Australia's National Science Agency

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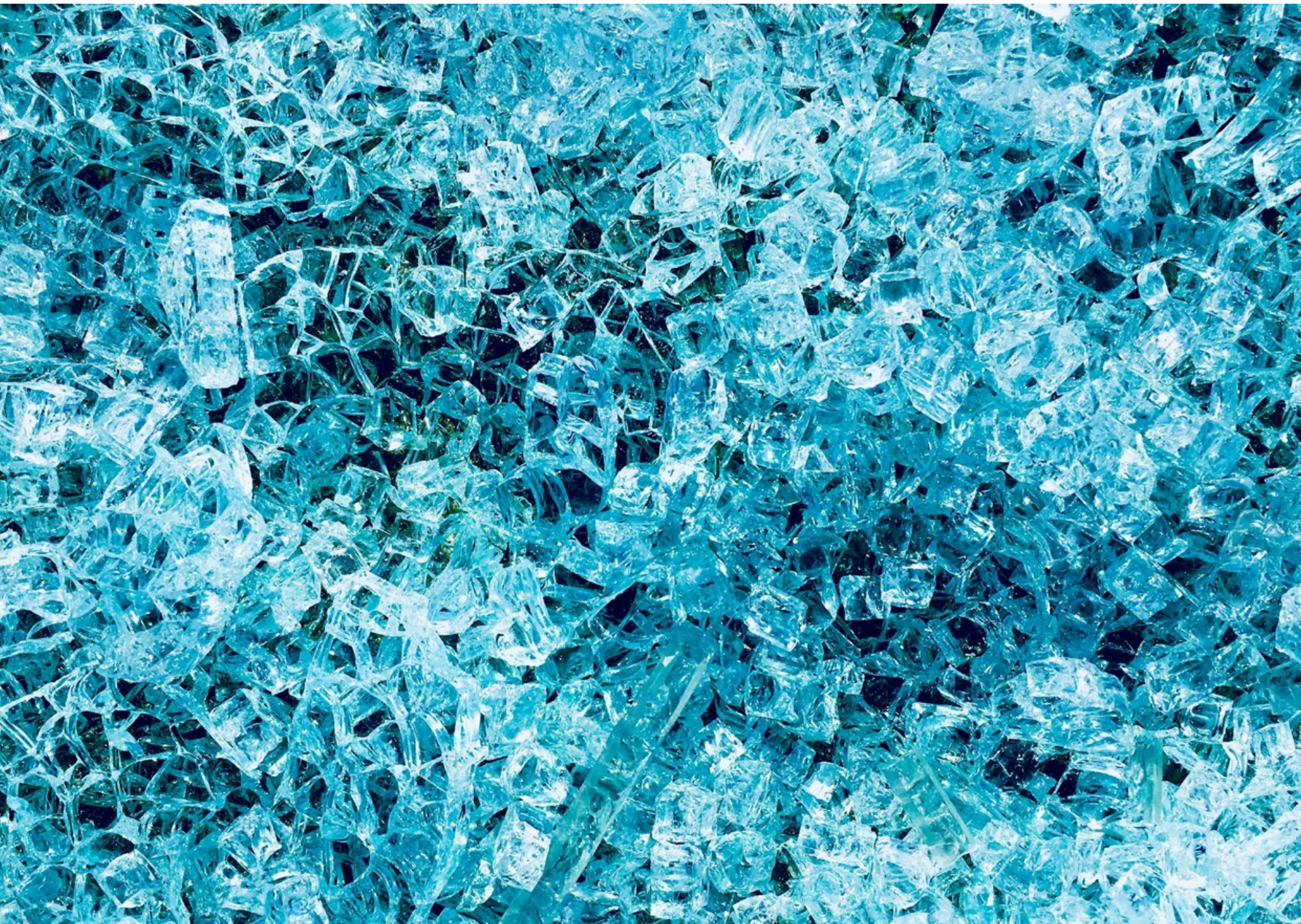
Circular economy roadmap for plastics, glass, paper and tyres

Pathways for unlocking future growth opportunities for Australia

JANUARY 2021



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Important disclaimer

This report is current as of August 2020. CSIRO continues to actively undertake research into the circular economy both internationally and for Australia.

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Abbreviations

ACT	Australian Capital Territory
APCO	Australian Packaging Covenant Organisation
ARRB	Australian Road Research Board
ATRA	Australian Tyre Recycling Association
CDS	container deposit scheme
C&D	construction and demolition
C&I	commercial and industrial
CO2e	carbon dioxide equivalent
COAG	Council of Australian Governments
EMF	Ellen MacArthur Foundation
EOL	end of life (tyres)
EPS	expanded polystyrene
EU	European Union
HDPE	high-density polyethylene
Kt	kilotonne
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
MRF	material recovery facility
MSW	municipal solid waste
mt	metric tonne
Mt	million tonne
MUD	multi-unit development
NIR	near infrared
NSW	New South Wales
OTR	off-the-road
PCPB	polymer-coated paperboard
PE	polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PREP	Packaging Recyclability Evaluation Portal
PRISM	Plastic Packaging Recycling using Intelligent Separation technologies for Materials
PS	polystyrene
PVC	polyvinyl chloride
PVDC	polyvinylidene chloride
R&D	research and development
ROC	Regional Organisation of Councils
rPET	recycled PET
SDG	Sustainable Development Goal of the United Nations
SME	Small and medium-sized enterprise
TSA	Tyre Stewardship Australia
UK	United Kingdom
UN	United Nations
USA	United States of America

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Executive summary

This industry and technology roadmap informs the Australian Government about the preparedness of industry and the Australian innovation system to collaboratively develop opportunities for waste innovation and a circular economy for plastics, glass, paper and tyres across the whole supply chain of these waste materials. It identifies strategies, enablers and opportunities Australia can invest in to create economic development, employment and reduce waste and pollution.

Why do we need a technology and innovation roadmap for waste materials management in Australia?

The way we produce and consume in Australia has led, over time, to increasing amounts of waste plastics, glass, paper and tyres from industry and households and significant amounts of those waste materials were exported. The way in which we deal with domestic waste in Australia has also entered the public consciousness and many industries and consumers share an ambition to reduce waste and to avoid waste going to landfill, leaking into the environment or being sent offshore. At the same time, exporting of waste materials has become more difficult with several countries refusing to accept exports of low-quality waste.

The Australian Government has decided to phase out the export of plastics, glass, paper and tyres and to take responsibility for Australia's waste and to make sure Australian waste does not contribute to environmental and health problems abroad. Such change in policy creates challenges but also opportunities. A question of importance is whether Australian waste management and recycling facilities are prepared to deal with an increased volume of waste and whether existing capabilities need to be extended.

There are also more fundamental questions about the opportunity of reducing waste across whole material supply chains to create an economy which manages material sustainably and builds circularity into its material supply chains. Many international examples have shown that it is possible to add value to materials multiple times and that business models and technologies that allow to keep material in circulation are economically attractive and help create employment.

Transitioning material supply chains and business models to circularity relies on innovation in technologies, products, and processes and can occur at each stage of the supply chain, from primary material extraction, product design, manufacturing, distribution; they can include consumers, and benefit from collection and recycling facilities. Identifying the opportunities for creating wealth from Australia's waste materials and reducing environmental and health impacts are identified in this technology and innovation roadmap which aims to support strategic and long-term planning by matching short-term and long-term objectives with available and emerging technology solutions. The roadmap identifies opportunities, analyses enablers that allow solutions to be developed and implemented and strategies that can guide the decision-making process of government and industry.

How was the roadmap done?

The process for creating the industry and technology roadmap for plastic, glass, paper and tyre waste materials commenced with an analysis of available and emerging technologies across the whole materials supply chain taken from the international literature and business experience. Existing options for improving the circularity of material flows and reducing end-of-life waste were then tested for their viability in the Australian economic and regulatory context. This was done by engaging with representatives from industry and industry bodies as well as government agencies and academia to explore enablers and barriers for such opportunities. The deep engagement with 83 participants in an extensive interview process allowed the identification of five core strategies that will benefit a circular economy and waste minimisation transition in Australia.

These strategies are suggested as high-level objectives by industry stakeholders and, if implemented, would retain and maintain the quality of primary materials. This would be through the improvement of collection and sorting systems; would include building a national reprocessing capability for all four waste materials; and would boost market demand for recycled materials. Related industries and communities would benefit from national harmonisation to provide consistent waste and material supply chain governance; and this would create a circular economy vision for the Australian economy enabled through innovation, new technologies, new business models and supported by institutional change that is co-developed by industry, government and communities.

Structure of the roadmap

In chapters 2 through 5, the roadmap presents opportunities for a circular economy along the material supply chain for each waste material. The focus is on opportunities for avoidance and substitution and good design, which are critical for a circular economy. Opportunities are also found in manufacturing and all steps of waste collection, sorting, recycling and reintegration of secondary materials into economic processing and includes the use of secondary materials in product manufacturing or in the construction sector.

Chapter 6 draws together the rich information that was gathered from engaging with industry and government stakeholders and sets out an integrated circular economy strategy that meets Australia's environmental, economic and social needs.

It presents five linked actionable strategies aimed at

- improving product design, collection and sorting outcomes to retain the quality and value of materials and prevent material loss
- building capacity for reprocessing and manufacturing of recycled products nationally aimed at increasing the ability to create wealth from waste domestically
- encouraging and facilitating market development to grow the circular economy including boosting market demand for recycled products and products that contain recycled content
- harmonising standards, regulations and messaging across jurisdictions to provide consistency in governance and create sustainable materials management capability in Australia
- facilitating systemic change from linear to circular material supply chains that foster sustainable consumption and production.

Taken together the five strategies focus on the whole value chain and the governance mechanism that will enable the industry community and consumers to transition from the current take–make–dispose economic model to circularity.

1 Introduction

Global demand for natural resources is unsustainable. It is said that by 2030 we will require two planets worth of natural resources (Esposito et al., 2018), and resource demand will more than double by 2060 – from currently 90 billion tonnes to 190 billion tonnes. To avoid valuable materials going to landfill Australia needs to reconsider how we consume natural resources. Transitioning to a circular economy can create opportunities and benefits for both Australian society and the environment. To be successful, the shift needs cooperation and innovation across the spectrum of government, industry, research and development, and consumption practices.

1.1 Waste reduction and the circular economy

The UN Sustainable Development Goals (SDGs) are a global blueprint for prosperity for people and the planet. The more efficient use of our resources is addressed by Goal 12 – to ensure sustainable consumption and production patterns (United Nations, 2015). A mechanism by which we can achieve this SDG is to shift from a linear 'take, make, dispose' economy, to a circular economy. In plain language, the goals of the circular economy are to retain products in productive use for as long as possible, to gradually de-couple economic activity from finite resources and to design waste out of the system (Meloni et al., 2018).

> "A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. (Geissdoerfer et al., 2017)"

Australia can learn from other countries that have already embarked on introducing circular economy policies and initiatives. Not all global solutions will be applicable in the Australian context. Australia has considerable innovation capacity that can be brought to bear to become a world leader in some aspects of waste innovation, building on pockets of excellence already existing domestically.

Transitioning to a circular economy could lead to multiple benefits (European Environment Agency, 2016), including:

1. Resource benefits: improving resource security and decreasing import dependency
2. Environmental benefits: less environmental impact
3. Economic benefits: opportunity for economic growth and innovation
4. Social benefits: sustainable consumer behaviour and job opportunities

Given these benefits, the circular economy is increasingly popular with policy makers in Australia and globally (Geissdoerfer et al., 2017) and there are an increasing number of policy and government white papers published on the circular economy.

The first comprehensive report on circular economy was published in 2013 by the Ellen MacArthur Foundation. It articulated the value proposition for implementing a circular economy in Europe. Annual net material cost savings were estimated to be USD 380–630 billion just for the EU manufacturing sector (Ellen MacArthur Foundation, 2013). The first country to commit to implementing a circular economy by 2050 was the Netherlands in 2016. The Dutch government expects this move to result in a 50% reduction in raw material use by 2030 with a focus on five economic sectors (biomass and food, plastics, manufacturing industry, construction, and consumer goods) and a reliance on completed industry roadmaps (Dutch Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, 2016).

Finland launched a Circular Economy Roadmap for 2016–2025 which estimates benefits of 2–3 billion euros by 2030 by engaging in the circular economy. Finland's five priority areas are food, forest-based systems, technical loops, transport and logistics, and common action and collaboration by different institutions (Sitra, 2016). Collaboration across stakeholders has been shown to be critical to implementing the circular economy at scale (Lieder and Rashid, 2016).

A circular economy is first and foremost an economic concept and a transitional project. It aims to benefit from technological disruptions that occur in the digital and biotechnology sectors, among other innovations, and create new growth opportunities. The circular economy can become a core component of Industry 4.0 which focusses on smart manufacturing and digital transformation enabling a fourth revolution in manufacturing.
In Australia Industry 4.0 and circular economy can create new opportunities in advanced manufacturing by leveraging Australian skills and its innovation culture.

1.1.1 Waste reduction and circularity in Australia

Australia is making progress in adopting circularity principles and transitioning towards a circular economy with plans and policies developed (or under development) in NSW, Victoria and South Australia. Queensland has launched a Circular Economy Lab which is an incubator for start-up companies. Western Australia references the circular economy in their Waste Avoidance and Resource Recovery Strategy 2030. However, a circular economy is a much broader ambition and not just a waste management strategy. It is important that a transition does not burden solely the end-of-life, waste management sector. Instead, all parts of the economy should be engaged and involved in a transition and this involves importers, manufacturers, consumers, households and local government authorities.

In addition to waste reduction and resource efficiency benefits, transitioning to a circular economy also offers Australia significant economic benefits. These benefits are comprised of three main elements: i) the market value of the materials being reused or recycled, ii) cost savings from the reduced burden from waste disposal, and iii) the reduced burden on natural resources from resource extraction for raw material (Andersen, 2007).

Additionally, circularity provides opportunities to boost jobs. The recycling sector in Australia currently generates 9.2 jobs per 10,000 tonnes of waste compared to only 2.8 jobs for the same amount of waste sent to landfill (Access Economics, 2009). For South Australia, engaging in the circular economy will create an estimated 25,700 additional jobs by 2030 compared to a business-as-usual approach. It would also deliver environmental benefits through reducing greenhouse gas emissions by 27% (7.7 million tonnes CO_2e) (Lifecycles, 2017).

There is a demonstrable economic benefit; for example, if Australia increased its recycling rate by 5% this would add an estimated $1 billion to Australia's GDP (Pickin et al., 2018). Analysis by CSIRO has shown Australia's low rate of lithium battery collection. In 2016, only 2% of lithium was collected and the remainder sent to landfill with the associated environmental consequences. This lack of collection and processing infrastructure equates to a forecast lost economic opportunity of up to $2.5 billion in 2036 (King and Boxall, 2019).

Despite the promising benefits that new socio-technical solutions could deliver, there are several trends and challenges hindering the widespread adoption of circularity principles and the rapid transition to a circular economy. Unfortunately, a circular economy and the methodologies to deliver it are still poorly understood notions (de Jesus and Mendonça, 2018). Similarly, while incorporating externalities into the cost of production is essential for ensuring a successful transition to a circular economy, the concept and implications of externalities are not widely understood beyond economist circles (Gigli et al., 2019).

There are also significant transaction costs and perceived or actual risks associated with changing processes and operations towards a more circular economy. Building a circular economy will require leadership and innovative effort to address the hurdles and transition costs associated with all the major opportunities. Poor market price signals are one of the factors that is hindering the widespread adoption of a circular economy today. Only when all or most of these costs are captured, will we have accurate market prices that truly reflect the costs and benefits of a circular economy. Other barriers, as evidenced by the international literature, include high up-front costs; complex international supply chains; resource-intensive infrastructure lock-in; failures in company cooperation; lack of consumer enthusiasm; and limited dissemination of innovation, across both emerging economies and developed countries (Chatham House, 2012 as cited in de Jesus and Mendonça, 2018). Lastly, a major cultural–cognitive barrier is that people largely prefer (and are used to) using new products (Ranta et al., 2018).

A transition to a circular economy will require profound changes to industrial, institutional, economic, social and consumption practices.

1.2 Policy context in Australia

The past 3+ years have seen increasing public and private sector interest in the adoption of circularity principles with the longer-term aim of developing a circular economy in Australia. This has manifested in several related inquiries and projects, supported by both industry and government, and has been reflected in the National Waste Policy Action Plan 2019, which has a specific focus on a circular economy.

At the Council of Australian Governments (COAG) meeting on 9 August 2019, and announced by the Australian Prime Minister on 13 August 2019, the federal and state governments agreed to develop a timetable to ban the export of waste plastic, paper, glass and tyres. They also agreed to develop a strategy to build Australia's capacity to generate high-value recycled commodities domestically and increase associated demand. Leaders agreed the strategy should draw on the best science, research and commercial experience, including that of CSIRO. The ban is a trigger point for Australian waste innovation but the complexities of growing amounts of waste and the need to grow the domestic recycling capability and markets for secondary materials need to be addressed by the strategy.

This has become even more important in the context of the COVID-19 economic contraction and the need to plan for and facilitate an economic recovery where a circular economy and waste innovation can make an important contribution. By taking responsibility for domestic waste, Australia will also fulfil its role as a good global citizen. Australian innovation in the waste sector may also create opportunities for economic and scientific collaboration with our regional neighbours and generate export opportunities for technologies.

1.3 A vision for circularity in Australia

Australia must endeavour to adopt more circularity principles and transition to a circular economy, pushing forward the development of high-value recycled commodities and greener manufacturing solutions based on domestic and global market needs and trends. To realise growth, Australia needs to focus on increasing its capacity and ability to develop and adopt commercially viable solutions for markets while also successfully navigating critical infrastructural, regulatory and behavioural challenges (Figure 1.1).

A circular economy creates a circular supply chain that commences with primary materials and aims to keep these materials in use as long and as often as possible, thereby adding value to the materials multiple times. We distinguish several phases of materials management that are relevant for supporting circular material use:

1. **Avoidance:** For some materials and uses the best strategy is to avoid them in the first place and to replace them with an equivalent material, product or service to avoid the harmful outcome at the end-of-life stage.

2. **Design:** Designing products for circularity, where the design process considers not only product use, but also end-of-life and how the product or components can be disassembled or reused offers perhaps the most economically attractive opportunities for a circular economy. Well-known concepts that capture this ambition are Design for Environment, Design for Disassembly, or Cradle to Cradle principles. This includes designing out products and materials that are difficult to recover because of economic or technical constraints.

3. **Consumption:** Extending the life and value of a product and maintaining materials in the productive economy for a longer period can be done through reuse and repair. An example is a reused iPhone, it retains almost 50% of its original value after 2 years, but once disposed of, the value of recoverable materials is only 0.24% of the phone's original value (Hazell, 2017). By accessing existing resources and reused materials, the automotive sector has shown up to 70% material savings to make new products (Hazell, 2017). Extended producer responsibility, product stewardship and lease instead of purchase are good examples for extending the use value of products and appliances.

4. **Collection:** Waste collection is an important step that, when organised well, contributes to a clean and high-value recyclable commodity that can be used for reprocessing. The way in which collection systems are designed has a large impact for avoiding contamination, which often occurs for comingled waste streams.

5. **Sorting:** Current collection systems are not ideally suited for successful waste separation and will need be improved to service a local recycling industry. This is a first step to create valuable export commodities.

6. **Recycling:** The process by which waste commodities are converted into reusable material may involve mechanical, chemical, biological and energy-recovery technologies. Once reprocessed, secondary material can be employed in industrial processes or used as input in infrastructure projects.

7. **(Re) Manufacturing:** This is a process in which components of machinery, vehicles or infrastructure are reused in new applications. For example, steel beams can either be recycled into secondary steel or be reused as beams. Another example of remanufacturing is the global equipment manufacturer Caterpillar who operates a remanufacturing division creating a second life for diesel parts and components. This division has experienced 8–10% growth over the last decade (Ellen MacArthur Foundation, 2013) and has achieved substantial costs savings.

8. **Disposal:** This is the last stepin the waste management hierarchy. It relies on well-designed landfills to avoid leakage of toxic substances into water and air and help reduce the risk of incidental fires and pollution.

The circular economy also requires new business models and scientific innovations on which new businesses and markets can be based (Leising et al., 2018) including service-based solutions. An example is the leasing of carpet where the material is processed by the manufacturer at the end-of-life stage (e.g. InterfaceFLOR).

The largest economic gains for Australia in terms of new industries and job creation lies in solutions at earlier stages of the supply chain and higher up in the waste hierarchy. Designing new products, materials and new processes based on innovative science and technology solutions and new business models will create new domestic and export markets.

In addition to a forward-looking circular economy strategy, Australia will need to solve the more immediate issue of both new waste and waste stockpiles through:

- adding value to end-of-life waste by separating and beneficiating materials to create new commodities
- establishing beneficiation facilities, separation capacity and collection systems that create a feedstock for recycling
- identifying recycling opportunities that can occur within Australia

As a rule, a circular economy will require global solutions. In the same way that production relies on global supply chains, end-of-life waste needs to rely on global solutions and infrastructure to reintegrate materials into new products and materials.

1.4 This Roadmap

As an active participant across the circular economy value chain, and with deep expertise in waste management and recycling research and development (R&D), CSIRO has been asked to deliver this Roadmap. It supports the response strategy to the waste export bans and complements the work of government and industry to maximise the capability of our waste management and recycling sector. The research has also been able to integrate information from stakeholder consultations conducted by the Waste and Recycling Taskforce.

This Roadmap will inform the policy and business community and the general public about short, medium and long-term opportunities for the circular economy for four materials – plastics, glass, paper and tyres – that exist in Australia by focusing on technical and institutional innovation. It defines enabling actions that will position the sector for sustainable and achievable growth in the future.

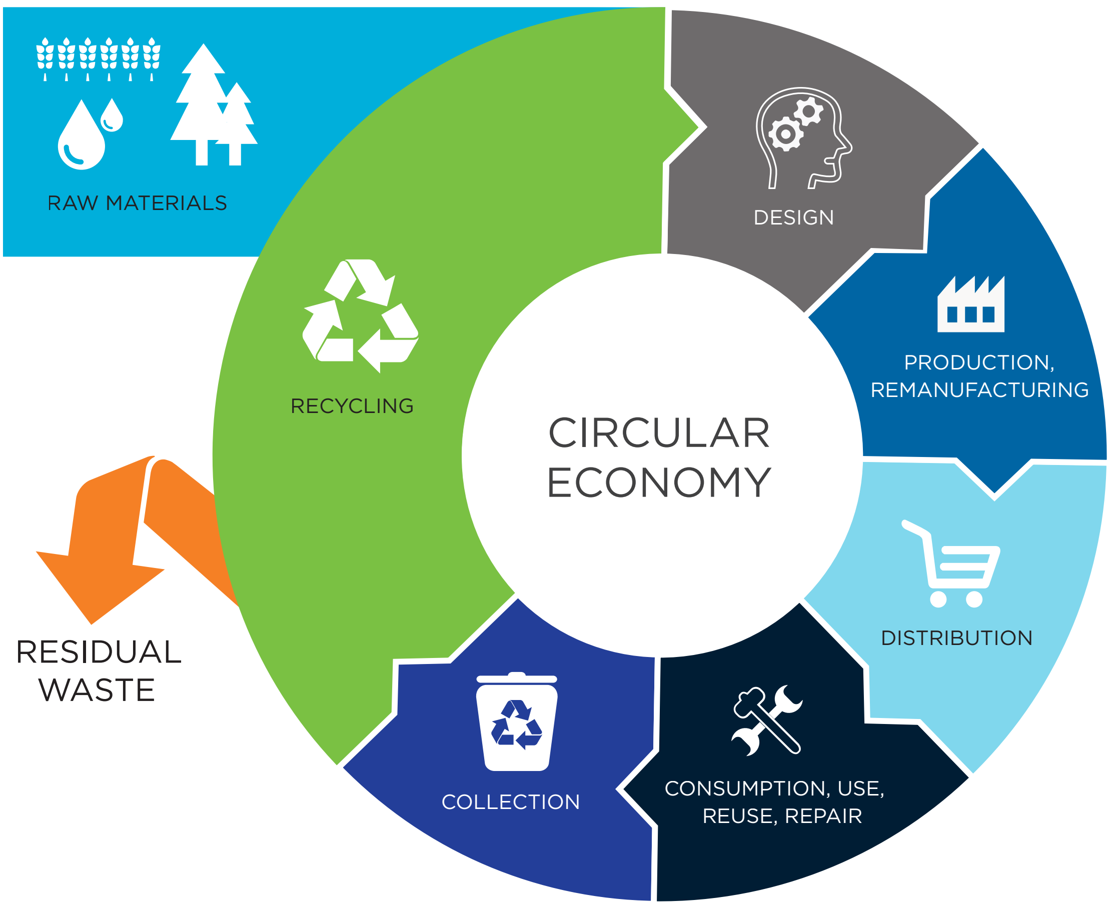


Figure 1.1 Circular economy opportunities across the material supply chain

This Roadmap aims:

- to support the development of Australia's waste management and recycling sector by identifying growth opportunities for the sector that are driven by current trends and that leverage both the sector's comparative advantages and circularity principles
- to identify new materials, products and processes supported by new business models that avoid the generation of low-value and hard-to-recycle waste flows

The ultimate beneficiaries of new waste management, recycling, and circularity systems are Australia's future generations, which is implicit in this Roadmap. However, in line with the objectives of the waste export bans, the Roadmap is delivered through a lens which primarily considers the economic and competitive positioning of Australian industry.

1.4.1 Methodology

The process started with a review of circular economy opportunities covering all stages of the material supply chain. It then identified enablers that would allow commercialisation of innovation more easily. Engagement with key industry, government and academic stakeholders allowed to identify the challenges and solutions for Australia in a circular economy. These stakeholders provided insights into what was applicable in the Australian context through more than 80 in-depth interviews.

The evidence gathered is presented in two main sections:

- opportunities for circular economy innovation for plastics, glass, paper and tyres across the material supply chain
- enablers for supporting the process by which opportunities are turned into new solutions that are economically viable and contribute to reducing waste going to landfill

Consistent with a circular economy approach and systems perspective, opportunities for the four materials are presented across each stage of the circular economy cycle: avoidance, design, consumption, collection, sorting, recycling and manufacturing.

The analysis is rounded off by an economic assessment of the unit cost of different opportunities for diverting waste from landfill by establishing experimental waste-abatement curves.

