Austroads

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Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications

Viability of Using Recycled Plastics in Asphalt and Sprayed Sealing Applications

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Abstract

This report examines the viability of using recycled plastics in asphalt and sprayed seals by Australian and New Zealand road authorities. The report presents the findings of a literature review, including case studies of local and overseas road trials. It finds that waste plastic can act as a partial aggregate replacement in bituminous mixes and a binder extender without having any significant influence on the properties of the asphalt mix. However, not all recycled plastics are suitable for bitumen modification at high temperatures. It also finds that while there may be environmental benefits associated with the use of recycled plastic, there are concerns regarding the potential health and safety hazards that road workers might be exposed to while handling these materials, sustainability impacts, and impacts on the surrounding environment.

Keywords

Recycling, waste, plastics, PET, modified asphalt, spray sealing, bitumen binders, sustainability

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Transport for NSW
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- The Department of Infrastructure, Transport, Cities and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

Summary

The plastic ban implemented by China on 1 January 2018, followed by other countries such as India, Indonesia and Malaysia, has heavily affected Australia's waste recycling industry. Over the past few years, the Australian plastic recycling market has been reliant on exporting its waste overseas because of the lower costs. The local recycling industry does not currently have the appropriate infrastructure to cope with this sudden change and new uses for these materials are being explored.

Plastic is a significant contributor to Australia's waste generation. With so much plastic waste generated and going to landfill, there is growing interest in exploring the viability of using recycled plastic in roads.

The concept of using recycled materials in roads is not new. Alternative materials such as reclaimed asphalt pavement (RAP), crumb rubber, glass and crushed concrete have been increasingly used for road pavement construction in recent times. The benefits associated with using recycled materials include a reduction in the use of virgin raw materials, energy savings, and reduced waste going to landfill and its associated environmental risks.

The purpose of this project is to gain a better understanding of the viability of using recycled plastics in asphalt and sprayed seals. The main element of the project is a review of local and international literature focussed on defining the benefits and challenges of using recycled plastics in road pavements. The main outcome of the project is guidance on future research and development priorities.

This report presents the findings of that literature review, including case studies of local and overseas road trials involving the use of recycled plastic in roads. It was found that waste plastic can act as a partial aggregate replacement in bituminous mixes, and a binder extender without having any significant influence on the properties of the asphalt mix. However, not all recycled plastics are suitable for bitumen modification at high temperatures. For example, heating Poly-vinyl chloride (PVC) at high temperatures can result in dangerous chloride emissions and Polyethylene terephthalate (PET) has a high potential for its own reuse. It is important to note that most of the laboratory testing was not performed in accordance with Australian bitumen standards and specifications.

All of the commercial products available in the Australian and New Zealand market are made from different classes of plastics and little is known about the manufacturing process. Since these Australian trials only commenced in 2018, it is important that the performance of these pavements be monitored over the longer term.

Whilst there may be environmental benefits associated with the use of recycled plastic, there are concerns regarding the potential health and safety hazards that road workers might be exposed to while handling these materials, sustainability impacts, and impacts on the surrounding environment. One of the recommendations in the report is the need for the development of a governance framework on the use of plastics in road construction.

More research is needed to develop a better understanding of the benefits and effects of recycled plastics in asphalt and sprayed seals in Australia and New Zealand. A list of priorities has been provided in this report for consideration by Austroads.

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1. Introduction

1.1 Background

For many years, Australia exported a substantial amount of its waste products overseas for a number of reasons, including the lower cost to export compared to recycling locally, a weak domestic market for recycled products, and a lack of investment in infrastructure. Much of this waste was sent to China and India. In 2016-2017, it was estimated that Australia exported 1.2 million tonnes of waste to China, nearly double the previous estimate (Laster 2018). Approximately 30% of Australia’s recyclable waste at that time was exported to China.

The enforcement of the China National Sword Policy on 1 January 2018 has restricted the importation of 24 categories of solid waste into China and limited the contamination levels in these materials to less than 0.5%. Following China’s lead, India, which was the fourth largest destination for Australia’s waste in December 2018, announced a complete ban on the importation of plastic waste from 1 March 2019 (Topsfield 2019).

These policies have impacted the global market for recyclable material, including the 1.29 million tonnes of waste currently collected in Australia based on the 2017-2018 export amounts (Topsfield 2019).

There has been a collaborative approach across Australia to tackling this immediate problem, including:

- The NSW Government announced a support package of up to $47 million to help local government and industry (EPA NSW n.d.)
- The Victorian Government announced a $13 million ‘rescue package’ to Councils to cover additional costs.
- The South Australia government, whilst waiting on a report from a working group before committing to a $7 million rescue package, announced a $300,000 grant fund for the development of secondary reprocessing infrastructure (Spragg, 2018)
- Western Australia government has created a task force to explore solutions (Spragg 2018).

With so much at stake, various parties such as local government, infrastructure owners and private consortiums are looking for alternative methods to manage waste disposal. According to the 2012 report on the Australian Recycling Sector, plastics are significant contributors to overall Australian waste generation (Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) 2012). With so much plastic waste generated which will be potentially entering landfill, the recycling of plastics has become a major sustainability issue. Hence, there is a growing interest in using recycled plastic as a modifier/ extender in bituminous binders and in hot mix asphalt as a sustainable and cost-effective pavement solution (White & Reid 2018).

In response to this issue, Austroads commissioned Project APT6192 ‘Viability of using recycled plastics in asphalt and sprayed seals’. The purpose of this project is to investigate the viability of using recycled plastics in asphalt and sprayed seal pavements. The output of this project is a literature review of current Australasian and overseas practice which focusses on defining the benefits and challenges of using recycled plastics in road pavements, including guidance on future research and development.

This report presents the findings of the literature review, including case studies of road trials in Australia and overseas using recycled plastic in roads.

The benefits of using recycled plastics in asphalt and sprayed seal pavements in terms of field performance – and their limitations – are not currently well understood.

If recycled plastic can be successfully incorporated into pavements, then there will be environmental and potentially commercial benefits arising from:

- reduced landfill
- reduced reliance on virgin non-renewable resources
- improved road-building material options
- a consistent and reliable source of recycled materials for the road building industry
- improved sustainability
- climate and infrastructure resilience benefits.

1.2 Structure of Report

The structure report is as follows:

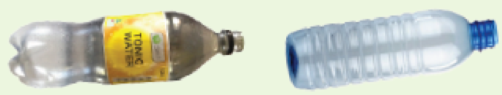
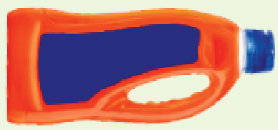
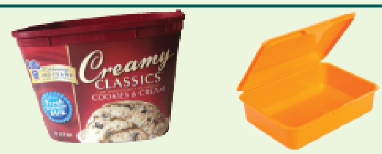
- Section 1 – background and purpose of the project
- Sections 2 and 3 – a general overview of waste plastic and how recycled materials (not just plastics) are used in roads
- Section 4 – the various uses of recycled plastics in roads and the methods of implementation
- Section 5 – details of recent road trials in Australia as well as a snapshot of overseas trial experience
- Section 6 – a general discussion of the main areas of concern associated with using plastics, including fumes generated during processing and construction, the use of microplastics, leaching problems, re-recyclability, incompatibility and storage stability
- Section 7 – governance issues, including sustainability frameworks and performance specifications
- Section 8 – a list of prioritised recommendations for road agencies to consider for future research and development.
- Appendix A – list of individuals and groups contacted during the course of this investigation
- Appendix B – list of acronyms.

2. Waste Plastic

2.1 Classification of Plastics

Plastics are classified into seven different categories based on material composition (KS Environmental Group 2015). Each category has been given a product symbol from 1 – 7. Each has different properties which makes it suitable for different applications. A description of the plastic recycling code, and examples of the types of plastic that fit into these categories, is shown in Figure 2.1.

Figure 2.1: Plastics identification code

Symbol	Description	
1 PETE	Clear tough plastic such as soft drink, juice and water bottles.	
2 HDPE	Common white or coloured plastic such as milk containers and shampoo bottles.	
3 V	Hard rigid clear plastic such as cordial bottles.	
4 LDPE	Soft flexible plastic e.g. squeezable bottles such as sauce bottles.	
5 PP	Hard but flexible plastic such as microwave ware, takeaway containers, some yoghurt/ ice cream/jam containers, hinged lunch boxes.	
6 PS	Rigid, brittle plastic such as small tubs and margarine/butter containers.	
7 OTHER	All other plastics, including acrylic and nylon. Examples include some sports drink bottles, sunglasses, large water cooler bottles.	

Source: KS Environmental Group (2015).

A more detailed summary of the plastic types, their general properties and their virgin and recycled applications is presented in Table 2.1.

Table 2.1: Summary description of plastic types

Type of plastic			Properties including specific gravity	Virgin applications	Recycled applications: MAJOR USE Minor use
1	PET	Polyethylene terephthalate	• Clear, tough, solvent resistant • Used for rigid sheets and fibres • Softens: 85 °C; SG = 1.38	• Carbonated soft drink bottles, fruit juice bottles, pillow and sleeping bag filling, textile fibres	BEVERAGE BOTTLES • Clothing, geotextiles, bottles for detergents, etc. • Laminated sheets, clear packaging film, carpet fibres
2	HDPE	High density polyethylene (HDPE)	• Hard to semi-flexible, waxy surface, opaque • Softens: 135 °C; SG = 0.96	• Crinkly shopping bags, freezer bags, milk bottles, bleach bottles, buckets, rigid agricultural pipe, milk crates	FILM, BLOW-MOULDED CONTAINERS • Agricultural pipes, pallets, bins for compost and kerbside collections, extruded sheet, crates, garden edging, household bags, oil containers, pallets
3	PVC	Unplasticised polyvinyl chloride (UPVC)	• Hard, rigid, can be clear, can be solvent welded • Softens: 70-100 °C; SG = 1.40	• Electrical conduits, plumbing pipes and fittings, blister packs, clear cordial and fruit juice bottles	PIPE, FLOORING • Pipe and hose fittings, garden hoses, electrical conduits, shoes, road cone bases, drainage pipes, electrical conduits & ducting, detergent bottles
		Plasticised polyvinyl chloride (PPVC)	• Flexible, clear, elastic, can be solvent welded • Softens: 70-100 °C; SG = 1.35	• Garden hoses, shoe soles, cable sheathing, blood bags & tubing, watch straps, rain wear	
4	LDPE	Low density polyethylene (LDPE) Linear: LLDPE	• Soft, flexible, waxy surface • translucent, withstands solvents • Softens: 115 °C; SG = 0.92	• Garbage bags, squeeze bottles, black irrigation tubes, silage and mulch films, garbage bins	FILMS: BUILDERS, CONCRETE LINING and BAGS • Agricultural pipes, nursery & other films
5	PP	Polypropylene (PP)	• Hard, flexible, translucent (can be transparent); wide property range for many applications, good chemical resistance • Softens: 165 °C; SG = 0.90	• Film, carpet fibre, appliances, automotive, toys, housewares, crates, palls, bottles, caps and closures, furniture, rigid packaging	CRATES, BOXES, PLANT POTS • Compost bins, garden edging, irrigation fittings, building panels
6	PS	Polystyrene (PS)	• Clear, glassy, rigid, brittle, opaque semi-tough • Melts at 95 °C; affected by fats and solvents • Softens: 90 °C; SG = 1.06	• Refrigerator bins & crispers, stationery accessories, coat hangers, medical disposables • Meat & poultry trays, yoghurt & dairy containers, vending cups	INDUSTRIAL PACKAGING, COAT HANGERS, CONCRETE REINFORCING CHAIRS • Moulded products, coat hangers, office accessories, spools, rulers, video cases and printer cartridges
		Expanded polystyrene (EPS)	• Foamed, light weight, energy absorbing, heat insulating • Softens: 90 °C; SG = 0.90–0.93	• Drinking cups, meat trays, clamshells, panel insulation, produce boxes, protective packaging for fragile items	SYNTHETIC TIMBER • Picture frame mouldings, under slab void pods for buildings

