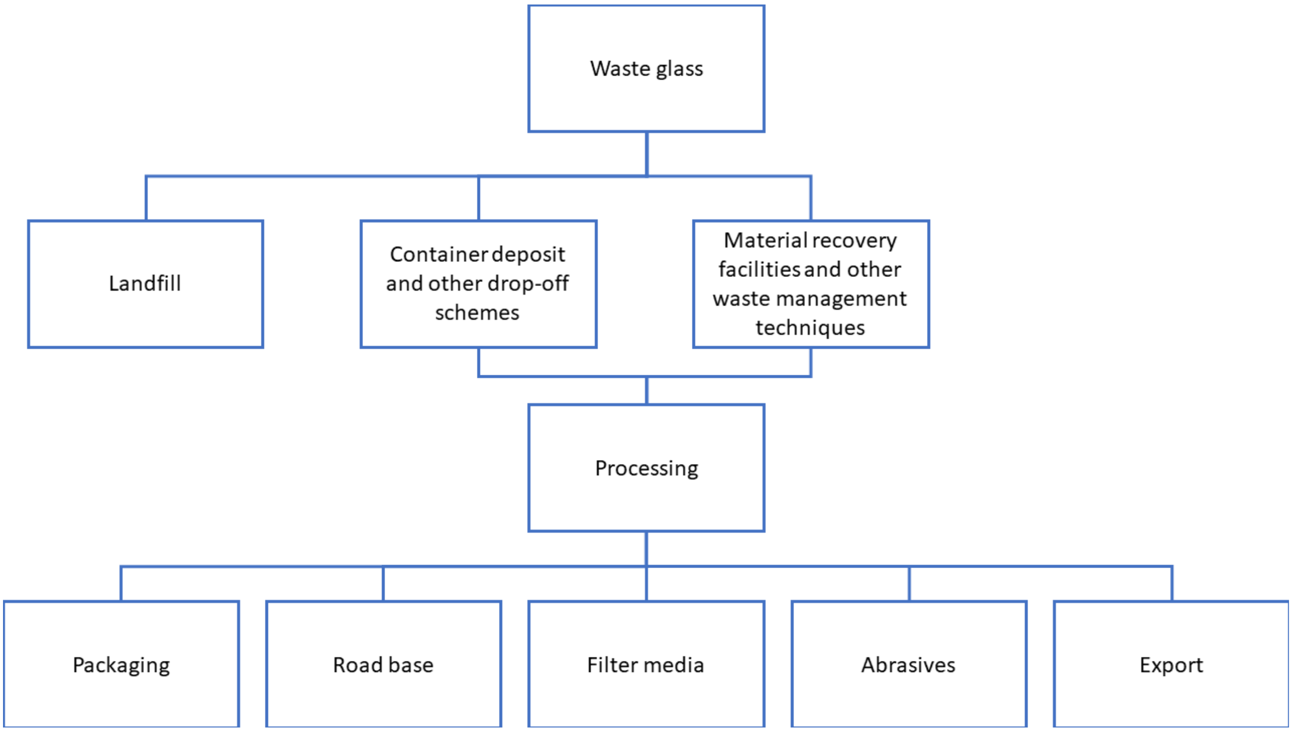
3.2 Recycled Crushed Glass

3.2.1 What is Recycled Crushed Glass?

RCG is a mixture of different colours and types of glass particles with debris. Glass from residential and industrial areas is collected, crushed, and sometimes cleaned. RCG can be crushed into any size, fine or coarse particles, depending on its end applications.

Figure 3.2, which is based on a report prepared for the Department of the Environment and Energy (Allan 2019) shows the flow of glass after consumption. Aside from the littered and landfilled glass, glass collected through container deposit schemes and material recovery facilities is processed for more beneficial uses. The higher quality recovered glass is used for packaging, while the remaining recovered glass can be used in other applications such as filter media for water quality projects, abrasive material in sandblasting of ships, and road base and sub-base applications.

Figure 3.2: Recycling options for waste glass



3.2.2 Recycled Crushed Glass in Numbers

A total of 1.16 million tonnes of waste glass was generated in 2018–19 in Australia, 59% of which were recovered and recycled Pickin et al. (2020).

With the ban on the export of whole or broken unprocessed glass items, which commenced in January 2021 in Australia, there is a great effort towards driving innovation, creating jobs and providing environmental benefits through recycling waste glass. Recycling waste glass back to glass products is the preferred approach. For this though, the waste glass needs to be of high quality and colour-sorted, which requires improvement to current collection practices. To this end, different states and territories in Australia are introducing schemes such as Container Deposit Schemes (CDS). SA's CDS is one of the longest running and successful product stewardship schemes in Australia, with container deposit legislation being first introduced in Sa in 1977. In 2003, the scope of beverage containers covered by the CDS was extended in SA. However, not all beverage containers are included under the SA scheme. CDS scope also varies in each jurisdiction. The SA CDS is currently being reviewed which leads to the modernisation phase of CDS. A second stage of modernisation of SA CDS could involve amending the scope to incorporate a wider range of beverage containers with national alignment.

Within South Australia

In 2019–20, 87,000 tonnes of glass were recovered in SA (Green Industries SA 2021b). As the demand for glass was high for bottle remanufacturing and road base materials (glass fines/unsorted glass), SA imported a further 88,700 tonnes from other states. Of the recovered glass, 61% was sourced from municipal solid waste (MSW) and 39% from commercial and industrial (C&I) sector. About 69% of the recovered glass was re-processed in SA, and the remaining 31% was sent interstate for re-processing due to the demand for lower grade/mixed glass for road base in other states (Green Industries SA 2021b).

Through consultation with Northern Adelaide Waste Management Authority (NAWMA) it was noted that in the 2020–21 financial year, NAWMA recovered approximately 13,000 tonnes of glass fines that can be used as aggregate replacement in footpaths, asphalt and as base course materials. This is about 20% of the intake of glass. Other glass such as that recovered from container deposit schemes is generally recycled back into higher value uses such as being sent to glass bottle manufactures.

3.2.3 Applications of Recycled Crushed Glass in Road and Transport Infrastructure

Utilising the collected glass in the construction of transport infrastructure is an avenue worthwhile exploring especially given the large volume of construction projects, therefore massive amounts of the waste glass could be utilised. This will reduce the use of natural quarried materials, increase the diversion of waste glass from landfill and help transition towards a circular economy. In addition, RCG could be used to improve engineering properties (e.g. permeability and resilient modulus) in drainage layers, embankments and subgrade (Eberemu et al. 2013); Yaghoubi et al. (2021). Table 3.3 summarises various applications for RCG in the road corridor. It is important to note that RCG needs to meet certain criteria including technical, environmental and WHS requirements before being used and this should be stipulated in relevant specifications.

Table 3.3: Overview of potential applications of RCG in road and transport infrastructure

Application	Description	Market readiness	Reference
Embankment and structural fill	RCG could be used to improve engineering properties (e.g. permeability and resilient modulus). Grubb et al. (2006) blended RCG with dredged material for use in the construction of embankments and structural fills and found that 20% RCG by mass could be used in the blend. In 2020, a 22 km four-lane dual carriageway was completed in Western Australia. Over 70,000 tonnes of RCG were used as embankment fill, primarily to stabilise clay-based soils and materials, and for dust suppression in the embankment layer, due to the higher water holding capacity of RCG compared to limestone.	Matured (1)	Eberemu et al. (2013); Yaghoubi et al. (2021), (Main Roads Western Australia 2021)
Subgrade material	Clay blends can be used in the improvement of subgrade and embankment of roads at an RCG content of 20% (80 clay + 20 RCG), by mass. Laterite soil blends can be used in the improvement of subgrade of roads at an RCG content of 30% (70 clay + 30 RCG), by mass.	Research phase (2)	Davidović et al. (2012), Yaghoubi et al. (2021)
Drainage layers, backfill and bedding material	RCG could be used to improve engineering properties (e.g. permeability and resilient modulus). Clay blends can be used in embankments, structural and non-structural fill, retaining wall backfill, drainage (foundation and drainage blankets) at an RCG content of 20% (80 lateritic soil + 20 RCG), by mass.	Matured	Eberemu et al. (2013); Yaghoubi et al. (2021)

Application	Description	Market readiness	Reference
Concrete	RCG can be used as a partial replacement of aggregates in concrete. Research studies have shown that the incorporation of RCG as aggregate had no significant effect on the workability of concrete. The Cairns Regional Council implemented a 108 m long and 2 m wide concrete footpath trial in 2019. Three different RCG mixes were trialled, where RCG mixes were implemented in 30 m lengths and a control mix over 18 m. The trial results showed that a 40% RCG content (40% of fines in the concrete) provided the optimum results from a performance, environmental and economic point of view. Australian testing requirements and production control for RCG in concrete are outlined in Table A.1 and Table A.2	Matured	Shi and Zheng (2007); Shin and Sonntag (1994), Flanders (2019)
Asphalt and granular materials	In 2010, Waverly Council in NSW, successfully constructed two 100 m pavements incorporating approximately 15 tonnes of RCG in the pavement materials. The council used 7.5 tonnes in the asphalt for one trial and another 7.5 tonnes in the concrete pavement, using a 56% glass-sand replacement, for the other trial. Recently in Adelaide (early 2021), the Regency Road to Pym Street (R2P) alliance in collaboration with the Department of Infrastructure and Transport, ResourceCo and City of Port Adelaide Enfield Council have started the first trial in SA to use RCG in the construction of transport infrastructure. A 5% RCG content was selected to be incorporated into the subbase layer of a heavy vehicle bypass road. This resulted in the utilisation of approximately 8.5 tonnes of RCG.	Matured	Department of Sustainability, Environment, Water, Population and Communities (2011) Department for Infrastructure and Transport (n.d.)

1. Matured: established application, requirements outlined in current specifications.
2. Research phase: laboratory testing at small scale to establish a proof of concept.

RCG is specified in many of the above applications around the country. SA does not have any specifications for the use of RCG. Table 3.4 summarises the limits for using RCG in various non-pavement applications, specified by different Australian road agencies.

Table 3.4: RCG in non-pavement applications: Australian standards and specifications

State	Road agency	Application	Max limit (content by mass, %)	Standards
NSW[1]	IPWEA [2]	Select fill (Class S)	10	Institute of Public Works Engineering Australia (2010)
		Bedding material (Class B)	50	
		Drainage medium (Class D75 & D20)	50	
		Drainage medium (Class D10)	100	
VIC	DoT	Subsurface drainage – granular filter material	100	VicRoads Section 702
		Type A, B and C fill	N/S [3]	VicRoads Section 204
	Metro Trains Melbourne (MTM) [2]	Replacement for quarried sand as bedding and embedment materials	N/S [3]	MTM L1-CHE-SPE-313
QLD[1]	TMR	Bedding and backfill material	100	MRTS04
WA	MRWA	Imported fill for embankment construction	20	MRWA Specification 302
SA	Not specified			
TAS	DSG			Aligned with Vic DoT
ACT	Not specified			
NT	DIPL	Bedding for drainage works	100	Standard specification for roadworks, DIPL

1. RCG to be compliant with requirements in MRTS36 – *Recycled Glass Aggregate in QLD* and TfNSW D&C 3154 – *Granulated Glass Aggregate in NSW*.
2. Not a road agency.
3. It is allowed, but the limit is not specified.

3.3 Recycled Plastic

3.3.1 What is Recycled Plastic?

Plastics are a group of synthetic or semi-synthetic organic materials that are mouldable under the application of heat. Plastics are typically high molecular weight organic polymers composed of long chains of carbon, hydrogen and traces of other compounds. Most of the synthetic polymers are derived from petrochemicals but many polymers are natural, such as natural rubber, silk and cellulose. Commonly used plastics identification symbols/codes with their associated polymer types are summarised in Table A.3.