Each chapter focused on a specific waste material starts with an analysis of the current status. It contrasts this with the opportunities for transforming the existing supply to a more circular fashion in order to reduce end-of-life waste going to landfill and create economic opportunities during the process. The analysis employs a supply chain logic and is further supported by identifying key actions and outcomes that would be available for each waste material.

By considering the challenges, opportunities, strategies and available actions, a synthesis of key actions and outcomes was then developed for each material. This results in a roadmap or pathway forward for each material, identifying the short (next 2 years), medium (next 5 years) and long term (10 years) actions and outcomes for each material. A Sankey diagram was generated to help visualise the potential material flows for plastics, paper, glass and tyres in 2030 as Australia transitions to a circular economy.

Drawing on the opportunities and challenges identified for the four waste materials, an integrated circular economy strategy is set out that meets Australia's environmental, economic and social needs. It presents five linked actionable strategies aimed at

- improving product design, collection and sorting outcomes to retain the quality and value of materials and prevent material loss
- building capacity for reprocessing and manufacturing of recycled products nationally aimed at increasing the ability to create wealth from waste domestically
- encouraging and facilitating market development to grow the circular economy, including boosting market demand for recycled products and products that contain recycled content
- harmonising standards, regulations and messaging across jurisdictions to provide consistency in governance and create sustainable materials management capability in Australia
- facilitating systemic change from linear to circular material supply chains that foster sustainable consumption and production.

1.4.2 Structure of the report

The Roadmap presents opportunities for four different material supply chains. Chapters 2–5 present opportunities for a circular economy along the material supply chains for plastics, glass, paper and tyres. Each chapter discusses opportunities for that particular material for avoidance, substitution and good design which are critical for a circular economy. The chapters also include opportunities for manufacturing and remanufacturing and all steps of waste collection, sorting and recycling.

Chapter 6 draws together information gathered through engaging with industry and government stakeholders and sets out an integrated circular economy strategy that meets Australia's environmental, economic and social needs.

2 Plastics

In 2017–18 Australia **consumed 3.4 million tonnes** of plastics.

Based on end-of-life plastics data compared to consumption, **Australia has a recycling rate of 12%**.

There are **many types** of plastics and their recovery rate varies significantly.

The COAG waste export ban for plastics commences in 2021 (mixed plastics) and 2022 (unprocessed single type plastics).

In 2018–19 Australia **exported 187,354 tonnes of plastics** at an estimated value of $43 million.

Australia is missing an estimated $419 million of value per annum for PET and HDPE that is unrecovered.

Of the 320,000 tonnes recovered in 2017–18, only 125,000 tonnes were locally processed.

Local processing capacity **must increase by at least 150%** to ensure previously exported plastic waste does not end up in landfill.

Key challenges

- Lack of plastics recycling infrastructure
- Contamination of plastics
- Lack of advanced material recovery facility (MRF) sorting technology
- Lack of reliable, consistent waste data
- The Australian Packaging Covenant (APC) is not mandatory
- Imported plastics not subject to controls regarding recyclability
- Lack of market demand for products made of recycled plastics
- Lack of standards for recycled materials and products
- Lack of solutions for mixed plastics
- Lack of data to inform decisions

Key opportunities

- **Avoidance:** Phase out or ban problematic, unnecessary single-use plastic packaging. Implement environmental campaigns to reduce plastics pollution.
- **Design:** Improve product design through brand owner education tools (e.g. PREP) to design recyclable packaging.
- **Consumption:** Address plastics' social licence to operate through action on plastics litter and evidenced-based decision-making regarding substitutes for plastics. Present clear, consistent information, labelling (e.g. ARL) and education on how to recycle for households. Maintain linkages with international initiatives to reduce plastic waste.
- **Sorting:** Improve MRF sorting technology to reduce contamination levels and sort plastics into types
- **Collection:** Implement regional and niche collection business models for plastics not collected via MRFs e.g. product stewardship.
- **Recycling:** Connect waste processing and manufacturing sectors and replace virgin resources with recycled material as feedstock (e.g. feedstock recycling). Develop standards for recycled plastics and products to support infrastructure development and confidence in specifications for substitution from virgin materials. Develop new infrastructure for processing plastics (washing, flaking and pelletising) and a supportive environment for new enterprise and infrastructure.
- **Manufacturing:** Improve domestic markets for products made from Australian recycled content. Roll out a coordinated national program for plastic research activity. Prioritise or remove barriers to government procurement of recycled plastic products. Measure and quantify increased market demand.

2.1 Overview of global and Australian landscape

Plastic has become an almost unavoidable part of our lifestyle due to its versatility, convenience, low cost and light weight. Plastics provide us with many useful products such as polystyrene (PS) which protects our high-value electronic and lifestyle goods and flexible plastics that protect and extend the life of food products while they are transported through the supply chain, thus preventing food waste.

Global plastics consumption has grown 23 times over the previous 20 years and will double in the next 20 years. Most of plastic consumption is for consumer applications (Dilkes-Hoffman et al., 2019) and plastic packaging represents 26% of the total volume of global plastics consumption. After plastic packaging has served its purpose, it is estimated that 95% is sent to landfill and thus lost to the economy at a rate of USD 80–120 billion per year (Ellen MacArthur Foundation, 2016). Globally, only 14% of plastic packaging is collected for recycling, and of this, only 5% of the material value is retained for reuse (Ellen MacArthur Foundation, 2016). In response to growing awareness of the need for plastic recycling, the global plastic recycling market is forecast to grow 5–7% to 2026 and it was valued at USD 34.8 billion in 2017 (Locock et al., 2019). Plastics recycling saves energy compared with the production of virgin material. One tonne of recycled plastic saves around 130 million kJ of energy (Garcia and Robertson, 2017). It also reduces our dependence on fossil-fuel resources by supporting the recovery and reuse of plastics.

While plastics are indeed useful, there is increasing consumer and community awareness of their adverse impacts when waste is not managed appropriately and pollutes our marine ecosystems and terrestrial environment while degrading plastics are also a source of greenhouse gas emissions. Data shows that by 2050, 95% of all seabirds may have ingested plastic waste from the marine environment (Hardesty et al., 2014). In particular, microplastics (of <5 mm in size) are of concern in the marine environment, arising from the breakdown of larger plastics (Vince and Hardesty, 2017) such as expanded polystyrene (EPS). In response to these challenges, global initiatives have been launched to combat plastic waste such as; the Alliance to End Plastic Waste[1], The Global Plastic Action Plan Partnership[2], the Ellen MacArthur Foundation[3] and Sea the Future[4], an initiative of the Minderoo Foundation.

1 https://endplasticwaste.org/ (accessed 12 July 2020)

2 https://globalplasticaction.org/about/ (accessed 12 July 2020)

3 https://www.ellenmacarthurfoundation.org/ (accessed 12 July 2020)

4 https://www.minderoo.org/minderoo-foundation/news/global-industry-initiative-launched-to-end-plastic-pollution/ (accessed 12 July 2020)

2.1.1 Plastics consumption and waste in Australia

Australia's plastic consumption is predominantly through imported and finished goods (66%) with the remainder from local manufacturing (34%) (O'Farrell, 2018). Australia has two major manufacturers of plastic, LyondellBasell Industries who are the sole manufacturer of polypropylene (PP) with production sites in Geelong and Dandenong in Victoria, and Qenos the sole company in Australia who produce high-quality polyethylene (PE) and resins with production sites in Altona, Melbourne and Botany, Sydney. Chemistry Australia is the peak industry body representing the plastics and chemicals industries. In March 2020, they announced Plastics Stewardship Australia to support the reduction of plastic waste.

One of the challenges with reporting on plastics is there are different types, each with different properties, uses and recovery rates. Box 1 and Table 2.1 summarises the seven plastic classifications and their uses. Plastics are used in packaging, agriculture, built environment, electrical and electronic goods, automotive and other unidentified applications.

The latest National Waste Report (2016-17) reports 12% of plastics were recycled which left 87% of plastics sent to landfill and a small 1% sent to energy from waste (Pickin et al., 2018). Notably, there is no estimate for annual leakage. The latest Australian data for 2017–18 reports consumption of 3.4 million tonnes and a decrease from 12% to 9.4% for the average recycling rate when compared to the previous year; however, this decrease is mostly associated with how the recycling rate is calculated[5]. The 2017–18 consumption and recovery rates (based on consumption divided by recovery) are shown for each plastic type in Figure 2.1 with a total of 320,000 tonnes of plastics recovered (O'Farrell, 2019).

In 2018–19 Australia exported 187,354 tonnes of recovered plastics at an estimated value of $43 million. Low-grade plastics comprise 80% of the waste plastic exported and much of this material is from municipal sources with weak international and domestic markets. The higher-value plastics (e.g. PET [polyethylene terephthalate], HDPE [high-density polyethylene]) are 19% of the total and comprise 26% of the value of waste plastic exports. High-grade plastics have strong market demand domestically and internationally (DEE, 2019a).

Of the 320,000 tonnes recovered in 2017–18, only 125,000 tonnes were locally processed. This means if exports are discontinued it would be necessary to increase local processing capacity by at least 150% to ensure previously exported plastics do not go to landfill. While that is a significant increase, it only maintains the status quo for the current rate of recycling when clearly, Australia requires even greater sorting, collection and processing capacity to increase from a very low 12% recycling rate.

5 The former takes waste audit data to calculate end-of-life divided by recovery rate to calculate average recycling rate. The latter uses consumption rate in place of end-of-life data, which is less accurate for plastics in use for greater than 1 year.

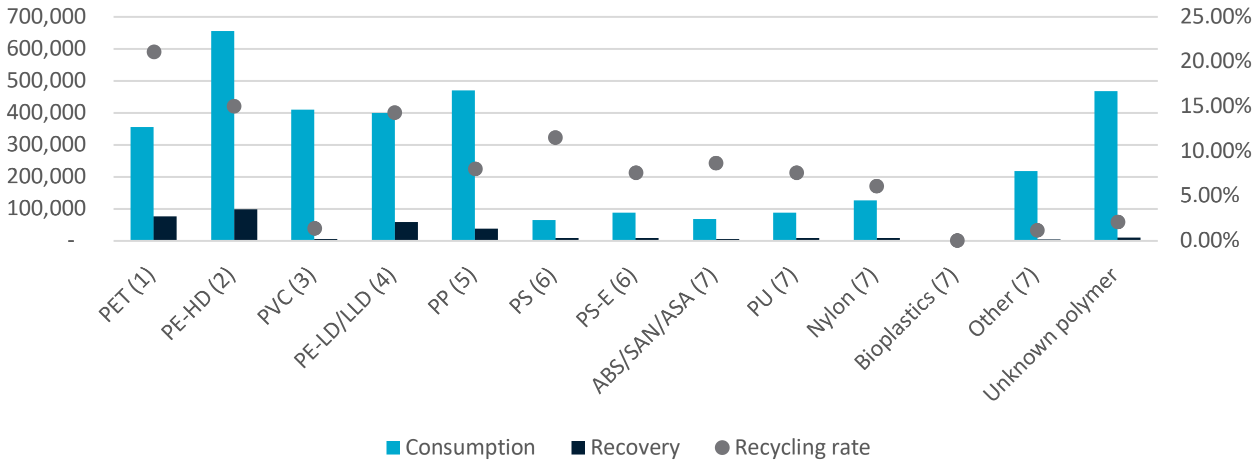


Figure 2.1: Plastics consumption and recovery by polymer type in 2017–18 (tonnes and % recycling rate)

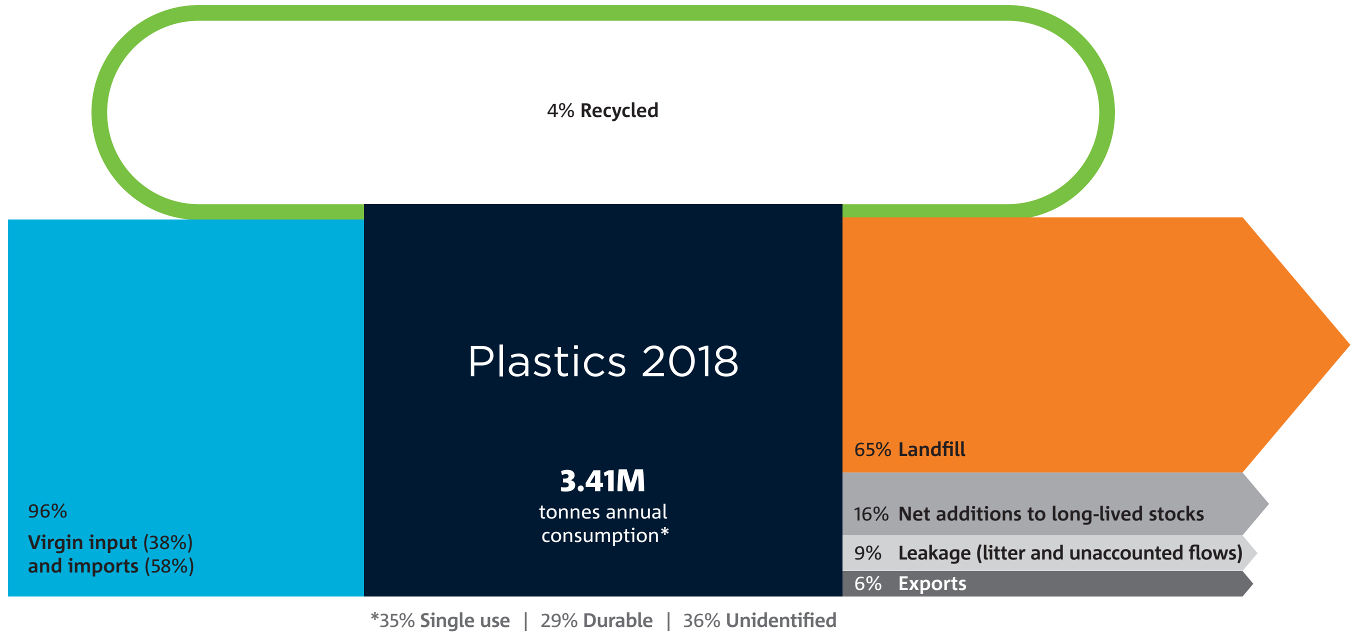


Figure 2.2: Sankey diagram of plastics flows for Australia as at 2017–18, derived from (O'Farrell, 2019a, 2019b)

Figure 2.2 shows the current flow of plastics through the supply chain. Note that end of life is not shown and thus while we know almost 90% of end of life plastics are sent to landfill, 65% is represented here when accounting for other flows. Net additions to long-lived stocks is calculated from the known proportion of plastics that are consumed annually but do not reach end of life. Leakage is also estimated from this flow and based on international estimates as Australia does not report annual leakage data. The large proportion of plastics to landfill represents a large loss of value to the economy, not only in the form of jobs and revenue but also in an ongoing reliance on virgin materials for the generation of new plastic products.

Box 1: Plastic classifications

A definition of plastic is: "A plastic material is any of a wide range of synthetic or semi-synthetic organic solids that are mouldable. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, but many are either partially natural or fully natural (i.e. biobased) (O'Farrell, 2018)."

Table 2.1 shows the plastic codes, names and examples of applications for each type of plastic. The recycling rate is the percentage of recovery compared to consumption of each plastic type by code. This table also shows examples of products made from recycled content.

Table 2.1: Plastic classifications. Compiled from Rahimi and Garciá, 2017; O'Farrell, 2018, 2019; Locock *et al.*, 2019

CODE	NAME	USE	RECYCLING RATE 2017/18	PRODUCTS MADE WITH RECYCLING CONTENT
1 PET	Polyethylene terephthalate (PET or PETE)	• Consumer drink, Medicine Bottles	21.1%	• Carpet fibre, fleece jackets • Food, beverage and non-food containers • Plastic film and straps
2 HDPE	High-density polyethylene (HDPE)	• Durable containers; detergent bleach, shampoo, motor oil • Cereal box liners, retail bags	15%	• Non-food bottles • Outdoor decking, fencing, tables • Pipe, buckets, crates, film and sheet, recycling bins, water tanks
3 PVC	Polyvinyl chloride (PVC)	• Packaging - rigid bottles, plaster packs. • Medical - bedding, shrink wrap, tubes, bags • Carpet backing, coated fabrics and flooring	1.4%	• Pipe, floor coverings • Packaging film
4 LDPE	Low Density Polyethylene (LDPE)	• Bags, film wrap, sealants, wire cable covering	14.3%	• Film (packaging, agricultural etc) Agricultural piping. Timber substitutes.
5 PP	Polypropylene (PP)	• Packaging containers, bottle caps, carpets	8%	• Box crates, plant pots
6 PS	Polystyrene (PS) and expanded Polystyrene (PS-E)	• Packaging Peanuts, styrofoam, protective foam.	9.3%	• EPS – can be added to concrete pavers and building products, • Insulation, egg shell cartons, office accessories, thermal insulation
7 Other	A mixture of polymer types; ABS/SAN/ASA, PU, Nylon, Bioplastic and other aggregated or unknown polymer types	• Multilayer barrier films, toothbrushes, some food containers,	3.5%	• Variable depending on plastic type: • PU – Carpet underlay • Nylon, ABS/SAN – Injection moulded products

Plastics packaging

Plastic packaging comprises around 32% of overall plastics consumption in Australia based on commercial and municipal applications, it accounts for just over 70% of recovered plastics (O'Farrell, 2019). Packaging waste occurs in our urban life (municipal waste) and as part of our commercial and industrial sectors. It can be classified as rigid or flexible (O'Farrell, 2018). A recent study on packaging waste for 2017–18 found Australia generated 907,401 tonnes of plastic packaging waste. Of this, only 32% was recovered, which was much lower than recovery rates for other packaging materials; glass (50%), paper (72%) and metal (54%) (Madden and Florin, 2019).

Soft plastics

Soft plastic packaging is described as plastic which can be 'scrunched' into a ball and is used in a variety of sectors, such as retail shopping bags, commercial and industrial shrink wrap, agricultural film, and in the building and construction sectors to protect timber and plasterboard (APCO, 2019d). Soft plastics are generally made of LDPE (low-density polyethylene), LLDPE (linear low-density polyethylene) or HDPE. It has been reported that Australia consumed around 336,000 tonnes of soft plastics in 2017 (APCO, 2019d). While some states have banned single-use plastic bags, Australia still consumed 5.7 billion single-use HDPE bags in 2016–17 (O'Farrell, 2018).

Box 2: The Australian Packaging Covenant Organisation (APCO)

APCO is the peak body in Australia for packaging and operates a co-regulatory model in partnership between industry members and government. It has been appointed by the Australian Government as the organisation to facilitate a national Australian vision for all packaging and is applicable not only to plastics but also to glass, paper and cardboard packaging. The 2025 National Packaging Targets were released in September 2018 (APCO, 2018) and updated in 2020 (APCO, 2020b). Figure 2.3 shows the four APCO targets, all of which are specific to plastics. Adherence to the APCO recommendations and targets is an option for companies with an annual turnover of $5 million or more. Smaller companies are not subject to the targets and some larger companies choose not to join APCO. APCO estimates their membership covers 75% of the market share (APCO, 2020b).

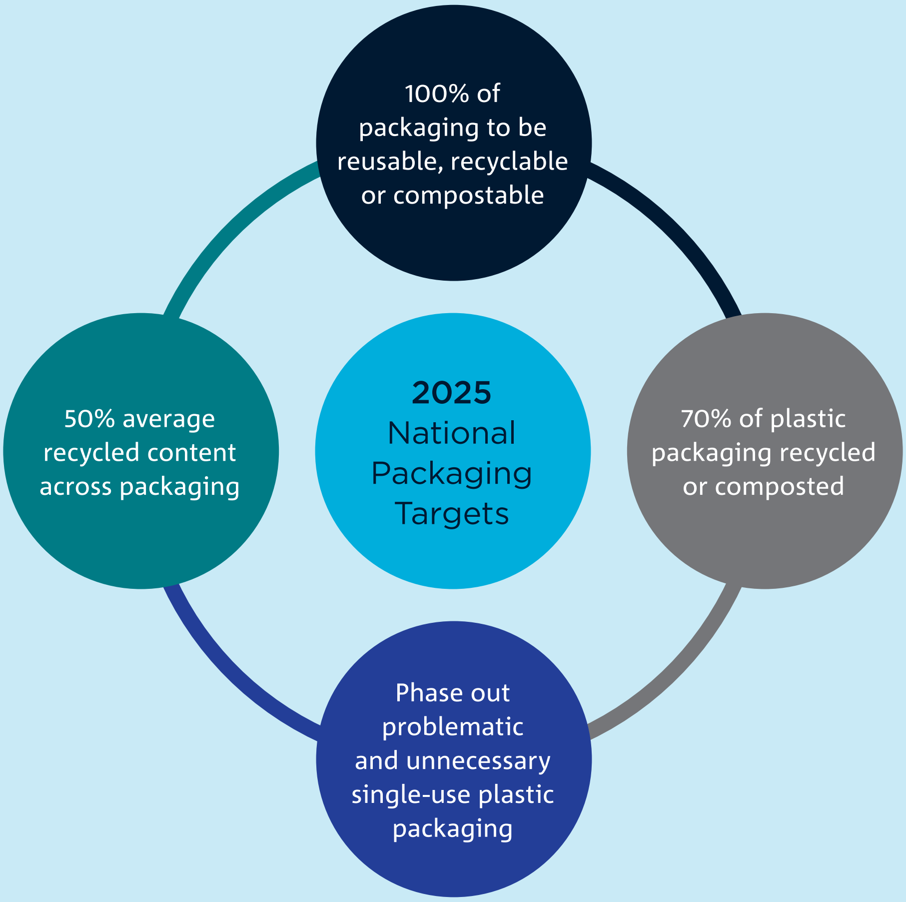


Figure 2.3: APCO National Packaging Targets and associated APCO projects, figure derived from (APCO, 2020b)

High-value plastics: PET and HDPE

The highest recovery rate was achieved for PET at 21.1%, where recovery has been supported by container deposit schemes (CDS) in all states and territories except Victoria and Tasmania which are scheduled to implement a CDS by 2022–23. HDPE has a recovery rate of 15% but, because of its high level of consumption in Australia, it results in the highest amount of unrecovered plastics in Australia – a total of 558,000 tonnes. For PET and HDPE, there was a combined total of 838,000 tonnes unrecovered[6] for 2017–18. By not collecting these materials, Australia is missing an estimated $419 million of value per year[7]. There are greater opportunities to produce recycled PET (rPET) in Australia through investment in producing high-quality hot-wash flake and new infrastructure. A new facility to be located in Albury by December 2021 will cost $30M and process 28,000 tonnes of PET bottles and recyclables into food-grade pellets and flake. This new facility is a collaboration between Cleanaway Waste Management and investment from the NSW Government. The PACT Group and Asahi Beverages have committed to purchase most of the material jobs (Evans, 2020; Gray, 2020).

PS/EPS

Polystyrene and expanded polystyrene have much lower consumption rates of 64,000 and 87,000 tonnes per year, respectively. Rigid PS is a problematic packaging material due to a lack of recycling markets and its manufacturing process using harmful chemicals (APCO, 2019c). EPS is lightweight and very durable and is readily used in the transport of a variety of goods, including fragile items due to its shock-absorption qualities. Its thermal efficiency also helps extend the shelf-life of consumables such as fruit, vegetables and seafood. This results in EPS being very important to the food retail supply chain and demand is growing at an estimated 5% per year. As EPS is used extensively for retail packaging, it is difficult to estimate the quantity of EPS that is imported to Australia. This results in data gaps for accurately quantifying consumption of EPS (APCO, 2019b). The domestic production of EPS involves approximately 40 manufacturers nationally, employing 1,000 people and revenue of $200–300 million. Of the domestic production of EPS, around 30% is used for packaging products, with around half exported in food packaging (APCO, 2019b).

The challenges with EPS are that it takes up space in waste bins and is lightweight, whereas bins are generally charged based on volume. It is a common litter from illegally dumped rubbish and although it can be collected at transfer stations, these collection points are fragmented, and it often goes to landfill. Consumer frustration is high for this packaging product as people do not know where to take the product at end-of-life. The industry price for recycling EPS is highly variable and ranges from $250–800 per tonne. Reducing contamination of EPS is critical to support its recyclability (APCO, 2019b). Despite these recycling challenges there are examples of EPS being used as a manufacturing input to concrete tiles and construction products.

PVC

The Vinyl Council Australia is the peak organisation for companies across the PVC (polyvinyl chloride) supply chain. In 2017–18 PVC recorded the lowest overall recovery rate (1.4%) of plastics. However, this figure neglects the durable nature of PVC products in the building, construction and commercial sectors, such as in window frames or floor coverings, which remain in use for years. PVC packaging is not currently recycled in Australia though it has been in the past. Improved recovery rates could be achieved by manual or improved optical sorting at MRFs. Even though the commercial and construction sectors are significant users of PVC, collection schemes for PVC in these industries are challenging due to the relatively low volumes of waste arising. PVC can be recycled mechanically or reused in flooring applications but the main challenges in Australia are the low volumes collected and the difficulty in securing a clean supply.

PVC is a contaminant for the reprocessing of other plastics. For example, it becomes corrosive for equipment used in rPET manufacturing and acts as a contaminant in products derived from feedstock recycling of other plastics types. In the past, PVC was collected and diverted through a manual sorting process. It is possible to install additional technology to sort PVC within MRFs. The PVC industry in Australia is obviously sensitive to a ban on PVC single-use and packaging products, however, there are international examples where PVC, along with PS and EPS are being intentionally designed out of packaging and substituted with other materials (Ellen MacArthur Foundation, 2016).

Plastics litter

Based on a 2018 attitudes survey, Australia's public considers plastics pollution the most serious environmental issue and ranked it higher than climate change (Dilkes-Hoffman et al., 2019). While plastic is littered in our terrestrial environment and sent to landfill rather than collected for recycling, the litter of plastics in our marine environment is also cause for concern. Marine litter has far-reaching economic consequences such as a reduction in tourism and the fouling of fishing gear, as well as the direct costs of collecting marine debris (Hardesty et al., 2014). Plastic waste is of particular concern for remote Australian areas and islands due to its accumulation and the lack of infrastructure available to process local waste (Lavers et al., 2019).