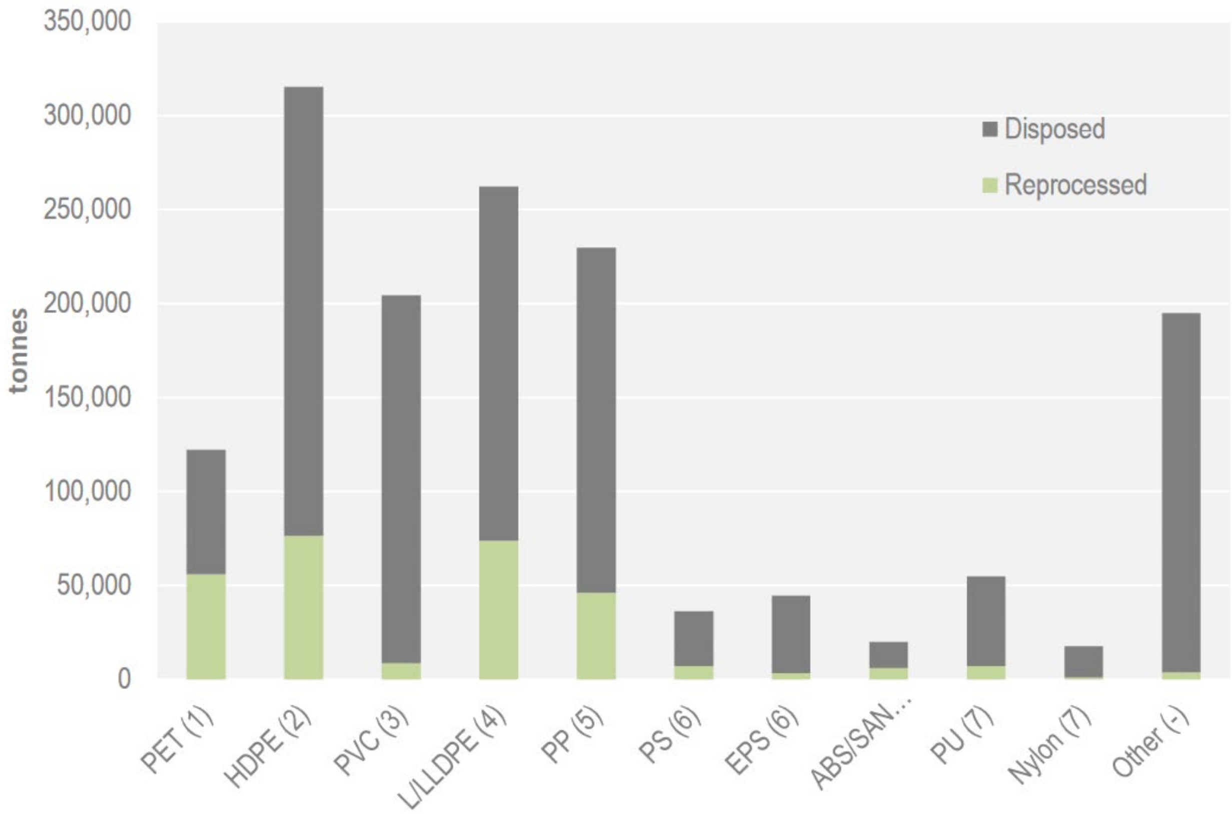
Type of plastic		Properties including specific gravity	Virgin applications	Recycled applications: MAJOR USE Minor use
7	Other	OTHER: Includes all other resins and multi materials (laminates) acrylonitrile butadiene styrene (ABS), acrylic, nylon, polyurethane (PU), polycarbonates (PC) and phenolics	• Automotive, aircraft and boating, furniture, electrical and medical parts	AGRICULTURAL PIPING • Furniture fittings, wheels and castors, fence posts, pallets, outdoor furniture and marine structures

Source: Chemistry Australia (n.d.).

The most commonly recycled plastics in Australia are PET, HDPE, LDPE and PP; they comprise over 85% of all reprocessed Australian plastics (DSEWPaC 2012). Some plastics are more difficult to reprocess owing to their chemical properties, resulting in increased proportions being sent to landfill. This is evident in Figure 2.2, which shows the lower overall proportion of these plastic streams being recycled.

In the review of the literature, most studies revealed the use of HDPE, LDPE and PET for binder and asphalt modification. However, it was found that soft plastics were the predominant material used in road trials in Australia. Soft plastics are those that can be scrunched into a ball e.g. plastic shopping bags, bread bags, cereal bags, bubble wrap, fruit and vegetable bags, packaging, netting and etc. Further details of Australian and New Zealand asphalt road trials are discussed in Section 5.

Figure 2.2: Consumption of plastics and proportion reprocessed and disposed, 2009-2010



Plastic types defined in Table 2.1 or Appendix B
Source: DSEWPaC (2012).

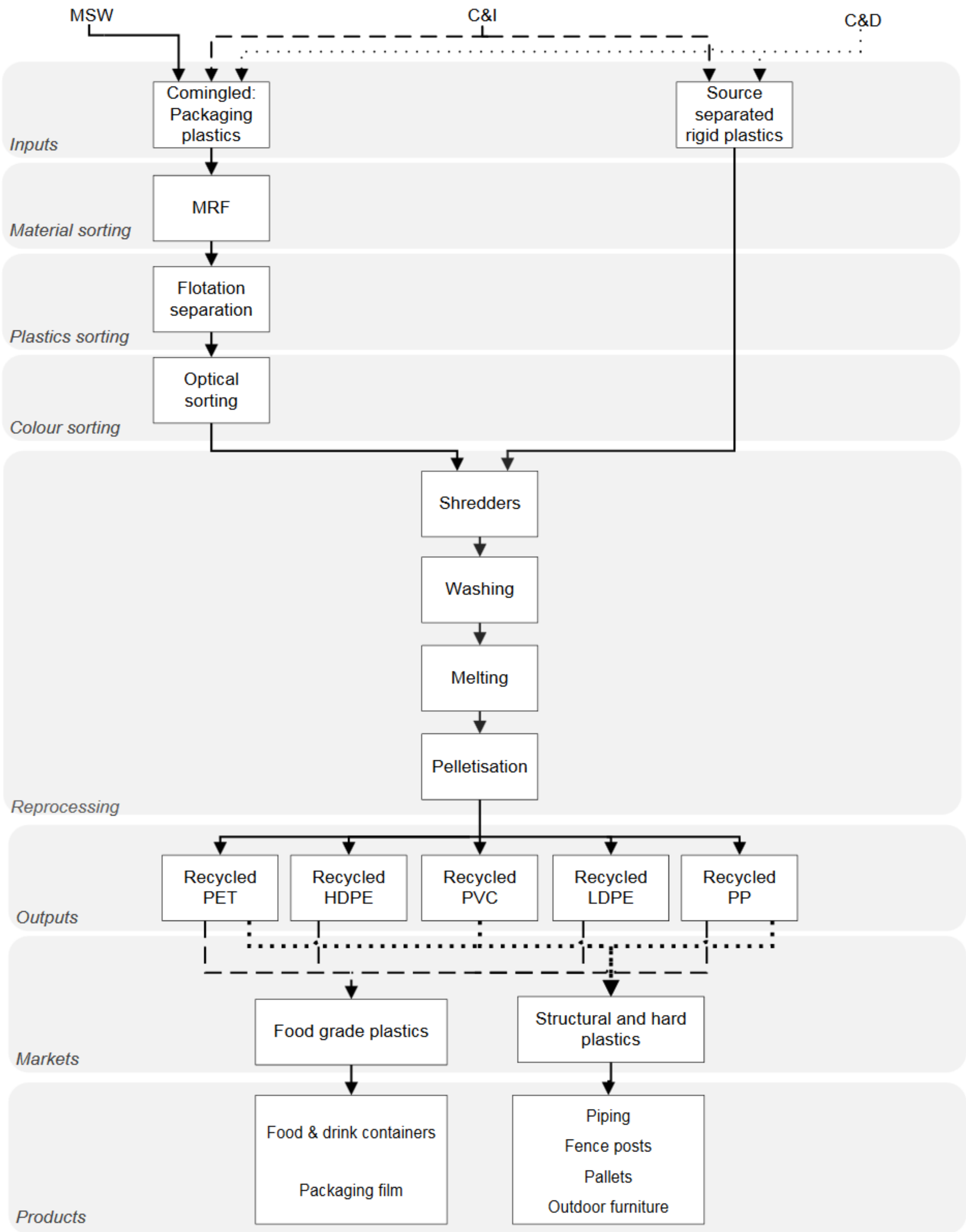
2.2 Plastic Recycling Processes

Waste collected from the local kerbside are delivered, co-mingled, to a Materials Recovery Facility (MRF) to be sorted automatically for plastics, metals, paper and glass. The plastics then undergo another level of individual sorting for streams of PET, HDPE, LDPE and PP. The separated plastics are cleaned to remove any contaminants (such as labels, glue residue and other mixed materials) and then reduced in size via shredding and grinding. Once it has been reduced in size, it goes through a further cleaning and separation process in order to produce a pure stream of only a single plastic type. This needs to occur before it can be reprocessed into new plastic materials. At this stage, the cleaned and sorted plastic is typically in a flake form.

The most common method of reprocessing plastics is via mechanical recovery. In this process, pure flakes are melted and reformed in a process called melt-extrusion. As a result, uniformly-sized pellets of recycled plastics are produced, which can then be used as raw material to be moulded into plastic goods (DSEWPaC 2012).

An overview of the flow of plastics, from generation through to the manufacture of products using recycled material, is presented in Figure 2.3.

Figure 2.3: Overview of flow of plastics through the recycling chain



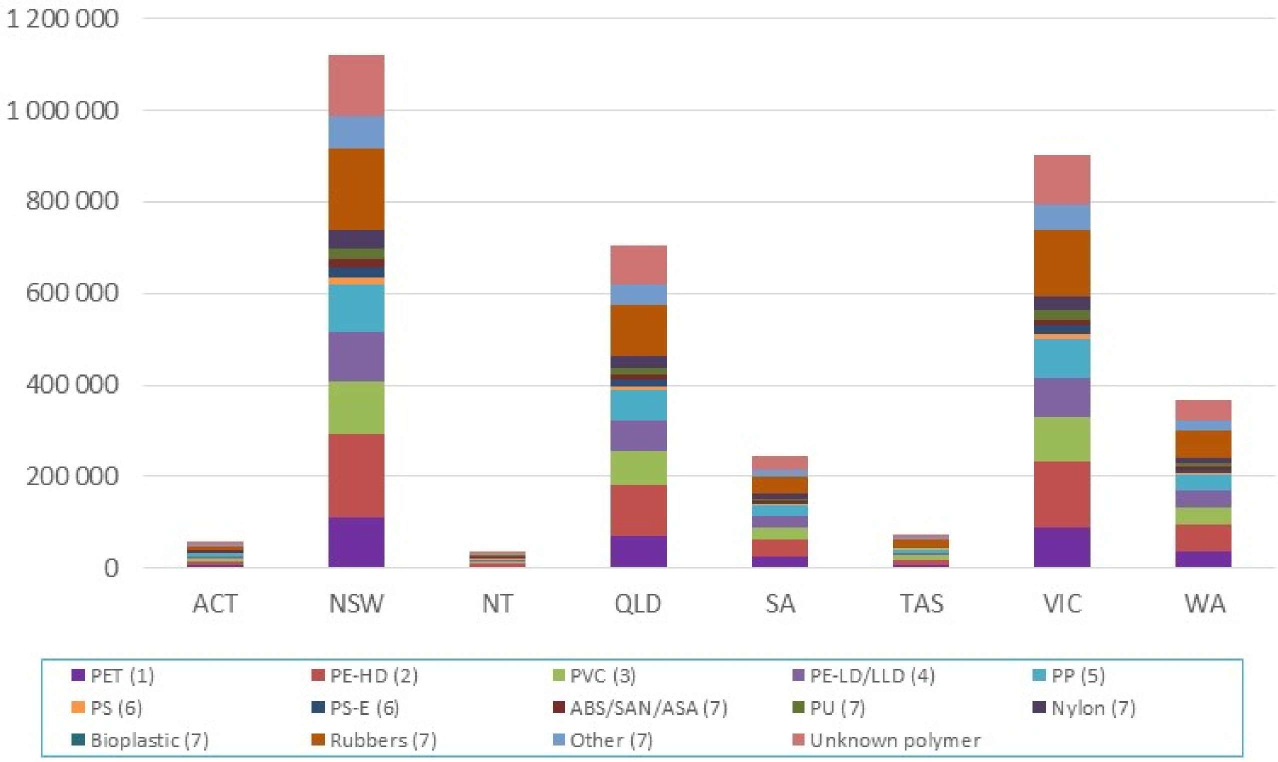
Source: DSEWPaC (2012).

2.3 Consumption and Recycling by State/Territory in Australia

According to the Australian Plastics Recycling Survey, the total consumption of plastics in Australia in 2016-2017 was 3,513,100 tonnes with a recycling rate of 11.8% or 415,200 tonnes (Department of the Environment and Energy 2018). It is important to note that the recycling rate quoted here is only an approximation: it was generated by quantifying plastics recovery for recycling in any given year. A true recycling rate would be calculated by quantifying the amount of plastics available to be diverted to recycling from landfill. Hence, the rate of recycling reported is probably too conservative and the true rate may well be higher.

Figure 2.4 shows the estimated consumption of plastic according to each state/territory and polymer type based on population as a proportion of the national population. The waste stream sources are from municipal, commercial and industrial construction, and demolition waste streams.