RP is made from post-consumer and post-industrial plastic. Post-consumer plastics (PCP) are recovered from consumers/commercial markets. PCP is collected by kerbside collection and shipped to recycling facilities to be sorted into bales, based on the plastic-type. The bales are then purchased and melted into small pellets and moulded into a variety of products. Examples of PCP are household consumer goods, medical devices, electronics and dispensers. Few councils and stewardship schemes collect post-consumer plastics and send them either to in-house or external material recovery facilities (MRF) for sorting (Austroads 2021c).

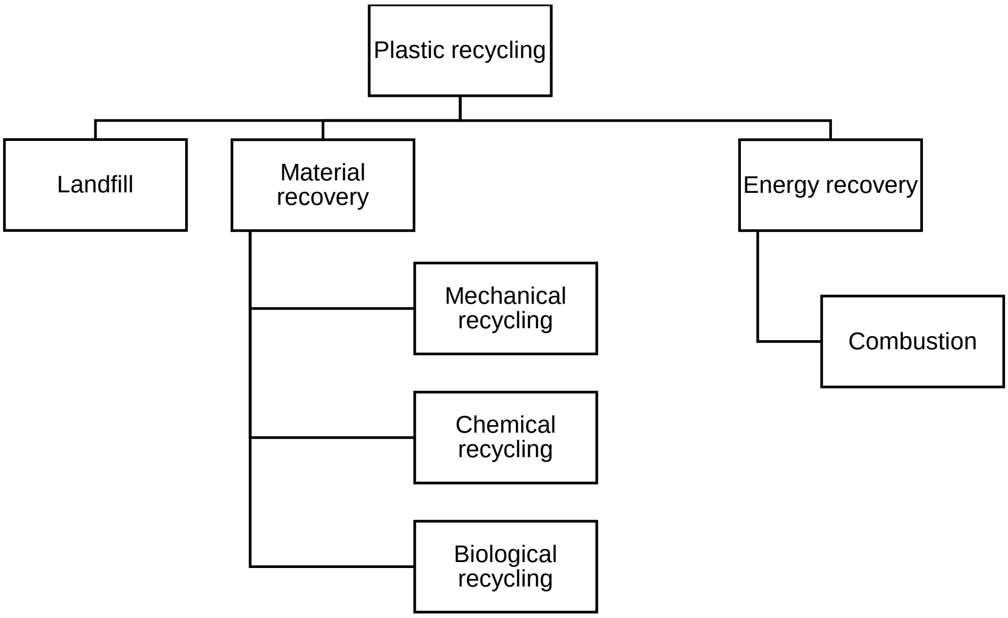
Post-industrial plastics (PIC) originate from industrial processes as a by-product. PIC has the advantage that the input resin type is known and controllable. Post-industrial plastics are also in a pre-contamination state, making the process of recycling back to useable high-quality plastic pellets simpler. Post-consumer plastics need to be cleaned of debris and contamination enough that the quality of the reprocessed output can be used to make new products. Examples of PIC are the packaging film, automotive, fishing, paint, agriculture and the plastic extrusion and mould industries (Austroads 2021c).

Many different types of plastics can be recycled into new products that can be labelled as RP products. Like CR, plastics can be mechanically, chemically, or biologically recycled and also be used in EfW processes. Figure 3.3 represents the recycling options for waste plastic.

Energy recovery and chemical recovery processes are well suited for co-mingled/mixed plastics as the purity of raw materials does not have a significant effect on the process efficiency and final product, especially during incineration or gasification. The materials recovery process refers to the mechanical processing of waste plastics such as sorting, grinding, moulding, extrusion and product manufacturing. Herein, recycled plastics are referred to as recycled materials obtained after their sorting and before reprocessing.

The use of waste plastics in road and transport applications predominantly falls under the materials recovery stream. It is recommended to have a single resin plastic for use in specific road infrastructure applications.

Figure 3.3: Recycling options for waste plastics



3.3.2 Recycled Plastic in Numbers

In 2018–19, 3.4 million tonnes of plastics were consumed in Australia, however, just 12% were recycled at the end of life. Around 60% of recovered plastic was exported. Australia would need to increase its capacity by 150% to recycle the recovered plastic (Schandl et al. 2020). Nearly all (96%) of the raw input for production was either virgin or imported materials, leaving just 4% Australian recycled materials in the input streams. It is anticipated that by 2030 Australia will be able to recycle 50% of its plastic back into the input raw materials while reducing that sent to landfills to 14% from the current 65% (Schandl et al. 2020).

Polyethylene terephthalate (PET) has the highest recovery rate of 21%, followed by high-density polyethylene (HDPE) at 19.7% and low-density polyethylene (LDPE) at 17.3%. Plastic package recovery rates from consumer, C&I sectors are relatively high as compared to other applications. In 2018–19, of all plastics recovered in Australia, 58% were recovered from the municipal sector, 38% from the C&I sector, and 4% from the construction and demolition (C&D) sector.

Within South Australia

In 2019–20, South Australia recovered 29,700 tonnes of waste plastic. The highest recovery of plastics is from the C&I sector (41%) followed by municipal solid waste (MSW) (37%) and the C&D sector (22%). Table 3.5 shows the quantity of plastics recovered (tonnes) in SA during 2019–20. Mixed plastics are the largest contributor to the recovery at 48%. HDPE has the second-largest recovery rate at 20% followed by 16% for PET. Generally, mixed plastic accounts for the left-over plastics after sorting. Mixed plastic before sorting is used for energy recovery. Mixed plastics also contain non-recyclable plastics such as white PET and laminated sachets. Road and transport infrastructure applications require mixed plastics to be sorted into single resins before use. Therefore, improvement of the recycling facilities could facilitate increased use of recycled plastics in road and transport applications. In 2019–20, 12,700 tonnes of mixed plastics were used for energy recovery before any sorting commenced.

Table 3.5: Quantity of plastics recovered (tonnes) in SA during 2019–20

Item	Material recovery	Energy recovery	Net recovery (1,2)
PET	4,700		4,700
HDPE	6,000		6,000
PVC	100		100
LDPE	3,000		3,000

Item	Material recovery	Energy recovery	Net recovery [1,2]
PP	1,100		1,100
PS	600		600
Mixed	1,500	12,700	14,200

1. Net recovery excludes re-processing losses.
2. Net recovery = material recovery + energy recovery.

Source: Adapted from Green Industries SA (2021b).

REDcycle is an initiative that collects post-consumer soft plastics that is used for the manufacturing of recycled plastic products. It was noted in consultation with Close the Loop and REDcycle that SA residents and businesses produce 1,104 tonnes of recycled plastic through REDcycle. The recovered plastic is then used by companies like Close The Loop for the manufacturing of TonerPlas™ (soft plastic product used in asphalt). Currently, SA imports 230 tonnes of TonerPlas™ from Close The Loop of which over 40% is soft plastics (99 tonnes). Therefore, 1,104 tonnes leave SA and 99 tonnes return as TonerPlas™ of which over 40% is soft plastics.

3.3.3 Applications of Recycled Plastics in Road and Transport Infrastructure

Owing to the varying characteristics of plastics, not all plastic is suitable for every application. Therefore, it is important to identify appropriate plastic types for specific applications. Table 3.6 shows potential infrastructure applications of RP depending on their type and properties.

Table 3.6: Potential infrastructure applications (within the road corridor) of recycled plastics depending on their type and properties

Recycled plastic type	Physical properties	Potential infrastructure applications
HDPE	Rigid	Plastic lumber, table, chairs, bitumen modifier
LDPE	Flexible	Bricks and blocks, bitumen modifier
PP	Hard and flexible	Asphalt
PS	Hard and brittle	Insulation material
PET	Hard and flexible	Fibres in cementitious composites, partial aggregate replacement in asphalt mixture
PC	Hard and rigid	Aggregates in cementitious composites

Source: Adapted from Awoyera and Adesina (2020).

The use of recycled plastics in road infrastructure is an emerging area. Many potential applications can use a high percentage of recycled plastic. Table 3.7 summarises the potential applications and Table 3.8 lists vendors in South Australia manufacturing recycled market-ready plastic products.

Table 3.7: Recycled plastic applications in road infrastructure

Applications	Description	Market readiness
Ancillary and aesthetics	Applications include noise walls, fencing, wheel stops, signage, roadside furniture, tree stakes, boardwalks, and decking. Applications such as bollards can typically use 100% recycled plastic. Noise walls, however, cannot currently be made from 100% recycled plastic due to specified property requirements (limit currently around 70% recycled content – potentially could go to 100% in the future. Multiple reprocessing steps could result in the decrease of mechanical properties and durability of recycled plastics.	Noise wall – implementation phase [2] Fencing, wheel stops, matured [1] Signage – implementation phase Bollards – matured

Applications	Description	Market readiness
Shared user paths	Bike paths and footpaths made of recycled plastics are promising options, however, there are not many options in Australia. Modular options allow for flexible design and significant amounts of recycled plastic to be used; however, they may not be cost-effective. In 2018, a Netherlands based company introduced the 'PlasticRoad' design that used prefabricated recycled plastic sheets to construct bike paths with a hollow interior. This method provides a 75% reduction in carbon emissions and an 80% reduction in the transportation of materials. It is also 70% faster than alternative construction methods and it can be done without traditional foundations. Recycled plastic decking such as Enduroplank™ is available in Australia.	Implementation phase (1) (overseas), Research phase (Australia)
Geogrids and geotextiles	Geogrids and geotextiles made from recycled plastics can replace virgin materials that are used for soft and unstable sub-grade soils in road construction providing a separation layer. Huesker has produced a version of its 'HaTelit® C 40/70' asphalt reinforcing grid which utilises recycled PET plastic yarn (Huesker 2020). This product can be used as an alternative to a traditional stress alleviating membrane interface (SAMI) seal when looking to protect against reflective cracking in asphalt overlays. While this product is available in Australia it is currently manufactured in Germany. Nonwoven geotextiles BIDIM ® Green is made from Australian sourced recycled materials and has multiple applications in roads, rail formations, embankments and liner protection. Geotextiles are lighter in weight, therefore, easier handling and laying on site. Knitted geotextile has a high tear strength.	Implementation phase
Recycled plastic pipes	Applications include conduits, flexible and ridged plastic pipes. Recycled poly vinyl chloride (PVC) can be used as an insulation material for electrical cables used in transport infrastructure. Victorian-based group NWC Recycling and Queensland company Allplas Extrusions produce PVC pipes from post-consumer and post-industrial waste. There are many recycled plastic pipe manufacturers around Australia. For example, RPM pipes produce a pipe suitable for non-pressure stormwater drainage applications made from 100% recycled HDPE ((RPM Pipes 2020). Recycled plastic pipes under pavement are not widely accepted and are still being established, however behind kerb uses are more mature.	Implementation phase
Concrete (as fibre reinforcement and fine aggregate replacement)	The recycled plastic fibre reinforcement can be used as a replacement for steel in the production of precast stormwater pits, risers and end walls for use in road infrastructure projects. It has also been used as a substitute for steel mesh reinforcement in footpaths. Fibercon has produced a fibre reinforcement product made from 100% recycled polypropylene plastic called 'Emesh', which like its virgin plastic counterparts, replaces the use of steel reinforcement in some concrete applications (Fibercon n.d.). Undefined service history, impurities and varying degradation temperature of recycled plastic led to processing difficulties and unstable mechanical properties of fibre reinforced concrete. Recycled plastic can be used as a fine aggregate replacement for concrete. However, research is still underway to improve the strength of concrete containing recycled plastics. Plastic aggregate has improved the ductility of concrete and shown promising characteristics such as low thermal, acoustical and electrical conductivity demonstrating the aggregate may be a good option to develop thermal and sound insulating concretes. There are significant challenges associated with re-recyclability.	Research and Implementation phase
Plastic derived products (carbon black, paint sludge, polymeric binders)	Applications include asphalt fillers, binder additives, paint additives. This is a way of increasing the uptake of secondary products derived from waste plastic. Research is in its preliminary stages and currently no conclusive evidence is available on their performance in road infrastructure application.	Research phase (2)