6 This assumes that landfill is the difference between consumption and recovery, which for long-life products may not be the case

7 By applying the February 2020 export price of $300 and $600 per tonne, respectively (Sustainability Victoria, 2020).

2.2 Summary of key challenges for plastics

Figure 2.4 is a summary of some of the major challenges raised during the interview process relevant to a plastics circular economy in the face of the upcoming waste export ban. In particular, a consistent message was received that there was a lack of time for industry to adapt to the ban and this risks plastics being either stockpiled or sent to landfill in the short term.

In order to address the challenges facing the plastics industry, it will be necessary to improve the circular economy for plastics. Enabling actions from a range of actors are specifically addressed in Chapter 6.

1. Lack of plastics recycling infrastructure	Australia is missing segments of the recycling supply chain (washing, flaking, pelletising) in order to process domestically what has been exported. It is challenging to increase recycling capacity quickly without that infrastructure in place and there is a risk that stockpiling or increased landfill will occur in the short term.
2. Contamination of plastics	Plastics contamination occurs due to a lack of sorting into plastic types and by materials such as glass and organics. This prevents value-add to plastics.
3. Lack of advanced MRF sorting technology	Australian MRFs lack advanced separation technology to reduce contamination levels and effectively sort PVC, PP and PS. This technology exists overseas but has not been installed in Australia. Upgrades to optical sorting is required.
4. Lack of reliable, consistent waste data	Australia lacks reliable waste data and consistencey across jurisdictions. There is an absence of stockpile data, tracking through the supply chain and reporting of annual litter volumes.
5. The APC not mandatory	As the Australian Packaging Covenant is not mandatory, some companies are not actively working towards national packaging targets. It is difficult to achieve targets without a mandatory scheme.
6. Imported plastics not subject to controls regarding recyclability	There is a lack of control over imported plastics and packaging as it is not subject to national packaging targets. This results in non-recyclable plastics entering Australia's supply chain.
7. Lack of market demand for products made of recycled plastics	Australia has additional capacity to produce recycled products but lacks markets, demand, acceptance and awareness of recycled plastics products as substitutes for existing products made of virgin materials. This is execerbated by the price difference between virgin and recycled materials.
8. Lack of standards for recycled materials and products	Standards are required for recycled plastics material across the supply chain to provide confidence to manufacturers and industry. Standards for recycled products are needed to demonstrate they meet specification and reduce risk for brand owners and engineers.
9. Lack of solutions for mixed plastics	Market value for mixed plastics is low or negative. Australia needs to support technologies that can process mixed plastics and divert plastics from landfill.
10. Lack of life cycle assessment data to inform decisions	Plastics may be being substituted without adequate life-cycle data to inform that decision. This results in substitution decisions that may appear more environmentally friendly but are actually more detrimental.

Figure 2.4: Summary of key challenges for plastics

2.3 Opportunities for plastics in the circular economy

This section highlights the opportunities across the circular economy system by dividing them into the following stages: avoidance, design, consumption, collection, sorting, recycling and manufacturing.

2.3.1 Avoidance

Avoidance is the first step on the waste hierarchy, and the first circular economy principle from the 2018 National Waste Policy (DEE, 2018b). Plastic waste avoidance is supported through strategies such as avoidance of single-use plastics, prevention of leakage (litter) into the environment and avoidance of problematic packaging.

Single-use plastics

Examples of avoidance of single-use plastics are supermarket bans on single-use plastic bags. This is increasingly being supported by major consumer brands, such as Uniqlo (see Figure 2.5), and supports a national target of ***reducing total waste generated in Australia by 10% per person by 2030*** (DEE, 2019b).

Avoidance is also supported by the APCO national packaging target where the goal is to ***phase out of problematic and unnecessary single-use plastics packaging*** (ACPO, 2020b).

Figure 2.5: Uniqlo commitment to reduction in single-use plastics

Prevention of plastics litter

Avoidance helps prevent plastic waste entering our environment which is of concern to Australian society. Litter is also an economic cost as Australia spent $70 million cleaning up dumped waste in 2016–17 (Pickin et al., 2018). Consumer education to reduce litter through environmental campaigns leads to a reduction in environmental pollution (Willis et al., 2018). Litter surveys are an important part of quantifying and tracking litter back to its source. These data are vital in the role of plastic litter prevention and undertaken by organisations such as Keep Australia Beautiful[8], Tangaroa Blue[9] and CSIRO.

Operation Cleansweep® is a collaboration between the not-for-profit Tangaroa Blue, industry and government to prevent pollution from plastic pellets lost through the transport of plastic products and from manufacturers.[10] This voluntary industry program prevents plastic pellets polluting the environment and is supported by the Victorian Government and Chemistry Australia. Another example of reducing plastics in the environment is CSIRO's development of digital detection of gross pollutant traps to coordinate their cleaning, prevent overflows and maximise efficiencies.

The prevention of plastic waste reaching our oceans can be achieved through the removal of plastic microbeads (<1mm) from personal care products, substitution with biodegradable materials and prevention of fibre fragments from clothes through improved water treatment such as advanced filters in washing machines to prevent microplastics (<5mm) from entering the sewer (Wu et al., 2017). A ban of certain consumer single-use products (e.g. plastic straws), also supports avoidance (this is further discussed in the Consumption section).

Problematic plastic packaging

Problematic plastics are broadly defined as plastics that are difficult to collect, contribute to litter, reduce recovery of other materials through contamination, or contain hazardous chemicals (APCO, 2019c). Multi-layered packaging can also be problematic and specific solutions are addressed in the Design section. Plastic types identified as problematic in the UNEP global commitment are: PVC, PVDC (polyvinylidene chloride), PS and EPS (UNEP, 2019). In particular, PVDC and PVC remain problematic materials due to the lack of recycling pathways and lack of collection. PVDC film has useful barrier properties that prevent discolouration and dehydration of meat. While there is no global regulation on these products, international companies are already making commitments to exit from problematic or single-use materials. From the 400 companies that are a signatory to the 'New Plastics Economy Global Commitment', 79% are either already eliminating or have plans to eliminate PVC and 60% for PVDC (UNEP, 2019). One of these companies is the UK supermarket chain TESCO which has undertaken to ban PVC as part of a commitment to ban all non-recyclable plastic by 2019.

8 https://kab.org.au/ (accessed 10 July 2020)
9 https://www.tangaroablue.org/ (accessed 10 July 2020)
10 http://www.opcleansweep.org.au/ (accessed 10 July 2020)

2.3.2 Design

The design stage is a fundamental focus of the circular economy. The plastics circular economy *'is an industrial system that must be restorative and regenerative by design'* (Ellen MacArthur Foundation, 2016, p.5). Design for circularity is the first strategy for Australia's 2025 packaging targets. Design is an often-neglected part of the life cycle as our traditional linear economy means addressing plastic waste with a focus on end-of-life. However, the design stage has the greatest potential to transition to a plastic circular economy. A focus on design allows us to create a plastic product that is ***reusable, recyclable or compostable***.

"If we really want to shift, it's about a complete redesign and rethink of what we do on a systems level." – interview participant

Reusable

The plastics industry has a role in producing less waste by developing reusable packages. The most basic example of this is the Australian-designed KeepCup. Reusing a KeepCup results in a significant reduction of carbon emissions compared to a single-use coffee cup (Almeida et al., 2018). New business models are part of the circular economy and Woolworths have announced a collaboration with TerraCycle to establish the 'Loop' platform which packages common household products in reusable packaging.

Recyclable

One of the biggest challenges for manufacturers and brand owners is to identify problematic multi-layered packaging and to design recyclable alternatives. Multi-layer products, such as chip packets, chocolate wrappers and pill blister packets, have combinations of plastic film and aluminium foil. These can vary from three to nine (or more) layers and provide a light product with strong barrier or mechanical properties. While they have superior mechanical properties, their layers make them difficult to recycle (APCO, 2019d) and multi-layered products containing PVC, PS or bioplastic are unable to be recycled through the REDcycle program (APCO, 2019c). AMCOR is one example of a company that is applying research and innovation to move away from multi-layer materials to develop recyclable, high barrier, flexible packaging as part of its pledge to have all packaging recyclable or reusable by 2025 (AMCOR, 2019).

One aspect of designing for recyclability might be the substitution of one material for another, although ideally, such substitution would be an evidence-based decision to prevent a switch to a material that has greater environmental harm. Some companies have substituted EPS for alternative materials such as cardboard, fungi or bamboo (APCO, 2019b). There is a lack of life-cycle assessment for plastic products such as certified biodegradable plastics (APCO, 2019a), EPS to landfill compared to EPS to recycling (APCO, 2019b), and products made from soft plastics (APCO, 2019d).

There are options available to brand owners that improve their awareness of the impact of their packaging. APCO has developed PREP (Packaging Recyclability Evaluation Portal) which is an online platform that helps companies verify if packaging is recyclable, non-recyclable, or conditionally recyclable. The latter depends on consumers following instructions. Chemistry Australia has delivered workshops known as 'Quick Starts' to show product designers how to develop a product or package using recycled content. This assists companies by providing them with information on how to get materials, specifications and identify a moulding company that designers can engage to produce their product.

Compostable

Certified compostable plastics have a niche role in packaging plastics where they can substitute for single-use plastics for takeaway food and events. When used in this way it facilitates collection of both waste streams – packaging and organics – to be processed with the FOGO (food and garden organics) system. The products generated from composting facilities can reach an urban, industrial or agricultural market which supports the circular economy by returning nutrients to the soil. Certified compostable plastics are made of bio-based or fossil-based feedstocks and have a role in the biological rather than technical side of Australia's circular economy. The role of certified compostable plastics is niche as generally, plastics should be retained at their highest possible value for reuse or recycling.

There are two main types of Australian standards for biodegradable products – home (Australian Standard (AS) 4736 (2006)) or industrial (Australian Standard (AS) 4736 (2006)). It is currently voluntary for manufacturers to verify that products confirm to these standards. Companies can be verified and apply through the Australasian Bioplastics Association to use the 'Home Compostable Verification' or 'seedling' logos which are consistent with European labels to indicate industrial composting (Australasian Bioplastics Association, 2020). Biodegradable products can be open to misleading information and this has led to consumer confusion over terms such as 'bioplastic', 'biodegradable', 'compostable', 'oxo-biodegradable', 'degradable' and 'home compostable' (Choice, 2020). Oxo-plastics are particularly problematic as they are designed to fragment over time and can contribute to microplastics pollution. The ACT and South Australia are in the process of phasing out oxo-degradable plastics (APCO, 2019c).

Data to inform design and planning

Improving information through the provision of cost-effective data collection through the life cycle of a product would support not only improved design decisions but also improved planning, management and policy development for plastics waste. These data are required to estimate the remanufacturing potential for plastics (Singh and Ordoñez, 2016) which is underpinned by standards to provide manufacturers confidence that recycled plastics are fit for purpose. It is suggested that data tracking of plastic packaging should be implemented so there is tracking from source to sink (Pickin et al., 2018) which helps to improve accuracy of waste and recycling reporting. The Northern Territory prioritised an electronic waste tracking system which was due for implementation by 2019 (Pickin et al., 2018). Examples of data-driven responses to waste management are the ‘smart bins’ that have been deployed in Melbourne and Tasmania to monitor odour and communicate when they are full. Another example might be cheap, real-time industry 4.0 monitoring solutions for gross pollutant traps in waterways that are managed and monitored by local government authorities.

2.3.3 Consumption

This section addresses household consumption practices, associated regulations, and consumer perspectives on the use of plastics, including a social licence to operate.

Improve education and harmonised household recycling

Consumer education with improved labelling to indicate the recyclability of products or packaging is important to support increased collection and reduced contamination. Clear and consistent messaging is key to successful household recycling. One common example of confusion is whether lids can be left on plastic bottles or not. An author attempting to resolve this question for their own household found the local council website advice was to remove lids from plastic bottles for recycling; however, in other linked recycling education material, lids where to be placed in the rubbish bin. Such conflicting information exacerbates the problem of recyclable plastic going to landfill.

Clear, consistent information will help reduce contamination and support improved recycling rate. The Australasian Recycling Label has an important role in reducing consumer confusion for how to correctly recycle packaging. Research indicates households do want to recycle (Walton et al., 2019) but receiving mixed messages on what is recyclable potentially undermines their efforts and their motivation (Miafodzyeva and Brandt, 2013).

Differences in what households can place in their recycling bin varies due to different infrastructure constraints and different contractual relationships between waste operators and councils. These pose challenges, however, there is a recognised need to work towards standardised infrastructure and contracts, and consistent and clear messages supporting plastics recycling for households.

Maintain plastics’ social licence to operate

A growing awareness of sustainability is driving consumer purchasing behaviour, and research on global consumers from Australia, China, the UK and the USA shows that 91% of consumers want brands to use sustainable ingredients or materials and 92% of respondents report sustainability practices should be standard business practice (Stafford et al., 2018).

The results of a survey collected in May 2018, which was representative of the Australian population, showed that Australians consider plastic waste a serious environmental issue and are concerned about the environmental impact of plastics. Most people associate plastic use with food-related packaging. However, despite the recognised benefits of plastic in extending the life of food products and preventing food waste, their increased use is not supported. This indicates that plastic packaging is starting to lose social acceptance and has negative sentiment associated with its use (Dilkes-Hoffman et al., 2019).

Australians support the reduction of plastics now and in the longer term with 80% of respondents indicating a desire to reduce their use of plastics. However, there was a gap between attitudes and behaviours: those indicating they were already acting to reduce plastics were fewer than those indicating they wanted to act. This gap on individual action extends to the perceived responsibility for reducing plastic waste where individuals were the lowest-ranked group seen to be responsible for reducing disposable plastic. Instead, the Australian public hold industry as mostly responsible for reducing disposable plastic, followed by the government through legislation controls and lastly, individuals though consumer choices (Dilkes-Hoffman et al., 2019).

While the attitudes of the Australian public have been collected on their views toward plastic, there is more research required on the types of actions that are acceptable to them. Included in this research is a need to understand where the role of individuals can support reduced plastic waste and improved understanding on the role of recycling, in addition to prevention and reuse of plastics (Dilkes-Hoffman et al., 2019). The results of this survey provide evidence of changing societal expectations and suggest that manufacturers and brand owners need to address issues such as recycling and problem plastics to maintain a social licence for the continued use of plastics.

Figure 2.6: Substituting plastic for paper packaging in grocery stores may have negative impacts on food waste and the environment.

While plastic offers consumers the benefits of convenience, low cost and positive outcomes such as the prevention of food waste, consumer sentiment towards plastics is increasingly negative, irrespective of these benefits. This negative sentiment is driving trials to remove plastic from grocery stores, such as a 10-week trial in an Auckland, New Zealand, grocery store (Figure 2.6) (NZ Herald, 2020). This is occurring despite UK life-cycle-assessment data showing that a lightweight HDPE bag performs better than paper when the HDPE bag is reused as a bin liner (Edwards and Fry, 2011) and shows again a lack of evidence-based data available to decision makers. There is a need for an Australian evidence base to inform substitution decisions, especially with food packaging where plastics can extend the shelf life of some products.

Reduce microplastics during domestic clothes washing

Microplastics (<5mm) are released during the use of products containing plastics, for example through using cosmetics embedded with microbeads or through fibre fragments being released during clothes washing. The release of microplastics into our environment can be prevented at the level of domestic washing or at waste water treatment plants (Wu et al., 2017). There are several commercially available, low-cost filters for domestic washing machines on the market, however, their effectiveness may require additional scientific evaluation and research.

Harmonise policy for single-use plastic products

Identification of products in plastic pollution has resulted in a UK ban on the sale and distribution of plastic straws, stirrers and plastic-stemmed cotton buds from April 2020. These products are also present in Australian litter and a community group 'Better Buds' are calling for a similar ban on plastic-stemmed cotton buds, which if flushed down the toilet, can ultimately appear on Australian beaches (Better Buds, 2020).

Consideration of banning certain problematic single-use plastics that have existing substitutes will prevent these products entering waste streams and littering Australian coastal and terrestrial areas. Each Australian state and territory has its own approach to implementing single-use plastic policy and are in various stages of progress for either implementing a ban or intending to take action (APCO, 2019c). The 2019 WWF Scorecards (Figure 2.7) shows the mixed approach taken for different products across Australia. These differences cause confusion for consumers and difficulties for business that work across jurisdictions and would benefit from national harmonisation. Australia lags behind Canada, Europe and the UK in taking action on single-use plastics although this is rapidly changing as jurisdictions (e.g. South Australia, Queensland, and ACT) move to take action on single use plastics. An ongoing challenge is working to harmonise each jurisdictions approach to tackling single use plastics.

Taken action · Taken some action · Taken no action

State action taken to ban:	NSW	VIC	ACT	QLD	WA	TAS	NT	SA
Plastic bags	Taken no action	Taken action	Taken action	Taken action	Taken action	Taken action	Taken action	Taken action
Microbeads (federal action)	Taken some action	Taken some action	Taken some action	Taken some action	Taken some action	Taken some action	Taken some action	Taken some action
Plastic & coffee cups	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken some action
Plastic lids & coffee cup lids	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken some action
Balloons and balloon sticks	Taken some action	Taken no action	Taken some action	Taken some action	Taken some action	Taken no action	Taken no action	Taken no action
Plastic plates	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken some action
Plastic straws	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken action
Plastic utensils	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken action
Plastic containers	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken some action
Plastic packaging eg. cling wrap, condiments	Taken no action	Taken no action	Taken some action	Taken no action	Taken some action	Taken no action	Taken no action	Taken no action
Plastic bottles (container deposit scheme)	Taken action	Taken no action	Taken action	Taken action	Taken action	Taken action	Taken action	Taken action

Figure 2.7: 2019 WWF Scorecards

Source: https://www.wwf.org.au/get-involved/plastic-pollution/plastics-scorecard#gs.6f8ajv

2.3.4 Collection

There are many different types of plastics, some of which need different collection methods or business models in order to recover and divert from landfill. A Victorian report shows that 90% of Victorians are open to changing how they sort their waste. Greater separation of waste in homes and businesses has been shown to reduce contamination and improve recycling outcomes. Improved education is key to facilitating improved outcomes (Infrastructure Victoria, 2019). The household-level separation of organics and glass would be highly beneficial to reducing contamination downstream. There is a greater need for collection initiatives given 88% of end of life plastics are sent to landfill and the majority (just over 70%) of plastics collected are packaging plastics.

Product Stewardship - Container deposit schemes (CDS)

Some of the resistance to CDS is that they are costly to implement, although the schemes have been shown to be most effective at reducing plastic waste into the ocean (Schuyler et al., 2018). One commonly stated risk is that a CDS will cannibalise existing kerbside-recycling programs.

The USA Container Recycling Institute estimates CDS are the most effective mechanism for recovering containers for the purpose of recycling. It estimates that the USA could achieve 80–90% recycling rates of containers based on a 10-cent deposit (Gitlitz, 2013).

In Australia, CDS schemes are useful for the PET and HDPE plastics used in beverage containers. NSW has recently implemented a CDS and as of November 2019, it had captured 2.7 billion containers.[11] There are estimates that the NSW scheme has reduced containers reaching landfill by 57% (Hannam, 2019). The South Australian scheme has been running for 40 years and that state also has one of the best recycling rates in Australia. Victoria and Tasmania have committed to implementing a CDS by 2022–23. Therefore, all Australian jurisdictions are on track to have a CDS in place which is known to reduce plastic litter in the environment. There is now potential to seek harmonisation between schemes in each jurisdiction.

Soft plastics consumer packaging

Social business innovation groups such as REDCycle play an important role in connecting parts of the supply chain to collect LDPE and PP – otherwise known as 'scrunchable' or soft plastics. REDCycle partners with supermarkets who act as collection drop-off points for consumers. This material is then cleaned and processed by Australian manufacturers Replas, Close the Loop and Plastic Forests (Redcycle, 2020). However, due to a lack of market demand for products made from recycled products, the RedCycle program is at capacity. Companies such as Replas have capacity to scale up but are prevented due to a lack of demand for their recycled-plastic products. Household soft plastics also have contamination levels of up to 20% (APCO, 2019d) which poses challenges for recycling.

Medical PVC

The Vinyl Council of Australia has implemented a PVC collection program in partnership with Baxter Healthcare to collect PVC from hospitals. PVC is estimated to comprise 25–30% of hospital waste. To recycle medical PVC is cheaper or cost neutral for a hospital compared to sending it to landfill. Recycling it also has significant environmental benefits. Recycling uses 85% less energy and 1.8 kg of carbon emissions per kg of product recycled. The PVC collected from hospitals is manufactured into new products (State Government of Victoria, 2020). This program has been implemented into 90 hospitals in Australia and New Zealand although with 693 public and 657 private hospitals in Australia (AIHW, 2019) this means fewer than 10% of Australian hospitals have adopted this program. Barriers are likely to be social rather than technical or economic. Therefore, there are further opportunities to explore incentives for hospitals to implement the PVC collection program.

Agricultural plastics

The agricultural sector consumed 91,000 tonnes of plastic in 2017–18. The recycling rate was 7%. The majority (51,000 tonnes) of plastics consumed is LLDPE and LDPE. A major use of these flexible plastics is silage wrap and horticulture wraps. PP is used in twine and netting products.

In the past there was an Australia collection system called Plasback that captured flexible plastics from farms. This system still operates in New Zealand, but significant challenges have halted its operation in Australia. There is no longer a plastic processer in mainland Australia who will accept agriculture plastics with their higher levels of contamination than commercial and industrial film. Envorinex in Tasmania will collect clean agriculture flexible plastics, but it is not feasible to transport mainland plastic across to Tasmania. The additional soil and on-farm contaminants reportedly can reduce plastic processing (wash and remove contaminants) throughput from approximately 1,400 kg per hour to around 600 kg per hour. Victorian recyclers currently have enough clean plastic to process from other sources and are at capacity and are therefore reluctant to accept agricultural plastics. Moreover, the glues on silage wrap produce a tacky substance during washing that affects machine processing. A New South Wales company, Plastic Forests processes agricultural plastics but has a wating list for new customers (Plastic Forests Pty Ltd, 2020) and processes agriculture plastics into agriculture products such as fence posts.

11 https://returnandearn.org.au/ (accessed 12 July 2020)

There has been a great deal of farmer education on returning farm plastics and farmers generally support recycling systems and want to reduce plastic being buried or burnt on farm. Investigation is needed into collection systems for on-farm plastics, recognising that solutions may vary depending upon farm crop type.

Implementing a collection system that allows a farmer to collect plastic at time of use, and possibly store these where contamination is minimised is a potential solution. Mobile, regional processing systems known as microfactories, may be a solution by providing low volume decentralised manufacturing options. A focus on Victorian dairy farmers and silage wraps could be an initial focus.

2.3.5 Sorting

Australian MRFs have developed to be attuned to export markets that could accept higher levels of contamination than are allowed now. They focus on separating out higher-value plastics, such as PET and HDPE. Our research consistently advised us that improved sorting technologies, including improved optical-sorting technologies, exist but have not been installed in Australia and this requires additional investment.

Sorting technology can recognise plastic bottles behind sleeves and can potentially separate plastic bags or film from paper. Removal of PVC and plastic film as part of sorting will reduce contamination levels for downstream processing. One of the challenges for plastics is that black plastics interfere with the near infrared (NIR) sorting technologies (Locock et al., 2019) that are present in standard recycling plants. Recycling technology company Steinert have a sorting solution that has been demonstrated to sort black plastics, by type, back into pure grades. This includes airflow technology that helps sort flat and lightweight black materials.

An example of improved sorting of food-grade plastics is the application of luminescent labels on packaging that can be detected and separated in MRFs using ultraviolet light. This technology complements existing NIR technology and has been tested in the UK. It is known as PRISM (Plastic Packaging Recycling using Intelligent Separation technologies for Materials) (Kosier et al., 2016).

Separation of plastics into clean sources during the collection stage provides a good pathway to higher-value solutions. This solves challenges such as contamination of material streams and mixed plastics, which often results in material pathways with lower-value outcomes. For example, only a small amount of PVC contamination causes problems for downstream processing; it can corrode rPET technology and contaminate feedstocks derived from feedstock recycling. Similarly, PVC recycling can be contaminated by the presence of other plastic types.

2.3.6 Recycling

To absorb previously exported material, Australian needs a 150% increase in plastics recycling capacity. ACOR estimates that 50% of current exports can be processed using planned or implemented infrastructure (ACOR, 2019). This leaves a significant gap in Australia's infrastructure for processing plastics (washing, flaking and pelletising) once they have been sorted and this is largely as Australia has come to depend upon exports to other countries. As Australia 're-shores' this capability we should be aware of Australia's relatively high labour and energy costs, which have forced at least one plastics recycler in Adelaide to close due to a $100,000 increase in energy prices over 18 months (Dayman, 2017). It is necessary to coordinate energy, manufacturing and waste policy in order to create a supportive environment for new investment into Australian recycling and manufacturing infrastructure. The importance of domestic manufacturing capability has been demonstrated during the COVID-19 pandemic when increased demand for goods is unable to be met through imports.

The COAG response strategy for the waste plastics export ban identifies that the Federal Government has a role to play in supporting investment through commercial and concessional loans, competitive grant funding or taxation measures (COAG, 2020). There also needs to be a consideration of regional needs, balanced with a national plan for critical infrastructure to process collected material. Some interview participants reported a lack of plans available for state and national infrastructure and these plans would inform priorities at the local government level resulting in more strategic investment in infrastructure.

It is important that reprocessing techniques deliver higher-quality resins that can compete with virgin materials on price and quality (Locock et al., 2019). Noting that a circular economy perspective means waste plastics should be processed with consideration that they can be an input to manufacturing, it is also vital that standards are developed across the supply chain to give companies confidence to utilise recycled plastics.

> "You (the waste sector) are the start of the supply chain because you are supplying us (industry) with feedstock. We need quality and therefore we need standards and clarity" – interview participant

Plastics recycling saves energy compared with the production of virgin material. One tonne of recycled plastic saves around 130 million kJ of energy (Garcia and Robertson, 2017). It also reduces our dependence on fossil-fuel resources by supporting the recovery and reuse of plastics. Materials recovery constitutes material-processing operations that include mechanical recycling, feedstock recycling or biological (organic) recycling. These methods aid in the conversion of waste plastic into lower or same-grade plastic materials or further, into monomer building blocks and other products.

Figure 2.8: Recycled PET

Mechanical recycling

Mechanical recycling is the dominant form of material recovery whereby plastic waste is processed into secondary raw material or products without significantly changing the chemical structure of the material. Such processing readily lends itself to recycling thermoplastics such as PET, PE, PVC and PP, but is not applicable to thermoset polymers such as unsaturated polyesters or epoxy resins due to their permanent crosslinking during manufacture (Locock et al., 2019).