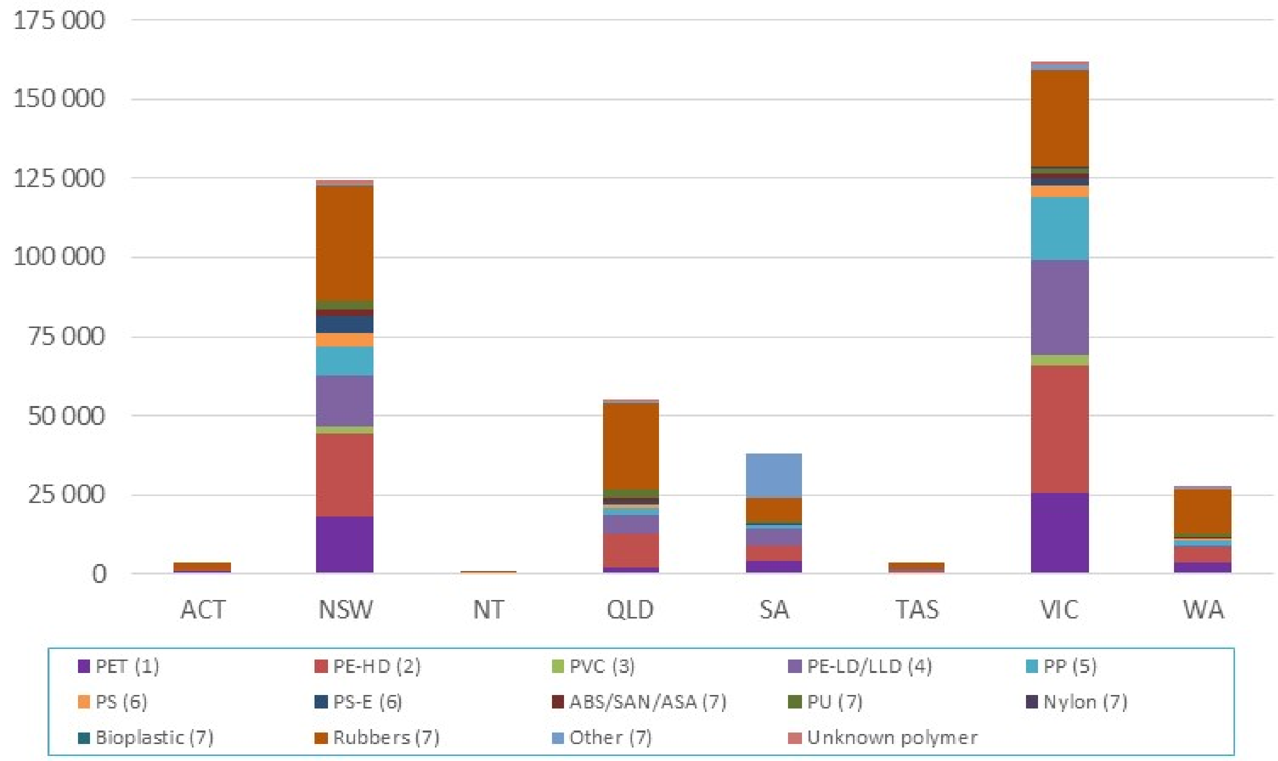
Figure 2.4: Estimated consumption of plastics according to State/Territory and polymer type in 2016-2017 (tonnes)



Source: Department of the Environment and Energy (2017).

Figure 2.5 shows the tonnage of plastic recycling according to state/territory and polymer type in 2016-2017. The high level of recycling in Victoria reflects the disproportionately large manufacturing sector based there. Many of these reprocessors are capable of handling more than one polymer type, resulting in an improved depth of the reprocessing market. This is further confirmed by the data shown in Table 2.2.

Figure 2.5: Recycling of plastic according to state/territory and polymer type in 2016-2017 (tonnes)



Source: Department of the Environment and Energy (2017).

Table 2.2: Number of reprocessing facilities in Australia in 2016-2017

Australian State/Territory	Number of Reprocessing facilities
ACT	0
NSW	20
NT	2
QLD	12
SA	12
TAS	2
VIC	24
WA	4
Total	**76**

Source: Department of the Environment and Energy (2017).

Table 2.3 shows the tonnage of raw material sent to, and processed in, a waste recycling plant or materials recovery facility (recyclates), either intrastate (same state), interstate and overseas reprocessors in 2016-2017. It shows that Victoria and NSW have the largest reprocessing sectors, with both states reprocessing around 30% of recyclate that is recovered from each jurisdiction.

Table 2.3: Raw material sent to, and processed in, a waste recycling plant or materials recovery facility (recyclates) in 2016-2017 (tonnes)

Destination Jurisdiction	Source								
	ACT	NSW	NT	Qld	SA	TAS	VIC	WA	Total
ACT	0	0	0	0	0	0	0	0	0
NSW	500	34,200	0	3,600	3,300	200	2,800	600	45,200
NT	0	0	0	0	0	0	0	0	0
Qld	0	0	0	24,500	0	0	0	0	24,600
SA	0	1,300	0	0	19,900	0	0	0	23,100
Tas	0	0	0	0	0	0	0	0	0
VIC	0	1,900	0	0	0	0	47,400	0	52,300
WA	0	0	0	0	0	0	0	5,200	5,200
Overseas	3,300	87,200	1,000	27,300	13,200	2,900	110,300	19,500	264,700
Total	**3,800**	**124,600**	**1,000**	**55,500**	**37,800**	**3,800**	**161,600**	**27,100**	**415,200**

Source: Department of the Environment and Energy (2017).

3. Use of Recycled Materials in Roads

3.1 Benefits of Recycling

According to the Australian Recycling Sector report published in 2012, recycling in Australia saves over 241,000,000 GJ of energy each year (DSEWPac, 2012). This is equivalent to powering 5 million homes. Table 3.1 shows the energy savings associated with materials recycled rather than sent to landfill in 2008-2009. Plastics contributed about 5 per cent of the total savings and about twice the contribution of glass.

Table 3.1: Energy savings associated with materials recycled rather than sent to landfill

Category	Annual Energy Savings in Australia, 2008-2009 (GJ)
Masonry materials	6,510,064
Metals	173,497,723
Organics	7,762,783
Paper/cardboard	31,926,417
Plastics	12,486,036
Glass	6,420,594
Textiles and rubber	3,274,488
Hazardous waste	Unavailable
Fly ash	Unavailable
Total	241,878,104

Source: DSEWPac (2012).

Another major benefit of recycling is reduced landfill waste. A built up of landfill waste may cause a range of environmental risks including:

- air quality and odour impacts
- decomposition of putrescible waste to form methane gas
- leaching of waste chemicals and decomposed materials into the natural water system.

The annual savings associated with the recycling of minerals and resources in Australia can be summarised as follows (DSEWPaC 2012):

- over 4,000,000 tonnes of trees for paper
- over 300,000 tonnes of oil for PET and HDPE plastics
- over 4,000,000 tonnes of iron ore for steel
- over 600,000 tonnes of sand for glass.

3.2 Purpose of Using Recycled Material in Roads

Australia has an extensive road network approximately 800,000 km in length. With the increasing unavailability of natural resources, large haulage distances, increasing axle loads and axle configurations and the issue of 'peak oil' looming, there is an increased interest amongst road owners to explore sustainable road construction and rehabilitation methods. The short- to medium-term approaches proposed in Austroads (2010) suggest that road managers should:

- plan to increase the recycling of bituminous surfacings and asphalt as much as practicable as a means of extending the life of bitumen surfacings and asphalt pavements
- explore the use of alternatives to virgin binder in the longer term.

For the purpose of this report, the focus is on the use of waste materials as an alternative to virgin materials. Although it is an environmentally friendly concept to recycle waste and in doing so cut down on the use of virgin/raw materials, road agencies/owners need to ascertain the real reasons and benefits associated with using these waste materials before adopting them; otherwise, solving one problem may create another. Some considerations might be (European Asphalt Pavement Association (EAPA) 2017a):

- is waste material a direct substitution for virgin material?
- does it enhance the properties and quality of the binder/asphalt?
- is it a stream to dispose these waste materials without affecting the properties of the asphalt?

The purpose might be a combination of two or three of the reasons. Nonetheless, the key is to consider all factors and run a risk assessment to establish the real reasons for utilizing waste materials on the road network.

To achieve sustainability objectives, there are benefits associated with increasing the use of recycled materials provided pavement performance is not adversely affected. Every tonne of recycled material that is used reduces the need for a tonne of new aggregate and/or bituminous binder acquired from finite natural resources. From the waste disposal perspective, this means one tonne less of material that might otherwise become landfill (White 2019).

3.2.1 Is it a value-added material?

The chemical compatibility of the components an asphalt mix plays a fundamental role throughout the life of the mix. When a non-bituminous component is added to an asphalt mix, it is important to ensure that this material does not affect the expected life-cycle cost of the project. Project feasibility and cost effectiveness are also determined by the availability and supply of recycled material. Therefore, cost, performance and environmental concerns must be heavily deliberated to determine the value-added element of a material or product.

The introduction of a value-added material can result in a reduction in costs by saving on raw materials (binder and aggregate) if its performance can be demonstrated to be equal to, or better than, mixes composed solely of virgin material.

3.3 Recycled Materials Currently in Use in Australasia

A comprehensive list of recycled materials used in pavement construction in Australasia is presented in Austroads (2009) – see Table 3.2.

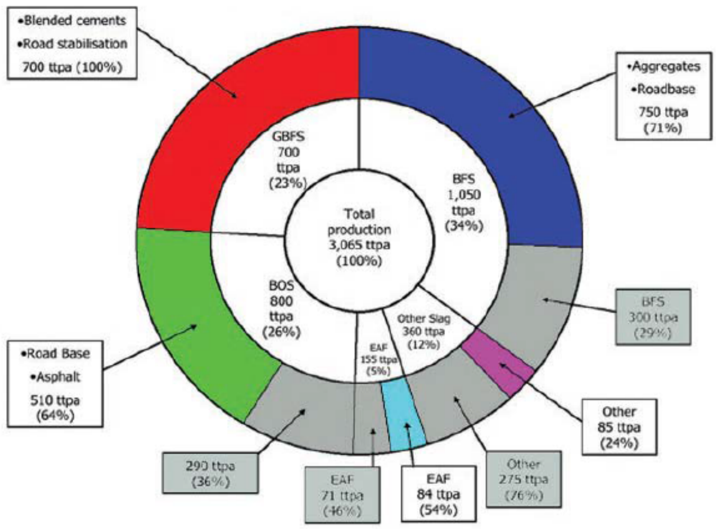
Table 3.2: Recycled materials used in road pavement construction in Australasia

<table>
<tr><th>Alternative material</th><th>Uses</th></tr>
<tr><td>Crushed concrete and masonry</td><td>• often becomes available from demolition waste from the building industry
• recently, recycled crushed concrete has been produced and supplied to a wide range of road applications, including the stabilization of subbases
• recycled concrete and masonry materials can be processed into unbound granular materials, aggregates and concrete manufactured from recycled aggregate</td></tr>
<tr><td>Reclaimed asphalt pavement (RAP)</td><td>• milled or excavated asphalt pavement
• obtained from the road and other sources; can be collected as a co-mingled stockpile, processed by crushing and screening to a graded material, free of contamination, ready for use in new asphalt manufacture
• In the form of crushed slab asphalt it can be used as an unbound granular subbase and base course material on minor roads and as a low-dust surfacing in unsealed road applications</td></tr>
<tr><td>Recycled glass</td><td>• used as a fine aggregate when crushed
• replacement for sand as it has a similar particle density
• typically 5% of reclaimed glass in the form of cullet is permitted in granular products</td></tr>
<tr><td>Industrial slags</td><td>• the use of industrial slags is described in the Australasian Slag Association publication ‘A Guide to the use of Iron and Steel Slag in Roads (ASA 2002)

The use of slags in Australasia is shown in Figure 3.3. The different types of slag are:

- GBFS – granulated blast furnace slag
- BFS – blast furnace slag (rock slag)
- BOS – basic oxygen steel slag
- EAF – electric arc steel slag.

Figure 3.3: Slag use in Australasia in 2000



</td></tr>
<tr><td>Ash and fly ash</td><td>• about 13% of coal combustion products is used in cementitious applications or concrete manufacture
• about 6% is used in non-cementitious applications
• About 27% is used in projects offering some beneficial use (e.g. mine site remediation, local haul roads, etc.)
• further information on the use of ash and fly ash can be found on the Ash Development Association of Australia (ADAA) website</td></tr>
<tr><td>Crumb rubber</td><td>• obtained from the recycling of vehicle tyres
• mixes with up to 20% of crumb rubber by mass of bitumen binder can be used in sprayed sealing work</td></tr>
</table>

Source: Austroads (2009), VicRoads (2011).

3.4 Toner

Since toner cartridges have been used in Australian road trials of plastics (refer Section 5.1), it is deemed important to provide a wider view of this recycled material.

A large amount of toner is produced for photocopiers and printers every year. Some of the toner does not meet the copiers' or printers' specifications; thus it becomes waste product. This waste material, along with the used toner residue from copiers and printer cartridges, is normally dumped into landfill. However, recent studies by Yildirim, Korkmaz & Prozzi (2003) and White & Reid (2018) have investigated the potential benefits of utilising waste toner in hot mix asphalt.