Applications	Description	Market readiness
Asphalt	The utilisation of recycled plastics as a bitumen modifier or partial aggregate replacement in asphalt is a fast-developing area. This increases rutting resistance, deformation, and cracking when appropriate waste plastic is incorporated as a modifier in bitumen or asphalt. Environmental impacts are not well understood such as short-term fuming and emissions or long-term generation of microplastics. Research is in its preliminary stages to overcome the compatibility and stability issues of waste plastic modified bitumen. There is a need for development of a robust set of specifications and standards to ensure the consistency of products and their performance.	Research and implementation phase

1. Implementation phase: transition from research to the commercialisation phase
2. Research phase: Laboratory testing at small scale to establish a proof of concept

Source: Adapted from ARRB (2021a)

Table 3.8: Recycled materials products, manufacturer and supplier details

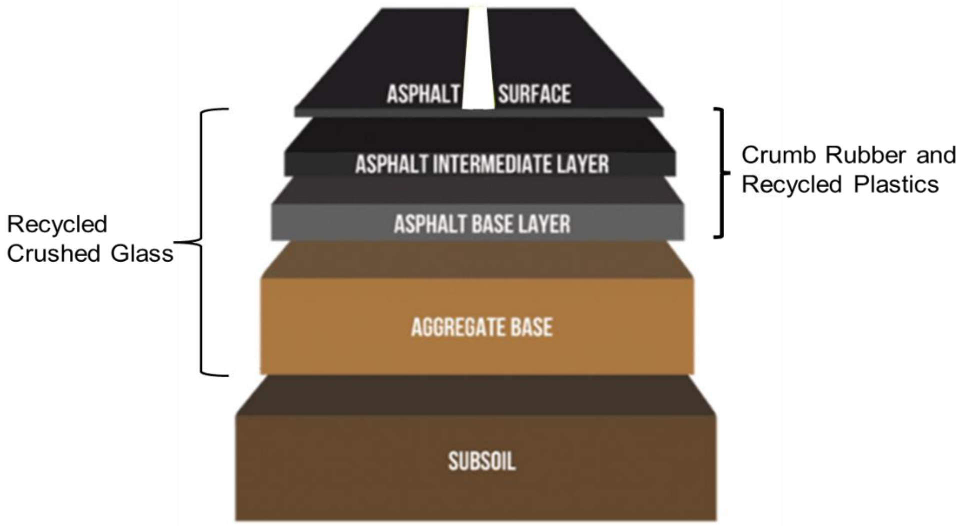
Company	Location	Products	Recycled plastic type
Replas	Manufactured in Ballarat, Vic. Receives tonnes from across Australia including a proportion from South Australia.	Bollards Decking Fencing Furniture	Mixed plastics including soft plastics from supermarkets
Advanced Plastics Recycling (APR)	Kilburn, SA	Bollards, decking, furniture, traffic control, profiling Screening Platforms Fencing	HDPE plastic
Mastec	Edinburgh, SA	Residential & commercial bins	HDPE
Trident	St Clair, SA	Residential & commercial bins	HDPE, PP
Draffin Street Furniture	Bayswater, SA	Bollards Benches (e.g. Kimberley Recycled) Plastic Park seats	Plastics
Lomman Irrigation	Hamstead Gardens, SA	Valves & fittings (various)	Plastic
Moodie Outdoor Products	Ryde, NSW (operating across Australia)	Bollards Seats/benches Garden beds Garden edges Dog parks	HDPE

Source: LGA SA (2020).

4. Technical Review on Recycled Materials in a Pavement Structure

This section provides an in-depth review of the use of recycled materials in pavement structures. The information will be used to develop an assessment and implementation framework as well as providing input into life cycle assessment studies. As described in Section 1, the term 'pavement' refers to asphalt, sprayed seal and granular materials (base, subbase) applications. Each recycled material has a favourable utilisation in one or all pavement applications. Figure 4.1 shows the schematic of use of recycled materials in different layers of pavements discussed in this report.

Figure 4.1: Pavement structure and use of recycled materials



4.1 Crumb Rubber

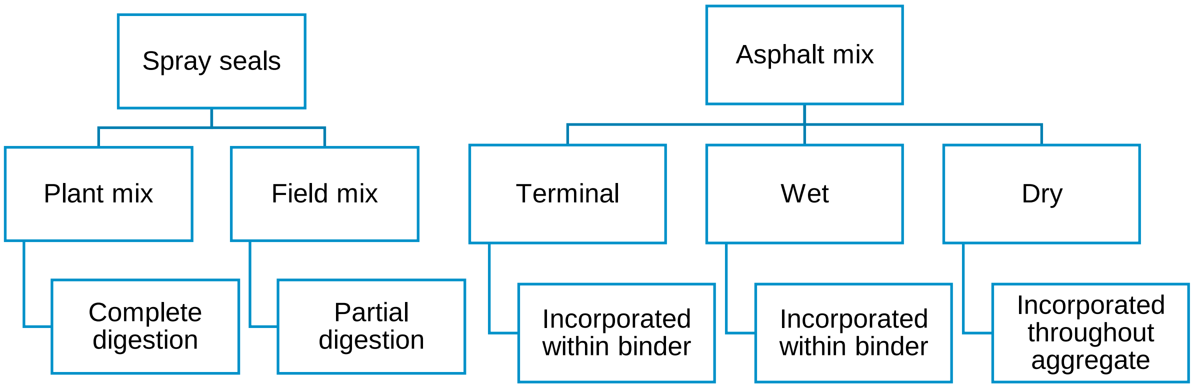
4.1.1 Incorporation of Crumb Rubber into the Pavement Structure

Current and historical applications for CR in road pavement is in sprayed seals and more recently asphalt applications. Since 2017 there has been accelerated investigation and rework of certain specifications and guides throughout Australia to increase the use of CR in asphalt materials (Austroads 2021b).

There are multiple methods of incorporating CR into the binders for sprayed seals and asphalt mixes (Austroads 2017). The size, shape and chemistry of the CR particles as well as the degree of 'digestion' into the hot bitumen will determine the performance outcomes of the final product. Figure 4.2 shows the mixing methods to produce binder for sprayed seals and asphalt incorporating CR. Three methods can be followed:

- Asphalt
  - Wet – CR digested into binder before mixing with aggregates, CR particles can still be present depending on mixing time, heat and particle size.
  - Dry – CR added in with dry aggregates and then mixed with binder. CR particles only partially digested into the binder.
  - Terminal – another form of the wet method where the CR is fully digested into the binder creating a homogenous mix.
- Sprayed Seals
  - Plant mix – CR is digested into binder during production at binder manufacturing plant.
  - Field mix – CR is partially digested into binder at the construction site using mobile blending plants

Figure 4.2: Mixing method to produce sprayed seals and asphalt



4.1.2 Standards and Specification

In Australia, many states and territories have developed specifications for crumb rubber used in sprayed seals and more recently asphalt mixes. Furthermore, other organisations such as Austroads and the Australian Flexible Pavements Association (AfPA) have developed guidelines and/or specifications. The Austroads Technical Specification ATS 3110 (Austroads 2020) provides the basis of most state and territory specifications whereas the AfPA specification is specifically for open graded asphalt (OGA) and gap graded asphalt (GGA). Table 4.1 provides a summary of relevant guidance documents by source.

Table 4.1: Summary of relevant state specs for use of crumb rubber in asphalt and spray seals

Jurisdiction	Relevant specification
Austroads	Technical Specification ATS 3110 *Supply of Polymer Modified Binders* Technical Report AP-T359-21 *National Specification for Crumb Rubber Binders in Asphalt and Seals*
Transport for New South Wales (TfNSW)	*Scrap Rubber Bitumen Guide* QA specification D&C R118 *Crumb Rubber Asphalt* QA specification D&C 3252 *Polymer Modified Binder for Pavements* QA specification D&C 3256 *Crumb Rubber*
Victorian Department of Transport	Section 408 *Sprayed Bituminous Surfacings* Section 421 *High Binder Crumb Rubber Asphalt* Section 422 *Light Traffic Crumb Rubber Asphalt*
Queensland Department of Transport and Main Roads (TMR)	MRTS11 *Sprayed Bituminous Treatments (excluding Emulsion)* MRTS18 *Polymer Modified Binder (including Crumb Rubber)* PSTS112 *Crumb Rubber Modified Asphalt*
Main Roads Western Australia (MRWA)	Specification 503 *Bituminous Surfacing* Specification 511 *Materials for Bituminous Treatments* Specification 516 *Crumb Rubber Open Graded Asphalt*
Department for Infrastructure and Transport (DIT) South Australia	RD-BP-S1 *Supply of Bituminous Materials*
Department of Infrastructure, Planning and Logistics (DIPL)	Crumb rubber modified materials in asphalt and spray seals are not currently standard practice in the Northern Territory
Department of State Growth Tasmania (DSG)	Adopts Victorian guidance

Source: Adopted from Austroads Technical Report AP-T359-2021.

4.1.3 Crumb Rubber Requirements

Within the context of sprayed sealing applications, there is a consensus from all Australian jurisdictions that crumb rubber must meet, or otherwise exhibit, similar requirements to a Size 30 mesh crumb rubber as specified by ATS 3110 (Table 4.2). Subsequently, all jurisdictions have adopted the requirement that crumb rubber modified bitumen satisfies the specifications of a S45R, S15RF or a S18RF class binder.

Table 4.2: ATS 3110 requirements for Size 30 crumb rubber

Property	Test method	Value
Grading (% passing)	AGPT/T143	
2.36 mm		100
1.18 mm		100
600 µm		60 (minimum)
300 µm		20 (maximum)
Maximum particle length	AGPT/T143	3
Bulk density	AGPT/T144	Report
Water content (% maximum)	AGPT/T143	1
Foreign materials (other than iron) (% maximum)	AGPT/T143	0.1
Foreign materials (iron) (% maximum)	AGPT/T143	0.1
Material source	–	Crumb rubber must be processed from waste tyres generated in Australia by a supplier accredited with Tyre Stewardship Australia or another organisation approved by the Principal.
Presence of other materials	–	Must be free from cord, wire, fluff and other deleterious material.

There is currently an ongoing discussion for a national consensus on the requirements for crumb rubber to be used within asphalt applications. Victorian, NSW and WA specifications state or otherwise imply that a size 30 crumb rubber conforming to ATS 3110 is suitable for use within asphalts, whereas AfPA and Queensland guidance suggest a more relaxed grading requirement would be suitable. ATS 3110 does not include crumb rubber binder grades suitable for use in asphalt. As a result, two Australian jurisdictions and AfPA recently developed specifications for crumb rubber binders for use in asphalt which were based on tests and testing protocols used in Arizona and California. These testing protocols differ from those used on crumb rubber for sprayed seals. The main aim of Austroads project APT6173 (Austroads 2021b) was to ascertain whether the crumb rubber binders that have been used and trialled in asphalt could be specified so that they were consistent with the current ATS 3110 specified properties of crumb rubber binders used in sprayed seals.

For both sprayed seals and asphalt applications, CR is typically added in quantities of 10–20% of the binder and up to 2.5–3% by mass of mixture via a dry process. The exact quantities and limits of crumb rubber are dependent on:

- the specific gradings and blend properties of each lot
- the source and properties of the bitumen
- the method of incorporation particularly the mixing temperature and overall mixing/agitation effort.

4.1.4 Performance Benefits of Crumb Rubber in Asphalt

Extensive research both domestically and internationally has been conducted in assessing the performance of CR modified asphalt. Work currently being done in Australia is focused on collating and harmonising standard practice.