Mechanical recycling covers primary, closed-loop recycling where the end product is used for the same purpose as the original, such as PET bottles made from both virgin and recycled PET (Figure 2.8). It also covers secondary recycling where the material is downgraded ('downcycled') for a different purpose and usually a lower-value end use. This process requires sorting, grinding, washing and extrusion (Rahimi and Garciá, 2017). Challenges to mechanical recycling arise from different plastics each responding differently due to their chemical composition, behaviour and thermal properties. Future work involves developing strategies for mixed or contaminated feedstocks (Garcia and Robertson, 2017) including understanding the properties and characteristics of mixed plastics. Polywaste Technology™ (https://newtecpoly.com/polywaste/) is one Australian technology that utilises mixed-plastic feedstock which is then extruded into products for commercial, industrial, agricultural or domestic products.

Hot-wash flake and rPET

There are significant opportunities to increase domestic production of rPET which requires high-quality, food-grade hot-wash flake which is often sourced overseas. Coca-Cola Amatil has a target of 70% recycled plastic in bottles by the end of 2019 (Coca-Cola Amatil, 2019). In order to achieve this, they are purchasing 16,000 tonnes of rPET from Thailand to meet their needs (Mitchell, 2019). In 2018 almost 20% of Australian plastic exports were high-value PET/HDPE so there is an opportunity to utilise exported PET locally once the infrastructure is in place.

A new facility to be located in Albury by December 2021 will process 28,000 tonnes of plastic waste (Evans, 2020; Gray, 2020). This involves a collaboration with Cleanaway Waste Management to provide feedstock, and both PACT Group (packaging expertise) and Asahi Beverage Group have committed to purchase most of the material from the new facility. This example illustrates the importance of collaboration across the supply chain linking waste management with markets for reuse.

Investment implications for increasing the circularity of plastic

- Statistics from 2017 to 2018 indicate that Australia exports 158–186 kt of plastic waste per year (Blue Environment Pty Ltd., 2019).
- Expected revenue loss to Australia from the plastic waste export ban is around $43.5M per year.
- An investment of approximately $2.65M in an MRF facility can process around 20,000 tonnes of plastic waste each year and generate around 46 jobs.
- An LDPE-processing plant in Bell Bay, Tasmania, with in investment cost of $1.47M, can process 1,500 tonnes of LDPE waste per year (Vinall, 2019).
- An rPET-processing plant in Albury, NSW, has an expected investment cost of $30M, can process up to 28,000 tonnes of plastic waste annually, and create 30 local jobs (Evans, 2020; Gray, 2020).
- The investment cost of Licella's Cat-HTR (Catalytic Hydrothermal Reactor) technology, where plastic waste is processed into a synthetic oil or biocrude, was estimated to be $40–50M. The processing capacity of this plant is approximately 20,000 tonnes per year, and the number of jobs created is around 18 jobs.
- The cumulative weight of plastic waste that could potentially be abated (i.e. not going to landfill) in a year is approximately 140 kt. The total investment cost would be approximately $99M.

- On average, the investment cost to process plastic waste is as follows:
  - MRF sorting of plastic waste $0.13M/kt
  - LDPE processing $0.98M/kt
  - rPET processing $1.07M/kt
  - Cat-HTR $2.25M/kt.

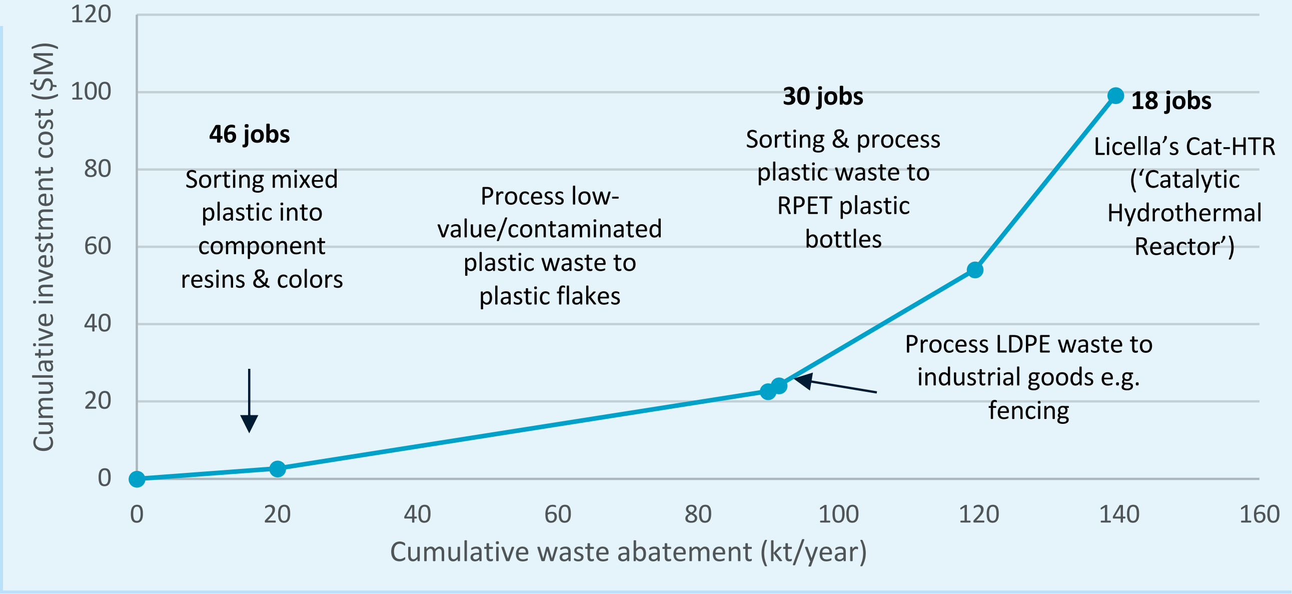


Figure 2.9: Plastic waste investment cost and kt of waste abated per year

Feedstock recycling

'Feedstock recycling' is sometimes called 'chemical recycling', but might involve chemical, biological or thermal processes. It involves the decomposition of a plastic or the conversion of a plastic to its monomers or petrochemical components. An example is pyrolysis, where plastics are heated to a high temperature with a catalyst (Rahimi and Garciá, 2017). This produces gases, fuels and waxes (Garcia and Robertson, 2017).

Feedstock or chemical recycling is not yet common on an industrial scale due to the high energy requirements and the low price of petrochemical feedstock compared to monomers developed from waste plastics (Hopewell et al., 2009). A recent report by Closed Loop Partners reviews 60 technologies that transform waste plastics into purified plastic or feedstocks and nearly all are at lab scale and requiring investment (Closed Loop Partners, 2019). Yet this type of recycling is critical to close the gap between waste recycling and manufacturing and transition to a circular economy. Where mechanical recycling compromises plastics after a number of processing cycles (e.g. PET is good for around 6 cycles (Tullo, 2019)), feedstock recycling generates new products, reduces dependence on fossil fuels and is a solution for low value mixed plastics.

Australian-developed technology, Licella, uses a catalytic hydrothermal reactor (Cat–HTR) which is a technology capable of returning mixed plastics back into oil using high temperatures and high-pressure water (Licella, 2019). The water is then reused which closes the loop on the process. The Licella process is a solution for mixed plastics (except PVC which will contaminate outputs) and can produce liquids, waxes, diesel, petrol and gases such as ethylene.

The Licella technology has been developed over the past 10 years in collaboration with the University of Sydney. A pilot plant has been operating on the NSW Central North Coast. The next stage is the first commercial or pioneer plant. There are challenges with securing investment and grants for pioneer plants as currently, Australian schemes do not support first commercial plants unless they produce energy. The cost for the Licella pioneer plant is estimated at $40–50 million (Licella, 2019). The first Licella commercial plant will be built in the UK with a capacity of 20,000 tonnes per annum. The example of Licella illustrates the importance of supportive environments for Australian waste innovation that follow the innovation pathway from laboratory to pilot, and on through to commercial scale.

In 2019, Deakin University was awarded a research grant of $190,000 by Sustainability Victoria (in partnership with Qenos and GT Recycling) to develop a project on Catalyst Assisted Polyethylene Recycling for High Value-Added Applications (Sustainabiity Victoria, 2020b). The project aims to transform inconsistent and highly variable PE plastic waste into product(s) with consistent properties. The project expects to generate new knowledge in PE recycling and processing through a unique combination of innovative methodologies and the synergy of a multidisciplinary team. The expected outcomes of the project include the foundation for a new Australian industry in plastic recycling and a potential game changer in the production of value-added products from PE waste, which allows the closing of the loop and depolymerisation of PE waste to be used as a raw material for new PE production.

Further future research in feedstock recycling is in catalyst development (Garcia and Robertson, 2017), which should help lower the energy requirements. International company LyondellBasell have announced a collaboration with Karlsruhe Institute of Technology (KIT) to advance chemical recycling of plastics with the goal of producing clean feedstock for polymer production (LyondellBasell, 2019).

New research is looking at the biodegradation of PET (and other plastics) using enzymes to convert PET polymers into monomers, PET surface treatments, degradation, and reduction strategies for microplastics and plastic microbeads (Taniguchi et al., 2019). CSIRO is also researching the conversion of PET to monomers using natural biological processes at room temperature, in order to develop new feedstocks.

Biological recycling

Biological or organic recycling involves microbiological treatment of biodegradable plastics. Under composting digestion conditions, outputs are organic residues, methane, CO_2 and water (Locock et al., 2019). A South Australian invention known as POET uses anerobic digestion to convert plastic and food waste into methane.[12] POET is said to require a $2.5 million investment to develop a 100 tonne per week plant[13] (however, the current status of the technology is unclear).

While there are approximately 150 compost facilities in Australia, some regions lack composting facilities that will accept biodegradable products. This is due to their use of short-rotation composting processes which doesn't allow time for certified biodegradable products to breakdown. There is a gap in knowledge of the infrastructure that will currently accept compostable plastics (APCO, 2019a) and in data characterising what packaging materials might be replaced with compostable plastic (Madden and Florin, 2019). In-vessel composting has been identified as the most favourable organics recycling route for certified compostable plastics (APCO, 2020a).

Waste to energy

Energy recovery of plastic wastes can be performed by several thermochemical conversion pathways – to produce heat and electricity via well-controlled combustion processes, to generate liquid fuel via pyrolysis, and to produce synthesis gas via gasification (this synthesis gas can be used to produce value-added products such as hydrogen, chemicals, and gaseous fuels).

Combustion-based processes are required to meet standard minimum operating conditions (at a minimum temperature of 850°C for 2 seconds after the last injection of combustion air) in order to minimise the formation of dioxins and furans (Bunce, 2010). Pyrolysis of plastics is well studied, however, primary liquid products may require further treatment or processing to manage impurities or contamination and to meet existing industry standards where applicable. In order to maximise the advantages of these technologies, integration into a hybrid design could lead to efficiency improvements in the overall system as well as the quality of the products (Wu and Williams, 2010).

In Australia, energy recovery is used in South Australia with a cement kiln. There is also thermal treatment of medical waste which includes plastics; however, this does not capture energy from the process (O'Farrell, 2018). It is known that gasification waste-to-energy plants are more efficient when the fuel contains waste plastic as it has a high calorific value and low moisture content (Hla et al., 2014). PVC is not suitable for waste to energy (APCO, 2019c).

There is a duality for waste to energy. On one side, Australia might adopt waste-to-energy technology that has been used globally as a solution for mixed waste and diversion of problematic waste from landfill. Alternatively, Australia might leap-frog the need for waste to energy through improved design, collection and sorting. This would allow higher-value processing to occur and result in retention of the material in the economy rather than incineration. One participant called for a national waste-to-energy framework and others recognised the potential for waste plastics to be required for their high calorific value, which may result in competition for other technologies that retain the material in the economy.

"Let's … prioritise recycling over waste to energy to reduce competition for recycling feedstock." – interview participant

Waste to energy is the second-last option on the waste hierarchy to disposal to landfill. Victorian Government policy recognises the need to provide clear policy to prioritise higher-value technologies while managing a one-way path for waste to energy by placing a cap of 1 million tonnes per year that can be diverted to waste to energy (DELWP, 2020).

12 https://reneweconomy.com.au/south-australia-machine-turns-waste-plastic-into-energy-15734/ (accessed 12 July 2020)

13 https://www.first5000.com.au/blog/waste-eating-system-targets-fast-food-industry/ (accessed 12 July 2020)

2.3.7 Manufacturing

Products manufactured from recycled content

There are companies that manufacture finished products where recycled content is part (or all) of the product. Many of these are SMEs and some have regional facilities. The types of products made from waste plastic are for the civil, commercial and agricultural sectors. Product examples include fitness circuits, outdoor furniture, bollards, decking, signage and more. Other initiatives for plastic reuse include examples such as plastic into roads through the collaboration between Close the Loop and Downer, plastic railway sleepers and acoustic panels from Integrated Recycling (Sustainabiity Victoria, 2020a).

Close the Loop accessed a $40,000 government grant to develop an additive for road base that includes recycled plastic (Close the Loop, 2020). The result is a road surface that is more durable and flexible than conventional road surface products (Tran and McIver, 2018). Close the Loop have two products: TonerPlas™ which enhances the properties of traditional asphalt so that it lasts 65% longer and uses problematic soft plastics; and TonerPave™ which is a new asphalt that reduces cracking and has a 23% lower carbon footprint compared to standard asphalt (Close the Loop, 2020). These solutions have arisen from a highly innovative SME, intent on developing new markets for its recycled products. Equally critical to commercialisation has been collaborative partnerships with Downer and initially, the Hume City Council for trialling the product on a road in their region (ECORoads, 2020). Since the trial in Victoria, TonerPave™ continues to be deployed in other areas, for example, it was used in resurfacing the Queenstown, New Zealand, airport in 2018.

A major challenge for manufacturers is the lack of market demand for recycled plastics products. The cost can sometimes be higher than existing substitutes due to smaller volumes being manufactured or the higher feedstock cost compared to virgin materials. Recycled plastics products are extremely robust, as well as being water and termite resistant. They won't crack, splinter or rot and will never need painting. The higher initial cost can be offset when reduced maintenance costs are recognised, however, these are not typically considered in procurement policy.

Initiatives to drive market demand for products using recycled plastics is urgently required. Changes in government procurement policy to incentivise recycled plastics products has been met with support by industry. However, procurement policy changes should be measured to ensure intended impacts are realised and tangible market demand for recycled plastics is realised. Major infrastructure projects are an opportunity for 'sinkhole' projects where large volumes of recycled plastics products can be substituted for products made from virgin materials (e.g. highway noise barriers and plastic railway sleepers). However, this will not occur without enough evidence to provide engineers with confidence and trust to specify a new product.

Options to grow markets for recycled plastics

- Develop government procurement policies preferencing or allowing recycled products
- Institute procurement targets, increasing over time
- Monitor and track impact of government procurement policies to ensure their effectiveness
- Remove structural barriers in infrastructure contracts and specifications that preference virgin material where a suitable recycled alternative exists
- Identify which plastic types are suitable for use in different products (i.e. roads, non-structural civil products)
- Undertake case studies for recycled products to raise awareness of their existence
- Develop products that have a local market, minimising transport costs
- Develop testing methodologies and specification evidence to build confidence and reduce risk for engineers responsible for substituting from virgin to recycled product
- Track plastics through supply chains, supporting confidence in the chain of custody for materials
- Develop or improve standards for recycled material throughout the supply chain: point of collection, MRF, recycling (wash, flake, pellet), final products
- Improve transparency and consistency of standards and link with global standards where relevant
- Maintain high-quality recycling infrastructure, ensuring material is processed at highest possible value and lowest contamination level (particularly important for food-contact plastics)
- Investigate socio-technical barriers for recycled content in government procurement, large infrastructure projects and industry applications
- Encourage forward procurement commitment

Third-party research and testing methodologies are needed to overcome industry preferences for existing virgin materials. New products could be supported by case studies to raise awareness of the availability of new products. Moreover, as companies manufacturing recycled products are often SMEs, support for these companies to market their products and connect with supply chain partners will facilitate market growth for recycled products.

Research innovation in partnership with industry

Innovation and partnerships between science and industry has an important role to play in developing a circular economy for plastics in Australia. Research interventions might occur across the circular economy life cycle but particularly in the design and manufacturing phase. It is also beneficial for Australia to **maintain a link with international initiatives** to reduce plastic waste. Examples include the UN, the Ellen McArthur Foundation, WRAP UK and the Alliance to End Plastic Waste.

There is a well-known challenge for the translation of R&D into industry, commonly referred to as the 'Valley of Death'. This challenge applies to Australia and while there is funding for research, and funding for the purchase of infrastructure, attendees at the National Plastics Summit, March 2020 requested strategies that **support technology transfer** and **access to capital** to bridge the valley of death. A recent study of technologies that modify waste plastic found an average 17-year time frame to reach a growth phase in the market (Closed Loop Partners, 2019), see Figure 2.10. Our interview data suggested that it might take 5–8 years to get a product ready for market or 10+ years to reach a point for the first commercial scale plant.

To accelerate early-stage R&D it is important to encourage those developing new products, either SMEs or researchers, that they engage with their end-user market early in the development phase. This is an important step in securing feedback that is relevant for industry trials and securing buy-in to a new product. **Accelerators or innovation hubs** are an approach to foster and accelerate innovation. Examples include the Queensland circular economy hub or the Indonesia-Australia Systemic Innovation Lab on Marine Plastic Waste.

Our data revealed a potential funding gap for projects that are scaling from pilot to commercial stages and adding value to waste streams (i.e. novel, new-to-market technology). In order to address this gap, existing institutions, such as the Australian Renewable Energy Agency (ARENA), might consider broadening their scope to include resource recovery. Alternatively, to leverage private investment, Australia might want to consider incentives (e.g. tax deductions) that are proportional to the investment necessary at industrial scale.

The Federal Government provided $20 million for short-term research collaborations (CRC-P Round 8) between industry and research institutions for pre-commercial activities. States and territories also have funding grants available from time to time. A more comprehensive **national program for plastic research activity** would help to coordinate and accelerate research and path-to-market activities. This would facilitate collaboration across the innovation system and industry and potentially result in improved applications to state and federal research grants. Table 2.2 presents a summary of the challenges for plastics where research capability can support a plastics circular economy.

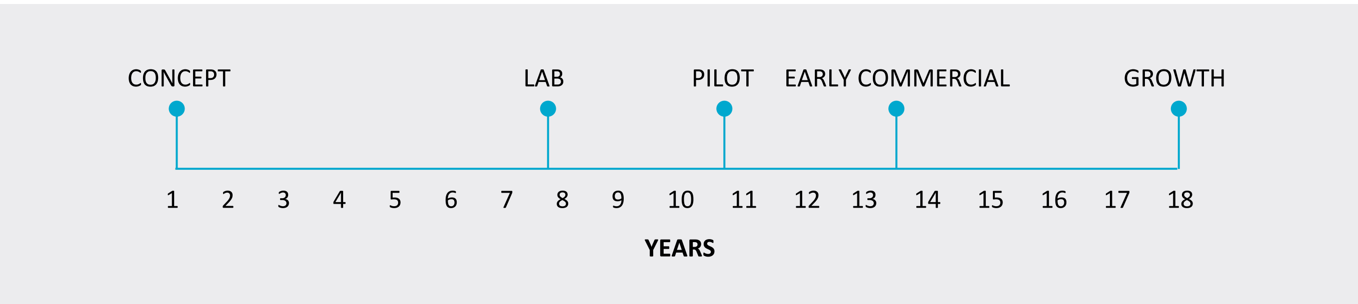


Figure 2.10: Average time to maturity based on review of 60 waste plastic transformational technologies

Source: CLP, 2019, p.16

Table 2.2: Research and innovation opportunities for plastics in the circular economy

RESEARCH AND INNOVATION OPPORTUNITY	DESCRIPTION
Problematic materials	Alternatives or substitutes for non-recyclable or difficult-to-recycle multi-layer plastics. Innovations that use single layers or single material plastics while retaining the properties and benefits provided by the layered product. (i.e. AMCOR [https://www.amcor.com/] investing in recyclable packaging solutions for flexible packaging). Solutions for other plastics that are difficult to recycle due to the contents they package such as chemicals or paint (i.e. Paintback [https://www.paintback.com.au/] investing in research to convert paint packaging into new products).
Data analytics	Data tracking of plastics through the supply chain including stockpiles and improved accuracy of waste, litter and recycling reporting. Methods for tracking and preventing illegal dumping. Metrics for measuring circular economy progress.
Market platform	An Australian database or system for recycled products that provides case-study data, recycled-content percentages, validation of waste source (i.e. Australian waste) and type of recycled plastic use. Matchmaking systems (e.g. ASPIRE [King et al., 2016, King et al., 2020]) that connect companies that have waste with companies that want waste. Provision of case-study information from any lab or industrial testing to support certification of products for procurement purposes.
Social behaviours	Research on household recycling behaviours, understanding myths against using recycled-content materials and products and social behaviours to boost market demand. Research on the types of actions acceptable to the Australian public for plastics waste reduction (Dilkes-Hoffman et al., 2019).
Material science	Microfactories such as UNSW e-waste microfactory to produce filament for 3D printing. Research into the properties (e.g. rigidity, tensile strength, temperature deflection) of mixed polymers, or certain proportional mixes of waste plastics being converted to products, to support evidence that they meet procurement specifications. Research into feedstock-recycling opportunities appropriate to Australian conditions and needs.
Product testing and standards	Research on in situ monitoring of environmental factors and product performance of recycled-content products. Testing methodologies and standards for new recycled-content products.
Business model design	Technologies and collection systems that can operate in regional–rural communities, low volume, unique mix environments. Manufacture products relevant to local communities using a system-based approach and sound business model for a circular economy.
Decision support systems	Life-cycle assessment for plastic products to support an evidenced-based approach for decision making, including: certified biodegradable plastics (APCO, 2019a); EPS landfill vs recycling (APCO, 2019b); products made from soft plastics (APCO, 2019d).
Plastic litter prevention	Understanding source and impact of microplastics, including potential to prevent pollution during washing of textiles and capture at waste water treatment plants (European Comission, 2018). Greater understanding of degradation rates of plastics in the environment (Chamas et al., 2020).

Biobased plastics – long-term transition to renewable feedstocks

Biobased plastics are made from renewable resources and it is important to note that not all bioplastics are compostable. There are no limitations for bioplastics being processed and recycled alongside traditional plastics. One of the benefits of using bioplastics is the reduction in carbon emissions, or in some cases negative global warming potential, for the life cycle of the product (Ellen MacArthur Foundation, 2016). Bioplastics must compete against the low cost of oil and while they offer a transition away from fossil-derived feedstocks, they are currently a small percentage of the global market. The transition towards renewable feedstocks should be a future target of plastics in the circular economy, preceded by greater amounts of collection, processing and reuse in our economy.

2.3.8 Summary of opportunities for plastics

Australia requires an immediate focus on infrastructure to process and recycle plastic in order to address the upcoming ban on plastic waste export. However, beyond that, there are big opportunities to improve the 12% recycling rate and divert plastic from landfill. This requires efforts across the plastic life cycle, including avoidance. Australia needs to focus attention towards design, consumption and collection, rather than depend solely on the waste management sector to solve the plastics waste problem. This requires collaboration across governments, industry and research institutions, in collaboration with communities and the not-for-profit sector. Product innovation that shifts Australia to a circular economy of plastics requires investment now to set us on this path. The link between waste streams and manufacturing feedstocks is the most critical link that supports retaining plastic in our productive economy. Strategies to address these opportunities is provided in Chapter 6.

A summary of the opportunities for each stage of the circular economy is provided in Table 2.3.

Table 2.3: Opportunities for plastics in the circular economy

CIRCULAR ECONOMY STAGE	OPPORTUNITIES
Avoidance	• Phase out or ban problematic, unnecessary single-use plastics packaging • Continue litter surveys around Australia to quantify and track plastic pollution • Encourage support of industry campaigns to prevent plastic pollution (e.g. Operation Cleansweep®) • Prevent plastic waste reaching our environment and oceans by banning or substituting microbeads and developing strategies to filter microplastics • Support environmental campaigns to reduce plastic pollution
Design	• Design plastic products for reusability, recyclability or compostability • Ban oxo-plastics as they contribute to the problem of microplastics • Substitute certified-compostable plastics for food packaging where linked with organics processing (e.g. food courts, takeaway food or events) • Research and innovation to develop recyclable packaging • Design out problematic or multi-layer materials • Improve data tracking • Employ brand-owner education tools (e.g. APCO PREP to design recyclable packaging) • Develop life-cycle assessment data to inform design substitutions • Develop new business models for reusable packaging
Consumption	• Provide clear, consistent information, labelling and education on how to recycle for households • Standardise recycling contracting for councils • Maintain plastics' social licence to operate through action on plastics litter and evidence-based data to inform substitution decision making • Prevent microplastics pollution during textile washing • Harmonise state and territory policy for single-use plastics
Collection	• Household education supports reduced contamination • Implement Container Deposit Schemes in Victoria and Tasmania and look for opportunities to harmonise approaches in each jurisdiction • Incentives to improve participation in PVC recycling for Australian hospitals. Research to understand barriers to adoption. • Implement regional and niche collection business models for plastic not collected via MRFs (e.g. soft plastics and Agricultural Plastics)
Sorting	• Improve MRF sorting technology to reduce contamination levels and sort plastic types • Improve household separation (e.g. bins for glass and organics)
Recycling	• Invest in new infrastructure for processing plastics (washing, flaking and pelletising) • Coordinate waste, manufacturing and energy policy to create a supportive environment for new enterprises and infrastructure • Support greater investment in hot-wash flake processing • Connect the waste processing and manufacturing sectors and replace virgin resources with recycled material, recognising that feedstock recycling is critical to the transition to a plastics circular economy • Support environments for Australian innovation that follow the innovation pathway from laboratory to pilot, and through to commercial scale • Implement technologies capable of processing mixed plastics • Collaborate across the supply chain, linking waste management with markets for reuse • Improve knowledge of infrastructure that processes certified-compostable organics across Australia • Develop clear policy guidelines for waste-to-energy infrastructure without impacting on higher-value processing opportunities
Manufacturing	• Improve domestic markets for products made from Australian recycled content • Support research–industry innovation for the development of new recycled-content products and markets, and support innovation hubs and linkages to international initiatives • Prioritise or remove barriers to government procurement of recycled-plastics products. • Measure and quantify increased market demand • Develop standards to provide engineers with the evidence they require to specify a new product • Maintain linkages with international initiatives to reduce plastic waste • Implement a coordinated national program for plastic research activity • Accelerate research and development through accelerators or innovation hubs and encourage early engagement of new products with end markets • Support SMEs to market their products, connect with supply chain partners and break into new markets • Include biobased plastics as part of a long-term (20–30 year) strategy for transitioning to a circular economy

2.4 The road forward – plastics

A possible future state of plastics flows for the year 2030 is presented in Figure 2.11.