In the work reported by Yildirim et al. (2003), a series of demonstration projects were performed to understand its blending time, performance grading (PG grading), storage stability and mixing and compaction temperature. It was found that the PG properties differed according to the amount of toner-modified binder used in each test section and the amount of polymer in the toner. Hence, one of the main objectives of the investigation was to determine the levels of toner required to achieve a given PG grade, as well as to understand the effects of toner level on the PG properties.

The testing showed that an increase in toner level caused the modified binder to stiffen. The modified binder was also found to be more susceptible to low-temperature cracking. Due to its poor storage stability, the mix needed to be agitated before mixing with aggregate and to undergo a blending time of at least 60-90 minutes before it achieved a homogeneous asphalt toner mix.

After one year following construction, the toner-modified asphalt pavement showed very minimal rutting but had a higher number of cracks. Yildirim et al. (2003) concluded that toner-modified asphalt improves high-temperature properties as far as resistance to permanent deformation is concerned. However, it had a negative effect on stiffness and there were issues related to the stability of the mix during storage.

In Australia, it was reported that a resource recovery and recycling company named Close the Loop (CtL) has processed approximately 12,320 tonnes of waste toner and cartridges (TonerPave™ 2014). CtL collaborated with Downer EDI to develop a toner-modified asphalt product called TonerPave™. Toner powder is made up predominantly of plastics, including styrene acrylate, styrene butadiene and polyester with minor amounts of minerals, pigments, wax, iron oxide and silica. TonerPave™ has been used in numerous developments around Australia, including a housing development in Hume City Council in the north of Melbourne (Sharp et al. 2017) and the Melba Highway in north-eastern Victoria.

The main ingredient used to manufacture TonerPave™ is toner powder. Toner-modified asphalt has a unique feature that lies in its low melting temperature, thus saving on the energy required to heat mixes to high temperatures. This allows it to be readily homogenised with the binder in asphalt plants. It has the added benefit of requiring the use of the same equipment and manufacturing plants as conventional asphalt.

According to carbon modelling conducted by ERM and Energetix commissioned by Downer EDI, TonerPave™ was found to reduce emissions by an average of 23% compared to typical VicRoads baseline products (TonerPave™ 2014).

The use of toner-modified asphalt also resulted in improved field performance – an 11% decrease in modulus, 30% increase in fatigue life and 50% reduction in cracking relative to the conventional control mix (Sharp et al. 2017).

4. Incorporating Recycled Plastics into Asphalt Mixes

4.1 General Approach

The practice of incorporating polymers into asphalt mixes to improve properties and performance is very common in Australia. Similarly, the use of recycled polymer may also result in similar (enhanced) performance compared to its virgin counterparts, provided a rigorous selection of plastic waste and suitable production conditions are used (Costa et al. 2013).

Generally, there are two ways of adding polymers/recycled plastics into the asphalt mix, i.e. adding solid additives directly into the mix (dry process) and modifying the virgin binder (wet process) (Sharp et al. 2017; Costa et al. 2013; Guru et al. 2014).

Recycled plastics can either be shredded or ground to a desirable size for easier blending with the asphalt binder (Dalhat & Wahhab 2017).

4.2 Mixing Processes

4.2.1 Dry Process

In the dry mixing process, solid modifiers (waste materials) are added directly to hot aggregate prior to the addition of binder. This is followed by a prolonged mixing process to ensure a homogenous mixture is achieved (Sharp et al. 2017).

4.2.2 Wet Process

In a wet mixing process, the modifier is added into the binder prior to mixing with the aggregate. This may take place on or off site with the latter requiring good storage and transportation facilities.

4.3 Role of Recycled Plastics

Most research work to date has focussed on the use of recycled plastics as a replacement for fine aggregate in concrete mixes and only recently has the focus shifted to the use of recycled plastics in road construction.

There is a difference between the role of waste plastic as an extender and as a modifier. The role of an extender is to substitute for a portion of the raw materials to decrease the original amount required. The difference is primarily characterised by the melting point of the waste plastic used. Some products:

- act as an aggregate extender (or replacement) or asphalt extender
- melt into the bituminous binder and extend it in volume without any performance improvement
- will melt, extend and modify the bituminous binder. This is the most valuable as it calls for an efficient use of waste material which will otherwise become landfill; it reduces the volume of raw material used, and improves the overall performance of the resulting asphalt mix (White & Reid 2018).

White & Reid (2018) also reported that HDPE (e.g. plastic bags) and PET (e.g. plastic bottles) have high melting points of 270 ˚C and 260 °C respectively (*note: there is a contradiction in the melting points quoted here and this is further elaborated in Section 8*). These temperatures are higher than those associated with typical asphalt production and storage. Therefore, these two types of plastics were not suitable to be used as binder extenders and modifiers. White & Reid concluded that low melting point waste plastics are suitable as binder extenders while the higher melting point waste plastics are better used as an asphalt or aggregate extender.

4.3.1 Aggregate extender

The use of waste plastic as a partial aggregate replacement in bituminous mix products was studied by Jafar (2016) and Rahman and Wahab (2013). Jafar (2016) tested an 8% 0-4 mm waste plastic by weight of total aggregate in a bituminous macadam surface layer. The type of waste plastic used was not reported. The waste material used by Rahman and Wahab (2013) in their asphalt mix was recycled PET bottles of sieve size 1.18–2.36 mm.

The strength of the bond developed between the bitumen and aggregate is one of the key factors in the performance of a pavement. One of the challenges with using recycled plastic as an aggregate replacement in bituminous mixes is the potential weakening of the bonding between the aggregate and bitumen. Guru et al. (2014) reported that, when aggregate was replaced with PET, the resistance to moisture damage decreased and the resistance to permanent deformation, Marshall stability, stiffness and fatigue life of the asphalt mix all increased.

Jafar (2016) suggested that the reason for the weakening of the bond between the bitumen and plastic was due to the high stability and inert nature of the plastic surface. The recommended treatment to overcome the issue was to introduce a strong oxidising agent (dichromate/sulphuric acid solution) to activate the plastic surface. This would introduce an active ionic functional group, which would then react further in the presence of a cross-linking agent such as polyethyleneimine. This would provide a crosslink with the plastic through the hydrogen bonding with other bitumen constituents to enhance the bitumen/aggregate adhesion.

Although chemical treatment of plastic addresses the bitumen adhesion problem, the feasibility of using waste plastic still needs to be driven by good economics. Quoting Jafar (2016), '*it is not economical to use these materials as alternative aggregates unless their use adds sufficient value to the bituminous product, so that the cost of the materials can be justified*'.

4.3.2 Binder extender/modifier

A review of recent studies of binder extender/modifier is presented in the following sub-sections.

Angelone, Martinez & Casaux (2016a)

Angelone, Martinez & Casaux (2016a) reported a laboratory study to compare the effect of various percentages of recycled polyethylene (PE) from silo bags added to a bituminous mix with two other mixtures containing conventional bitumen and one PMB, using both the wet and dry processes.

'Silo bags' are commonly used in Argentina and many other countries to store grain. They are low-cost plastic bags composed of three thin layers of PE. Due to the action of cattle, birds, rodents and the machinery used to fill and empty the bags with grain, the bags damage easily and have to be replaced after only a few uses. However, as this material is not bio-degradable it goes straight to landfill. As a result, large amounts of PE were available for recycling.

For the binder modification using the wet process, different percentages of recycled plastics in flake form were tested using a high-speed stirrer at 11,000 rpm at 170 °C for a period of 20 minutes. It was concluded that the addition of recycled PE (by weight of the bitumen) had a large impact on the drop-in penetration at 25 °C, the softening point and rotational viscosity increased while there was a minimal increase in elastic recovery. The modified bitumen also had a smaller temperature susceptibility compared to the conventional bitumen (which is desirable), and poor storage stability when samples from the upper and lower parts of the container were examined under a microscope. A summary of the properties of the bitumens tested is presented in Table 4.1.

Table 4.1: Characteristics of the considered bitumens

	Conventional bitumen	Bitumen modified with 2% PE	Bitumen modified with 3% PE	SBS modified bitumen *(produced in Argentina)*
Penetration 25 °C	55	18	17	62
Softening point (°C)	49	63	68	65
Penetration index	–1.2	–0.6	+0.2	+2.5
Rotational viscosity @ 85 °C (Pa.s)	165	760	1840	1690
Rotational viscosity @ 110 °C (Pa.s)	23	69	130	109
Elastic recovery (%)	0	7	6	65

Source: Angelone et al. (2016).

Costa et al.

Costa et al. (2013) evaluated the benefits of modifying bitumen with the following plastic wastes: HDPE, LDPE, EVA, SBS and ABS. Crumb rubber was also evaluated. In order to assess performance, a conventional bitumen and a commercial PMB, Styrelf, were used as the control. A series of binders were produced using these modifiers, not exceeding 5% by weight. They were added to the base bitumen using the wet process.

Laboratory tests such as basic characterisation, dynamic viscosity, resilience and storage stability were used to determine the most suitable plastic waste for modification that would provide the most optimum results. Some of the conclusions were:

- HDPE and LDPE were the most promising recycled waste materials that could be used for bitumen modification compared with PET, PVC and ABS.
- The Softening Point of the HDPE modified binder was higher than both Styrelf and the unmodified bitumen.
- EVA, HDPE and LDPE had lower penetration values than Styrelf.
- HDPE, LDPE and EVA had good digestion in bitumen.
- Some of the recycled polymers improved the binder properties but not all of them were suitable for bitumen modification at high temperatures. For example, heating PVC at high temperatures can emit chloride to the atmosphere.

4.3.3 Asphalt modifier

Numerous studies have investigated the effect of adding recycled plastics into bituminous materials. The general consensus from various studies was that modification using recycled plastics produces a noticeable change in the binder / mix properties.

Dalhat & Wahhab (2017)

Dalhat & Wahhab (2017) examined the use of recycled HDPE, LDPE and polypropylene (PP) modifiers and found that all three modified asphalt mixes had a higher resilient modulus relative to an unmodified asphalt mix.

The rutting of the asphalt surface layers for each type of hot mix asphalt was predicted over a period of 20 years using a pavement simulation model. The model suggested that all of the modified mixes would remain within the allowable rutting range for 17 years without the need for maintenance and that the extent of surface cracking would be as low as 10% compared with the unmodified mixes. However, it is important to note that this model was based on the viscoelastic properties of the binders. In reality, the performance of the mixes is affected by various factors (internal and external) (Sharp et al. 2017).

Some of the other conclusions of this study were:

- The melting point of recycled PET is 250 °C, which is beyond the suitable range of blending with asphalt binder. Hence, blending asphalt with PET is not suitable as it will cause excessive oxidation that will completely undermine the objective of the modification.
- Rutting performance was improved more significantly in the HDPE than the LDPE and PP blends.
- All the recycled plastic modified mixes did not meet the elastic recovery requirements for polymer modified asphalt set by AASHTO TP 70 (2013). Some form of elastomeric polymer has to be supplemented to compensate for the lack of elastic recovery.

Fang et al. (2014)

In another study done by Fang et al. (2014), the focus was on the modification of asphalt with recycled PEs. The results were positive, i.e. high temperature stability, low temperature anti-cracking properties, good rutting resistance properties, and improved fatigue resistance properties.

Fang concluded that the improvement in asphalt properties could be due to the swelling of the recycled plastic and the network structure of the recycled plastic-asphalt. When the plastic content was increased from 2% to 4% (weight of mix), swelling occurred because the absorbance of the lightweight fractions in the binder/asphalt increased its properties and distributed in the continuous asphalt phase. As the recycled plastic content increased to 6%, it began to form an interconnected network (two continuous phase), which limited the free flow of bitumen molecules, resulting in improved toughness, viscoelasticity and overall pavement properties of the asphalt mix.

Another reason for the improvement in properties could be due to the fact that PE has a wider viscoelastic range of –80°C to 120 °C. The long, flexible and linear PE chain has a greater ability to adapt to external forces, therefore, exhibiting better performance.

Australia and New Zealand

Recently, several proprietary products made from recycled plastics have been introduced to the Australian and New Zealand market as asphalt modifiers. Further information about these products, their use, benefits, performance testing outcomes and road trial information are provided in Section 5. These products are:

- MR6, MR8 and MR10 (MacRebur)
- Reconophalt (Downer Group)
- PolyPave™ (Alex Fraser)
- PlastiPhalt® (Fulton Hogan).

4.4 Optimum Size of Plastic for Recycling

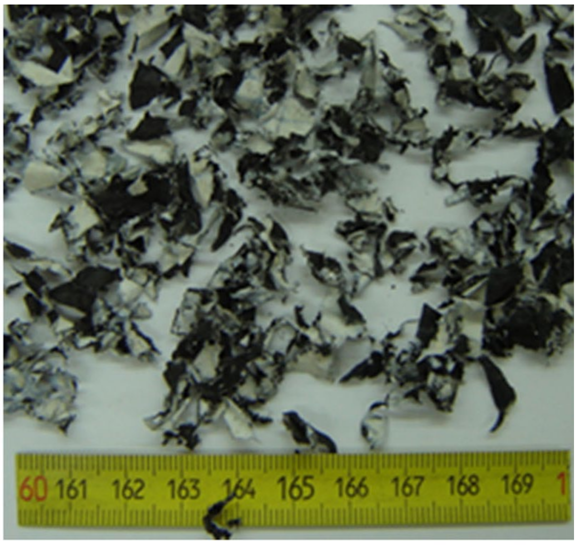
Recycled plastic needs to be broken up into smaller pieces before blending into a bituminous mix. Angelone et al. (2016b) compared PE made from silo bags in the form of flakes, pellets and chips, against a control standard asphalt mix and a SBS modified mix. Refer to Figure 4.1 for diagram of flakes, pellets and chips.