The Austroads report *National Specification for Crumb Rubber Binders in Asphalt and Seals* (Austroads 2021b) contains an in-depth literature review into the performance benefits of utilising crumb rubber in asphalt. Key learnings include:

- reduction in traffic noise
- CR modified binders more appropriate for use in gap graded asphalt (GGA) and open graded asphalt (OGA) as these mixes have sufficient voids within the aggregate skeletons
- improved fatigue cracking resistance due to higher binder content and elasticity
- improved oxidation resistance
- improved rutting resistance
- potential to reduce asphalt layer thickness when compared to conventional binders
- terminal blends do not provide the same performance increases as wet and dry blended mixes. They are more appropriate for use in emulsions and dense graded asphalt (DGA).

4.1.5 Performance Benefits of Crumb rubber in Spray Seals

Austroads (2021b) also contains an in-depth literature review into the performance benefits of utilising CR in sprayed seals. Key learnings include:

- increased aggregate retention
- reduction in rate of oxidisation (hardening)
- reduced risk of low severity fatigue cracking
- the increased moduli and softening point in conjunction with the decreased rate of oxidation have made CR modified bitumen an attractive option for strain alleviating membranes (SAM), stress alleviating membrane interface (SAMI), high-stress seals (HSS) or extreme stress seals (ESS) in high-risk areas such as tight curves, braking zones or roads with high volumes of heavy vehicles.

4.1.6 Challenges for Use of Crumb Rubber in South Australia

Potential issues that may restrict the use of CR within asphalt and sprayed seals include:

- Local supply. There are currently no CR producers in SA. This is predominantly due to the small market for CR in SA. End-of-life tyres are sent to Victoria for processing into CR and then sent back to SA.
- As CR increases viscosity and softening points, spraying, and mixing temperature of binders and asphalt need to be higher introducing a practical and environmental challenge.
- Storage stability of crumb rubber binders. CR particles may segregate and settle within binder storage tanks if not properly heated and agitated causing a significant issue in spraying/pouring and cleaning. This is particularly a problem for long hauls; however, this issue can be mitigated with mobile onsite blending if available.
- CR particles may degrade if stored at high temperatures for extended periods. As with storage stability, this can be mitigated with onsite blending.
- Utilising CR may increase overall construction costs as the materials do not have mature supply chains and higher temperatures increase expenditure on energy. The cost of CR binder compared to a virgin binder is typically around 30% (variable depending on market). Furthermore, the addition of CR also typically increases the amount of binder required in an asphalt mix and hence increased cost of asphalt mix. This cost is dependent on the type of asphalt mix and percentage CR.
- There is a lack of specifications for crumb rubber asphalt mixes, particularly those suitable for local government type roads (i.e. low trafficked).
- There is a lack of national consensus on the grading of crumb rubber to be used within asphalt, including clarifying any difference in requirements for crumb rubber to be incorporated via the wet and dry process or as a terminal blend.

4.1.7 Occupational, Health and Safety (OHS)

Fuming is a common OH&S concern when using crumb rubber binders. The Victorian Department of Transport TR 220, East Boundary Road crumb rubber asphalt trial emissions monitoring report indicated that crumb rubber modified asphalt trials exhibited minimal negative impacts from harmful fumes and emissions relative to conventional asphalt mix controls. However, literature contained within the Denneman (2015) on *Optimising the use of Crumb Rubber Modified Bitumen in Seals and Asphalt* (Year 1 – 2014–15) report highlight studies that suggest there may be an increased risk of harmful emissions from CRM binders relative to conventional bitumen. It was noted that with the increased use of warm mix additives (WMAs), the overall lower temperatures of asphalt construction will reduce the total volumes of emissions, improving worker safety.

4.1.8 Field Trials

Recent and ongoing field trials of crumb rubber modified (CRM) asphalt across Australia of select sites are summarised in Table 4.3.

Table 4.3: Summary of select crumb rubber modified asphalt field trials

Company	Location	Description	Reference
Topcoat Asphalt	Stanlake Avenue, St Marys Adelaide, SA	December 2018, a 335 m stretch of the innovative road surface was laid at Stanlake Avenue, St Marys, in the Adelaide satellite municipality. The trial asphalt used to resurface Stanlake Avenue recycled 850 used tyres or the equivalent of tyres from three cars for each house on Stanlake Avenue.	Institute of Public Works Engineering Australia (2018)
	City of Mitcham City of Port Adelaide Enfield City of Campbelltown City of Onkaparinga City of West Torrens City of Salisbury Adelaide, SA	May 2020, The Topcoat trial used the equivalent of around 3,400 passenger vehicle tyres or more than 20,000 kilograms of crumb rubber collected in South Australia.	Tyre Stewardship Australia (2020)
Downer	Emu Mountain Rd, Peregian Beach Sunshine Coast, QLD	February 2017, crumb rubber demonstration project using CRM OGA was constructed by TMR and Downer Group. The aim of the demonstration project was to evaluate the constructability, performance and health and safety aspects of CRM OGA in Queensland. Three asphalt mixes were tested. Emissions monitoring was also undertaken.	Grobler et al. (2017)
SAMI Bitumen	Nielsens Road, Carrara Gold coast QLD	Trials involved laying open-graded asphalt surface in three sections. The first section involved placement of a conventional polymer-modified open-graded asphalt as the control section. The second section included CRM binder open-graded asphalt and the third was CRM binder open-graded asphalt with warm mix additives. Roughly 100 tonnes of each material were laid.	Roads & Infrastructure (2018)
Downer group	Kwinana Freeway WA	March 2019, 3.8 km of Kwinana Freeway and Marmion Avenue used for crumb rubber trials. Crumb rubber was used in OGA. The equivalent of over 4,000 car tyres recycled, instead of going into landfill.	Main Roads Western Australia (n.d.)
	City of Sawan Perth, WA	West Swan Road, 200 tonnes of Crumb Rubber asphalt was laid which is made from over 250 light truck tyres.	City of Swan (2019)
Boral, Fulton Hogan, and Downer	East Boundary Road, Bentleigh Melbourne, VIC	March 2020, the trial included four different crumb rubber asphalt mixes (DGA, GGA and SMA) and two control sections to provide a basis for the comparison of the new mixes. (See section 4.5.1)	Patrick (2020)
Fulton Hogan	Church St, Keysborough	Low traffic crumb rubber asphalt was laid which was made of 128 recycled tyres. (see section 4.5.2)	ARRB (2021b)

Company	Location	Description	Reference
	Melbourne VIC		
Fulton Hogan	Meander Valley Council TAS	The trial diverted 393 tyres from landfill and will reuse almost 91,000 glass bottles.	Meander Valley Council (2020)

4.2 Recycled Crushed Glass

4.2.1 Incorporation of Recycled Crushed Glass into the Pavement Structure

RCG can be incorporated in asphalt and pavement layers as an aggregate or fine sand material. It is added to the asphalt mix or aggregate blend as other aggregates would be.

The advantages of using recovered glass in road applications can include utilising large volumes of material and the ability to utilise materials containing contaminant levels higher than those required for packaging production (Allan 2019). In addition, RCG has been reported to have resistance due to friction that helps to reduce the runoff from base courses (Stroup-Gardiner & Wattenberg-Komas 2013).

4.2.2 Standards and Specifications

In Australia, different states and territories have specified the use of RCG for various road infrastructure applications including both pavement and non-pavement applications. Pavement applications include subbase, base, wearing course and surfacing. Table 4.4 summarises the limits for using RCG in various pavement applications, specified by Australian road agencies.

Table 4.4: RCG in pavement applications: Australian standards and specifications

Layer	State	Road agency	Application	Max limit (% by mass)	Reference
Asphalt	NSW	TfNSW	Asphalt (2) (wearing course)	2.5	TfNSW D&C R116 TfNSW D&C R117 TfNSW D&C R118 TfNSW D&C R121
			Asphalt (2) (other than wearing course)	10	
		Lake Macquarie City Council	Asphaltic concrete (roadways)	30 (1,2)	Lake Macquarie City Council (2022)
	VIC	DoT	Intermediate and base course layers in dense-graded asphalt	Not specified(5)	VicRoads Section 407
	QLD	TMR	Dense graded asphalt layers (other than surfacing)	10	MRTS30
			Dense graded asphalt surfacing	2.5	MRTS30
	WA	MRWA	Not specified		
	SA	DIT	Not specified		
	TAS	DSG	Aligned with DoT		
	ACT	TCCS	Not specified		
	NT	DIPL	Not specified		
Base and subbase	NSW	TfNSW	Granular base and subbase	10	TfNSW D&C 3051
			Slab replacement work for	15 (1)	TfNSW QA 3201

Layer	State	Road agency	Application	Max limit (% by mass)	Reference
			concrete pavements		
		IPWEA [2]	Road base & subbase (Classes R1 & R2)	10	Institute of Public Works Engineering Australia (2010)
		Lake Macquarie City Council [2]	Lean mix concrete subbase	30 [1]	Lake Macquarie City Council (2018)
			Plain and reinforced concrete base	30 [1]	
	VIC	DoT	Granular base	5 to 10 [3]	VicRoads TN 107, VicRoads RC 500.02
			Granular subbase	15 to 50 [4]	VicRoads TN 107, VicRoads RC 500.02
	QLD	TMR	Unbound pavements (subtypes 2.3, 2.4 and 2.5)	20	TN193 1, MRTS05
	WA	MRWA	Not specified		
	SA	DIT	Not specified		
	TAS	DSG	Aligned with DoT		
	ACT	TCCS	Granular base and subbase	10	MITS04
	NT	DIPL	Not specified		

1. Of total fine aggregate.
2. Not a road agency.
3. 5% and 10% allowed in Class 1 and Class 2 crushed rock, respectively.
4. 15% and 50% allowed in Class 3 and Class 4 crushed rock, respectively.

4.2.3 Recycled Crushed Glass Requirements

RCG aggregates need to meet certain requirements to be used in asphalt and pavement applications. The specific criteria vary depending on the application. However, there are generally physical and chemical properties that need to be determined for RCG and checked against the relevant jurisdictional specifications. The physical and chemical properties together with the test method(s) conducted to determine the properties are presented in Table 4.5 and Table 4.6 respectively.

Table 4.5: Test methods to evaluate the physical properties of RCG

Property	Test method
Particle size distribution	AS 1141.11.1 AS 1141.12
Density	AS 1141.4 (R2014)
Dry particle density	AS 1141.5 (R2016)
Water absorption	AS 1141.5 (R2016)

Table 4.6: Test methods to evaluate the chemical properties of RCG

Chemicals and other attributes	Test method
Mercury	EPA SW-846 Method 7471B
Cadmium	EPA SW-846 Method 6010C
Lead	
Arsenic	
Chromium (total)	
Copper	

Chemicals and other attributes	Test method
Molybdenum	
Nickel	
Zinc	
Total organic carbon	NEPC Schedule B Method 105 (Organic Carbon)
Electrical conductivity	NEPC Schedule B Method 104 (Electrical Conductivity)

4.2.4 Occupational, Health and Safety (OHS)

Similar to any other recycled material, environmental implications of using RCG in the transport infrastructure sector must be assessed. The environmental and OHS risks associated with the use of RCG that need to be considered are as follows:

- **Abrasion:** General recommendations for handling natural construction aggregates, such as the use of appropriate personal protective equipment (PPE), apply to RCG aggregates. The risk of skin cuts or penetration hazards for RCG aggregates smaller than 19 mm has been reported to be similar to that of conventional crushed aggregates (Shin & Sonntag 1994)
- **Airborne contamination:** RCG dust can cause respiratory problems as well as skin, ear and eye irritation. However, taking safety measures such as using suitable PPE and dust control training will mitigate the risks.
- **Chemical contamination:** The leachates from RCG used in pavement layers can potentially result in contaminating the soil and groundwater. The potential contamination through leachates, the extent of which is dependent on parameters such as site geology or groundwater, should be assessed to be below those specified by relevant authorities such as EPA.