The key assumptions to develop this vision of 2030 is an average 80% recovery rate of plastics once they reach end of life. Of these recovered plastics they are either recycled using mechanical or feedstock recycling or sent to energy recovery or composting facilities. Leakage to the environment has been reduced by 90% compared to 2018. There has been an overall increase in consumption in line with increased population but at a reduced rate compared to increases between 2014-2018. There is an increase in net additions to stocks in line with a transition from single-use plastics towards durable or reusable plastics.

Figure 2.12 shows a prioritisation of the short, medium and long-term actions for plastics, presented with their associated outcomes. While it might be argued that some medium-term activities could be short term and vice versa, decisions have been made to prioritise core strategic activities that should be completed within the short, medium and long-term time frame. Note that activities presented in 2025 may commence earlier.

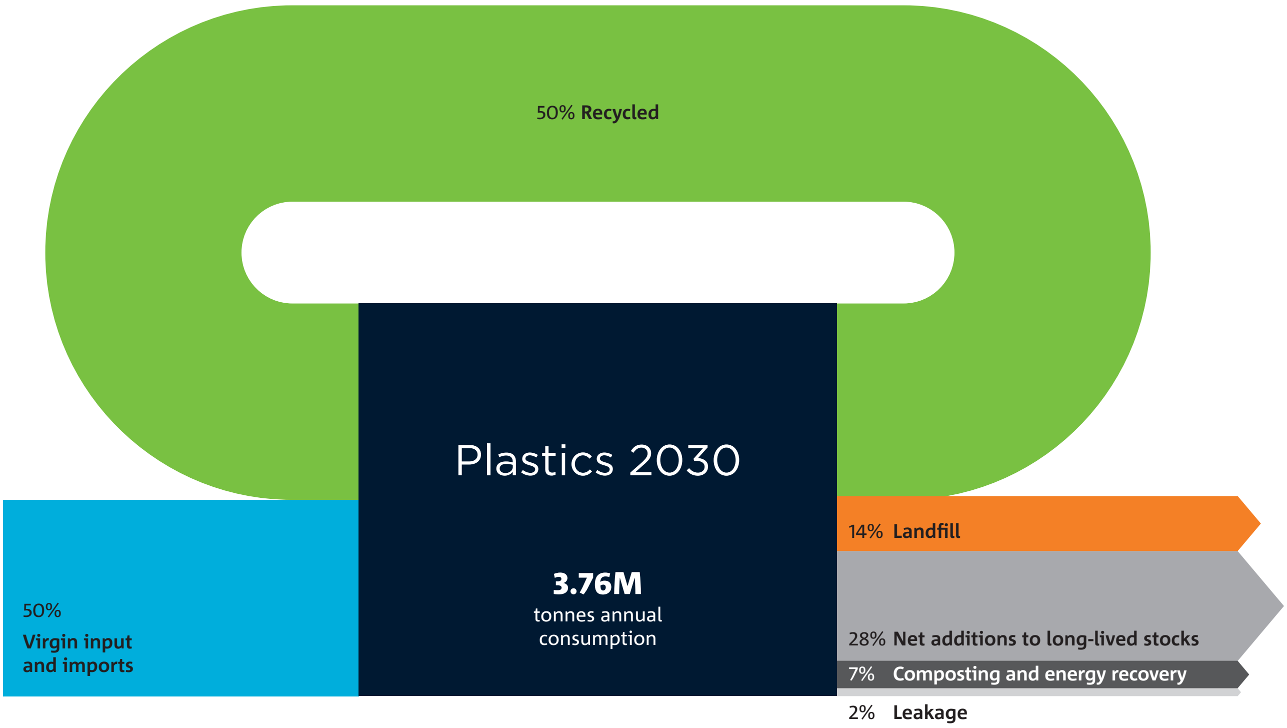


Figure 2.11: Sankey diagram of estimated plastics flows for Australia in 2030

2022

The short term is a consolidation of work that has been commenced by government in the harmonisation of policy across jurisdictions. The most significant activity needed is the rapid investment in plastics-processing infrastructure as a consequence of onshoring waste processing through the waste export ban. This includes investment in sorting technologies or manual sorting to develop a cleaner, less contaminated waste stream. Also required are activities that boost market demand for recycled-plastics products, initially led through government procurement. The critical issue of design should also be addressed to assist with the incorporation of recyclable material into the supply chain.

2025

The medium term is used to consolidate work that will have commenced earlier on standards for recycled-plastic materials. This work is necessary to provide confidence to the market in specifications which support the adoption of recycled plastics and products by industry. This activity supports increasing market demand. Further infrastructure will be implemented to process niche or regional plastics. This might involve the use of strategic regional hubs, investment in the recycling of agricultural or medical wastes or technologies such as energy recovery or microfactories. Building further on driving market demand, it is important that activities continue to support the expansion of markets.

2030

The longer term will see a continuation of the earlier strategies, but with an emphasis on realising the circular economy for plastics and achieving the national target of 80% average resource recovery. This can be achieved by implementing commercial-scale feedstock recycling which connects the waste and plastics-manufacturing sectors in Australia. If achieved sooner, this key activity will greatly accelerate Australia's transition to a circular economy. In addition, Australia would benefit from evaluating biobased feedstocks as a substitute for imported fossil-derived feedstocks. By 2030 Australia would benefit by achieving consistency across Australia for council waste contracts, which are often long term. While this activity is represented in 2030, work to achieve this goal would need to have been commenced years earlier.

In Figure 2.12, a code has been entered at the start of each key activity to indicate the relevant actor(s) responsible for that activity: G = government, I = industry, R = research, and C = community. As we would expect, most activities are either government or industry led, or some combination of the two. Community rarely features in Figure 11 as communities are generally the target or beneficiaries of activities and outcomes (e.g. education campaigns) rather than drivers of activities, however community pledges (e.g. Better Buds) can drive avoidance behaviours.

2022

Key outcomes

Export ban for non-value-added plastics waste

195,000 tonnes new processing infrastructure to recycle previously exported plastics

Container deposit scheme established in Victoria and Tasmania

Improved sorting outcomes arising from increased use of the ARL resulting in cleaner waste streams for recycling

Accelerated innovation for adding value to plastics waste

Improved domestic market opportunities for products made from Australian recycled content

Increased participation in product stewardship by industry

Key activities

G: Use grants, loans and streamlined approvals to stimulate recycling infrastructure investment

I: Support new infrastructure for processing plastics (washing, flaking, pelletising) and improve the efficiency of existing infrastructure

I: Invest in optical sorting technology and/or manual sorting to reduce plastics contamination

G: Harmonise state and territory policy on problematic, unnecessary single-use plastics packaging

G/I/R: Evaluate and prioritise recycling infrastructure needs that are matched to market demand

G: Review the plastics packaging product stewardship scheme and increase engagement by industry

G/I/R: Coordinate a national program for plastic research activity

G/R: Adopt procurement policy for recycled-plastics products and investigate barriers to procurement at all government levels

I: Design plastic products for reusability, recyclability or compostability, supported by training tools

G/I: Develop and implement industry and community environmental campaigns to reduce plastic pollution

I: Industry pledges for recycled plastics

2025

Key outcomes

100% of packaging to be reusable, recyclable of compostable

80% recovery rate for rigid-plastic packaging

60% recovery rate for flexible-plastic packaging

Increased community awareness for where to recycle plastics and reduced collection contamination

Increased market demand and improved confidence of recycled-plastics products

Improved technology options for plastics processing; organics, microfactories, regional hubs and energy recovery where recycling is not possible

Key activities

G: Monitor effectiveness of government procurement policies for recycled-plastics products

I/G/R: Implement regional, niche, microfactory and mixed plastics processing infrastructure

G: Provide clear, consistent information, labelling and education campaigns for how to recycle for households

G/I/R: Consolidate standards for recycled plastics

G: Harmonise strategies for local council recycling bins

G/C: Conduct ongoing litter surveys and environmental campaigns to prevent plastics pollution

G/R: Maintain links with international initiatives to reduce plastics waste in oceans

I/R: Develop data to support evidence-based decisions for plastics substitution

I: Improve clarity on facilities that can accept certified-compostable plastics

2030

Key outcomes

80% average resource recovery rate for plastics

Significant reduction in plastics litter and waste to oceans

Certified-compostable plastics available in multiple jurisdictions

Improved data transparency for waste plastics to inform policy and decision making

New jobs provided by Australian domestic plastics recycling capacity and infrastructure

Australia closing the loop on plastic waste processing and resin manufacturing by replacing virgin resources with recycled material

Key activities

I: Implement feedstock recycling at commercial scale in Australia

I/R/G: Review potential for bio-based, sustainable feedstocks to be produced in Australia

G/I/R: Achieve significant improvements to plastics waste data flows and transparency for stockpiles and flows across jurisdictions

G/I: Standardise long-term waste contracting for councils

I: Implement compostable packaging for food courts, takeaway food and major events in Australia and link with organics processing

R/I: Innovate to prevent microplastics from entering wastewater

Figure 2.12: Key outcomes and activities for a circular economy for plastics by 2022, 2025 and 2030. (Actors: G = government, I = industry, R = research and C = community).

3 Glass

Glass is used mainly for food and beverage packaging, with other uses ranging from windows to household goods, solar panels and automotive components.

In Australia, approximately **1,280 kilotonnes (kt) of glass packaging is consumed each year** and approximately 181 kt of flat and architectural glass is produced annually.

Glass manufacturing in Australia is dominated by a few large companies.

Imports meet 18% of domestic glass demand and Australia exports a small amount of glass cullet (<2% of recycled glass).

Key challenges

- Collection systems – the predominant system in Australia is co-mingled kerbside collection. The highly mechanised system leads to glass breakage. This exacerbates cross-contamination with other recyclable flows and small fragments are more difficult to recover.
- Sorting and re-processing technology – cullet needs to be colour sorted into clear, green and amber for recycling into glass containers. Furthermore, ceramics, porcelain and other glass composition types and contaminants need to be sorted out of the stream for various applications. These processes are capital intensive.
- Some hindrances to re-processed glass markets concern compliance of recycling operations with environmental standards for waste handling, and duplication of compliance burden for recycled glass products in different jurisdictions.
- Losses to landfill: although 78% of post-consumption glass packaging is collected and 50% recovered, only 36% is returned to the economy in recycled packaging.
- Sophisticated sorting is available in limited locations and mostly owned by a small number of large companies. The destination of glass consumption may be far from the places of re-processing or glass manufacture.

Key opportunities

- Maintain the quality of glass flows throughout its life cycle to reduce the need for large capital investments, enabling market entry for SMEs and regional operators.
- Use separation-at-source systems to decrease cross-contamination, including segregation of recyclables, lower compaction rates for glass and reuse schemes.
- Invest in sorting and re-processing technologies, and improved quality assurance to remove contaminants.
- Strengthen end markets through government procurement and incentives to increase the use of recycled glass or glass fines and aggregates in new products.
- Engage with civil construction and regulatory bodies to increase uptake of recycled glass and aggregates in building and construction, and harmonise materials standards and compliance requirements across jurisdictions (federal, state and local).
- Encourage behavioural and cultural change, including consumer education about the value of glass recycling, industry education on design and procurement, and incentives to increase recycling in public and commercial places.
- Implement tracking technologies and data collection from beginning to end of the value chain to pinpoint and measure losses in efficiency, inform decision making and measure effectiveness for further improvement.

3.1 Overview of global and Australian landscape

From an environmental perspective, there's no question of the benefit of recycling glass in Australia. For every tonne of glass collected from the kerbside and recycled, the net savings are more than half a tonne of greenhouse gases, 2.3 KL of water, over 6 GJ of energy, and nearly a tonne of solid waste to landfill is avoided compared to using virgin materials (EPA NSW, 2010).

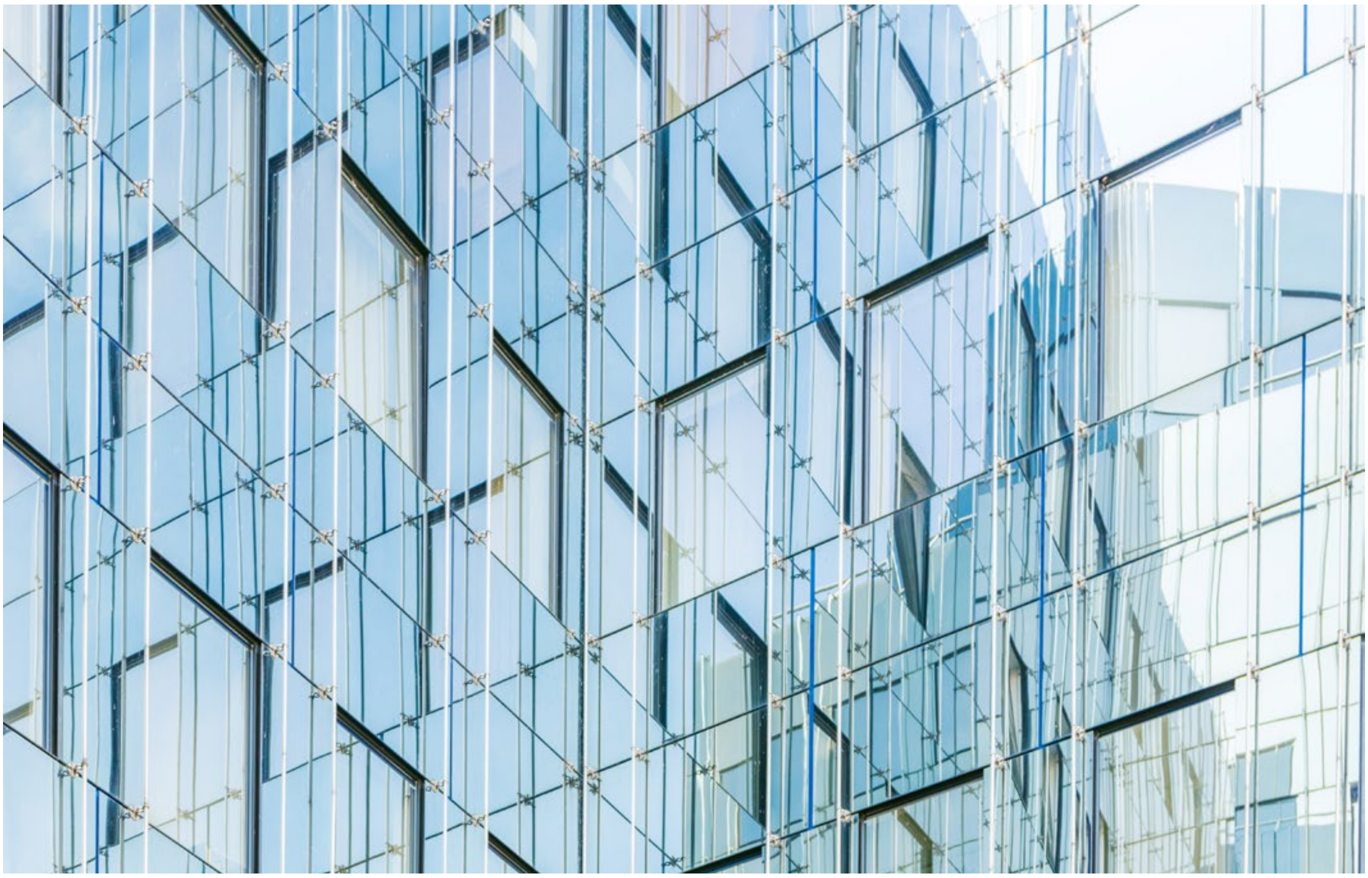
From a material circularity perspective, the most prominent use of recycled glass is in packaging and much more packaging glass can be recycled. Although 50% of waste packaging glass is recovered, only 36% of glass waste ultimately returns to locally produced glass packaging products (Madden and Florin, 2019b). This compares with recovery rates of 33% in U.S. where recyclable flows are often comingled and contrasts with the recycling rate of container glass in the EU-28, which is stable at 74% (Harder, 2018)

From recent industry reports and interviews across the sector, the main technical issues are in collection, sorting and logistics, and maintaining quality throughout the glass consumption–production–consumption cycle. When the quality of glass flows is compromised through excessive crushing or contamination, this leads to a greater need for (and investment in) beneficiation, and more of the glass ends up as glass fines in lower-value terminal end products.

Retaining the quality of the glass in waste flows is important because the value of waste glass at collection can be low or negative. Stockpiling activity is sensitive to the differential between the cost of beneficiating and recycling, and the cost of virgin material inputs. There are opportunities to better support local markets for recycled glass products (cullet[14] and sand) and no issues with the quantity of supply. Current flows to landfill could be diverted either to recycling for glass packaging, construction or other terminal uses, some of which are at an early stage of development (Flood et al. 2018; Heriyanto, Pahlevani, and Sahajwalla 2018a). Some hindrances to re-processed glass markets concern compliance of operations with environmental standards for waste handling, and duplication of compliance of recycled glass products in different jurisdictions.

The COAG Waste Export Ban will have a minimal effect on the glass recycling industry as less than 20Kt of an estimated 1.3 Mt of annual waste glass flows in Australia is exported, and this is sold as value-added glass cullet. However, within the COAG Waste Export Bans - Response Strategy (2020) companies and individuals all have a role in working to reduce waste where possible and make productive use of our waste as resources where we can't avoid its generation.

14 Cullet is recovered glass pieces 8–50 mm in size that have been sorted by colour and separated from other materials.



3.1.1 Glass consumption and production in Australia

In mass flows, more than 80% of glass is used in packaging such as bottles and jars. In terms of monetary flows, however, more than 50% of the value of glass production is in other products:

- automotive and other transport windows and windscreens
- building windows, skylights and architectural features
- solar panels

Approximately 1,280 kt of glass packaging was consumed in Australia in 2017–18 (APCO, 2019d). Volumes of the other glass uses are difficult to find. By value, glass packaging makes up 42% of the $4.2 billion glass and glass product manufacturing industry in Australia, and 53% is flat glass and architectural glass (Kelly, 2019). The remaining 5% is made up of products such as household and commercial drinking glasses, plates and cookware, electronics, medical technologies and fibre optic cables.

We have used this market share of flat and architectural glass in Australia, the global mix of non-packaging glass consumption in 2017–18[15], and current Australian prices[16] to derive volume flows in kt.

An estimated 181 kt per year of flat and architectural glass is produced in Australia, assuming Australia's consumption mix of non-packaging glass types is the same as the global average. From the ABS Waste Accounts (ABS, 2019), reported waste glass flows from construction and demolition were 32.3 kt in 2017. Thus, we estimate a net ~149 kt per year of flat glass has been added to building stock in recent years.

Over the next few years, there are several trends impacting demand for glass in Australia. Flat and architectural glass for residential and non-residential building construction is expected to decline following completion of many large-scale developments and a fall in investment (Kelly, 2019). Demand for glass packaging in production is expected to increase with long-term growth in wine exports, and despite falling per capita consumption of alcohol[17]. Demand for household products that contain glass is also expected to rise. The reduction of car manufacturing in Australia has also reduced demand for automotive glass production.

15 https://www.adroitmarketresearch.com/industry-reports/flat-glass-market (accessed 30 April 2020)

16 See e.g. https://www.oneflare.com.au/costs/glazier (accessed 5 May 2020)

17 From interviews with industry, the effect of COVID-19 has been increased glass packaging waste flows counter to seasonal variation. Anecdotally, this may be from increased alcohol consumption.

Glass packaging manufacture in Australia is dominated by Owens-Illinois Australia and Orora Limited, while Viridian (CSR Limited) is the largest Australian flat glass manufacturer. Small-to-medium companies make up the rest of the domestic glass manufacturing industry. About 18% of the value, and 13% of the physical volume of domestic demand for glass is met by imported glass products (Kelly 2019; APCO 2019d), mainly low-priced products from China and Indonesia. Australia exports a small amount of glass products, estimated at 2% of industry revenue (Kelly 2019).

The 1.3Mt of glass waste in Australia is from three primary waste streams: municipal solid waste (MSW), commercial and industrial (C&I) and construction and demolition (C&D). Nearly 80% of glass packaging waste comes from MSW. Kerbside collections are sorted in a material recovery facility (MRF), and further cleaning and colour sorting occurs in a secondary process called beneficiation. The two outputs are: cullet which can be used in re-manufacturing of glass packaging and; glass fines which can be used in small quantities in industrial applications and large flows into construction.

3.2 Key challenges

There are considerable losses of glass to landfill during collection and processing (see Figure 3.1). Although 78% of post-consumption glass packaging is collected and 50% recovered, only 36% is returned to the economy in recycled packaging (Madden and Florin, 2019b). Approximately 10% of all waste glass ends up in construction or industrial uses (the remainder in export and stockpiles). Even before collection, over 280 kt of glass per year is destined to landfill due to incorrect disposal at the kerbside.

Co-mingling and compaction of collected recyclable material can lead to irretrievable cross-contamination and the creation of glass fines (pieces smaller than 8mm often mixed with ceramics, bottle caps and other detritus). Glass fines can be recovered and recycled, but this involves more sophisticated sorting and beneficiation plant, which in turn are investments that are dependent on long-term contracts and prices.

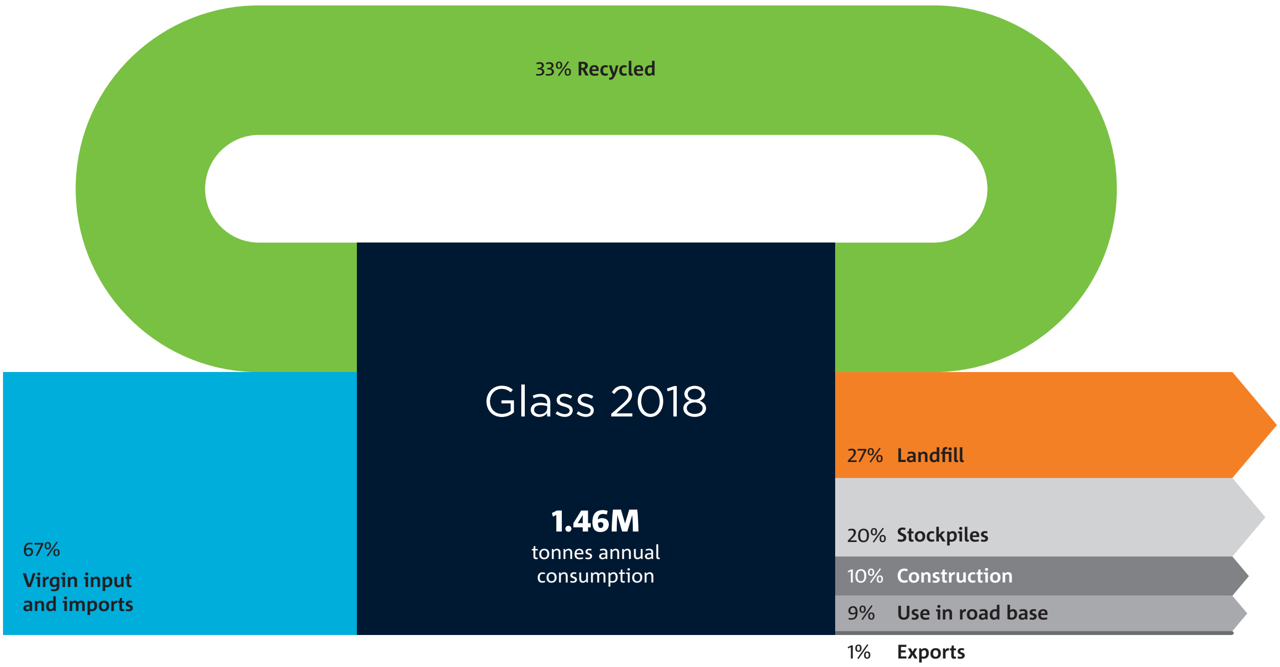


Figure 3.1: Sankey diagram of current glass material flows for Australia

Source: Allan, 2019; APCO, 2019d; Madden and Florin, 2019b

If more glass were to be diverted from landfill, more recycled flows would be available to re-manufacturing and ultimately displace the need for virgin material in glass packaging. There is also the opportunity to displace the need for virgin material in 'terminal' uses for glass, for example, glass sand in road construction. The demand for processed glass fines and engineered sands in civil works can be substantial but they are connected to the specific and discontinuous timing of major projects. Another common challenge for glass recyclers delivering to construction is meeting compliance for product standards, sometimes across several jurisdictions. To quote the Response Strategy to implement the August 2019 agreement of the Council of Australian Governments:

"To support procurement of recycled glass, there is a need to develop national specifications and standards to increase confidence in the use of recycled crushed glass and glass fines in construction and civil works (particularly roads). Local governments are looking to utilise glass fines in civil works but in some cases have indicated uncertainty regarding appropriate engineering specifications..." - COAG (2020) p25

Glass per tonne has a relatively low commodity value compared to plastic or cardboard. The value of glass at collection is –$30 per tonne (Centre for International Economics, 2019). That is, collectors pay MRF operators to take the mixed waste glass. Through processes of sorting glass from contaminants, and further cleaning in beneficiation, the glass can be returned to a quality that is comparable with virgin material. Clean, recycled glass cullet prices are $70–$75 per tonne, but depending on how much treatment is needed, and demand for locally produced glass, the price of the output may not compete with cheaper imported glass.

Waste glass reprocessing is sensitive to price and when prices are low, glass waste (particularly glass fines) is stockpiled. There are current challenges in recovering glass from mixed waste loads, and in 2018, recycled glass fines were priced at $0–$49 per tonne (Sustainability Victoria, 2014; Victorian Parliamentary Budget Office, 2019)[18].

In addressing the challenges facing the glass industry, it will be necessary to improve the circular economy for glass. Enabling actions from a range of actors are specifically addressed in Chapter 6.