The recycled plastic was added into the asphalt mixture in a dry mixing process. Aggregates and filler were first mixed with plastic, before incorporating it with bitumen. Angelone et al. (2016b) concluded that:

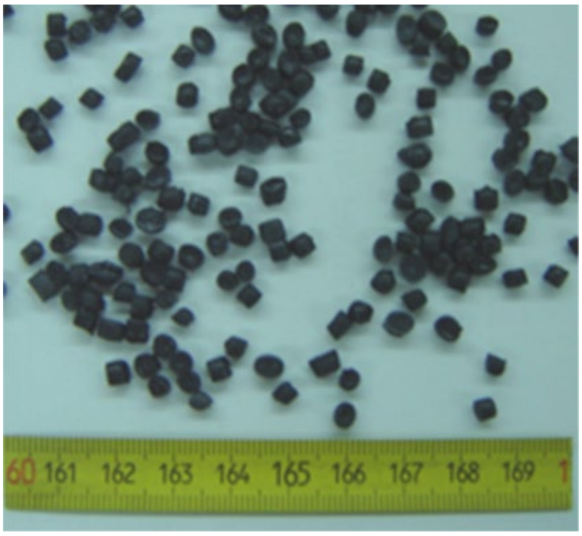
- mixes containing flakes and pellets of recycled plastics had greater stability than the control and SBS mix
- flakes were observed to be more soluble than pellets
- the addition of recycled plastics in pellet form provided better tensile strength results. However, properties decreased as the amount of recycled plastic added increased (from 2% by weight to 6% by weight).

Unfortunately, the literature did not provide any commentaries on the PE made in the form of chips.

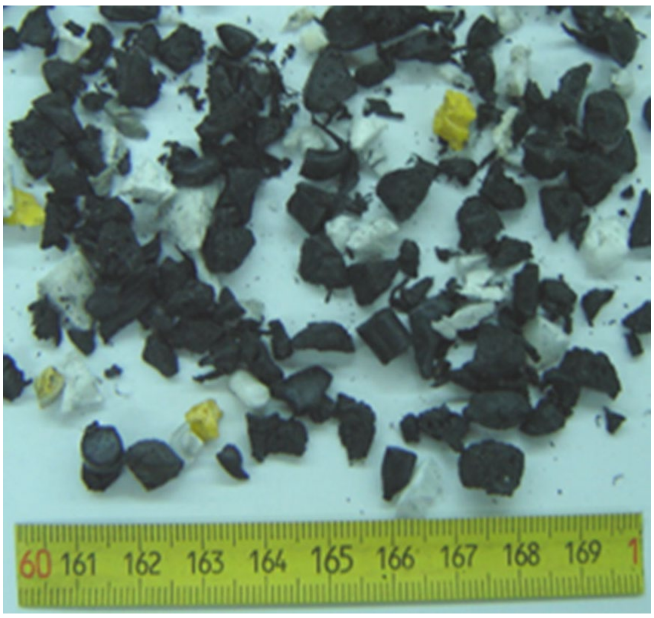
Figure 4.1: Different sizes of recycled plastic



(a) Flakes (6-10 mm)



(b) Pellets (2-5 mm)



(c) Chips

Source: Angelone et al. (2016b).

In the work reported by White (2019), the recycled plastic came in two forms, i.e. shreds (or flakes) and pellets. The pellet form was manufactured to be incorporated directly into the asphalt production plant. It is claimed that the pellet will melt into the bitumen to extend and modify the asphalt. The study conducted by White (2019) will be further discussed in Section 5.1.

In terms of the effect of the different sizes of recycled plastics on the overall performance of the asphalt mix, limited information of relevance to Australian conditions was identified in the review of international literature.

5. Case Studies – Road Trials

This section summarises some local and overseas experience in recent years in trialling the use of recycled plastics in road construction.

5.1 Australian Experience

In 2018, a series of road trials took place around Australia. These trials mainly involved two proprietary products from suppliers MacRebur and Downer EDI. This section covers the details and performance testing results reported by the manufacturer of these two products.

5.1.1 MacRebur

In 2015, a commercial plastic waste recycling venture was released in Scotland (UK). White & Reid (2018) reported that the use of this product would lead to:

- consumption of a portion of waste plastic otherwise destined for landfill
- a reduction in the cost of new road construction and maintenance
- an increase in the strength and durability of local roads.

The idea behind the product was inspired by practice in Southern India of retrieving waste plastic to fill up potholes. Diesel was then poured over it and the mix set on fire until the plastic melted into the craters and formed a makeshift plastic pothole filler.

This company has now produced three products (MR6, MR8 and MR10) made from domestic and industrial waste plastic. No information was provided on the type of plastics used. What is known is that these products have a melting point lower than that of typical asphalt and binder production temperatures; thus enabling it to melt into the binder to extend and modify it (White & Reid 2018).

These three products come in a different colours and forms, as shown in Figure 5.1:

- MR6 – comes in pellet form and is intended to be incorporated directly into the asphalt production plant. It modifies the asphalt by increasing its tensile strength and the softening point. It is flexible but rigid and unbreakable. It is reported to work well in hot conditions (like Australia) as it has a melting point of 110 °C.
- MR8 – a shredded plastic. It was developed to be a more economical bitumen extender without any performance enhancement. It is a cheaper version of MR6.
- MR10 – comes in pellet form (looks similar to MR6). It was developed to provide a more crack-resistant binder. In contrast to MR6, it is flexible in a solid form. It rebounds when it is flexed. It was reported by White & Reid (2018) that it worked well in colder climates such as the UK, Canada and Russia.

Cumbria County Council was the first highway authority in the UK to trial MacRebur's plastic-based material in 2017. It was reported that an equivalent of 500,000 plastic bottles and over 800,000 one-time-use plastic bags were recycled for a 400 m long by 20 m wide strip of road (Cumbria County Council 2017; Barry 2018). MacRebur also claimed that the company aims to use a ratio of 50/ 50 domestic and commercial waste for local road applications.

Locally in Australia, MacRebur performed a road trial for Brisbane City Council in 2018 (Barry 2018). There is limited information about this trial in the public domain. However, through personal communications, it is understood that a series of performance tests has been conducted by Brisbane City Council's Pavement Division in association with the University of Sunshine Coast, Boral and Fulton Hogan.

Figure 5.1: MacRebur products: a) MR6, b) MR8, c) MR10

(a) MR 6 (b) MR 8 (c) MR 10

The objectives of the testing were to: (1) compare the behaviour of the binder that had been supplemented with recycled plastic with standard bitumens, a Multigrade bitumen or PMB, and (2) if the addition of the recycled material into the asphalt would result in any property improvements.

Addition to C170 bitumen

The MacRebur products (MR6, MR8 and MR10) were blended into the C170 bitumen. The results indicated that, when 4.5% of MR6 was added to the C170 binder, the properties were similar to a A35P bitumen with good torsional recovery and an increased softening point to approximately 78 °C. This concurred with the manufacturer's claims that MR6 mimics a plastomeric polymer and MR10 an elastomeric polymer (White & Read 2018). However, the MR10 blend was much stiffer than the MR6 blend, which contradicted the claim that it would exhibit elastomeric properties.

There was no significant difference in the properties when the MR8 was added to the C170 bitumen.

Addition to C320 bitumen

Six per cent (by mass of bitumen) of MR6 and MR10 was added to the C320 bitumen through a batch plant. Another two batches of asphalt were prepared which were C320 and Multigrade M1000 control mixes.

The deformation resistance of the MR6 mix was superior to the M1000 mix. However, the tensile strength of both the MR6 and MR10 mixes dropped drastically when the mix was exposed to moisture. This could be due to the weakening of the bonds between the recycled plastic and the binder.

The addition of MR6 to the C320 mix resulted in an increase in stiffness similar to the M1000 mix, but very little difference with the MR10 mix. However, the fatigue results for the MR6 were poor, suggesting no improvement to the life cycle of the asphalt. The fatigue life of the MR10 mix, on the other hand, was slightly higher but minimal compared to the results for the C320 and M1000 mixes. It was suggested by White & Read (2018) that this behaviour could be due to the poor digestion of the waste plastic material in the samples, as some pellets were still visible.

Addition to 40/60 bitumen to produce asphalt mixture

White (2019) reported the results of testing of an asphalt mix containing British pen grade 40/60 bitumen (equivalent to C320) modified with 6% MR6, MR8 and MR10. Testing was conducted according to the British asphalt specification performance tests (British Standard EN 13108-5:2016).

It was found that the addition of all three products resulted in an improvement in deformation resistance and overall structural contribution, noting that MR8 was developed to be an economical bitumen extender without noticeable performance-enhancing properties. MR10 had the highest stiffness modulus, whilst MR6 had the most significant effect on asphalt fracture resistance and deformation resistance. This contrasted with the original intention of MR6, i.e. to exhibit plastomeric properties rather than MR10.

White (2019) also suggested that the addition of MR6 and MR10 resulted in improved fracture toughness and fatigue life, which contradicts the work conducted by the University of Sunshine Coast and Brisbane City Council. However, White (2019) also reported that the fatigue life was more variable compared to some of the other asphalt properties. This may have been due to the fact that the moduli of the materials differed, and the interaction between the applied load, the resulting strain magnitude and the measured fatigue life.

5.1.2 Downer Group

On the 29 May 2018, the first road trial of Reconophalt was laid in Rayfield Avenue, Craigieburn, located in the north of Melbourne. It was reported (Downer 2018) that approximately 200,000 plastic bags, 63,000 glass bottles (substitute for sand), more than 4,500 used printer cartridges and 50 tonnes of reclaimed asphalt pavement were diverted from landfill to the site. This project was sponsored by Downer Group and the Hume City Council, in collaboration with a resource recovery and recycling company, Close the Loop, and RED Group.

Through the REDcycle program (hosted by the RED Group), unwanted plastic shopping bags and other soft plastics (such as food packaging) are collected from bins placed at major supermarkets to be re-used in an environmentally responsible manner. Close the Loop then transforms the soft plastics collected by the REDcycle program along with waste toner collected through programs such as Cartridges 4 Planet Ark to develop an asphalt additive called TonerPlas. TonerPlas is then mixed with glass and RAP to produce the final proprietary product named Reconophalt.

Downer (2018) reported that every 1 km length of a two-lane way road would involve the use of: 530,000 plastic bags, 168,000 glass bottles, and 12,500 waste toners from printer cartridges (Downer 2018).

Downer claims that Reconophalt is a high-performance material even under heavy traffic compared with standard asphalt: it enhances the characteristics of the asphalt, lasts 65% longer than standard asphalt and is less likely to rut. The performance testing results provided by Downer ED are shown in Table 5.1.

However, it costs 2-5% more than standard asphalt due to the additive production and transport costs. For example, the asphalt additive TonerPlas, manufactured by Close the Loop, only operates in Somerton, Victoria. Despite this, it was claimed that it was still 25% cheaper than PMB-modified asphalt (Downer 2018).

While a cost comparison between Reconophalt and PMB-modified asphalt was provided by the producer, no further information on the performance comparison of these two products was provided.

Table 5.1: Reconophalt Performance Tests

Parameter	Reconophalt (20% RAP, 5% glass, 5.6% binder, 0.75% additive)	Reconophalt production trial 29/05/2018	Reconophalt Testing by ARRB 24/05/2018	Standard Baseline AC10H	VicRoads AC10H Specification
Stiffness modulus @ 25 °C (MPa)	4200	3820	5200	4100	2500-5500
Wheel tracking depth @ 60 °C (mm)	1.6	1.8	2.0	9.0	<11
Fatigue life @ 20 °C (k cycles)	477	926	505	156	>140
Moisture sensitivity – tensile strength ratio (%)	84	81	Not tested	91	>80
Moisture sensitivity – wet tensile strength (kPa)	998	1068	Not tested	1251	>850
Particle loss, unconditioned (%)	8	12	Not tested	14	Not applicable
Particle loss, moisture conditioned (%)	11	13	Not tested	15	Not applicable
Air voids @ 50 Marshall blows (%)	4.9	5.1	Not applicable	5.0	4.9% to 5.3%

Source: Downer (2018).

5.1.3 Alex Fraser

Alex Fraser has recently resurfaced two municipal streets in the City of Yarra (Victoria) with its proprietary product, PolyPave™. The resurfacing of Stanley and Margaret Street in Richmond was reported to contain recycled glass, asphalt and HDPE plastic (hard plastic/bottles), amounting to almost 100 tonnes of recycled waste.