4.2.5 Field Trials

Table 4.7 summarises local government authority (LGA) implementation trials that have used RCG in transport infrastructure in Australia.

Table 4.7: RCG field trials

Company	Trial type	Location	Details	Reference
	Asphalt	Waverly Council, NSW	Two 100 m pavements were constructed in its local road network incorporating approximately 15 tonnes of RCG in the pavement materials. The council used 7.5 tonnes in the asphalt for one trial and another 7.5 tonnes in the concrete pavement, using a 56% glass-sand replacement, for the other trial	Department of Sustainability, Environment, Water, Population and Communities (2011)
Fulton Hogan		City of Greater Geelong, VIC	March 2021, RCG was used in the asphalt base layer at a content of 3%. A total of approximately 50 tonnes of RCG were utilised in the construction of two roads	City of Greater Geelong (2021)
Downer		Craigieburn, VIC	For every kilometre of road, 200,000 recycled plastic bags, 63,000 recycled glass bottles, toner from 4500 used printer cartridges and tonnes of reclaimed asphalt pavement (RAP), with a 20% RAP content, were used A similar blend was trialled on roundabouts in ACT in 2019, where 800 plastic bags, 300 glass bottles, 18 printer toner cartridges and 250 kg of RAP were used in one tonne of asphalt	Sustainability Victoria (2018), Roberts (2019)
Alex Fraser		Richmond, VIC	A trial to use approximately 7,300 plastic bottles and 55,000 glass bottles to repave two local roads resulted in the diversion of almost 100 tonnes of waste from landfills.	Alex Fraser Group (2018)

Company	Trial type	Location	Details	Reference
Alex Fraser		City of Bayside, VIC	Utilised more than 100,000 plastic bottles and 3.4 million glass bottles for resurfacing residential streets in 2019.	Keys (2019)
Alex Fraser and Suncoast Asphalt		Maribyrnong, VIC	Utilised approximately 3,100 plastic bottles and 23,400 glass bottles to repave a street. This resulted in the diversion of approximately 40 tonnes of waste from landfills (Green Roads 2020).	Green Roads (2020)
		Gold Coast, QLD	410 m road was constructed, where 3.5 tonnes of recycled plastic, 200 tonnes of crushed glass and 300 tonnes of RAP were used.	Echo (2019)
Downer	Granular materials	Adelaide, SA	This was the first trial in SA to use RCG in the construction of transport infrastructure. A 5% RCG content was selected to be incorporated into the subbase layer of a heavy vehicle bypass road. This resulted in the utilisation of approximately 8.5 tonnes of RCG.	Department of Infrastructure and Transport (n.d.)
		Lockhart Shire Council, NSW	In trials on using RCG in footpaths, drainage works and unsealed road bases, an RCG to gravel ratio of 1:6 was chosen for the unsealed road base. It was found out that blending gravel, RCG and water using a mobile pugmill resulted in better efficiency in the placement of materials. The trials have been reported to be successful so far and resulted in the uptake of approximately 5000 tonnes of RCG in the construction of transport infrastructure.	Lockhart Shire Council (2015)

4.3 Recycled Plastics

4.3.1 Types of Plastic Used in Pavements

Unlike recycled glass and crumb rubber, plastic is not a single commodity, rather it is a broad term that encapsulates many different types of polymers. Therefore, at the centre of this section is discussion of the types of plastics that can be used in asphalt and sprayed seals. Then properties of such products are related to their manufacturing processes. Laboratory testing methods are also benchmarked with available polymer types used in asphalt or sprayed seal applications. Unlike crumb rubber products (S45R or S15R), plastic products are recognised as proprietary products under a trading name. Therefore, a list of available proprietary products is discussed in relation to the type and composition of plastics.

Plastics are the subclass of polymers that can be classified as thermoplastics, thermosets, or thermoplastic elastomers. Depending on the type of plastic, they have a varying effect on the final characteristics of the pavement. A typical example of polymers in pavements is the use of polymer modified bitumen (PMB) to enhance the durability (rutting and fatigue resistance) of the pavement. For instance, thermoplastic polymers such as Ethylene-vinyl acetate (EVA) improve the stiffness modulus and rutting resistance, thermoplastic elastomers such as SBS provide better elasticity and resistance to permanent deformation, thermosets (rubber) improve fatigue performance, provide excellent adhesion and resistance to deformation.

The selection of polymer type to achieve specific characteristics of the pavement is a crucial parameter in pavement design. Currently, many different types of polymers are used to modify bitumen of which EVA, Styrene-butadiene-styrene (SBS), Acrylonitrile butadiene styrene (ABS) and styrene-butadiene rubber (SBR) are most common. These polymers can be replaced with recycled plastics (polymers) to achieve higher environmental benefits and the same level of performance. Therefore, the selection of recycled plastics as a replacement for virgin polymer modifiers should be made on vigilant performance and durability criteria. Austroads report AP-R648-21 recommends the possible inclusion of eight types of recycled plastics streams into asphalt based on different factors such as price, volume, recycling rate and national availability (Austroads 2021c). The recycled plastic list comprises LDPE, Linear low-density polyethylene (LLDPE), HDPE, polypropylene (PP), commingled PE/PP, commingled LLD/LD/HD PE, coloured PET and ABS. The chemical compatibility of a specific plastic type in the asphalt mix plays a fundamental role throughout the life of the mix. Therefore, any material added into bitumen or asphalt must not affect the life-cycle cost of the project.

4.3.2 Commonly Used Plastics in Proprietary Products

There are many proprietary recycled plastic products available for road surfacing. Some of these products are a combination of recycled plastic with other recycled materials, for recycled plastic bags with printer ink toner, recycled glass, fly ash or rubber. A few commonly available proprietary products are listed in Table 4.8.

Table 4.8: Details of proprietary products containing recycled materials.

Company	Proprietary product	Ingredients
Alex Fraser	PolyPave ™	Incorporates HDPE (waste plastic bottles) in a binder
Boral	INNOVO ®	Plastic bottles, glass, RAP
		Asphalt containing alternative materials of choice that could include recycled glass, recycled plastic, steel slag, toner through wet, dry and hybrid process
		Plastic bottles, car tyres, glass bottles, RAP
Close The Loop	TonarPlas™ (additive)	Soft plastic glass bottles, waste toner and RAP through the hybrid process.
	TonerPave™ (additive) TonerSeal™ (additive)	Bitumen modified with TonerPlas™ (Toner polymer, LDPE/LLDPE).
Downer	Reconophalt™	Recycled materials i.e. crumb rubber, soft plastics, waste toner, glass, RAP etc.
Fulton Hogan	PlastiPhalt ®	Waste plastic, crushed glass and RAP

It is worth noting that the compositions of each product under the same trade name might not be consistent. There is no such regulation or standards available to ensure the consistency of the product for the same application i.e. the proprietary products are badges that encompass any of the recycled materials. This could have a potentially adverse impact on the performance of roads as the same material under the same trade name could differ significantly in performance.

4.3.3 Incorporation of Recycled Plastics into the Pavement Structure

In asphalt, RP can be used as an aggregate extender, binder extender and binder modifier. In sprayed seals, RP is primarily used as a binder modifier.

RP as an aggregate extender means replacing some of the virgin aggregates in the asphalt mixture using the dry process. During the manufacturing process, some of the plastic pellets may melt into the mixture however, most of the plastic pellets remain as a solid aggregate. The size, form and strength of recycled plastic pellets may have an impact on the final performance and workability of the asphalt.

RP can be added to the asphalt as a binder extender through the dry or wet process. However, the recycled plastics should have a melting point lower than the mixing temperature to ensure the sufficient mixing of the binder with plastics. The intent of the binder extender is to modify the properties of the binder.

RP as a binder modifier should have the same effect as those for polymer modifiers. Recycled plastics completely melt into the binder and enhance their performance. This can be achieved through a hybrid or wet process. In the case of the hybrid process, the melting point of plastic should be lower than the mixing temperature.

Mixing method

Dry process

This is a method of adding solid recycled plastic pellets to asphalt into the direct mixing chamber of the asphalt plant. RP added through a dry process does not alter the chemical properties of the mixture, instead, the interaction is purely mechanical.

Wet process

In the wet process, the binder is first blended with the recycled plastic at a specific temperature and then mixed with hot aggregates. Generally, the mixing temperature for the wet process is in the range of 160–180°C. The recycled plastics content in the modified bitumen usually ranges from 3 to 10% by weight of bitumen (depending on type and properties of RP).

Hybrid process

For the hybrid process, the aggregates are heated first then the recycled plastic and bitumen are added to the hot aggregates. Plastic creates a thin layer covering the aggregates and then is mixed with a binder. The final performance of the asphalt mixture depends on the degree of interaction between plastic and bitumen.

4.3.4 Standards and Specifications

The use of RP as a binder modifier involves understanding the compatibility complexities of bitumen and modifiers. Recycled plastic modified binders should serve the same purpose as other modified binders. Therefore, the specifications and standards applicable for polymer modified binders should be followed and considered as a baseline for recycled plastic modified binders. Currently, Austroads technical specification ATS 3110 is widely adopted for polymer-modified bitumen (Austroads 2020. ATS 3110 applies to both asphalt and sprayed seal applications.

Currently, many proprietary products are used by suppliers and contractors in the recycled plastic asphalt or sprayed seal markets. These proprietary products can be incorporating different waste streams and be manufactured through different processes. Due to the inconsistency in the product manufacturing and lack of information on their compliance, it is difficult to understand the performance and durability of the product. This is a high risk for councils and the durability of their assets in the long run. Therefore, it is recommended that during the procurement process suppliers should verify compliance of their proprietary products with ATS 3110 and councils should ensure that the product is validated against those tests specified in ATS 3110 (Austroads 2020).

There are no state-based specifications available for recycled plastics in asphalt or sprayed seals. Few state road agencies are working to fill this gap and create a streamlined approach for the use of recycled plastics on roads. There is an opportunity for councils to step up and initiate the development of specifications for the use of recycled plastics into their network that suit their needs.

4.3.5 Occupational, Health and Safety (OHS)

The addition of recycled plastics into bitumen increases the stiffness of the binder thus posing issues with the workability of typical DGA asphalt manufactured at 165 -170°C with C320 bitumen. An increase in the temperature may improve the workability but also increase the emission of fumes and affect the compatibility of recycled plastic with bitumen. Storage stability of recycled plastic modified bitumen is still not fully understood therefore, it is important to avoid prolonged storage time of bitumen before mixing with aggregates. In applications where recycled plastic is mixed chemically with other products to enhance its properties such as bitumen modification or where a very small quantity of recycled plastic is used i.e. 0.2–0.8% in asphalt, generation of microplastics is very unlikely. However, in the chemical modification of products with recycled plastics, special care must be taken to avoid fuming and the emission of harmful chemicals.

Environmental degradation of plastics is a major concern when it comes to multiple recycling of plastics into new products. The UV radiations in Australia is extreme and likely to give considerable ageing to plastic products and plastic containing products. Increased ageing and embrittlement of bitumen or asphalt containing recycled plastics could be a concern. The degradation of recycled plastics could lead to the generation of microplastics or leachates during their functional life.

4.3.6 Field Trials

Table 4.9 summarises various asphalt trials incorporating recycled plastic.