1. Collection systems that compact and contaminate glass flows	The predominant system in Australia is co-mingled kerbside collection. The highly mechanised system leads to glass breakage. This exacerbates cross-contamination with other recyclable flows and small fragments are more difficult to recover.
2. Hindrances to new and existing local markets for recycled glass	Concerns raised by industry in interviews centre around compliance of recycling operations with environmental standards for waste handling, and duplication of compliance of recycled-glass products across different jurisdictions.
3. Investment in sorting and re-processing technology or alternative systems	Glass cullet needs to be colour sorted into clear, green and amber for recycling into glass containers. Furthermore, ceramics, porcelain and other glass composition types and contaminants need to be sorted out of the stream for various applications. These processes are capital intensive.
4. Losses to landfill	Although 78% of post-consumption glass packaging is collected and 50% recovered, only 36% is returned to the economy in recycled packaging.
5. Transport costs and logistics	Sophisticated sorting is available in limited locations and mostly owned by a small number of large companies. The destination of glass consumption may be far from the places of re-processing or glass manufacture.

Figure 3.2 Summary of key challenges for the glass circular economy

18 This can be compared to $220 per tonne for newsprint and magazines, $400 per tonne for PET and $600 per tonne for HDPE (Sustainability Victoria, 2019a)

3.3 Opportunities for glass in the circular economy

The opportunities discussed next are firstly about retaining and maintaining the quality of glass flows throughout the recycling process. This 'de-risks' the sensitivity of the whole glass recycling system to prices and makes it more likely that recycled-glass products connect to the input needs of the packaging, construction and other industries. Secondarily, this incentivises retaining volume flows and thereby alleviates losses to landfill (higher recovery rates). Ultimately, with more certainty and volume, this may encourage more private investment. If the initial emphasis was on collection efficiency and greater waste glass volume flows rather than quality, this would not address low prices, losses to landfill or stockpiling issues.

There has been significant investment over the last 20 years in large scale MRFs and beneficiation to handle low quality input from co-mingled collection. These facilities are mostly on the east coast and owned by a handful of large companies. Emphasising quality input first permits a more distributed resource recovery sector that is accessible to SMEs.

A strategy of separation at source and retaining higher quality of glass in waste flows, reduces the need for economies of scale, expensive equipment and costly transport of recyclate from regional areas to facilities in major cities. This allows more opportunities for SME recyclers, micro-factories and recycled glass applications at regional scale. For example, since 2014 Northern Rivers Waste has operated a glass processing plant in Lismore, NSW that recycles waste glass into glass sand for road construction. Concurrently they enabled separation at source through providing residents with special collection satchels to separate out problem waste that might normally contaminate waste glass and other recyclables.

There are also some early-stage innovations in looking for alternative 'terminal' uses for glass. These can be high-value products, but the glass can no longer be recycled e.g. engineered glass sand in road construction, and novel recycled products like glass tiles (Heriyanto et al., 2018a; Flood et al. 2018; Heriyanto et al., 2018b).

This section highlights the opportunities across the circular economy system by breaking these into the following stages: avoidance, design, consumption, collection, sorting, recycling and manufacturing.

Figure 3.3: An automated BottleDrop® redemption centre that's part of the Oregon Beverage Recycling Cooperative

3.3.1 Avoidance

Glass is 100% recyclable without loss of material quality, so there is a low incentive to avoid glass. There is still good reason to avoid single-use glass containers just as with other packaging materials.

Develop reuse of glass containers

Reusing and refilling glass containers avoids the additional crushing, melting and re-manufacturing processes in recycling glass, and can create opportunities for local economies[19]. For example, the Oregon Beverage Recycling Cooperative[20] in the USA uses a cooperative governance model to oversee a glass container reuse scheme that operates across the full supply chain and works with local businesses. Collection of whole containers in public spaces (see Figure 3.3) is established and the reuse scheme involves glass manufacturers also operating in Australia[21].

There may also need to be a techno-cultural shift to extend consumer responsibility for refillable packaging. For example, in hospitality it is common to crush waste glass on-site to save on space. If reverse logistics were part of a reuse scheme, consumers may have to return containers to a place near the original retail location. Neither of these are difficult cultural changes but some education and promotion of a reuse scheme would be required.

19 See also https://www.reusablenation.com/zero-waste-living/return-and-refill-revolution-small-businesses-are-creating-local-circular-economies-for-these-5-industries (accessed 12 July 2020)

20 https://www.obrc.com (accessed 12 July 2020)

21 https://www.o-i.com/wp-content/uploads/2019/04/2018csrreportupdate.pdf (accessed 12 July 2020)

3.3.2 Design

Design out breakages and cross-contamination

Thicker glass used in glass packaging may avoid breakages in collection, transport and sorting. Although this may add marginally to the cost of the consumer product, it helps retain the quality of the waste glass flow through reducing the creation of glass fines that are harder to sort and can cross-contaminate with other waste flows. Irrecoverable contaminated flows go to landfill. Owens-Illinois operating in Oregon, USA, have designed and manufactured thicker glass bottles for the container reuse scheme mentioned earlier (see also Avoidance).

Design for separation at source

Some glass containers may be sold with a lot of other materials embodied in the product (e.g. with significant amounts of aluminium or plastic shrink wrap). This may be interpreted wrongly as unrecyclable by the consumer who sends the whole used package directly to landfill, or it may actually lead to technical difficulties in the recovery of the glass. Designing out problematic mixed materials on glass containers or designing product parts to be disassembled, enables consumers to properly separate and dispose of recyclable (and non-recyclable) materials.

3.3.3 Consumption

Raise responsibility for recycling efficacy

Around 22% of waste glass is put directly into bins for landfill (Sustainability Victoria, 2014; APCO, 2019d). A key element to effective recovery of glass waste flows is education on better practice of 'separation at source' for homes and businesses (see also Collection). Separation at source refers to the separation of waste flows at the point where they enter the waste system, usually where a consumer places the waste into a bin.

Knowing what products, or parts of products, are recyclable is key to enabling a culture of extended consumer responsibility. Labelling such as the Australasian Recycling Label[22] allows consumers to assess, and packaging manufacturers and brand owners to declare, the recyclability of materials in different applications (see Figure 3.4). Consumers and producers need to be aware of the label, and understand how to use it, for it to be an effective design element. To alleviate consumer confusion and provide clarity in the waste collection and treatment industry, it would help to have a nationally consistent approach. Investment in equipment for separated collection would also be an enabler (see also Collection).

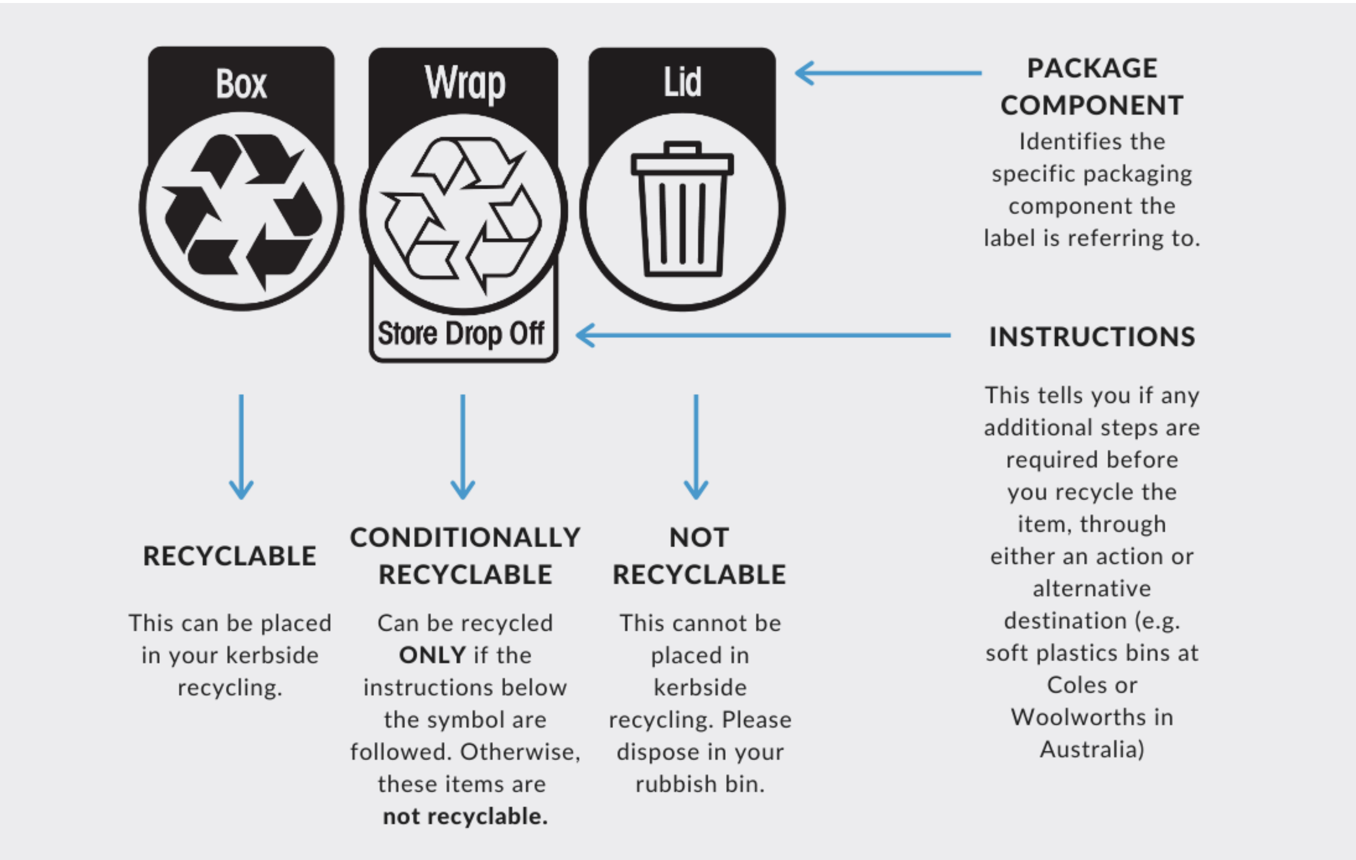


Figure 3.4: The Australasian Recycling Label allows producers and consumers to understand recyclability of products or product components and direct materials to the correct waste stream

Source: https://recyclingnearyou.com.au/arl/

22 https://recyclingnearyou.com.au/arl/ (accessed 13 July 2020)

Planning to consume more recyclables

In glass packaging recycling and in terminal uses of waste glass, government can set procurement standards for recycled content in consumables, building construction and infrastructure projects. The C&D sector is responsible for nearly a third of all waste flows nationally (Blue Environment Pty Ltd, 2018) and much of this is recycled, but the input of recycled material back into construction is less well known. Through local and state building codes and procurement requirements on government-funded projects, large flows of recycled glass and other materials can be directed to secondary uses in construction.

According to Sustainability Victoria (2019b), the use of glass sand in road construction in Victoria has measurably reduced glass stockpiles at a rate of around 400–700 tonnes per day (this is variable with construction schedules but would amount to around 146 kt per year if operating continuously). Encouraging the use of waste glass that cannot be recycled into glass packaging is an identified opportunity for all levels of government in the COAG Waste Export Bans – Response Strategy (Council of Australian Governments, 2020).

3.3.4 Collection

Separation at source

Separation at source removes glass as a contaminant of other recyclable flows and maintains a higher quality and value of the glass to be passed on to sorting and beneficiation.

Co-mingled kerbside collection commonly leads to cross-contamination and breakages during compaction in collection trucks. Separate kerbside collection of glass (and reduced compacting), can address this issue but there is also the need to consider additional costs to councils and rate payers (LGNSW, 2020). A structural–institutional consideration is the usual duration of contracts that local government and business have with collectors. This is often 3–7 years (Allan, 2019) and, from interviews with industry and local government, usually greater than 5 years. Similar contract durations occur in the subsequent stages between material recovery and consumers of recycled glass. Any policy intervention on the waste collection sector with shorter time frames, needs to allow for grandfathering of existing contracts before imposing new requirements.

All states have, or are planning to have, a CDS. Through this method of collection, the quality of material waste flows is high enough that the glass by-passes the MRF stage and proceeds to beneficiation, generally at a higher price (around $70 per tonne [Centre for International Economics, 2019]). South Australia has had a CDS scheme since 1977, and 41.4 kt of containers was returned to collection depots for recycling in 2018–19 (a return rate of 76%).[23] Other states report similarly high recovery rates, and CDS schemes are generally effective though not necessarily more so than dedicated bins for kerbside collection.

Nationally, only about 10% of waste glass packaging (126 kt of total glass packaging sold) is collected through CDSs (APCO, 2019d). CDS schemes could expand to include glass bottles for wine and spirits[24] and in New Zealand, around 30% of the population is served by a system that collects glass at kerbside in a crate separate from other materials (Allan, 2019). There is a trial of glass-only kerbside collection currently underway in Yarra City, Victoria.[25]

Public bins for glass-only collection

Another action that could reduce direct flows to landfill is bins for glass-only collection in public spaces. This enables separation at source for away-from-home consumption where source separation does not usually happen (e.g. in public buildings, food courts and public parks).

3.3.5 Sorting

The majority of MRFs lack the technical capacity to sort co-mingled, contaminated municipal waste into specific material types that have low levels of contamination (Department of the Environment and Energy, 2018). Almost all MRFs in Australia sort materials by hand. Out of 193 facilities, 9 are semi-automated, 9 are fully automated, and the remaining 175 are hand-sorted (Seadon, 2019). Semi-automated and fully automated ‘clean’ MRFs[26] utilise optical sorters to detect anywhere between three and eight materials, such as plastics, paper, metals and glass. For glass, there is additional beneficiation: sorting out ceramics and non-spec glass, and sorting by colour.

23 https://www.epa.sa.gov.au/environmental_info/container_deposit (accessed 20 May 2020)

24 Originally these bottle types were excluded because they were not significant in litter, which was an early driver for CDS schemes.

25 https://www.sustainability.vic.gov.au/Grants-and-funding/Research-Development-and-Demonstration-grants/Case-study-Yarra-City-Council-trials-glass-and-food-waste-recycling (accessed 20 May 2020)

26 A ‘clean’ MRF further sorts partially segregated dry recyclables, such as a kerbside co-mingled stream, into materials suitable for sale on to recycling. This includes the beneficiation stage.

Investment in sorting technology

Optical sorting is capital intensive ($5–20 million AUD depending on scale) but it leads to higher recovery rates, even for co-mingled input. Seven beneficiation plants equipped with optical sorting and X-ray technologies are located in Adelaide, Melbourne, Sydney, and Brisbane. Large-scale 'clean' MRFs or beneficiation plant such as in Brisbane rely on high volumes (>100 kt per year) of glass for commercial viability (Owens-Illinois, 2017). There is a $20 million 'Super MRF' in Guildford, Western Australia, with optical sorting to perform beneficiation in addition to basic sorting. This facility uses economies of scale to turn co-mingled input into clean output for re-manufacturing (Sustainability Victoria, 2018). Due to the need for volume and their location, these plants receive loads from regional areas, and interstate transfers. They are not always located near glass recyclers and there can be an additional transport cost for that transfer.

Robotic sorting is also possible, though slower, and it tends to favour low-volume flows, sorting for quality not quantity (Redling, 2018). One advantage of robotic sorting over straight optical sorting is its potential to use learning algorithms to enable more sophisticated sorting.

A comparison of the relative costs and economic benefits of investment in glass waste abatement in shown in Figure 3.5. Sorting equipment involves investments of the order of $10 million, generates 26 jobs and recovers approximately 150kt/year. Glass processing for civil works (road and other construction) is more investment but potentially generates more jobs and can recover just as much per year.

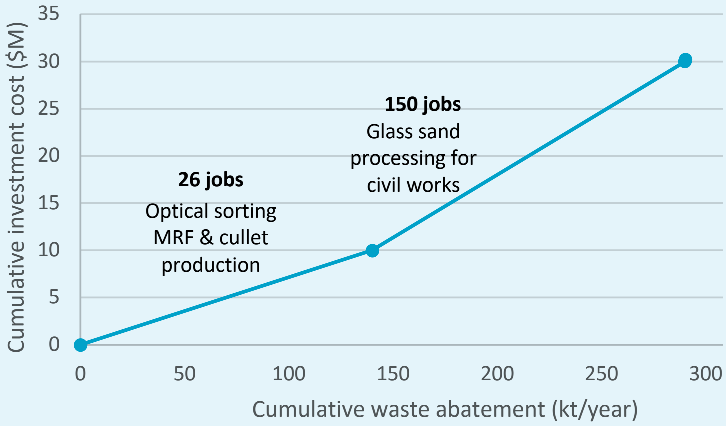


Figure 3.5 Glass waste investment cost and kt of waste abated per year

3.3.6 Recycling and Manufacturing

The combined annual output of Australia's two dominant glass packaging manufacturers is approximately 1,100 kt per year while the recycled content of that flow is just over 360 kt per year (Madden and Florin, 2019b; Centre for International Economics, 2019). From interviews with industry, we understand there is the technical capacity to have more than 80% of the input into glass packaging manufacture be recycled glass cullet. There is an unknown quantity of recycled flat glass returning to new construction in Australia and it would help to track high-value flat-glass flows.

Lower-value terminal uses can divert large volumes of material away from landfill including glass in asphalt, sand and abrasives, concrete, materials, drainage, road aggregates, and landscaping. Higher-value uses for glass fines and aggregates include glass wool insulation, filler powder for various resins paints and glues, and water-filtration media (Sustainability Victoria, 2018; Flood et al., 2018). For commercial viability, lower-value uses depend on large sales volumes, and this implies either greater capacity to produce, or greater allowance to stockpile large inventories of recycled glass, or both.

If we realise the opportunities outlined in the previous stages, more recovered material could be diverted from landfill and make it to re-manufacturing. At this point, there is ample spare capacity to take on more recycled glass cullet into new glass packaging. For glass fines, re-manufacturing mostly involves terminal secondary uses. Here, the restrictions are less about technology and fixed capital, and more about regulations and compliance.

For example, in one Australian state, a maximum tonnage limit for all recycling facilities is applied to reduce stockpiling. Due to the density of glass, facilities can only stockpile a limited amount and this inhibits their ability to provide glass aggregate to the civil construction sector at scale. Conversely, an estimated 16% of cullet is stockpiled at the beneficiation stage when demand for recyclate is low 'at the time of beneficiation' (APCO, 2019c). This can lead to expensive transport of stockpiles to avoid compliance issues, while attempting to accommodate variable demand.

Per year, 150 kt of treated waste glass could go into construction (Centre for International Economics, 2019), which is in addition to our estimate of the net approximately 149 kt per year of architectural glass added to building stock. One of the opportunities identified in the COAG Waste

Export Bans – Response Strategy is a: *'framework that allows* [industry] *to produce and store recovered glass in sufficient quantities to meet demands for a sand substitute for larger infrastructure projects…'* and to *'update the waste regulations, so that collected glass is considered a valuable feedstock rather than a waste'* (Council of Australian Governments 2020).

Improve access[27] to markets for products made from recycled glass

In construction applications, virgin sand can be obtained cheaply, although this depends on declining local resources. At the same time, a barrier to the use of recycled glass in construction materials is the updating of standards to allow of the use of materials that contain recycled glass (Victorian Parliamentary Budget Office, 2019).

From interviews and some reports (Sustainability Victoria, 2018), there is a perception in the construction market that recycled glass may be substandard. Another opportunity identified in the COAG Waste Export Bans – Response Strategy is to: *'develop and align specifications for the use of recycled glass in a range of construction applications'* (Council of Australian Governments 2020).

If it would be useful to have standards for recycled glass that meets the expectations of the construction industry, it would be yet more useful to coordinate standards across jurisdictions. One irritant expressed in interviews with industry was the time and cost to meet compliance for the same product and application, multiple times in different jurisdictions.

There are also new markets where industry and government can play a part encouraging innovation. For example, microfactories that produce glass (and other waste) composite tiles and operate on small sites (50 m^2), offer an alternative to large capital-intensive plants, for regional locations (Heriyanto et al., 2018a).

Recycling of flat and architectural glass is not well tracked and yet this product class is among the highest-value end uses of glass. Momentum Recycling (USA) partnered with the End of Waste Foundation (USA) to track glass from bin to brand. Using blockchain software, glass movement was tracked from kerbside to new products to measure what quantities are recycled, where efficiencies are lost, and provide data to increase recycling rates. The data are used to create a glass certificate with the amount recycled, chain of activity and carbon offsets, which consumers and business can purchase.[28]

We have estimated that a considerable volume of glass is added to the building stock each year and, ultimately, it would be useful to know when glass is likely to come out of the building stock. This also applies to the substantial amount of glass in Australia's 13 million solar panels.

3.3.7 Summary of opportunities for glass

Table 3.1 summarises the range of possible opportunities that in combination could decrease flows of glass to landfill and increase the recovery of glass for use in the economy.

Table 3.1: Opportunities for glass in the circular economy

CIRCULAR ECONOMY STAGE	OPPORTUNITIES
Avoidance	• Support reuse and refill schemes for glass containers
Design	• Design out breakages and cross-contamination • Simplify packaging design to avoid composite materials • Design for disassembly to enable separation at source • Use thicker glass to avoid breakages and enable reuse schemes
Consumption	• Raise responsibility for material recovery • Plan to consume more recyclables
Collection	• Implement dedicated-glass kerbside bin systems for recycling • Improve separation at source in public spaces and food courts • Improve consumer recycling behaviour to separate at source
Sorting	• Invest in infrastructure to achieve sorting best practice • Dedicate systems to improving quality of sorted glass
Recycling and Manufacturing	• Track high-value flat-glass flows • Enable processing of more recovered materials (e.g. solar panels) • Improve access to markets for products made from recycled glass • Encourage use of glass fines and engineered san in road construction • Innovate to use glass that is unable to be recycled in novel building products and industrial applications

27 Access is defined here as the ability to enter a market – a qualitative change in conditions.

28 Maile K. (2019). Momentum Recycling partners with End of Waste Foundation. Recycling Today. https://www.recyclingtoday.com/article/momentum-end-of-waste-software-to-track-glass-recycling/ (accessed 10 December 2019)

3.4 The road forward – glass

It is possible to envision what the material flows of a 2030 circular economy for glass might look like (for comparison with Figure 3.1). In such a future, the proportions of glass material flows through all stages of the circular economy are shown in Figure 3.6. A summary of key activities for glass waste management and expected outcomes for the 2022, 2025, and 2030 timeframes are shown in Figure 3.7.

Through changes to procurement and harmonised compliance standards, there are enlarged, well-defined end markets for recycled glass, and more consistent governance that enables industry to develop and supply to that demand. This, combined with processes to improve separation at source and retain material quality, supports a system with larger and higher-valued glass flows.

Secondarily, this environment encourages industry investment in capital to track and capture more waste glass (e.g. improved collection systems and collection of new waste sources such as solar panel glass). Responding to these issues first means that the latter stages will involve less investment in 'end-of-pipe' solutions to deal with contaminated flows and, ultimately, the target of 80% recovery of glass in packaging will be realised by 2030.

In Figure 3.7, a code has been entered at the start of each key activity to indicate the relevant actor(s) responsible for that activity: G = government, I = industry, R = research, and C = community. As we would expect, most activities are either government or industry led, or some combination of the two.

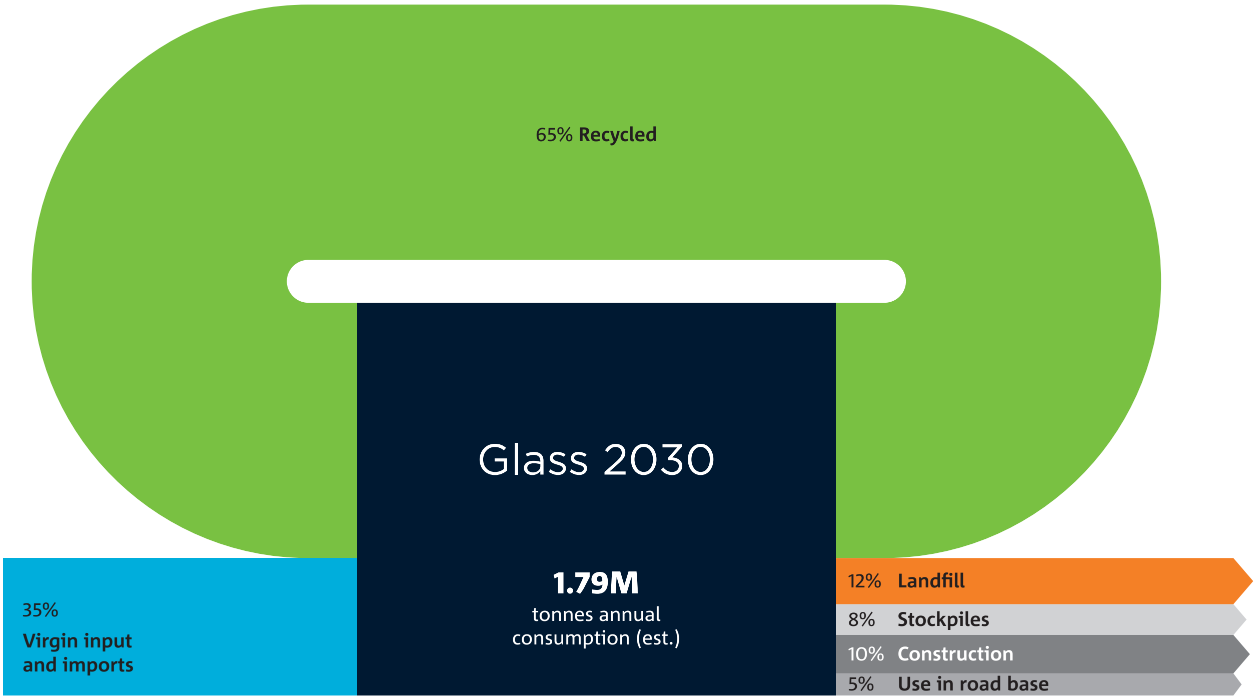


Figure 3.6: Sankey diagram of estimated glass flows for Australia in 2030

(Note the reduction in both virgin material inputs and flows to landfill and stockpiles when compared to Figure 3.1)

Key outcomes:

Reduced cross-contamination in collection and sorting

Reduced direct waste glass flows to landfill from households

Retaining quality and value of glass flows at collection reduces flows from MRFs to Landfill by more than half (estimated)

Industry can plan to invest for expanded future recycled glass markets

Reduced compliance burden for facilities to process waste glass to road base and asphalt

Waste glass in stockpiles is used for road construction

Glass flows to stockpiles are reduced to 40% of current streams

2022

Key activities:

G/I: Separate bins for glass

G/C: Education on separation at source practices for homes and businesses

G/I/C: Uptake of recyclability labelling and education

G/I: Procurement standards and practices for minimum recycled content in consumables, building construction and infrastructure projects

G/I: Harmonised quality standards for uses of recycled glass in construction across jurisdictions

G: Procurement planning for new infrastructure and repairs to create recycled glass markets

G/I/C: Local re-use & refill, and CDS schemes reduce direct flows to landfill

I: Design out problematic mixes of materials

Key outcomes:

Flat and architectural glass is tracked to EOL and recycled increasing return flows to construction

Industry invests in the capital to better capture waste glass flows and begins to innovate in new recycled products and processing

Larger flows of higher quality waste glass are recycled

SMEs and regional operators can exploit higher quality waste glass flows to deliver to small-scale & regional demand

Export flows negligible

2025

Key activities:

I: Investment in optical sorting and other 'clean' MRF technologies to handle any remaining co-mingled streams

G/I: Financial and institutional support to secure recycling as an essential service

Key outcomes:

80% of packaging waste glass is recovered

Virgin material drops from 50% to less than 20% of input to glass production

Glass recovered from C&D waste increases

Recycling industry an essential service in resource and material supply

2030

Key activities:

I/R: Supporting innovation for more recycled material in products

I/R: Tracking high value glass flows in construction and automotive uses and EOL solar panels

G/I: Contractual arrangements in collection and sorting transition to assume glass separation at source as standard

Figure 3.7: Key outcomes and activities for a circular economy for glass by 2022, 2025 and 2030. (Actors: G = government, I = industry, R = research and C = community).