The City of Yarra has re-engaged Alex Fraser to repair and repave several more streets in the near future. It is estimated that an additional 100 tonnes of asphalt will be used, saving nearly 25,000 plastic bottles from entering landfill. This information was obtained from Alex Fraser's official website (www.alexfraser.com.au). No further information was found on the performance of this material.

5.1.4 Fulton Hogan (Australia)

Road trials have been conducted in the City of Port Philip using recycled plastic. However, no relevant information on these road trials has to date been published.

5.1.5 Sprayed sealing applications

The use of recycled plastics in recent times has been focused on asphalt applications. In the late 1970s and early 1980s, some work was carried out on plastic (virgin) modified binders used in sprayed seal applications. For example, a proprietary product, Polybilt 101, was developed by ExxonMobil. It contained virgin plastic and was used to modify bitumen. However, due to field performance issues such as segregation, handling and storage and stripping, this product has not gained common usage.

5.2 New Zealand Experience

Fulton Hogan, in partnership with Christchurch Airport, conducted a trial with recycled plastic modified asphalt mix. PlastiPhalt®, which was developed by Fulton Hogan and used to pave half of Christchurch Airport's fire station. PlastiPhalt® is made from used oil containers collected through Fulton Hogan's Recovering Oil Saves the Environment (ROSE) scheme. Previously, these containers could not be reused due to the residual oil left on the inner surface. In 2014, the company began its research program by shredding these plastic containers to an ideal size before incorporating them into an asphalt-grade bitumen.

PlastiPhalt® is used to modify the asphalt mix required to meet the performance requirements of any given site. Once it is blended and ready to be used, it is sampled and laboratory tested to ensure the level of modification is achieved. Additional plastic material can be added to fine-tune the mix, if required.

This information was obtained through personal communication with Clare Dring, National Products Manager of Fulton Hogan Ltd (NZ) on 29 May 2019.

5.3 Overseas Experience

There are various applications of recycled plastics in road applications overseas. A summary follows.

5.3.1 Netherlands

In September 2018, a new 30-metre-long bicycle path composed of plastics was installed in Zwolle, Netherlands (see Figure 5.2). This innovation, called PlasticRoad, was the result of collaboration between three companies, an engineering firm KWS (a VolkerWessels company), Wavin (a subsidiary of the plastic piping company Mexicham), and an energy company Total (Giasson 2018).

The first pilot trial in Zwolle involved the use of 70% recycled plastic, including plastic bottles, beer cups, cosmetic packaging, plastic furniture, etc. Besides the effective use of waste plastic that would otherwise have been incinerated or dumped into landfill, the construction of the path was fast and easy. This was because the road design incorporated prefabricated and lightweight modular pieces (like Lego). The path was installed in a matter of days, thus reducing of the normal downtime and traffic obstruction often related to traditional road construction methods. The modular design also resulted in a reduction of in the levels of greenhouse gas emissions typically associated with conventional road construction methods.

Another interesting feature of the design of PlasticRoad is it is hollow. As a result, it offers many benefits, including the ability to cater for utility services such as pipelines and cables for high-speed internet, and the storage of rainwater to mitigate flooding. It was reported that this concept offers opportunities for further innovation such as solar roads, light poles and traffic loop sensors.

A second pilot trial was established by the same partnership in November 2018 in the town of Giethoorn. Similar to the first trial, this was also a 30 metre long bicycle track. The method of installation of the second track was reported to be different from the first one. A smaller and lighter equipment was used to 'pick and drop' the fabricated pieces as shown in Figure 5.3.

Figure 5.2: First pilot trial of PlasticRoad in the Netherlands

Source: PlasticRoad website.

Figure 5.3: Second trial of PlasticRoad in the Netherlands

Source: PlasticRoad website.

5.3.2 Canada

In 2012, the City of Vancouver, Canada, became the first city ever to use wax made from municipal recycled plastic containers in warm mix asphalt (WMA). The City of Vancouver collaborated with a recycling company, Greenmantra, that developed a simple concept of converting 100% plastic into recycled plastic wax which is compatible with WMA with a high RAP content. The wax is produced from HDPE and LDPE recycled plastics typically found in squeeze bottles and plastic bags (Sharp et al. 2017). Trials were also conducted using soy mixed with the recycled wax to produce WMA at low temperatures.

Some of the City's main criteria when considering new technology are:

- no additional infrastructure required to produce WMA
- no major change to operations during trials
- current asphalt mix designs are used
- the use of RAP continues
- the re-recyclability of asphalt would continue without major impact to current emission standards, health and safety, and quality control
- the system needs to be cost effective (Sharp et al. 2017).

The City of Vancouver confirmed that the product from GreenMantra met all of these requirements.

The manufacture of the product is similar to the conventional method of manufacturing asphalt. Flaked wax is blended with RAP which is then fed through a bin. Typically, 20% of RAP is used but it was reported that it could now be as high as 25%. The final temperature was also reported to reduce from 160 °C to approximately 120 °C after the modification with the recycled wax. Initial measurements indicated a 25% reduction in volatile organic compounds (VOCs), hence creating a more conducive environment for the workers at the plant and construction site. The City currently uses a weight ratio of wax to mix of 0.25-0.5% depending on the different variables in the mix. This means that 1 tonne of wax could yield approximately 400 tonnes of WMA (Sharp et al. 2017).

Overall, the results were positive with good field compaction and the meeting of conventional design criteria. The most desirable property from the City of Vancouver's point of view is tensile stress ratio (TSR). If the ratio is above 80%, the wax would be accepted for use in WMA. The TSR of the wax-modified WMA ranged from the low 80s to the 90s, whilst the shear strength of the unconditioned samples was up to 21,000 Newton. The voids filled with asphalt (VFA) were in the range of 65-76% (Hein 2014).

The next goal for the City is to create a recycled plastic waste with a lower melting point to improve on workability at low temperatures.

The Canadian Technical Asphalt Association reported that the incorporation of wax in WMA lowers the viscosity to a level similar to a hot mix asphalt, with the added benefit of cutting down on the need for high temperatures which requires more energy and emits more fumes (Hein 2014). The finished product is user-friendly and reusable in the future. However, it was also noted that these types of waxes, if compared to other waxes from coal tar, may make the asphalt more sensitive to cold temperatures and fatigue.

5.3.3 India

The first plastic road in India was constructed in Chennai in 2002 from shredded waste plastic. This plastic road is reported to be durable and pothole free (Subramaniam 2016; Manju, Sathya, & Sheema 2017). Today, there is more than 33,000 km of plastic road in India with most of them being rural roads and a small number in cities such as Chennai and Mumbai (Subramaniam 2016).

A recent road safety report by the World Health Organisation (WHO) found that 17% of the world's traffic fatalities occur in India and in 2014, it was reported that potholes alone caused more than 3,000 deaths. This has prompted the Indian government to look for more cost-effective treatments for their roads. In November 2015, the government made it mandatory for road developers to use waste plastic along with bituminous mixes for road construction in urban areas (Arora 2015).

Dr R Vasudevan, a chemistry professor and Dean at the Thiagarajar College of Engineering in Madurai, developed the idea of shredding plastic bags and mixing them with hot aggregates and bitumen before laying it on the road. It is suggested that every kilometre of road uses an equivalent of 1 million plastic bags, saving around 1 tonne of bitumen and costing 8% less than conventional asphalt.

In March 2016, a modified version of the design was trialled on a major highway connecting Chennai with Villupuram. This was the first time that plastic road technology was used on a national highway in India. Approximately 1 km of the four lane national highway was re-paved with 65% RAP and 35% new aggregate coated with waste plastic (Annamalai 2016).

In 2013, the Indian Road Congress published a specific guideline for the use of waste plastic as a modifier for asphalt. The guideline specified that only HDPE, LDPE, PET and PU can be used in pavement construction and the plastic size must pass the 2.36 mm sieve but be retained on the 600 µm sieve (Indian Roads Congress 2013). The waste plastic content for dense-graded and open-graded mixes is set at 6-8% of the mass of the bitumen (Sharp et al. 2017).

A recent trial conducted by Jamsedpur Utility and Services Company (JUSCO) in the east Indian state of Jharkhand has reported improved properties compared with conventional asphalt, including improved moisture resistance, enhanced binding properties, higher softening points, the ability to withstand high temperatures and heavy load, lower penetration values, reduced construction costs and no toxic gas emissions (India Times 2017).

In the short term, recycling waste plastic for road construction might provide India with a 'clean image'. However, the concern associated with plastics breaking down into microplastics might create another problem to the environment. Subramaniam (2016) quoted a Professor of Plant and Soil Ecology at Freie Universität Berlin, '*once in the soil, these particles may persist, accumulate and eventually reach levels that can affect the functioning and biodiversity of the soil*'.

5.3.4 Other countries

Countries such as Indonesia, Thailand, Saudi Arabia (Khan et al. 2016; Dalhat & Wahhab 2017) and Ghana (Appiah, Berko-Boateng & Tabor 2017) have also trialled and used recycled plastics on their roads.

The world's largest plastic producer, Dow Chemical, recently partnered with the Indonesian government to develop a proprietary product which can be mixed into asphalt (Bendix 2019). India and Thailand are also working with Dow Chemicals to develop recycled plastic additives for road construction. Since this is a proprietary product, information and literature on the product's properties, performance and manufacturing process is not accessible at this time.

6. Areas of Concern

6.1 Occupational Health and Safety

There are major concerns about the potential occupational health and safety hazards that workers will be exposed to while handling recycled plastic modified binders during road construction.

Plastics are not just molecules of carbon and hydrogen. In the manufacturing process of converting them into everyday products, various chemical additives are used to provide the product with the following properties:

- flexibility 'feel' (softeners and plasticisers)
- delayed degradation from heat or sunlight (stabilisers and anti-oxidants)
- colour
- fire proof (flame retardants)
- body (fillers).

The toxicity and inherent properties of these additives are not known. It is possible that these potential toxic elements remain in the environment and build up in the food chain and subsequently, building up in the human body which can be harmful or deadly (Royer et al. 2018). They reported that heating plastics such as PP, PE and PS release moderate to highly-toxic emissions such as carbon monoxide, acrolein, formic acid, acetone, formaldehyde, acetaldehyde, toluene and ethylbenzene.

White (2019) described a fuming generation evaluation test that was developed to analyse binder samples modified with and without recycled plastics. This test is not in line with any specific British or Australian international test methods. It was conducted by a specialised laboratory holding UK National Accreditation (UKAS) accreditation to ISO/IEC 17025: 2017 for similar test methods. The fuming test showed the presence of toluene and benzene. It also revealed that the aliphatic, cyclic and aromatic hydrocarbons identified were from normal bitumen rather than recycled plastics. Therefore, White (2019) concluded that there was no significant difference between the fume samples with and without recycled plastics.

The research in this area is currently inconclusive. Worker safety is clearly an area of high importance and one that requires priority for research and investigation. Fuming and the management of emissions is not just an issue for plastics, it also applies to other additives. There may be an opportunity to combine work in this area with work being conducted by Austroads on other recycled materials such as crumb rubber.

6.2 Microplastics

It is known that plastic has the ability to break down into tiny particles. These particles are better known as microplastics and they can be a huge problem to the environment (Royer et al. 2018). If recycled plastics used in pavements are broken down into microplastics and flushed down watercourses into rivers, lakes and seas, then they could pose a major threat to marine life. This is because they absorb other pollutants such as pesticides and carcinogenic hydrocarbons from the aquatic environment and are often mistaken for food and ingested by zooplankton. Plankton is the foundation of any aquatic food chain and it is not desirable for them to be contaminated by plastics.

White (2019) had more positive news to share about the effect of recycled plastics on the environment. He evaluated the leachability of a modified binder by placing nominal 2.5 g samples of binder, with and without recycled plastic, in 50 mL of deionised water for 18 hours at 40 °C. The water was then cold evaporated under nitrogen before the residual was dissolved in 5 mL of ethanol and analysed for mass spectrometry by gas chromatography. This test was not performed according to international test methods but was conducted by a specialised laboratory.

No harmful materials were found leaching out from the modified binder. White (2019) concluded that recycled plastics in roads pose no negative impact to the environment (leachability) and / or workplace safety (harmful fumes).

The use of waste-derived materials is regulated in all states and territories via state-based environmental protection acts. Proponents/manufacturers of waste-derived materials must demonstrate that the product is ready and intended for imminent use without the need for further treatment to prevent any environmental harm that might result from such use.

Because the use of plastics in roads in Australia and New Zealand remains relatively new, and there are not yet sufficient answers for many of the areas of concern, more work is needed to assess the environmental impacts. In the interim it would be sensible for precautionary measures to be applied until sufficient research has been undertaken to show that road projects using recycled plastics in their different forms will not result in microplastic pollution in waterways.

6.3 Future Reuse of Waste-modified Bitumen or Asphalt

To date, no studies have been conducted on the future reuse of this waste-modified bitumen or asphalt. This could be due to the fact that most road trials are recent and the use of recycled plastics in roads is still in its early stages.