Table 4.9: Summary of select recycled plastics modified asphalt field trials

Company	Location	Plastic type	Description	References
Alex Fraser	Melbourne, VIC	PolyPave™ incorporates HDPE (waste plastic bottles) in a binder	February 2020 – Maribyrnong City Council worked with Alex Fraser to resurface Harriet Street in Seddon with Green Roads PolyPave™ Recycled materials contained 3,100 two-litre plastic bottles and 23,400 glass bottles.	
	Melbourne, VIC		September 2018 – Stanley and Margaret Streets in Richmond repaved with PolyPave™, containing recycled glass, asphalt and HDPE plastic (hard plastic/bottles) amounting to almost 100 tonnes of recycled waste.	GreenRoads (2018)
Alex Fraser and Suncoast Asphalt	Brisbane QLD		October 2019 – Redland City Council, Princess Street, Cleveland. PolyPave™. The trial claims to incorporate 90 000 plastic bottles (HDPE), or the equivalent of nine months of kerbside collection from the local street involved into the 1 km project.	Redland City Council (2019)
	Brisbane QLD		December 2019 – The Moreton Bay Regional Council worked with Alex Fraser and Suncoast Asphalt to resurface six Caboolture streets with Green Roads PolyPave™; asphalt product containing reclaimed plastics (recycled plastic milk and shampoo bottles.	Green Roads (2019)
Boral	Adelaide, SA	INNOVO® (included plastic bottles and RAP) *INNOVO® is Boral's asphalt containing alternative materials of choice that could include recycled glass, recycled plastic, steel slag, toner through wet, dry and hybrid processes.	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 450,000 600 ml plastic bottles, which laid end-to-end these bottles would stretch 60 kilometres.	Boral (2022)
	Bendigo, VIC	INNOVO® (plastic bottles, glass, RAP)	Recycled plastic, local recycled crushed glass, and recycled asphalt pavement (RAP) were included in the paving of the entrance to the City of Greater Bendigo's landfill in Eaglehawk in March 2020.	
	Perth, WA	INNOVO® (plastic bottles, car tyres, glass bottles, RAP)	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. Boral used the 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.	

Company	Location	Plastic type	Description	References
	Newcastle, 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.	
Downer and Close the Loop	Brisbane QLD	TonerPave™ (toner polymer)	2016 – James Street, New Farm. Brisbane City Council.	Roberts (2019), Sustainability Victoria (2018), Downer (2018)
	Brisbane QLD	TonerSeal™ (toner polymer)	June 2016 – Moreton Bay Regional Council.	
	ACT and VIC	TonerPlas™ (soft plastic glass bottle, waste toner and RAP) through the hybrid process.	March 2019 – 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 2018 – trial in Craigieburn, Victoria used 4,500 printer cartridges, 50 tonnes RAP, glass and LDPE recycled plastic bags. Downer has undertaken recycled materials trials in multiple local governments across ACT, Victoria, NSW and SA	
Downer	City of Onkaparinga SA	Reconophalt™	December 2018 – approximately 139,000 plastic bags and packaging and 39,750 glass bottle equivalents were diverted from landfill.	City of Onkaparinga (2018)
Fulton Hogan	Gold Coast QLD	PlastiPhalt ® (waste plastic, crushed glass, and RAP)	June 2019 – The City of Gold Coast, 410 m 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)
	Adelaide, SA		Castle Road in Glanville was resurfaced with PlastiPhalt®, a proprietary asphalt product developed and manufactured by Fulton Hogan. Approximately 110 tonnes of PlastiPhalt® were laid using waste plastic and 20% RAP.	FultonHogan (2020)
MacRebur	Brisbane QLD		May 2018 – Brisbane City Council, Allan St, Kedron. One truckload (approx. 20 tonnes) of each mix: MacRebur products MR6 & MR10 were used for the trials.	Austroads (2019)

Source: Adapted from: ARRB (2021a)

4.4 Testing and Evaluation

To ensure consistency in performance and meet the criteria for OHS and environmental standards, the raw materials and final pavements containing recycled materials should comply with a set of standards and specifications adopted across the country. There is currently no streamlined testing and evaluation framework available for the safe and effective use of recycled materials in pavements. This section provides a potential testing and evaluation regime that can be adopted by South Australian road agencies when using recycled materials in pavement applications. This section provides the list of test methods for raw materials and final pavement containing recycled materials. Test methods and standards outlined in this section will be part of the assessment framework that will be developed later in this project.

4.4.1 Raw Materials

RCG, RP and CR as raw materials for aggregate replacement should meet the aggregate testing and standard requirements to be considered for the replacement of virgin materials (Table 4.10). RCG should be free from ceramics, cathode ray tubes, fluorescent light fittings or laboratory glassware.

Table 4.10: Test methods to assess raw materials

Test method	Standard
Sampling and testing aggregates	AS 1141
Water absorption and apparent particle density	AS 1012.21 (R2014)
The particle density of fine aggregate	AS 1141.5 (R2016)
Particle density and water absorption of coarse aggregate	AS 1141.6.2 (R2016)
Grading of aggregates	AS 1141.11.1
Organic impurities	AS 1141.34
Sugar impurities	AS 1141.35
Fine particle size distribution	AS 1141.19

Source: Lim et al. (2020).

4.4.2 Final Product

The mechanical properties of the pavement structure should meet the following default standards. The material supplier must provide a test certificate of the raw materials to the purchaser. Table 4.11 outlines the standard test methods for engineering properties e.g. shrinkage, strength, viscosity, and resilient modulus.

Table 4.11: Mechanical properties test methods

Test method	Standard
Shrinkage	AS 1012.13
Unconfined compressive strength	AS 1141.51
Methods of testing bitumen and related roadmaking products	AS 2341
Viscosity by flow through vacuum capillary tubes	AS/NZS 2341.2
Methods of sampling and testing asphalt	AS 2891
Bitumen content	AS/NZS 2891.3.1
Resilient modulus of asphalt	AS/NZS 2891.13.1
Methods for the preparation and testing of stabilised materials	AS 5101
Cement content	AS 5101.3.3 (R2017)
Soil treatment	AS 1289

Source: Lim et al. (2020).

Recycled plastic and crumb rubber modified bitumen should comply with specifications and limits outlined in Table 4.12 and Table 4.13 for their corresponding polymer modified bitumen applications in asphalt and sprayed seals i.e. the chemical composition of recycled plastic modified bitumen such as polymer modified bitumen S10E should comply with test limits for S10E. However, additional information on the percentage of RP and CR in bitumen could be useful in this regard.

Table 4.12: Properties of polymer modified binders for asphalt applications

Test method	Binder property	A35P	A25E	A20E	A15E	A10E
AS/NZS 2341.4 or AGPT/T111(1)	Viscosity at 165 °C (Pa.s) max.(1)	0.6	0.6	0.6	0.9	1.1

AGPT/T122	Torsional recovery at 25 °C, 30 s (%)	6–21	17–30	38–70	55–80	60–86
AGPT/T131	Softening point (°C)	62–74	52–62	64–95	82–105	88–110
AGPT/T125	Stress ratio at 10 °C min.	TBR (2)	TBR	TBR	TBR	TBR
AGPT/T121	Consistency 6% at 60 °C (Pa.s) min(3)	1,000	400	500	900	1,000
AGPT/T121	Stiffness at 25 °C (kPa) max.	120	45	35	30	30
AGPT/T108	Segregation (%) max.	8	8	8	8	8
AGPT/T112	Flash point (°C) min.	250	250	250	250	250
AGPT/T103	Loss on heating (%mass) max	0.6	0.6	0.6	0.6	0.6

1. L series Brookfield is recommended together with spindle SC4-31. The shear rate involved in determining viscosity by AS/NZS 2341.4 and AGPT/T111 must be calculated and recorded.
2. 'TBR' throughout = to be reported.
3. Consistency 6% at 60 °C of A25E must be determined using mould B (breakpoint of 5 mm and a test speed of 1.5 mm/s). Other grades must be tested using mould A (breakpoint of 10 mm and a test speed of 1 mm/s).

Source: Adapted from Austroads (2020).

Table 4.13: Properties of polymer modified binders for sprayed sealing applications

Test method	Binder property	S10E	S15E	S20E	S25E	S35E	S45E(1)
AS/NZS 2341.4 or AGPT/T111(2)	Viscosity at 165 °C (Pa.s) max	22–50	32–62	38–70	55–80	16–32	25–55
AGPT/T122	Torsional recovery at 25 °C,30 s (%)	22–50	32–62	38–70	55–80	16–32	25–55
AGPT/T131	Softening point	48–64	55–75	65–95	82–105	48–56	55–65
AGPT/T125	Stress ratio at 10 °C min	TBR(3)	TBR(3)	TBR(3)	TBR(3)	TBR(3)	TBR(3)
AGPT/T121	Consistency 6% at 60 °C (Pa.s) min.(4)	300	400	500	900	250	800
AGPT/T121	Stiffness at 15 °C (kPa) max.	140	140	NA (5)	NA	180	180
AGPT/T121	Stiffness at 25 °C (kPa) max.	NA	NA	35	30	NA	NA
AGPT/T132	Compressive limit at 70 °C, 2 kg (mm) min.	NA	NA	NA	NA	NA	0.2
AGPT/T108	Segregation (%) max.	8	8	8	8	8	8
AGPT/T112	Flash point (°C) min.	250	250	250	250	250	250
AGPT/T103	Loss on heating (% mass) max.	0.6	0.6	0.6	0.6	0.6	0.6

1. Class S45R binder must be manufactured by the incorporation of crumb rubber derived from used vehicle tyres.
2. L series Brookfield is recommended together with spindle SC4-31, except in the case of S45R where spindle SC4-29 is recommended. The shear rate involved in determining viscosity by AS/NZS 2341.4 and AGPT/T111 must be calculated and recorded.
3. 'TBR' = to be reported.
4. Consistency 6% at 60 °C of S10E and S35E must be determined using mould B (breakpoint of 5 mm and a test speed of 1.5 mm/s). Other grades must be tested using mould A (breakpoint of 10 mm and a test speed of 1 mm/s).
5. 'NA' throughout indicates that the property is considered not applicable for that PMB class.

Source: Adapted from Austroads (2020).

4.5 Performance Monitoring

Ongoing performance monitoring of pavements is an important component of road asset management. Long-term performance monitoring of pavements containing recycled materials provides useful data to road managers that could play a key role in increasing the use of recycled materials in roads and making it standard practice. This section provides an overview of the recommended tests needed to monitor the performance of recycled materials in road infrastructure. The applicability of these tests is supported by two of ARRB's crumb rubber field trial case studies.

With the increasing complexity of using recycled materials and a lack of consistency in field trials, it is of foremost importance that the performance monitoring data should be collected frequently and at regular intervals. The overall functional behaviour of pavements is their ability to provide a smooth, comfortable, and safe ride. The functional performance of the pavement can be measured in terms of its roughness, cracking, rutting and texture.

Councils usually conduct digital condition surveys every four years to assess the condition of the road network to help prioritise capital investment programs. The data, collected by a survey vehicle, generally consists of crack detection mapping and measurement, ravelling, potholes, roughness, rutting, surface texture and stripping. This data is uploaded into a pavement management system for analysis and prioritisation of works.

4.5.1 Case Study 1: Crumb Rubber Demonstration Trial – East Boundary Road, Victoria

A crumb rubber asphalt demonstration trial was constructed at East Boundary Road, East Bentleigh, Victoria in March 2020. It was a collaborative project organised by Tyre Stewardship Australia (TSA), Vic DoT, and the ARRB.

Objective

Ongoing monitoring of the trial site was established to collect data regarding in situ performance, including cracking, roughness, rutting, texture and skid resistance.

Methodology

The trial included four different crumb rubber asphalt mixes and two control sections to provide a basis for the comparison of the new mixes (Table 4.14). The trial site is located at East Boundary Road, East Bentleigh, Victoria, between Centre Road and South Road (Figure 4.3). East Boundary Road features a parking lane, and two through lanes in each direction, separated by a median. The trial encompassed all three lanes of the southbound direction of East Boundary Road.