4 Paper

Most paper production in Australia is used in packaging, particularly in manufacturing cardboard boxes.

Cardboard and paper **manufacturing is a concentrated market dominated by three companies** and the barriers to entry are high.

In 2019, eight facilities nationally were producing paper goods, and clustered in four states (NSW, Victoria, Queensland and Tasmania).

In 2018–19 and like previous years, **Australia consumed an estimated 4,318 kt** of paper, paperboard, and paper products.

Of the consumed paper, **an estimated 62% was recovered** (2,676 kt) and **38% went to landfill** (1,642 kt).

Of the recovered paper fibre almost 60% was reprocessed (1,559 kt) in local mills for paper and paperboard (cardboard) manufacturing, which is almost fully consumed domestically as recycled products. The remaining 40% of recovered paper was exported to overseas markets, including mixed paper (370 kt). Mixed paper represents 14% of recovered paper fibre and will be subject to the forthcoming waste export ban in July 2024.

Of the reprocessed paper fibre (1,559 kt), almost 94% was turned into cardboard boxes and industrial packaging (1,475 kt), and the rest into recycled office paper (55 kt), pet care (25 kt), newspaper (20 kt), and moulded fibre (12 kt) such as egg cartons. A small amount generated from the paper production process is turned into compost or used for waste to energy.

Key challenges

- Contamination of paper in the co-mingled recycling bin reducing the recyclability of recovered fibre
- Sorting outcomes not able to meet contamination specifications
- Packaging design not supporting recyclability and longevity of recovered fibre
- Limited domestic demand and end markets for recovered paper products
- Small profit margins and tight operating conditions for parts of the paper and paperboard supply chain
- Reduced capacity and end markets to handle increases in recovered mixed paper post-ban
- Lack of infrastructure in some states of Australia and many regional areas limit solutions for recycling and reprocessing
- Lack of accurate and in-depth data including life-cycle assessments of substitution products

Key opportunities

- **Avoidance and prevention:** Support the digitisation of information (the 'paperless' office); elimination of unnecessary packaging and substitution of disposable paper products with reusable products.
- **Design:** Design eco-friendly packaging, including aspects such as simplifying packaging design to avoid composite materials; replacing problematic paper coatings with biodegradable options; removing hazardous inks from paper products; and incorporating consistent labelling to facilitate recycling and reuse.
- **Consumption:** Educate users of paper how to preserve and recover the value of paper and reduce the application of difficult-to-recycle 'stickies'.
- **Collection:** Encourage separation at source through: establishing multiple-bin systems for kerbside recycling; dedicated collection of polymer-coated paper products (and other coated-paper products); multi-unit development solutions; improving collection at public events, stadiums, and food courts; improving consumer recycling behaviour; and harmonising messaging about recycling.
- **Sorting:** Invest in infrastructure to achieve sorting best practice, and in systems dedicated to improving quality of collected paper and sorting.
- **Recycling and manufacturing:** Support opportunities for increased production and end markets for packaging and industrial paper products (e.g. corrugated cardboard boxes) and procurement of recycled office and printing paper; increase the amount of recyclate used in a variety of products such as hygiene and tissue products, moulded fibre, pet care, and construction and support growth in these industries; invest in and develop recycling infrastructure; support investment in composting technologies and waste to energy solutions for end-of-life paper.

4.1 Overview of global and Australian landscape

The paper industry has long been perceived as a closed-loop system with its ability to generate and reuse recycled paper. Despite this, the industry still loses considerable fibre throughout the production and consumption of paper-related products. The industry has made significant progress to mitigate fibre damage and loss but changes are still required at a whole-of-system level to preserve the value of fibre for as long as possible throughout the cycle (WEF, 2016), preventing loss to landfill and achieving increased circularity of paper.

On an annual basis, the global consumption of paper approximately equals the production of paper and both continue to gradually increase over time, with more than 400 million tonnes consumed per year (Garside, 2019; Haggith et al., 2018). Even though some societal and technological trends reduce the consumption of paper, these are offset by global trends that increase its production and consumption. Broadly, a shift to the internet and a digital economy is seeing a reduction in the production of office paper and stationery-related products, along with decreases in newsprint and paper products connected to marketing, such as catalogues and brochures (IBISWorld, 2019a). These downward trends are typical of advanced world economies yet demand for traditional paper goods remains high in the developing world where there is less penetration of the internet and computers.

In contrast, an increasing global population with rising consumer incomes has led to increases in consumer spending and greater consumption of paper products. Moreover, online retail has continued to grow. These changes have driven a growth in packaging and an increased market for hygiene and tissue products, such as nappies and paper towels (IBISWorld, 2019a). This increased demand has stabilised the pulp and paper industry and offset the significant decline in demand from office paper and print media. As a result, global revenue in the paper and pulp industry has remained relatively steady over the last 5 years at approximately $US422 billion in 2019, with more recent growth (0.8%) demonstrated in 2019 (IBISWorld, 2019a).

The shift from the more traditional paper production of graphic paper and newsprint to packaging and hygiene products continues to drive demand for fibre and pulp. In addition, environmental concerns about single-use plastic packaging and a preference for paper and paperboard as a low-cost packaging material for food and beverages has also helped to boost the pulp and paper industry (IBISWorld, 2019a).

Fast facts

- The global production of paper and cardboard was approximately 419 million tonnes (mt) in 2017, with a similar amount consumed annually, approximately 423.3 million mt.
- The three largest paper producers are China, the USA, and Japan – together producing almost half of all paper.
- China is the world's largest paper and paperboard consumer, consuming 113 million mt annually. The USA is the second-largest consumer, using 71 million mt annually.
- There has been a shift away from paper being the industry's predominant product to packaging.
- Half of paper production goes into packaging paper, and almost one-third into graphic paper.
- Global industry revenue was estimated at $US422.4 billion over the 5 years to 2019.

Sources: Garside, 2019; IBISWorld, 2019a

4.1.1 Paper consumptions and production in Australia

In Australia, consumption of paper reflects global trends, and paper production is geared toward meeting domestic paper needs and overseas market opportunities.

Typical of developed economies, there has been a gradual decline in the production of newsprint and office-based paper in Australia as the internet and digital office reduce the need for these types of paper products. However, production of packaging and industrial paper products remained strong in 2018. Most paper production in Australia is used in packaging, particularly the manufacturing of corrugated paperboard for cardboard boxes and customised containers, such as cardboard fruit crates, product displays, beverage packaging, and recycled paper bins made from cardboard (IBISWorld, 2019b; Industry Edge, 2019). In 2019, revenue for corrugated paperboard container manufacturing in 2019 was $3 billon (IBISWorld, 2019c) with products serving nearly all sectors of the economy.

Demand for cardboard packaging is driven by downstream industries including manufacturers, wholesale traders, and agriculture, and is dependent on the state of the broader economy and factors affecting import competition. Most corrugated and paperboard products manufactured in Australia are used locally and the remainder exported (Industry Edge, 2019). The export of corrugated paperboard has slowly declined over recent years due to difficulties competing in overseas markets where competitors operate with lower manufacturing costs. In 2018–19, exports remained a low share of industry revenue and are expected to represent less than 0.1% of industry revenue in 2023–24 (IBISWorld, 2019c).

In other end markets, there has been consistent growth in alternative uses of paper such as moulded fibre used in egg cartons and fruit trays; pet-care products such as kitty litter; and composting products such as soil conditioner (Industry Edge, 2019; RRMB, 2019b). However, despite their growth these alternative uses remain a small segment of paper production end markets.

Paper production in Australia is a concentrated market with eight facilities nationally producing paper goods. These are concentrated in four states (NSW, Victoria, Queensland and Tasmania) and dominated by a few companies (Visy Industries, Australian Paper, Norske Skog and Orora[29]) (Industry Edge, 2019). The barriers to entry are high with paper production requiring large capital expenditure, lengthy approval processes for new infrastructure, and long contract times to secure supply chains and end markets. The profit margins are also considered marginal (IBISWorld, 2019b).

Using recycled content in paper production

The amount of recyclate used in paper production depends on the type of product being produced and the relative prices of recyclate and virgin fibre. Virgin pulp is used in conjunction with recycled content to provide added strength properties to the produced goods. For example, packaging that requires extra strength will typically contain liners made from virgin pulp with recycled content making up the middle layer of a cardboard box. In 2018–19, it is estimated that paper production in Australia used 1,559 kt of recycled content, representing 45% of the total fibre used to manufacture paper and paperboard. This percentage has declined over the last decade (from 55% in 2008–09) and reflects the declining quality of recovered paper in Australia, the demand for high strength and virgin fibre packaging, and international trade factors (Industry Edge, 2019).

Recycled paper fibre is reused up to seven times before the fibres are no longer suitable to be used in paper products. At this end point, the fibre can be composted, or used in processes where energy is recovered (waste-to-energy technologies). Disposal to landfill is also used to manage the sludge generated from paper production. Australian paper manufacturing companies are developing ways to reduce their disposal of produced waste to landfill. For example, Australian Paper, working with a local organic reprocessing company, turned its production waste into soil conditioner to reduce its disposal to landfill (AFPA, 2018).

29 In May 2020, Australian Paper merged with the fibre business of Orora to form Opal Packaging owned by Nippon Paper Industries. https://opalanz.com/app/uploads/2020/05/Opal-Media-Release_20200501_Final.pdf (accessed 13 July 2020)

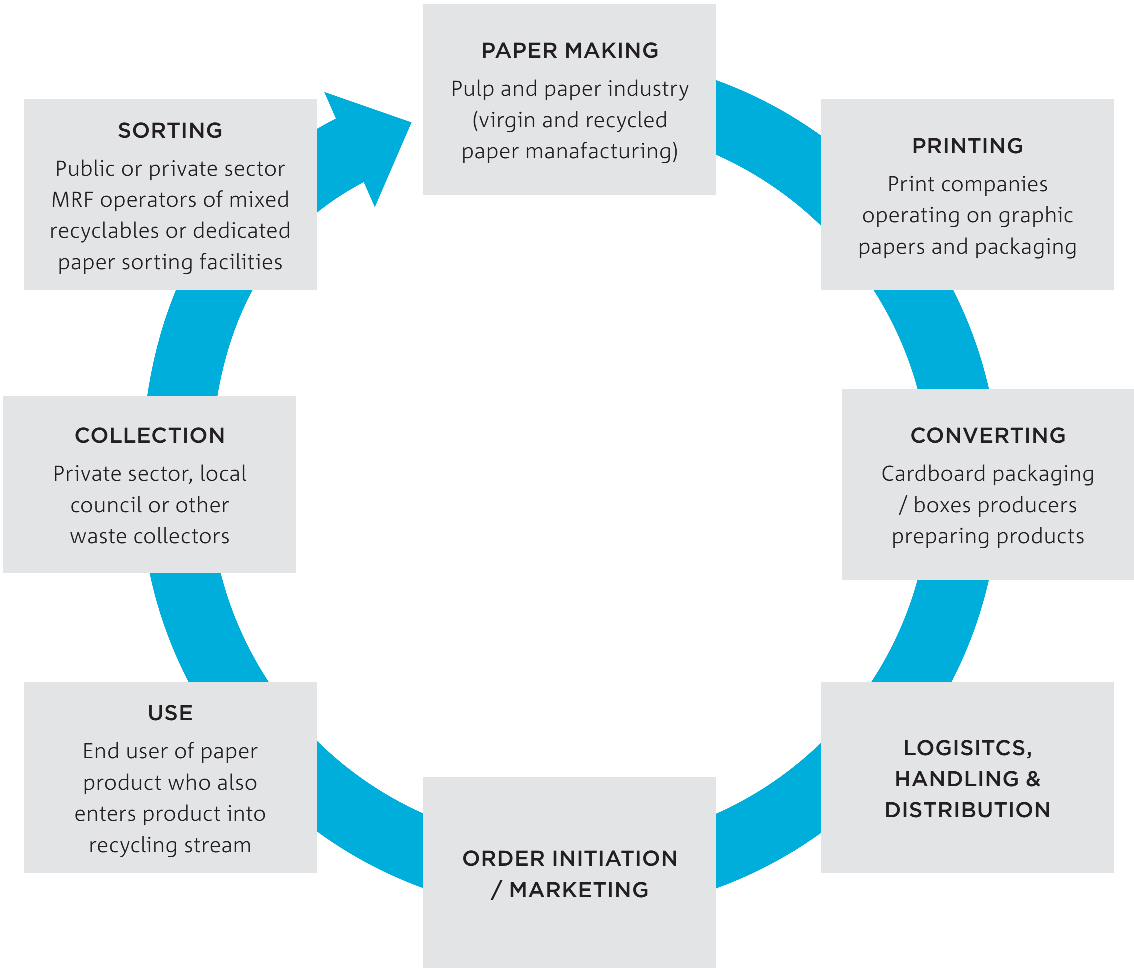


Figure 4.1: The life cycle of paper

Source: adapted from World Economic Forum, 2016

The flow of paper fibre from production to consumption and back to reuse in a further paper product involves multiple steps and processes, and numerous actors are involved directly and indirectly in the supply chain. Figure 4.1 shows each part of the process and the actors involved in the life cycle of paper, all of which can contribute to maintaining the quality of the paper fibre and preserving its longevity for ongoing reuse.

Paper flows in Australia

Paper flows in Australia are complex and data presented below are drawn from an assessment of paper recycling infrastructure and paper exports report prepared for the Department of Agriculture, Water and the Environment in 2019 (Industry Edge, 2019). Paper flows are estimated as follows:

- In 2018–19, Australia consumed an estimated 4,318 kt of paper, paperboard and paper products, which was similar to previous years.
- Paper fibre recovery for the same period was 2,676 kt, representing 62% of paper, paperboard and paper products consumed, though not all is available for recycling.
- Of the recovered fibre there were two main destinations:
  - 60% (1,559 kt) was used in local mills for paper and paperboard manufacturing and recycled-paper product manufacturing
  - 40% (1,071 kt) was exported to overseas markets as either pulp, intermediate inputs, or final products, of which 370 kt was mixed paper, and which will be subject to an export ban in July 2024.

Local manufacturing using recovered fibre

Australian paper manufacturers predominantly use recovered fibre to produce packaging and industrial paper products, such as corrugated cardboard boxes, industrial sacks, and recycled bags. The production of carboard boxes and packaging has grown and some of Australia's domestic production is exported overseas.

In 2018–19, approximately 95% (1,475 kt) of the recovered paper fibre was used to produce packaging and industrial paper products, collected mainly as carboard boxes sourced from the commercial and industrial sectors (75%) and the remainder from the MSW sector (25%). The remaining recovered fibre goes into much smaller market segments for the production of recycled office paper (55 kt) and newspaper (20 kt), which are both considered markets that are saturated and in decline (IBIS, 2019b).

Other domestic manufacturers using recovered fibre produce pet care such as kitty litter (25kt) and moulded fibre (12kt), such as egg cartons and moulded cardboard fruit trays. These alternative products use recovered newsprint and C&I collected paper and are small market segments but showing rapid growth. Recovered fibre also ends up used in organic composting (10 kt) where it is used in soil conditioners, which is strictly regulated, and in waste-to-energy plants. Other documented uses of recovered fibre have been in the construction industry where it is used in gypsum though it is unclear the size of this market segment but likely small.

Even though the largest portion of Australia's paper consumption is recycled (62%), a large amount of paper and paperboard products are disposed to landfill (38%). Most of this comes through the general waste stream though some does come from the co-mingled recyclable system.

Exports of recovered fibre

Paper production is a globalised industry and Australia provides a range of intermediate inputs into the supply chain through the international market. In 2018–19 Australia's exports of recovered paper declined by 16% on the previous year, a fall of 211 kt (Industry Edge, 2019).

In describing exports of recovered paper, a different set of terms are used and refer to four export products based on the type of pulping process that is used:

- The main product Australia exports is 'unbleached kraft', which comprises the packaging and industrial paper grades that are dominated by corrugated (cardboard) boxes. Australia exported 657 kt of unbleached kraft in 2018–19, largely to China where it is used in packaging manufacturing.

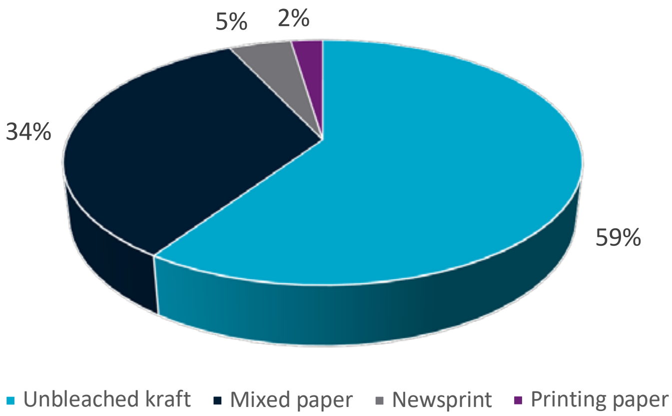


Figure 4.2: Export segments of recovered paper in 2018–19

- The second-largest recovered paper export, at 370 kt, is 'other', also referred to as 'mixed' paper or 'unsorted' recovered paper.
- Two smaller export market segments, exporting 51.4 kt and 26.2 kt, respectively, were 'newsprint' or 'mechanical' grade based on mechanical pulping, and 'bleached chemical' which is bleached office and printing paper made from chemical pulping.

In 2018–19, all market segments for exports of recovered paper declined, except for 'mixed paper', which increased by 18% (Industry Edge, 2019). From July 2024, mixed paper will be banned from export in Australia. Figure 4.2 shows the size of the different market segments exported in 2018–19.

Figure 4.3 summarises the flow of paper, paperboard, and paper products, in a simplified form, starting with virgin material. Using the figures discussed previously it applies a Sankey diagram to show the general flow of recovered fibre from consumption, collection, recovery, production, and destination into end markets.

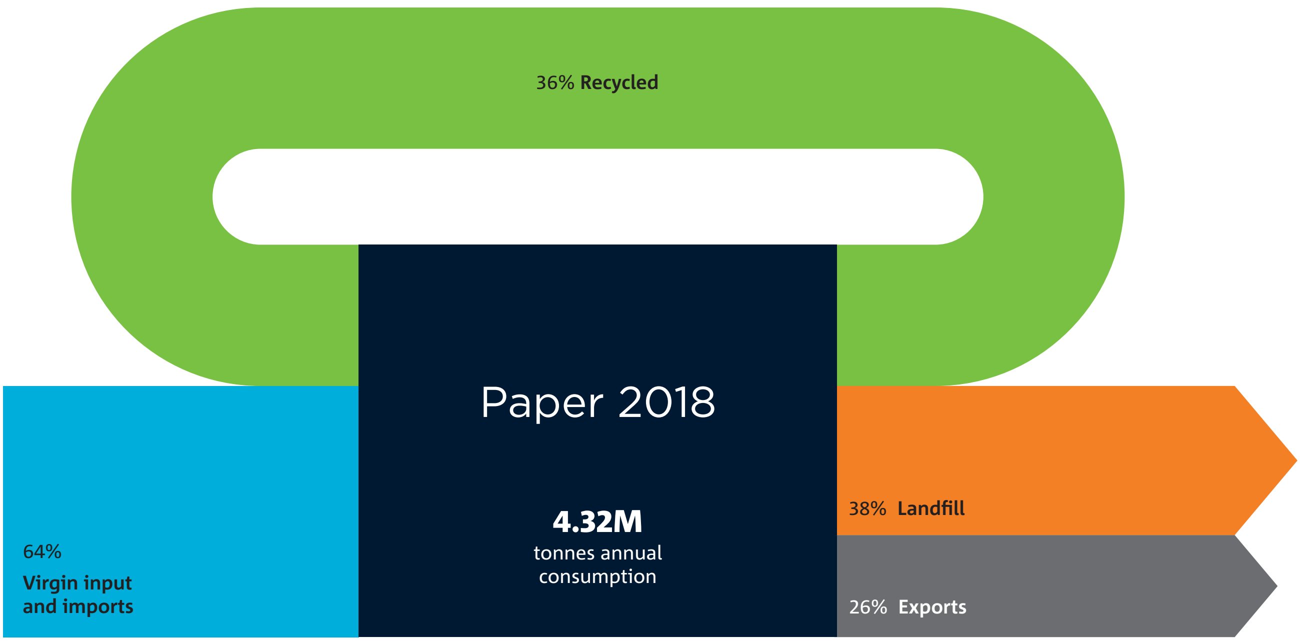


Figure 4.3 Sankey diagram of current paper flows for Australia

4.2 Summary of key challenges for paper

The key challenges facing the circular economy of paper in Australia are evident in each of the various stages typically used to describe circularity, for example the design, consumption, collection, and remanufacturing stages. In addition, there are also industry challenges that are structural such as a concentrated market dominated by few companies and an industry connected to the global market of pulp, paper, and paperboard and subject to international trade and currency factors. Moreover, short-term challenges include the forthcoming waste export ban of mixed paper, imposed by the Australian Government and commencing July 2024.

The ban highlights a range of weaknesses in the waste and resource recovery system, many of which are interconnected and identified through government and industry reports, government submissions and consultations, and stakeholder consultations through this project. Figure 4.4 lists these key challenges.

Addressing the range of challenges facing the pulp and paper industry will be necessary to improve the circular economy for paper. Many factors influence these challenges and require enabling actions from a range of actors to facilitate optimal outcomes. These are specifically addressed in Chapter 6.

1. Contamination of paper in the co-mingled recycling bin reducing the recyclability of recovered fibre	The presence of glass fines, food, organics, nappies, batteries, and clothes are all extrinsic sources of contamination limiting the quality and longevity of recovered paper fibre.
2. Sorting outcomes not able to meet contamination specifications	Reduced technology in MRFs around Australia results in an inability of MRFs to sort mixed paper and contaminated recyclables from potentially recoverable material.
3. Packaging design not supporting recyclability and longevity of recovered fibre	The use of certain dyes, inks, polymer layers, and mixed materials in packaging intrinsically limits the recoverability of the paper fibre.
4. Limited domestic demand and end markets for recovered paper products	The end markets for recycled paper products are affected by a range of factors including global trade influences such as supply and demand and the value of the Australian dollar, consumer choice including government procurement policies, and the barriers to entry for new manufacturers of recycled paper products.
5. Small profit margins and tight operating conditions for parts of the paper and paperboard supply chain	Larger vertically integrated companies are more likely to manage the operational costs in the industry going forward. Australia now has two companies which are vertically integrated.
6. Reduced capacity and end markets to handle increases in recovered mixed paper post-ban	Long approval processes, high capital investment, and considerable regulatory burdens reduce the speed and likelihood of increasing reprocessing infrastructure.
7. Lack of infrastructure in some states of Australia and many regional areas limit solutions for recycling and reprocessing	Low volumes of recovered material and long travel distances make the business cases for traditional recycling solutions in regional areas unviable. Some states, particularly Western Australia, lack reprocessing infrastructure for paper, paperboard, and paper products.
8. Lack of accurate and indepth data including life-cycle assessments of substitution products	Data gaps reduce the ability to target improvements and build business cases for investment, particularly data related to collection, sorting, and contamination of recyclables.

Figure 4.4: Summary of key challenges for paper

4.3 Opportunities in the circular economy of paper

This section highlights the opportunities across the circular economy system by breaking these into the following stages: avoidance, design, consumption, collection, sorting, recycling and manufacturing.

4.3.1 Avoidance

The avoidance and prevention of waste generation is fundamental to mitigating many of the issues undermining a transition to a circular economy. Waste prevention refers to any measure taken before a substance, material or product becomes waste, is applicable to all phases of a product lifecycle (European Parliament Directive, 2008), and is commonly described as three groups of measures:

- *Reduction at source* focuses on preventing waste in the pre-use stage, for example, through elimination of unnecessary packaging (APCO, 2019a), and through product design, taxes on packaging, and procurement guidelines (Hutner et al., 2017). Eliminating waste during the production of paper and paper products is also a critical aspect of waste prevention and the pulp and paper industry globally and nationally are continually developing more sustainable solutions for paper production (WEF, 2016; AFPA, 2018).
- *Substitution* includes replacing the product with an alternative such as with a non-paper product.
- *Intensification* particularly targets the use stage of a product, where use is increased through sharing or lengthening the life of the product.

Implementing these types of changes for paper requires design of alternative products, and redesign and changes to paper products, workflows, work practices, consumer habits, and societal expectations in how products and services are delivered and consumed.

Even though waste prevention has been part of the waste hierarchy for some years it still faces challenges and issues that limit its uptake and effectiveness (Hutner et al., 2017; Van Ewijk and Stegemann, 2016; Zacho and Mosgaard, 2016), including a lack of public education (Victorian Auditor-General's Office, 2019). Nonetheless, wastepaper has been identified as having the second-highest potential for prevention, second to food, largely due to the relative ease for consumers to reduce paper waste compared to other waste types such as plastic (Zacho and Mosgaard, 2016).