Based on the principles of using reclaimed asphalt pavement (RAP) in new hot mix asphalt, some areas to be considered in determining the future reuse of this material are suggested as follows:

- quality, durability and structural performance
- enhancement of properties
- gaseous hydrocarbon emissions during the production process
- whole of life-cycle cost
- processing methods
- specifications and guidelines.

6.4 Compatibility and Storage Stability

Another major challenge to the widespread use of recycled plastics is the compatibility and storage stability of the final modified mixture at high storage temperatures, because this can adversely affect the properties of the binder (Nasr & Hossein Pakshir 2019).

The difference in density between the binder and polymer/plastic particles, and the immiscible nature of polymer in the binder matrix, can lead to phase separation when it is subjected to high temperatures in storage and truck tanks. Consequently, the mix needs to be stirred constantly at a high frequency during the production process.

The use of high percentages of PET will also lead to an increased instability of the binder at hot storage temperatures. The lack of stability may be minimised with the use of more viscous binders; however, this measure may be inadequate to fully achieve specification requirements for storage stability. Consequently, this could potentially lead to another problem, viz. the inability to maintain the performance properties of the asphalt mix during construction.

It is also important to note that this study did not find a consistent trend between the increase in the amount of PET used and hot storage stability. It did, however, deduce that instability is more pronounced at high temperatures and low frequencies.

Costa et al. (2013) carried out storage stability testing according to European standard DIN EN 13399 on a range of plastic waste ranging from HDPE, LDPE, EVA, ABS, SBS and crumb rubber with a commercially-available PMB, Styrelf. The storage stability test is based on the difference in property between the properties of the top and bottom of the sample. Low stability means that a separation (polymer and bitumen) has occurred.

It was found that the level of separation was more prominent for the EVA, SBS and the polyethylene (LDPE and HDPE) materials. Different polymers exhibited their low storage stability in different ways. The main differences in the properties of the top and bottom of the samples produced with polyethylene polymers were their softening temperature and viscosity at high temperatures (as these properties were more heavily influenced by the presence of these polymers). The binders that demonstrated the highest storage stability were those modified with ABS powder and rubber. However, these polymers also showed very minimal improvement in terms of the performance of the base bitumen, which in many ways justifies the minor differences found in its storage stability.

Due to the good performance of the plastic modified binder, further investigation of production conditions was recommended by Costa et al. (2013), including the possibility of using higher shear mixes, lower percentages of polymer and/or compatibility additives such as polyphosphoric acid, in order to improve storage stability.

6.5 Materials Lifecycle Sustainability

Many road agencies are now registering projects for infrastructure sustainability ratings with the Infrastructure Sustainability Council of Australia (ISCA). One of the requirements of the infrastructure sustainability rating tool is the modelling of material lifecycle impacts across the infrastructure lifecycle using the ISCA Materials Calculator (or other internationally-accepted lifecycle assessment calculators or techniques). The calculator contains a library of construction materials with known lifecycle impacts, which are used to calculate the overall impact of the project, and to allow comparison of different materials' impacts.

It would be worthwhile to calculate lifecycle impacts of asphalt containing different recycled plastic compositions and to compare this with conventional asphalt to quantify the sustainability benefits. This approach could also be used by suppliers of proprietary products to quantify the sustainability benefits of their products and take into account any increased pavement life arising from the improved performance characteristics. Ultimately this data could be included in the ISCA materials calculator, which would potentially be an incentive for greater uptake of the product.

In assessing recycled plastic road products, there is a need to consider:

- the source of the material (where is the waste material turned into a product)
- how it is intended to be used (e.g. how much? where in the road profile / corridor?)
- any known or potential environmental risks (including any research undertaken) and how they will be managed
- end of life considerations – can the product be reused effectively/how will it be disposed?

7. Governance

7.1 Governance Framework

Governance frameworks structure and delineate the management of an activity. They set the rules, procedures, specifications, and other information guidelines including assessment and enforcement processes.

The development of a governance framework on the use of plastics in road construction to address issues of sustainability while maintaining pavement performance is an important consideration. It will define the processes for managing the use of recycled plastics in asphalt and sprayed seals to achieve the outcomes desired by the road authorities and the industry.

7.2 EAPA Position Statement on Waste in Asphalt

In Australia, using recycled plastics in road applications has only recently started to become popular (refer to Section 5) and several areas of concern have been highlighted for further research and assessment (refer to Section 6).

The concerns raised in Australia have also been echoed in a position statement on the 'use of secondary materials, by products and waste in asphalt' released by the European Asphalt Pavement Association (EAPA 2017a). EAPA is the European industry organization representing manufacturers of bituminous mixes and asphalt as well as companies engaged in asphalt road construction and maintenance. It is similar to the Australian Asphalt Pavement Association (AAPA).

In Europe, the asphalt industry strongly encourages the reuse of reclaimed asphalt as it is economical and environmentally friendly.

With the tightening of waste exports to certain overseas markets and the increasing difficulties associated with disposing waste to landfill, some waste producers are attracted to road construction as a source of waste disposal. More than often, economic incentive also plays a role in driving these initiatives.

Recently there have been concerns raised over the incorporation of 'other' additives in specialty asphalt mixes. Waste legislation itself is ill-defined and complex, and so are the benefits of recycling with respect to hazard classification and risk assessment. The asphalt industry in Europe is keen to identify the additives contained in mixes to ensure that they are not harmful to workers' health, the environment and future recyclability. Hence, the EAPA developed a position statement to provide an industry position on the inclusion of waste and waste-derived products into new bituminous mixes (asphalt).

As per Australia and New Zealand, one of the common hurdles to recycling and reusing waste in Europe has been the lack of confidence in the quality of recycled materials as well as an uncertainty about the potential health risk posed to workers dealing with this material. Some recommendations were made in the EAPA position statement, including:

- The first priority should be the re-use of reclaimed asphalt in hot and warm mix asphalt as there is a significant potential energy consumption savings.
- Asphalt producers must provide proof that the waste or waste-derived materials incorporated into their asphalt mix have been subject to a risk assessment process to prove that:
  - there will be no health and safety concerns to the workers or the general public during processing, use and application, now or in the future
  - there will be no environmental impacts and/or liability problems at the time of use, or in the future

- the recycling of asphalt is permissible
- there will be no significant negative impacts on the technical performance of the asphalt
- the life cycle analysis (value for money) remains highly positive for the client.
- the introduction of waste should not affect the competitiveness of asphalt solutions versus alternative pavement types.

7.3 The Need for an Australian Framework on the Use of Waste Plastic

The Australian pavements industry can also collaboratively express their position that their asphalt mixes should never be seen as a product to solve the waste stream problems of other industries.

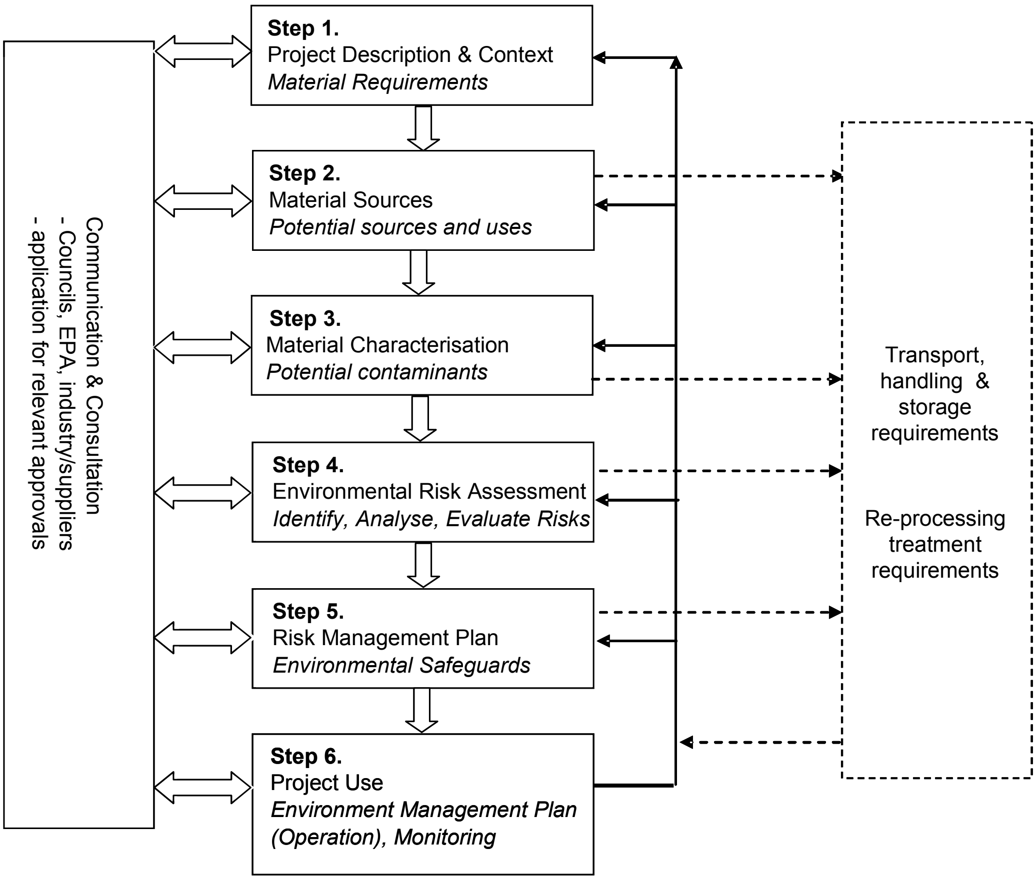
In many parts of the world there is a movement towards the adoption of Environmental Product Declarations (EPD). The US National Asphalt Pavement Association (NAPA), AAPA and other equivalent organisations around the globe are moving in this direction.

The broad framework for the use of recycled and alternative materials in roadworks is shown in Figure 7.1 below. It is based on AS/NZS ISO 31000-2009, *Risk management*. This framework presents an overall approach generally undertaken in conjunction with the appropriate legislative organisations and regional councils where decisions concerning material needs, material sources, material characterisation, risk assessment and treatment, project use and operational phase issues can be considered.

Some of the other aspects to be considered for an Australian framework for waste plastic could be:

- the reason for using waste material is well identified and defined
- rigorous health, safety and environmental risk assessment to be carried out prior to accepting a waste derived product
- a suite of testing programs to be carried out to ensure performance enhancement
- whole of life cycle costing to be determined
- systematic use of product safety and environmental data sheet is recommended
- an environmental product declaration is made based on a sustainability calculator and local and international accredited data
- the future re-use and recyclability of asphalt is not affected.

Figure 7.1: Broad framework for the use of recycled and alternative materials in roadworks



Source: Austroads (2009).

7.4 Performance Specifications and Performance Indicators

Plastic is not homogenous and comes in a variety of different forms. It can be used to modify or extend asphalt and bitumen. There are different methods of application, mixing and blending with other materials such as crumb rubber, RAP, glass and many others. Many of these asphalt mixes are proprietary. There are a multitude of variations and technical complexities. In this context there would be merit in exploring a performance-related approach that incentivises industry to deliver sustainable long-term performance outcomes through 3rd party testing and certification.

This might include elements such as:

- managing the plastic selection from the waste stream
- performance assessments using standard tests
- durability proving and potential system certification
- adoption of performance-related specifications and outcomes
- market-driven performance incentives and opportunities for branding of proprietary products.

7.4.1 Approaches to specify the required performance of a product

A performance-related specification describes a desired performance level or performance target but does not make specific demands on how that level of performance or target is achieved. The specifications describe the result that is required and leave it to the producer/contractor to satisfy that requirement. They can be broad enough to accommodate proprietary products/designs. In other words, instead of prescribing the need in terms of inputs, it is described in terms of outputs.

The objective is to allow producers more flexibility to innovate when selecting the materials to be used in a pavement (in this case an asphalt or sprayed seal surfacing). In return, they are required to provide performance guarantees regarding their asphalt mixes, binders and proprietary products.

Performance-related or performance-based specifications should clearly specify the test methods and the acceptance criteria that will be used to verify and enforce the requirements. Some testing may be required in the laboratory and some might be needed for field acceptance. The specifications should provide flexibility to the contractor/producer to provide an asphalt mix or spray seal application that meets the performance criteria in the way they choose. The contractor/producer will also work to develop an asphalt mix design that meets additional requirements for laying and profiling while ensuring that the performance requirements are not compromised. Performance-based specifications should avoid requirements regarding the cross-section designs and form of construction or limit the type of materials used.

Non-technical issues that could be addressed in developing a performance-based specification include (AAPA 2018):

- tender schedules – requires the contractor to provide mix design reports, construction procedures, and inspection and test plans, as part of the tender
- warranty schedule – the Works Contract should include a warranty schedule for performance guarantee by the contractor
- risk and maintenance pricing – the costs of risks associated with compliance with the specification, performance guarantee and maintenance services during the performance period
- maintenance provisions – provision for the contractor to be involved in the planning and/or execution of maintenance works during the warranty period
- responsibility – the contractor is responsible for the delivery of the works to a high quality
- testing requirements – the specification could include testing requirements where the limit is ‘report only’.