Table 4.14: Mix design details of each trial section

Section	Chainage		Mix design
	Start (m)	End (m)	
Section 1	0	200	Downer 10 mm DGA (20% crumb rubber)
Section 2	200	447	Boral 10 mm SMA-H (control)
Section 3	447	647	Fulton Hogan 14 mm GGA (18% crumb rubber)
Section 4	647	847	Boral 10 mm SMA-N (10% crumb rubber)
Section 5	847	1,200	Downer 10 mm SMA-N (control)
Section 6	1,200	1,450	Boral 10 mm SMA-N (1% crumb rubber dry mix)

Figure 4.3: Map of trial site sections

Source: Patrick (2020).

Pre-trial condition assessment

A detailed condition assessment of the trial site was completed before construction. Investigations of the existing pavement structure and the behaviour of the surface were undertaken to identify factors that may influence the ongoing performance of the trial asphalt mixes and to guide the required site preparations.

The trial site was assessed by the following methods:

- pavement strength evaluation (PaSE) – the VicRoads PaSE vehicle evaluated the pavement strength
- ground-penetrating radar (GPR) – GPR testing was completed to determine the structure of the existing pavement, in particular the asphalt layer thickness
- coring at seven locations across the site
- crack detection using the ARRB network survey vehicle (NSV). Roughness, rutting and texture data was collected as part of this process
- visual assessment of cracking and rutting to identify areas of patching.

Post-trial condition assessment

A survey of the trial site (post-construction) was conducted by the ARRB NSV. The site will continue to be monitored by the NSV at 6, 12, 18 and 24-month surface life. Initially, data was collected at one-month intervals for cracking, rutting, roughness, texture and skid resistance.

The initial results showed an improvement in condition for all measures with the new surface in place. The short- and longer-term outcomes of these assessments will inform the Department of Transport how these products may be incorporated into its specifications, which will encourage their widespread use and an improvement in sustainable road construction practice.

Pre-trial, the cracking was consistent throughout the site. One month after the trial, the new surface has eradicated the surface cracking. Furthermore, the amount of rutting reduced considerably throughout the extent of the trial sections. After 2 months, the measured skid resistance exceeds the DoT investigatory level throughout the entire section, indicating good performance.

4.5.2 Case Study 2: Low Traffic Crumb Rubber Asphalt Road – City of Greater Dandenong, Victoria

A light traffic crumb rubber asphalt road surface was constructed at Church Road, Keysborough, Victoria in May 2021. This project is a joint venture between ARRB and the City of Greater Dandenong and partly funded by Tyre Stewardship Australia's Low Traffic Crumb Rubber Fund. This fund was aimed to facilitate the use of crumb rubber modified asphalt mixes in low traffic roads such as those owned by local government. This project has been highlighted to show an example of the type of performance monitoring available for local council projects.

Objective

ARRB's role in this project is to assist with post-trial condition assessment by collecting long-term performance data of the council's light traffic crumb rubber asphalt.

Methodology

For the data collection aspect of this project, ARRB has been engaged to monitor the long-term performance for five years at one-year intervals.

ARRB collected initial data on the newly surfaced low crumb rubber modified asphalt road in May 2021 using its Network Survey Vehicle (NSV) to collect roughness, rutting and texture data, along with cracking data using its automatic crack detection (ACD) equipment. The NSV also collects comprehensive video imagery that allows a basic visual rating of the road defects, identifying patches, potholes, ravelling and stripping (should it be required). Strength was measured with a trailer-mounted falling weight deflectometer (FWD) device. Testing was conducted at 20 m intervals for both wheel paths. The same data will be collected at one-year intervals for five years. The data collected will be part of the big data used to evaluate the durability and long-term benefits of using recycled materials in asphalt specifically designed for local councils.

Assessment outcomes

At the time of writing this report, the yearly monitoring of this trial had not yet commenced therefore no performance outcomes are able to be reported.

5. Stakeholder Engagement

As part of this report, ARRB engaged with South Australian councils to identify the barriers and opportunities in the implementation of recycled materials in the local road network. The engagement was done via a survey.

5.1 Survey Outcomes

The responding SA councils identified the applications in Table 5.1. for the use of recycled materials in their road and transport infrastructure. Councils are either already using recycled materials in the following applications or willing to do field trials.

Table 5.1: Applications of recycled materials identified by SA councils

Glass	Plastic	Rubber
Granular pavement materials Asphalt Concrete Embankment fill Backfill Drainage works Bike paths/footpaths Line marking	Boardwalks/footbridge Roadside furniture Playgrounds Bike paths Concrete Asphalt Planks, bollards, rails, posts Bins i.e., mobile garbage bins supplied to residents are 30-40% recycled plastic)	Playgrounds (soft fall material) Asphalt Bike paths Granular pavements materials

The councils indicated that the main reasons for the use of recycled materials in road and transport infrastructure projects are due to:

- the usage ability of a high quantity of recycled materials in a particular application
- the material is considered a priority waste.

However, most of the participants were unaware of the durability and long-life of the final product. There was also a mixed response on the cost-effectiveness of replacing virgin materials with recycled materials. It was also noted that councils were unaware of the economic feasibility of using recycled materials as a replacement for virgin materials.

Few participants emphasised that the durability and the life of the product should be at least equal to or better than the currently available product. Most councils agreed that RCG, CR and RP are priority materials. Councils provided useful insight and commented on the reasons that hinder or encourage them to use recycled materials (Table 5.2).

Table 5.2: Survey participants comments and insight on the use of recycled materials

Reasons	Recycled glass (RCG)	Crumb rubber (CR)	Recycled plastics (RP)
Durability and life	Councils are not confident about the durability and life of the final product. Only familiar with glass incorporated into Downer's Reconophalt™. Durability and the life of the product should be at least equal to or better than the currently available product.	Crumb rubber asphalt is a durable product if implemented in the right application and using the right specifications.	Councils are not confident about the durability and life of the final product.

Reasons	Recycled glass (RCG)	Crumb rubber (CR)	Recycled plastics (RP)
The material being the priority waste	SA has very good glass recycling schemes and is potentially better used in other products than locked away in asphalt.	Agreed that crumb rubber is a priority waste that can be used in road and transport infrastructure.	Similar to glass, councils are unsure about locking away plastic in asphalt when it potentially has better uses. Hesitant about the benefits or its need to be used in asphalt in terms of its recyclability. The use of recycled plastics in concrete raised concern about its large-scale reusability and how easy that would be.
Cost-effectiveness	In South Australia, the use of RCG in road and transport infrastructure is not a cost-effective replacement of virgin materials. This is mainly due to well-established recycling schemes of glass and its other useful end applications.	Crumb rubber is not considered a cost-effective replacement for virgin materials in asphalt.	Councils are unsure about the cost-effectiveness of using recycled plastics on roads. However, the use of recycled plastic roadside furniture, accessories and pedestrian walkways are considered an economical option.
Government support and funding	Government incentives and funding are some of the key reasons to encourage councils to use recycled materials.		

Survey participants also recorded their comments on barriers and challenges in using recycled materials (Table 5.3).

Table 5.3: Survey participants comments on identified barriers and challenges for each recycled material

Barriers	Glass (RCG)	Crumb rubber (CR)	Plastics (RP)	General comments
Complex procurement and contractual protocols	Procurement and contractual protocols for the use of glass in granular pavement materials are not complex. However, for asphalt, procedures are not straightforward.	There was a mixed response, for some councils, it is complex while others use crumb rubber as business-as-usual and have fully developed their procurement and contractual protocols.	–	In the case of asphalt, most mixes incorporating recycled content are proprietary products, which can make procurement difficult for a supply and lay contract.
Lack of relevant standards and specifications	There is a lack of relevant specifications for the use of recycled materials in asphalt.	Councils rely heavily on DIT master specifications. These are very limited with respect to crumb rubber.	In furniture/decking councils rely on contractors/designers rather than having their own standards/specs.	In the case of asphalt, recycled mixes have only been lab-tested to demonstrate equivalent or better performance when compared to virgin mixes suitable for low volume roads (not all road operating environments).
Uncertainty in the adaptation of standards and specifications	In all applications of recycled materials, there is uncertainty in the adaptation of standards and specifications.			Regulation of supply and material installation on-site and established inspection & test plans (ITPs) to ensure performance issues.

Barriers	Glass (RCG)	Crumb rubber (CR)	Plastics (RP)	General comments
Lack of government funding and support	It is not a barrier but would help increase the uptake.	Government funding is not a barrier. Few applications such as crumb rubber permeable surfacing have proven to be a better permeable option.	–	–
Environmental regulatory pathway	Councils are unsure of available regulatory pathways for the use of recycled materials.	Relying on contractors to comply with EPA regulations.	–	Few councils mentioned that they rely on contractors to ensure their use of the product is up to regulations.
Lack of internal knowledge of recycled materials	Knowledge of recycled materials and their use in the appropriate applications is limited.	Crumb rubber is fully adopted by a few councils.	Hesitant in using plastics in asphalt and its whole-of-life benefits. Moreover, there is a hesitance on the recyclability of asphalt containing recycled plastics. The use of recycled plastics in roadside furniture, pedestrian, walkways etc, is fully adopted and understood.	–
Contractor preference	Contractor preference is a potential barrier. For example, some asphalt contractors prefer to work with crumb rubber and some with glass. There is competition and a limited choice of recycled materials for use in road construction.			

Discussion with SA councils indicated the two most crucial challenges are lack of specifications and standards and lack of awareness on environmental regulations and protocols for the use of recycled materials in road and transport infrastructure. Key remarks on these barriers are as follows:

Specifications and standards

Most councils use DIT master specifications for the use of recycled materials in road projects. It is also a common practice by councils to modify DIT master specifications to suit their needs, specifically adding recyclables.

Barriers in the adaptation of specifications are:

- DIT has limited coverage of recycled materials. Councils heavily rely on DIT master specifications for asphalt.
- Project work not complying with specifications is due to contractors' knowledge limitation, inadequate quality inspection plans and lack of site supervision during installation.
- There is a lack of standardised guidelines and specifications in terms of performance, cost-effectiveness, quality control and adherence to the specification.
- Some small contractors and consulting engineers are unfamiliar with bespoke specification/installation requirements.
- Councils are finding it difficult to get third party advice or test data for IP protected asphalt mixes.

Environmental regulations and protocols

- One of the key barriers in the use of recycled materials is the availability and awareness of environmental regulations and laws, protocols, and procedures.
- Generally, councils have a minimum environmental team (1–2 staff members). This puts the reliance on the engineering team to work out the associated procedures.

- In-house Work Health & Safety (WHS) refers to EPA regulations. However, these are generally around storage of materials on-site, washout/drag out etc. There is nothing specific to recycled materials or councils are unaware of those specifications if there are any.

6. Summary

6.1 Crumb Rubber

Asphalt and sprayed seal applications are well established and are the most common applications for CR. Although, current practices for using crumb rubber in asphalt and sprayed seals is not sufficient to deal with large volumes of end-of-life tyres as the application requires only a small amount of CR. In terms of OHS and environmental concerns, many studies have shown that working with crumb rubber modified bitumen during road construction is safe and has no associated occupational, health and safety concerns. For both sprayed seals and asphalt applications, CR is typically added in quantities of 10–20% of the binder and up to 2.5–3% by mass of mixture via a dry process.

The use of CR in non-pavement applications should be considered in addition to pavement applications. There are opportunities for larger volumes of end-of-life tyre utilisation such as incorporation into bulk earthworks and ancillary applications such as embankment fill, slope stabilisation, stabilisation of expansive soils, drainage backfill material, footpaths, driveways, car parks, tree protection zones. Further research and specification development is needed to encourage suppliers and support market development of these products and applications.

6.2 Recycled Crushed Glass

RCG can be used as bedding and backfill material, in embankment fill, as a drainage medium and as a partial fine aggregate replacement in concrete. In road pavements, RCG can be used as a partial replacement of granular materials in unbound base and subbase, and within asphalt and concrete paving materials.

Granular pavement applications are allowed to contain up to 20% RCG (by mass of total material) in Australia, up to 30% overseas. Research and case studies, though, have recommended that RCG can be used up to 30% for granular pavement applications.

Asphalt applications (excluding surfacing) are allowed to contain up to 10% (by mass of total material) in Australia, and up to 15% overseas. Research and case studies, though, have recommended that RCG can be used up to 15% for asphalt applications. For asphalt surfacing, different Australian authorities allow up to 2.5% of RCG to be used. SA does not have a specification for recycled glass. The only application of RCG in SA is specified for anti-skid mixtures under DPTI's RD-LM-S1 (Department for Infrastructure and Transport SA 2019).

Developing specifications for the use of RCG in pavement applications can build confidence for practitioners and promote the uptake of RCG usage in pavement applications.

The use of RCG in non-pavement applications is allowed up to 100%, depending on the application, in Australia and overseas. In applications such as drainage, bedding and non-structural backfill, 100% RCG can be used, whereas in an embankment fill, for instance, the use of RCG is limited to 20% in Australia and 25% overseas. While other states including QLD and NSW have specifications in place on RCG and its usage, SA does not have a specification for recycled glass.

6.3 Recycled Plastics

There are various options and routes through which RP can be utilised including roadside furniture and accessories such as bollards; large instalments such as noise walls; shared use paths; geogrids; pipes etc. There are no single criteria that make one application better than the other. Each application should be evaluated independently and selected based on its requirement whilst ensuring the circular economy principles at every level of the procurement. Therefore, multiple avenues continue to be engaged moving forward to tackle the waste plastic problem. The use of recycled plastics in asphalt or granular applications for road construction is still in the research phase and field trials. Current research indicates that the recycled plastic modification of bitumen or asphalt is unlikely to ever reach the performance levels of premium polymer-modified binders, they will not see the volume usage that people might expect. Few proprietary recycled plastic asphalts are dominating the market.

Generally, recycled plastics i.e. soft plastics in these proprietary products are in the order of 0.2% by mass of asphalt (wet process) to 0.7% by mass of asphalt (dry process). It is important to understand where these recycled plastic products provide the highest benefits in terms of their durability, recyclability, and recovery.

6.4 Key Challenges for SA Councils

The challenges for SA councils that could hinder the uptake of recycled materials in local roads and infrastructure were discussed in detail in Section 5 and are summarised in Table 6.1.

Table 6.1: Key issues, barriers and impacts based on stakeholder and council consultation

Issue	Barrier	Impact	Control action
Increased capital cost	Increased capital cost is often not considered when developing budgets for the upcoming financial year.	Recyclables are often not considered for use because of their increased cost. Without this being budgeted for, the risk of being over budget is a barrier.	Understanding the impact of recycled materials products on the lifespan of assets. Preparing budgets to account for the change in unit rates.
Performance evidence	Given the scrutiny on councils to succeed and not waste public funds, many councils are waiting for others to fully test new products.	Low confidence in using recycled materials.	Development of guidelines, standards and their implementation frameworks.
Recyclability	Are these products recyclable in the same way that 'standard' asphalt is? Are we just turning our roads into a linear dump?	Uncertainty among road managers and low confidence could result in reduced uptake of recycled materials and lead to incorrect decisions on the selection of recycled materials for a specific job.	Further research to be undertaken to ensure recyclability of new products.
OHS and environmental implications	Perceived impact of harmful fumes during production and implementation. Perceived impact of microparticles entering stormwater/environment.	Not a governing barrier, but something often brought up in relation to these products. Often anecdotal with little research.	A better understanding of past research into fumes.
Products not being considered at the design stage	Pavement designs do not include recycled materials as there is limited information to inform the design criteria.	Reliance on relationships with existing contracted asphalt producers as to the roll-out of recycled materials.	Development of design criteria for specific recycled material containing asphalt mixes.
Material quality and specifications	There are limited/poorly known specifications detailing recycled materials' quality requirements.	Lack of quality specifications (or knowledge of existing specifications) limits the potential for further product development and adoption. Consumers will be hesitant without quality standards and guarantees.	Existing specifications to be better understood by road agencies, and gaps to be filled by new specifications.

6.5 Guiding Documents

Many field trials incorporating these recycled materials have been successfully conducted over the last few years through initiatives from not-for-profit stewardship schemes and government incentives. However, there is no transition plan into the next phase of deploying these applications into the circular economy through normal practices. Furthermore, it has been identified that there is inconsistency in the planning, management, monitoring and dissemination of knowledge for trials. A central knowledge platform for sharing of outcomes from field trials and research would fill an important gap by enabling asset owners to make more informed decisions when using recycled materials as they move towards being business as usual.

It is of foremost importance to devise the mechanism to streamline these efforts through the development of guidelines and specifications for the use of recycled materials in different road infrastructure applications.

Table 6.2 presents the list of documents that can be used as guidelines and referred to when using recycling materials in road constructions.

Table 6.2: List of guidelines and related documents

Document title	Document no.
Guide to Pavement Technology Part 4E: Recycled Materials	AGPT04E-09 (Austroads 2022b)
Use of Recyclable Materials in Roads and Road Assets	AAM6255
Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications	AP-T351-19 (Austroads 2019)
Use of Road-grade Recycled Plastics for Sustainable Asphalt Pavements	AP-R648-21 (Austroads 2021c)
Interim Guidelines for the Use of Recycled Waste Plastic in Local Government Road Surfacing Applications	AP-G96-21 (Austroads 2021a)
Recycled Plastics in Road Infrastructure (NACOE/WARRIP)	In press
National Specification for Crumb Rubber Binders in Asphalt and Seals	AP-T359-21 (Austroads 2021b)
East Boundary Road Crumb Rubber Asphalt Trial Emissions Monitoring Report	TR 220 (Department of Transport 2020)
Literature Review on Passenger Vehicle Tyre Usage in Bitumen	TR 216 (Department of Transport 2019)
Optimising the Use of Crumb Rubber Modified Bitumen in Seals and Asphalt (Year 1 – 2014–15)	NACOE P31 and P32 (Denneman, 2015)
Specification Framework for Polymer Modified Binders	AGPT/T190
Supply of Recycled Crushed Glass Sand	ATS 3050-22
Development of a Specification for Recycled Crushed Glass as a Sand Aggregate Replacement	AP-T362-22 (Austroads 2022a)

7. Recommendations

Adaptation of circular economy principles within SA councils has a pivotal role in achieving the waste reduction targets outlined in the SA waste strategy 2020–2025 (Green Industries SA 2020). Based on the literature review and stakeholder engagement, the following applications (Table 7.1) for the key three materials have been recommended. These applications are considered to be easily implementable and give the best value and environmental benefits.

Table 7.1: Key applications of CR, RCG and RP in road and transport infrastructure

Material	Key applications
Crumb rubber	Footpaths Tree protection zones Car parks & driveways Asphalt & spray seals
Recycled crushed glass	Embankment and structural fill Subgrade material Drainage layers, backfill and bedding material Asphalt Non-structural and low-risk concrete applications
Recycled plastics	Recycled plastic pipes Geogrids and geotextiles Ancillary and aesthetics i.e. wheel stops, signage, roadside furniture, tree stakes, boardwalks and decking Bitumen and asphalt modification (subject to demonstration that fuming and emissions and long-term environmental impact (e.g. microplastics) are not an issue)

In order to increase the confidence of councils to incorporate recycled materials in their road and transport infrastructure applications, the following future work should be considered for successful implementation:

- a better understanding of recycled material specifications, performance and where materials can be sourced
- more open and transparent producers with regard to the content and components of their products
- inclusion of specifications for recycled materials in DIT Master specifications especially for councils e.g. VicRoads Section 422
- funding for R&D, supported by field trials on the use of recycled materials to address concerns regarding durability and inclusion of long-term performance monitoring programs
- a centralised location of what products are available, application of products, performance statements/product datasheets, specifications, installation methodologies, environment product declaration (EPD) and costs
- development of an assessment framework
- development of a field trial and data collection framework for performance monitoring and platform for capturing and sharing the learnings of trials
- awareness campaigns/workshops on the funding and support available for the use of recycled materials
- development of an environmental regulatory pathway and workshops or training for the implementation of environmental regulatory procedures
- quantifiable environmental benefits of using recycled materials in roads and infrastructure application during full life cycles.

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Appendix A Supplementary Information

A.1 Recycled Crushed Glass

A.1.1 Recycled Crushed Glass Requirements for Concrete

Table A.1 and Table A.2 present Australian testing requirements for RCG and production quality control for RCG.

Table A.1: Australian testing requirements for RCG

Property	Test method
Particle size distribution	
Nominated particle size distribution	AS 1141.11.1
Material finer than 75 µm	AS 1141.12
Dry density	T279 (TfNSW)
Percentage of oversize material	
Flow time	
Uncompacted void content	
Apparent particle density	AS 1141.5
Dry particle density	
Saturated surface dry density	
Water absorption	

Source: Transport for NSW (2020).

Table A.2: Production quality control for RCG

Test	Standard	Requirement	
Particle size distribution	AS 1141.11.1:2020	Sieve size (mm)	Percent finer
		9.5	100
		4.75	85 – 100
		2.36	50 – 90
		1.18	20 – 45
		0.3	8 – 25
		0.075	0 – 2
Sugar in aggregate	AS 1141.53:1996 *Sugar in Aggregate* (note document superseded by		No traces
Chloride content	AS 1379:2007		0.06% m/m
Organic impurities (other than sugar)	AS1141.34:2018		0.08% m/m
Contaminants (TfNSW Test Method T276:2012)	Asbestos		0
	Metal		0.25% by mass
	Plaster and friable materials		0.25% by mass
	Rubber, plastic, bitumen, paper, cloth, paint, wood		0.3% by mass

Source: Andrews (2010).

A.2 Recycled Plastics

Table A.3: Types of recyclable plastics and their applications

Plastic identification code	Type of polymer	Applications: virgin grades	Application: recycled grades
1 PETE	Polyethylene terephthalate (PET)	Textiles, soft drink bottles, juice bottles, rigid packaging	Beverage bottles, clothing, textiles, bottles for detergent, fibres, furniture, carpets
2 HDPE	High-density polyethylene (HDPE)	Shopping bags, freezer bags, milk bottles, bleach bottles, buckets, rigid agricultural pipe, milk crates	Laundry detergent bottles, oil bottles, pens, recycling containers, floor tiles, drainage pipe, lumber, benches, doghouses, picnic tables, fencing, shampoo bottles
3 PVC	Polyvinyl chloride (PVC)	Electrical conduit, plumbing pipes and fittings, blister packs, fruit juice bottles, garden hose, shoe soles, cable sheathing, blood banks and tubing	Decks, panelling, mudflaps, roadway gutters, flooring, cables, speed bumps, mats
4 LDPE	Low-density polyethylene (LDPE)	Garbage bags, squeeze bottles, black irrigation tubing, garbage bins	Trash can liners and cans, compost bins, shipping envelopes, panelling, lumber, landscaping ties, floor tiles
5 PP	Polypropylene (PP)	Film, carpet fibres, appliances, automotive, toys, housewares, crates, bottles, caps and closures, furniture, rigid packaging	Signal lights, battery cables, brooms, brushes, auto battery cases, ice scrapers, landscape borders, bicycle racks, rakes, bins, pallets, trays
6 PS	Polystyrene (PS)	Refrigerator bins & crispers, stationery accessories, coat hangers, medical disposables, meat & poultry trays, yoghurt & dairy containers, vending cups	Insulation, light switch plates, egg cartons, vents, rulers, foam packing, carry-out containers
7 OTHER	Acrylonitrile butadiene styrene (ABS), acrylic, nylon, polyurethane (PU), polycarbonates (PC) and phenolics	Automotive, aircraft and boating, furniture, electrical and medical parts	–

Source: ARRB (2021a).

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