A performance-based specification would include provisions that clearly define the long-term performance requirements of the pavement. The producer/contractor would also be required to provide a reasonable warranty on their material for a minimum period of five years or for a period that is consistent with the producer’s claims.

7.4.2 What is a prescriptive specification?

A prescriptive specification describes a specific approach or clearly-defined set of procedures that must be followed to a set standard without deviation. It advises precisely what should be done and how it should be done.

Prescriptive specifications generally provide the client with a higher degree of assurance about the form of the end-product when they make their final investment decision (i.e. when they appoint the contractor).

7.4.3 Performance related/ based specification for using plastic in asphalt and sprayed seals

The benefits of performance related/ based specifications include:

- They encourage the use of alternative and innovative materials, construction or designs to meet certain prescriptive requirements – provided that the intent of the client is met – while still allowing acceptable existing practices through any deemed-to-satisfy provisions.
- They permit designs to be tailored to a particular requirement.
- They provide clear information on what is trying to be achieved.
- They focus on high quality performance outcomes rather than inputs.

The possible elements of a performance related/ based specification for the use of plastics in asphalt and sprayed seals is as follows:

- There would potentially be a qualification/certification system that establishes the requirements for a quality control management system, qualification of personnel and requirements for production facilities.
- The specification would have provisions that clearly define the long-term performance requirements of the pavement.
- The producer/contractor would be required to ensure that the correct asphalt mix or sprayed seal application is developed and placed.
- The producer/contractor would be required to certify that the asphalt mix design or sprayed seal surfacing application, including plastics, meets the specification requirements, including standard test methods.
- After the material is placed, a series of standard field acceptance tests should be conducted to determine if the construction meets the performance criteria.
- The producer/contractor should be required to provide a reasonable warranty on their material and construction for a minimum period of five years or for a period that is consistent with the producer’s claims.
- A clear set of corrective action responses should be provided when the construction outcomes do not conform with the performance criteria.

7.4.4 Setting measurable performance indicators

It is very important that producers/contractors and the client to agree on what is a successful outcome of the contract and also that they understand the performance measurables over time. Both the level of required outcome and the related key metrics need to be considered and clearly set out. At its simplest, the contracted outcomes and performance metrics should be objective, measurable, clear and realistic. This is fundamental in a performance-based contract.

7.4.5 How is risk allocated/transferred?

Performance-based contracts are used to drive performance outcomes and manage outcome uncertainty. One of the most important concerns is how to quantify performance-based risk on both sides of the contract. As a general rule the risk should always be allocated to the party best able to manage it, placing responsibility for risk on designated parties consistent with their ability to control and insure against that risk (Cerosky 2017).

In defining the allocation of risk to the producer/contractor, the following broad principles should be considered (adapted from Mead 2017):

- the risk should lie within the producer/contractor’s control
- the producer/contractor should be able to transfer the risk, e.g. through insurance
- the preponderant economic benefit of controlling the risk should lie with the producer/contractor
- placing the risk on the producer/contractor should be in the interests of efficiency, including planning, incentive and innovation efficiency
- if the risk sitting with the producer/contractor eventuates, then the loss falls on them in the first instance.

Warranties can be used to allocate risk by (Thomson Reuters 2013):

- apportioning exposure to potential losses and shifting risk from the client to the producer/contractor
- creating a direct claim against the producer/contractor if representations and warranties are inaccurate
- serving as a basis for the parties’ indemnification rights.

The broader the representation or warranty, the more risk is assumed by the producer/contractor. Producers/contractors commonly attempt to narrow their risk by:

- qualifying their representations and warranties
- limiting the survival of representations and warranties
- including anti-sandbagging provisions
- including a limitation on the overall amount of a party’s liability for inaccuracy or breach (commonly called a cap)
- designating express, exclusive contractual remedies for inaccuracy or breach, often limited to the recipient’s indemnification right.

8. Conclusions and Recommendations

The aim of this project was to assess the current status with respect to the use of recycled plastics in asphalt and sprayed sealing applications and to make recommendations on priority research and development for Austroads and its member agencies in Australia and New Zealand.

The main focus of the project was a national and international literature review. The majority of studies on the topic were found to be conducted overseas, and therefore were subject to local conditions and specifications not necessarily directly applicable to Australia and New Zealand. While there has been a reasonable amount of work conducted on recycled plastics in asphalt, there has been very little research conducted in the use of recycled plastics in sprayed sealing applications.

There is very little performance data available and what is available is sometimes contradictory. Road trials of asphalt mixes containing recycled plastic have commenced in most states. These trials have assessed a range of engineering properties and the overall results have been found to be positive. It should be noted that these products have not as yet been subjected to extensive 3rd party assessment and public scrutiny. However, most of these studies have concluded that the use of recycled waste plastic in asphalt mixes has resulted in good short term service performance.

There are different methods of application and mixing of plastic with other materials such as crumb rubber, RAP, glass, etc. These multitude potential applications fit best with a performance based approach rather than a more prescriptive specification/standard. This should form part of a wider governance framework to drive positive outcomes and give clear and consistent national guidance on industry practice.

Clearly, more research is needed to develop a better understanding of the benefits and the effects of recycled plastics in asphalt and sprayed seal pavements in Australia and New Zealand. In prioritising research and development activities, a range of factors have been considered, including:

- cost savings to road agencies/communities
- potential for the greater use of recycled plastic materials
- workplace safety and health effects
- performance benefits
- industry sustainability
- national consistency and harmonisation
- complementarity to other work being done
- the expressed need.

These are now briefly discussed.

Priority 1: A Governing framework for the assessment of recycled plastic in asphalt (an evaluation protocol for the assessment of recycled plastic in asphalt)

A governance framework needs to be put in place to ensure consistency of approach, effective quality control and safe handling of these materials. The flexible pavements industry and road authorities need to collaborate to develop a suitable approach to ensure that the road network does not become a ‘landfill’ for unsuitable waste materials, especially with the increasing pressure to recycle waste plastics.

During the initial stages of the development of this governing framework, it is recommended that the following elements should be considered seriously and assessed:

- Pavement performance long-term durability

  The performance and long term durability of asphalt modified with recycled plastics need to be monitored and studied closely to better understand pavement behaviour under different traffic loading and environmental conditions. This investigation should be conducted by an independent third party reviewer

- Environmental, health and safety

  Further work needs to be conducted to address concerns such as leaching, microplastics and fumes emitted during the manufacturing process and during road construction.

  The development of Environmental Product Declarations (EPDs) should be considered as an approach to 'providing' quantified environmental data using predetermined parameters and, where relevant, additional environmental information for products over their life cycle (EAPA 2017b).

  There are tools available in the market to help quantify the environmental impact of an asphalt mix such as the Emerald Eco-Label introduced by the National Asphalt Pavement Association (NAPA) in the USA. The aim of the Emerald Eco-Label Program is to provide credible environmental data to users so that they are empowered to make well-informed decisions aimed at improving the environmental impact of asphalt pavements (NAPA no date).

- Digestion and storage stability

  Further testing needs to be conducted to ascertain the digestion and storage stability of these materials under Austroads specifications and local working conditions.

Priority 2: Independent review

It is recommended an independent 3rd party review be conducted of the most commonly used proprietary products and that they be compared with standard Australian bitumen and asphalt mix specifications, as well as against individual state road authority standards and guidelines. This would provide road authorities with a better understanding of the properties of these materials. Further to this, appropriate test methods, storage and handling protocols should also be established.

Priority 3: Long-term economic benefits

The use of recycled plastic needs to be supported by sound economic assessments before it could be widely introduced. For example, certain grades of plastics have a high reusable value and would not need to be used in road construction. Those categories of plastics which are suitable for re-use in road construction should be assessed for their long-term economic benefits.

Priority 4: Lifecycle sustainability assessment

A study could be conducted using an internationally recognised infrastructure sustainability calculator (e.g. EN15804) to identify the lifecycle impacts of asphalt containing different recycled plastic compositions compared with conventional asphalt to quantify the sustainability benefits.

An EN15804-compliant EPD would allow proprietary products to be included in the ISCA Materials Calculator to allow ready comparison with conventional asphalts.

Priority 5: Use of recyclates HDPE and LDPE

The literature revealed conflicting information regarding the suitability of HDPE and LDPE as a bitumen modifier (Costa et al. 2013; White & Reid 2018). White & Reid (2018) claimed that HDPE (e.g. plastic bags) and PET (e.g. plastic bottles) have high melting points of 270 °C and 260 °C. However, this contradicts the *Material Safety Data Sheet* (Qenos Pty Ltd 2016) for HDPE which reports a melting temperature of 120-135 °C.

Further studies and tests are required to gain a better understanding of the properties (including contamination levels) of recyclates HDPE and LDPE as a bitumen modifier and the durability of the blended product in asphalt and sprayed seals.

Priority 6: Performance and/or prescriptive based specification

A generic performance-related specification for the use of recycled plastics in both asphalt and sprayed seals should be developed that incorporates:

- managing the plastic selection from the waste stream
- performance assessment through standard testing
- durability proving and potential system certification
- the establishment of performance-based outcomes and assessment procedures
- market driven performance incentives and opportunities for branding of proprietary products.

If a prescriptive approach is to be adopted, then suitable test methods and requirements need to be produced and prescribed.

Priority 7: Road trials

Road trials conducted in Australia and New Zealand have only recently commenced. The long-term performance of these trials needs to be closely monitored and assessed as a national project. A research project embracing as many of these projects as possible is needed to capture and share the knowledge.

Priority 8: Sprayed sealing research

Although the use of virgin plastic modified binder has not been successful in the past for sprayed seal application (refer to Section 5.1.5), new technologies may be employed to overcome past challenges. The viability of using recycled plastics in sprayed seals is a potential area of research.

Priority 9: Monitoring complimentary projects

RMIT University, in partnership with SAMI Bitumen Technologies, the City of Whittlesea and the Office of Projects Victoria, have received funding from Sustainability Victoria to ‘develop a performance-based classification system of the waste plastic modified bitumen’. This means that the inclusion of the recycled material would be determined by performance measures rather than prescriptive limits. This is a positive initiative and progress in this project, and similar projects, should be monitored and supported.

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Appendix A Consultation List

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1	Warren Carter	National Technical Manager	Downer
2	Graham Henderson	Business Development Manager	Downer
3	Jerry Tan	Blended Products Manager	Downer
4	Bryan Pidwerbesky	National Manager – Technical	Fulton Hogan NZ
5	Clare Dring	National Products Manager	Fulton Hogan NZ
6	Neal Johnson	Manager	Fulton Hogan AU
7	Bevan Sullivan	National Technical Manager	Fulton Hogan AU
8	Stuart Nugent	WA State Manager	Colas
9	Trevor Distin	Technical and Marketing Manager	Colas
10	Mike Pickering	Director: Pavements Research and Innovation	TMR
11	Peter Evans	Deputy Chief Engineer (Pavements Materials and Geotechnical), Engineering and Technology Division	TMR
12	Erik Denneman	Director, Technology and Leadership	AAPA
13	Rob Vos	State Executive Director	AAPA
14	Kieran Sharp	Author of paper referenced in report	Sole trader
15	Sebastien Chatard	National Technical Manager	SAMI
16	Iulian Man	Technical Support Manager	SAMI
17	Prof Hamid Nikram	Professor, Faculty of Science and Engineering	Curtin University
18	Jon Griffin	Program Manager, MRWA	WARRIP
19	Jennifer Slocombe	Principal Sustainability Manager	DPTI
20	Graham Wilson	International Technical Manager	PUMA Bitumen
21	Kevin Thomson	Member of PACIA	Plastic & Chemical Industry Association (PACIA)
22	Dr Greg White	Author of paper referenced in project brief	University of Sunshine Coast
23	Greg Stephenson	Senior Engineer, Civil Infrastructure	Brisbane City Council
24	David Fricke	Asset Manager	Hume Council, Vic
25	Peter Lazarus	Technical Manager	Alex Fraser
26	Mark Barraclough	General Manager, Recycling	Alex Fraser
27	Brendan Camilleri	General Manager	Alex Fraser

	Group
1	Austroads Bituminous Surfacings Working Group (all members)
2	Austroads Asphalt Research Working Group (all members)
3	Austroads Assets Task Force (all members)

Appendix B Acronyms

Abbreviations	Description
AAPA	Australian Asphalt Pavement Association
ABS/SAN	Acrylonitrile butadiene styrene/ styrene acrylonitrile
EAPA	European Asphalt Pavement Association
EPD	Environmental Product Declarations
ISCA	Infrastructure Sustainability Council of Australia
PET	Polyethylene terephthalate
HDPE	High density polyethylene
L/LLDPE	Low/linear low density polyethylene
MRF	Material Recovery Facility
NAPA	National Asphalt Pavement Association
PE-LD/LLD	Both low density polyethylene and linear low density polyethylene Typically referred to as LDPE/ LLDPE
PET	Polyethylene terephthalate
PIC	Plastic identification code
PP	Polypropylene
PS	Polystyrene
PS-E/ EPS	Expanded polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride

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