Mechanisms for supporting change require: introduction of procurement guidelines and policies that stipulate waste reduction as a criterion and address product attributes such as durability and unnecessary packaging; incentives to encourage waste reduction and recycling; regulation; and promotional and education campaigns including packaging reduction (APCO, 2019a; Hutner et al., 2017; Victorian Auditor-General's Office, 2019).

Examples of avoidance and waste prevention

Digitisation of information – the 'paperless' office

The paperless office concept provides opportunities to avoid the consumption of paper yet is still met with challenges and limitations associated with implementation of an e-office. Public administration changes such as electronic submission and handling of forms (Hutner et al., 2018; Mirabella et al., 2013) demonstrate the potential waste prevention from e-government. Academic institutions including schools and universities have also been identified as opportunities for considerable paper waste prevention.

Elimination of unnecessary packaging and ordering of 'extras'

Design, manufacturing, and distribution of paper products involves multiple actors along the supply chain who each have a role to play in minimising waste. For example, initiators of orders of paper products can avoid schemes that encourage the over ordering of extra copies (WEF, 2016).

Substitution of disposable paper products with reusable products

Examples of the cultural shift towards reducing wastepaper in the takeaway food industry has been replacement of cardboard beverage cups with 'keep' cups. Studies show a combination of initiatives such as pricing, environmental messaging, and the provision of reusable cups support change in consumer behaviour away from using disposable cups for beverages (Poortinga and Whitaker, 2018). In addition, the potential to prevent waste at public events has also been demonstrated through the use of reusable cups at sports stadiums (Hutner et al., 2018). Disposable paper products in food courts could be reduced through substituting with reusable plastic plates (with a compostable paper liner that can be easily removed from each plate to manage food waste) that undergo a hygiene process between patrons.

4.3.2 Design

Designing products for circularity covers all aspects of the consumption cycle and at its core is designing to maintain the inherent value of the materials. In the context of paper circularity, this refers to designing paper, paperboard, and paper products to maintain the quality of the paper fibre and prevent its loss during paper recovery, reprocessing, and remanufacturing (WEF, 2016). Thoughtful eco-design ensures products can be readily reused, mitigating the need to go to landfill and prolonging the life of the paper fibre. Design changes also involve changes to packaging and labelling that facilitate the recycling and reuse process and enables change in consumer behaviour.

Designing eco-friendly packaging

Simplifying packaging design to avoid composite materials

Simplifying the design of packaging to single-stream materials and avoiding a composite of materials would be beneficial. For example, redesigning a package made from cardboard with two different sorts of plastic, plus wires and staples with a single material stream. Simpler packaging would increase the ease and efficiency of recycling, prevent damage and loss of paper fibre, reduce the likelihood of disposal to landfill, and mitigate risk of damage to equipment at paper mills.

Replacing problematic paper coatings with biodegradable options

Improvements in biodegradable food packaging can mitigate the issues of contaminated packaging and subsequent reduced recycling rates. One such improvement is the use of biopolymers to improve the strength and barrier properties of packaging and replace the polymer or wax-coated liners that are not biodegradable. Seaweed extract and various starch derivatives have been successfully tested and shown to be viable options (Beltrán et al., 2014).

Another approach for improving the biodegradability of packaging is to use starch-based edible films, though these films typically lack the strength and barrier resistance properties of traditional packaging (Jeevahan and Chandrasekaran, 2019). Research has shown the addition of nanocellulose (e.g. from dried banana pseudo stems) to the starch-based film improves the film's properties and offers a solution for reducing synthetic plastics in packaging materials.

Advancement in biodegradable food packaging has also included the recent development of nanomaterials to improve the barrier and strength properties of packaging. Nanomaterials can also add 'smart' properties to packaging that improve food monitoring and shelf life (Huang et al., 2018). However, nanomaterials are still in the evaluation phase for food packaging, undergoing safety assessments for their potential impact on human health and possible environmental issues.

Removing hazardous inks from paper products

Redesigning disposable packaging to be eco-friendlier also includes changing attributes such as hazardous inks, which are raising health concerns as well as environmental issues (Deshwal et al., 2019; Pivnenko et al., 2015). Three solutions for dealing with hazardous inks on packaging include prevention, removal, and constraining their use.

Prevention would require the banning or phasing out of hazardous inks through legislation of industry standards, which is estimated to take at least a decade to take effect (Pivnenko et al., 2016). The removal of ink requires improved efficiency in the de-inking process in which chemicals are removed from paper during reprocessing. However, yields may be lost during de-inking processing and increased sludge produced, which would also need to be managed (Pivnenko et al., 2016; Van Ewick et al., 2016). Constraining relies on improved collection systems to divert contaminated paper from clean paper flows.

Consumer behaviour research shows support for cups with no printed messages, no lid, use of eco-friendly paper, and embossed logos (Hong et al., 2019) among consumers in South Korea where there is a ban on disposable coffee cups for in-store customers.

Incorporating consistent labelling to facilitate recycling and reuse

Improved and consistent labelling and other packaging changes that enable correct recycling behaviour and improved consumer choices would also help address contamination issues. Changes to Australia's packaging covenant are working to improve recycling outcomes (APCO, 2019a, 2019b). Harmonisation of recycling messages across jurisdictions would also support improved household recycling behaviour.

4.3.3 Consumption

In a circular economy framework, consumption refers to the reuse and repair of a product whilst largely maintaining the integrity of the initial product. In the wastepaper context this could include reuse of packaging for repeated functions. The problems with reusing paper products are twofold. First the product may be changed in a way that does not support its eventual recycling. For example, reusing a cardboard box may require strengthening through applying adhesive tape, which in turn creates issues with contamination and recycling efficiencies (Hubbe et al., 2006; Rita et al., 2013). A broader system change would be required to modify the use of adhesive products or develop strategies, such as eco-friendly protein solutions (Tayeb et al., 2017), for improving the re-pulping of products contaminated with 'stickies'.

A second problem of consumer reuse and repair also relates to contamination where a product is reused in a way that contaminates the paperboard to such an extent that composting for soil use is the only solution. It is likely that as the quality of paper reduces with repeated use the final end use is limited to composting or combustion, or other markets for low-grade paper products which are yet to emerge (Centre for International Economics, 2019).

Educating users of paper at all levels that paper is a recoverable resource

Education and awareness programs to inform users of paper, paperboard, and paper products on how to preserve and recover the value of the paper so that it can be reused would be beneficial. This includes information on avoiding destroying, dirtying, and crumpling paper during its use and increasing the paper's efficiency, for example photocopying both sides, and reducing printing margins on documents. In addition, informing paper users about contamination from glass, food, and other organic material and how to enter paper products into the recycling stream after use would enable improved outcomes (WEF, 2016).

4.3.4 Collection

Collection systems in the circular economy are critical to support the ongoing value extraction of resources into alternate and recycled products. For recovered paper, collection is the cornerstone for mitigating contamination issues, which underpin one of the main limiting factors for successful recycling of paper products. Paper contamination with glass fines is particularly problematic and evolves from co-mingling recyclable paper with glass. In traditional kerbside collection systems, increasingly rubbish is compacted to such a point that glass is often crushed, contaminating paper products and reducing the quality of the collected paper delivered to MRFs, making it more difficult to sort (Department of Environment and Energy, 2018; Victorian Auditor Generals Office, 2019). It is estimated that in 2018–19, 62% of consumed paper in Australia was recovered for reprocessing or export (Industry Edge, 2019), with contamination of paper, particularly from co-mingled kerbside recycling, significantly limiting this recovery rate.

Similarly, food contamination, organics, textiles, nappies, batteries, and paper coatings are all sources of contamination that further necessitate source separation of paper products from other contaminants. The quality of paper recovered from selective systems is considerably superior to that recovered from co-mingled systems of collection (Miranda et al., 2013). Although larger MRFs with advanced sorting mechanisms are able to recover more contaminated paper, they are still limited in what they can achieve from a co-mingled system, and not as effective as separation at the source (Miranda et al., 2013).

Multiple bin systems for source separation of kerbside recycling

A two-bin system (a bin for organics and a bin for dry recyclables) that separates organics from dry recyclables (paper and other packaging) has the advantage of reducing food-contaminated paper. Such changes require consumer education, end markets for organic composting, and a two-bin recyclable system Australia wide. One limitation of this approach is that it does not solve the issue of glass fines contamination (APCO, 2019b).

A multiple-bin system separates recyclables into multiple sources so that food-contaminated paper goes into organics and glass contamination is prevented through glass separation from paper and cardboard. This type of system requires improved labelling, consistent messaging across jurisdictions, consumer education, end markets for increased recycled paper, multiple bins, and new systems for collection of multiple bins (APCO, 2019b).

Dedicated collection of polymer-coated paper products (and other coated-paper products)

Increased recovery of polymer-coated paperboard (PCPB) from municipal waste and C&I waste streams to prevent contamination of paper recyclables could be achieved through dedicated collection and incentive schemes. Success would also require improved labelling, consistent messaging, consumer education, end markets for these types of products, and a dedicated collection system.

Multi-unit development solutions

Collection problems specific to multi-unit developments (MUDs) have been identified and require dedicated planning and policy interventions (Victorian Auditor-General's Office, 2019). Resource recovery rates and contamination rates in MUDs are sub-optimal compared to single dwellings and recognised as a growing problem with increasing numbers of people residing or working in MUDs. Opportunities to improve waste management and recycling in MUDs have been identified (Sustainability Victoria, 2018) and require the necessary planning and policy changes to implement appropriate collection systems and services (Victorian Auditor-General's Office, 2019).

Improving collection at public events, stadiums, and food courts

Initiatives in Australia to increase collection of recyclables and prevent contamination through reduced co-mingling of waste have already been successfully undertaken at some of Australia's largest sporting venues (Cuthbertson, 2018). Opportunities exist to extend these initiatives more widely.

Improving consumer recycling behaviour and harmonising messaging about recycling

Changing consumer behaviour to increase recycling rates, decrease contamination, and reduce waste going to landfill has been underdeveloped in parts of Australia (Victorian Auditor-General's Office, 2019) and provides opportunity for a cultural shift towards a circular economy. A range of approaches for improving consumer recycling behaviour have been described and mechanisms used to support other pro-environmental behaviour could also be used (Steg and Vlek, 2009). Interventions include incentives, penalties, use of targets and feedback, promotional campaigns, prompts, pledges, and waste education. Digital sorting games that incorporate feedback mechanisms for increasing recycling have also been effective in decreasing contamination rates and used as an effective education tool (Luo et al., 2019).

One significant opportunity for improving household and business recycling behaviour is for consistent and straightforward messaging about recycling and harmonising these messages across jurisdictions. Education campaigns that focus on source separation and presenting materials for collection along with teaching consumers how to preserve the value of paper fibre during its use will help to ensure clean and sorted paper products are collected, aiding the recoverability and recyclability of paper fibre and preventing its loss (WEF, 2016).

4.3.5 Sorting

Opportunities exist in Australia to optimise the sorting process of recyclables to avoid fibre loss and the loss of potentially recoverable materials. This includes changes to both MRFs where co-mingled kerbside recyclables are sorted and single-stream facilities that receive only paper and cardboard. MRFs in Australia vary in their capacity and capability to sort co-mingled recyclables, from small to large volumes and from basic to highly advanced sorting (Madden and Florin, 2019; MRA, 2018). Single-stream facilities are important in the recovery of paper and at the industrial level these facilities target unbleached kraft such as corrugated cardboard packaging collected from shopping centres and large users. The material is baled and made ready for export or reprocessing (DoEE, 2018).

Sorting of 'mixed' paper is particularly problematic, with most paper and paperboard at MRFs left unsorted and baled into a mixed-paper bale comprising multiple material types, and usually contaminated (from 5% to 20%) – mainly from glass fines but also food, organics, clothing, batteries, and nappies. The value of mixed-paper bales in 2019 was virtually negligible (RRMB, 2019b). Issues related to sorting of mixed paper are particularly salient as the introduction of the Australian government waste export ban in July 2024 targets mixed paper. It is estimated the ban will result in an additional 377 kt of mixed paper remaining in Australia, which previously had gone to export (CIE, 2020).

Table 4.1 shows an example of the makeup of a mixed paper bale and demonstrates the relatively high proportion of newsprint and magazine (31%), and corrugated carboard (47%) that are currently not being sorted at the MRF. These paper types can attract prices up to $340 per tonne if baled and able to meet contamination specifications (RRMB, 2019a). Until MRFs undertake secondary sorting of mixed paper to meet standards for local processing or export quality it will remain virtually unsaleable (DoEE, 2019).

Table 4.1: Makeup of a mixed paper bale in Victoria

MATERIAL TYPE	QUANTITY (KT)	PERCENTAGE MAKEUP
Fibre – boxboard	3,300	12%
Fibre – liquid paperboard	200	1%
Fibre – newsprint and magazine	8,700	31%
Fibre – office paper	1,400	5%
Fibre – old corrugated cardboard	13,300	47%
Fibre sorting losses	1,400	5%
Total	28,300	100%

Source: Resource Recovery Market Bulletin, March 2019

Investment in infrastructure to achieve sorting best practice

Opportunities to improve sorting outcomes require investment in MRF infrastructure, to upgrade sorting capability and capacity to achieve best practice sorting. These changes include optical-sorting technology, slowing throughput, and increased manual sorting to improve removal of contaminants and possibly to undertake a 'positive sort' of high-value materials (DoEE, 2018; Madden and Florin, 2019; MAR, 2018). In addition, taking upstream measures such as improving source separation, reducing contamination, and using dedicated single-stream collection systems would help improve the efficiency and reduce the potential cost burden on the MRF.

Systems dedicated to improving quality of collected paper and sorting

Opportunity exists to establish glass-free collection systems and sort large quantities of paper and cardboard free from major contaminants into recovered paper grades suitable for sale. For example, to meet the quality requirements for domestic reprocessing or export, Australian Paper Recovery operates a 'glass-free' MRF in Victoria to ensure the quality of recovered fibre. The company uses a dedicated collection system for paper and carboard products supported by an increasing number of local participating councils (DoEE, 2019; Industry Edge, 2019).

4.3.6 Recycling and Manufacturing

These stages of the circular economy involve recycling and manufacturing activities such as mechanical, chemical, biological, and energy recovery technologies to convert the recovered product into a reusable material and alternate products. Opportunities for recovered-paper reprocessing and remanufacturing depends on the quality of the recovered paper, technical requirements of the remanufactured product, and end markets for products, which need to be sustainable and cost effective. Technology issues and capacity are also currently limiting some of the reprocessing outcomes for recovered paper in Australia (Australian Government, 2019a).

Opportunities for remanufacturing include a diversity of options ranging from end products with large market segments to smaller niche markets. Also, some opportunities represent new uses of recovered paper and are still in an innovation phase where taking recyclate into industrial uses requires further support for testing and development of standards for use in new markets. Furthermore, remanufacturing options may be limited due to geographic location and available infrastructure. Nonetheless, finding a local use of the sorted material to reduce travel distances is an important consideration in the circularity of a resource.

Packaging and industrial paper products opportunities

Production of packaging and industrial paper products such as corrugated cardboard boxes, folding boxes, industrial sacks, and paper bags not only use the largest amount of recycled content but also are a large and steady market both domestically and internationally. Table 4.2 shows the relative portion of recovered paper in a range of paper grades and sub-grades. Corrugated cartons have by far the highest recovered paper content. Because of the large volumes of corrugated carboard boxes generated domestically, opportunities to utilise large volumes of recovered paper are possible if contamination can be reduced and sorting improved, potentially utilising recyclables from MSW streams currently ending up at MRFs as mixed paper (CIE, 2020; RRMB, 2019c).

Table 4.2: Estimated recovered paper used in four main grades of paper and paperboard

MAIN PAPER GRADE	SUB-GRADES	ESTIMATED RECOVERED PAPER %
Packaging and industrial	Corrugated cartons	>50%
	Folding boxes	<20%
	Sacks and bags	<10%
Newsprint		<20%
Printing and communication	Magazines and catalogues	+/– 15%
	Office and copy paper	<15%
	Printing	<10%
Tissue		<3%

Source: Resource Recovery Market Bulletin, November 2019

Recycled office and printing paper opportunities

The second-most produced product of recycled-paper content in Australia is the production of recycled office paper. In recent years the size of this market segment has declined due to the digitisation of information and use of the internet. Moreover, cheap imports and paper made from virgin material still comprise almost half the supply of office paper used in Australia. Governments, as the largest users of office and printing paper (RRMB, 2019c) could increase the market of recycled office paper through procurement policies to preference purchase of recycled office and printing paper over virgin materials (CIE, 2020).

Increasing the amount of recyclate in products – particularly post-consumer recyclate

Increasing the amount of recyclate in products is another way of providing opportunities for increased reprocessing of recovered paper. APCO targets this strategy through their goal of achieving 50% average recycled content included in packaging by 2025 (APCO, 2020b). Important to this goal is to ensure that the level of post-consumer recycled content increases so that recovered paper recycling is maximised. In many instances, material derived from production waste referred to as ‘pre-consumer content’ is used to achieve the recycled content (RRMB, 2019c). A system for verifying recycled content and its provenance would strengthen initiatives to include increased recyclate in packaging.

Hygiene and tissue products

At present hygiene and tissue products, a stable though competitive market with rising import penetration, do not use large amounts of recovered paper in their products. However, niche manufacturing of recycled tissue paper is a growing albeit small market segment where people are prepared to pay premium prices for a high-value product (IBISWorld, 2019d). For example, Queensland Tissue Products manufactured by ABC Tissue produce 20 kt of hygienic recycled tissue at an advanced paper-recycling plant in Brisbane from high-quality recovered paper. The tissue is used to produce recycled toilet paper (Queensland Tissue Products, 2020).

Moulded-fibre products and pet care

Domestic manufacturers are using recovered paper to produce moulded-fibre products such as egg cartons, fruit trays, and other mouldings used in packaging. In addition, recycled newsprint is used in pet-care products (e.g. kitty litter). Both market segments though small are showing rapid growth (IndustryEdge, 2019).

Building and construction opportunities

New engineering approaches are identifying additional opportunities for using reprocessed paper and cardboard in building and construction products. These include as sound absorbers and insulators (Secchi et al., 2016) and for improving thermal qualities in concrete (Fraile-Garcia et al., 2019). Studies show cardboard-based panelling is more effective than traditional methods for absorbing sound and its environmental footprint is more favourable than conventional gypsum board (Secchi et al., 2016). Corrugated cardboard added to reinforced concrete slabs has been shown to improve the thermal qualities of concrete, and increased costs incurred during production were offset by the improvement in thermal performance (Fraile-Garcia et al., 2019).

Opportunities to export recovered paper pulp

The global impact of importing countries, such as China, demanding lower levels of contamination in mixed paper has contributed to a recent increase in the global market for recovered paper pulp. Although this pulp product has been available for many years, it has not attracted the international demand and price experienced more recently (RRMB, 2020). In 2018, China imported 295 kt of recovered paper pulp which represented a major increase on previous years and just over a third (36%) of the worldwide total.

In producing recovered paper pulp, the source country is responsible for removing contaminants and processing the pulp so that it is ready for manufacturing. The pulp is then dried and exported to paper and paperboard manufacturers internationally. Alternatively, recovered paper pulp is used domestically as part of the local supply chain for manufacturing packaging such as cardboard boxes (CIE, 2020). In reality, pulp is often processed into paper products at the same facility (paper mill), which is the case in vertically integrated companies.

Recycling infrastructure

Recycling infrastructure in Australia requires planning approvals and considerable time to build and develop (Centre for International Economics, 2019). In addition, new recycling activities and infrastructure require the social acceptance of host communities (Sustainability Victoria, 2018b; SWRRP, 2018), which add to the time and expense of developing new proposals such that they can operate with a social licence. Investment in reprocessing capacity includes upscaling existing mills or building new facilities (MRA, 2018).

Investment implications for increasing the circularity of paper fibre

- Clean paper will be exempt from the waste export ban, therefore, the impacted volume of the ban would be 436 kt, at a material value of $22M (CIE, 2020).
- For 2016–17 it was estimated that 5.6 Mt of paper and cardboard waste were generated in Australia (Centre for International Economics, 2019; IndustryEdge, 2019).
- Approximately 60% was recycled and 40% was sent to landfill or stockpiled (Centre for International Economics, 2019; IndustryEdge, 2019).
- An investment of $244M in a mixed MSW paper-processing facility could potentially abate 280 kt of paper fibre per year (CIE, 2020).
- On average, an investment of $468M in a C&I paper-to-recycled-corrugated-packaging facility could potentially abate 430 kt of paper fibre to landfill per year (CIE, 2020).
- An investment of $438M, on average, in a recycle carton board/folding box board facility could potential abate 322 kt of paper fibre per year (CIE, 2020).
- Opal invested approximately $90M to processes paper waste into high quality recycled office paper. At full capacity, approximately 80 kt of paper waste can be processed per year and the facility can support 250 manufacturing jobs (Planet Ark, 2015).
- The cumulative weight of paper fibre abated (i.e. not going to landfill) in a year is approximately 1,110 kt. The total investment cost is approximately $1,240M.

- On average, the investment cost to process paper fibre is as follows:
  - Processing paper fibre to recycled paper $1.1M/kt
  - Processing of mixed MSW paper to recovered pulp $0.87M/kt
  - Processing of C&I paper to recycled corrugated packaging $1.1M/kt
  - Recycled carton board/folding box board $1.4M/kt
- Cost savings from sending paper fibre to landfill is around $70 per tonne.

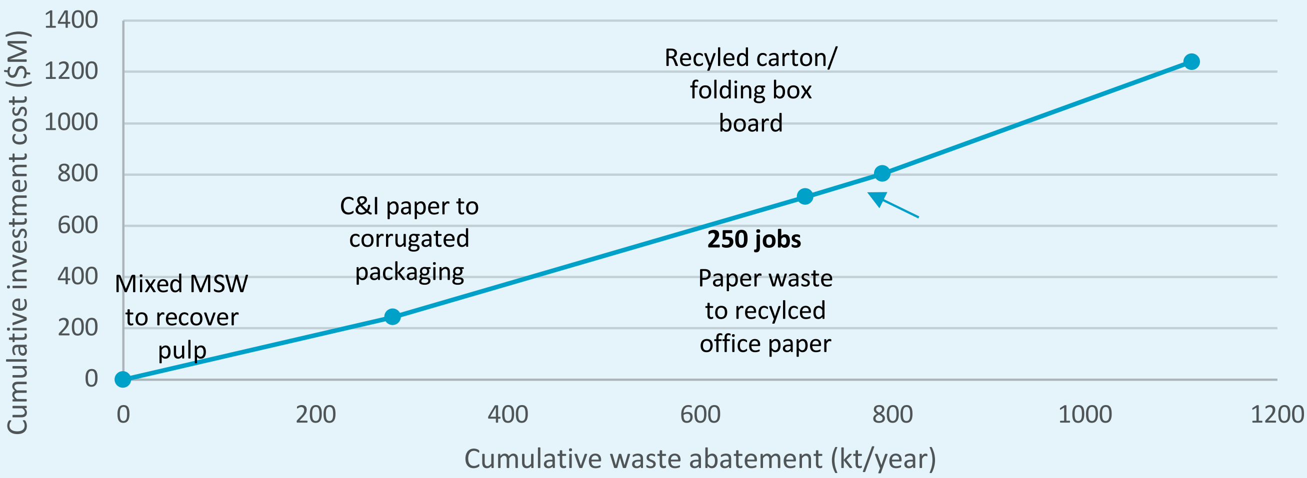


Figure 4.5: Paper waste investment cost and kt of waste abated per year (Estimated from CIE, 2020 and Planet Ark, 2015)

Paper-production waste for organic recycling

Waste generated during paper production and paper reprocessing has often ended up in landfill, but companies are developing more efficient processes to reduce waste and more sustainable solutions for its disposal. Reprocessing of paper involves de-inking to remove inks and paper coatings from recovered paper products using physico-chemical treatments. This process creates a by-product of rejected wood fibres called sludge. Opportunities exist to compost mill sludge as an alternative to landfilling, which can then be used to improve soil nutrients (Gea et al., 2005; Hubbe et al., 2010). For example, in 2017 Australian Paper, an integrated pulp and paper manufacturer, reduced organic production-waste material being sent to landfill from its Maryvale Mill in the Latrobe Valley by recycling it into agricultural products used for composting and soil remediation, working towards a zero waste to landfill target (AFPA, 2018).

Technologies for paper unable to be re-manufactured

At some point the quality of the paper fibre will become degraded to such an extent that recovery of fibre in the material form is unable to be achieved and recovery in the energy form or as a downcycled product are the remaining solutions beyond sending to landfill for disposal. Three possible options include organic composting, waste to energy, and anaerobic digestion.

Composting paper products

Even though it is preferable to recycle wastepaper back into packaging, opportunities exist to include wastepaper in organic processing, particularly for packaging that is heavily contaminated with food or other organics (APCO, 2019a). Produced compost could be used for rehabilitating former mine sites (APCO, 2019a) or to improve nutrients and water-holding capacity in soil, with the end use dependant on quality control and meeting certification standards. Potential to use wastepaper as a bulking agent to improve composting of green waste and difficult organic material, such as pig manure, has been identified but its effectiveness depends on achieving the optimal percentage combination of wastepaper with the organic material (Wong et al., 2017; Zhang and Sun, 2018). Wastepaper mingled into organic processing tends to slow down the efficiency of the biodegradability process unless the proportion of paper is strictly controlled (Alvarez et al., 2009). Even so, water-resistant coated-paperboard products common in wastepaper are also able to be successfully used in composting (Hubbe et al., 2010).

Waste to energy facilities

Waste-to-energy facilities are a relatively expensive alternative but would be a potential option for lower-value recovered paper (Centre for International Economics, 2019) and residual wastepaper. However, it requires a long approval process over many years and may face social resistance if not part of an overall plan for sustainable waste management solutions (Walton et al., 2019).

Anaerobic digestion

Another form of waste to energy, anaerobic digestion could provide a solution preferable to disposal to landfill. Compared to waste-to-energy plants, anaerobic digestion has a smaller geographical footprint, can operate at smaller capacities, has fewer regulatory hurdles for approval, and is likely to encounter less social resistance. For these reasons, anaerobic digestors are suited for regional communities, particularly if the energy produced from the digestor can be linked into an agricultural production process.

4.3.7 Summary of opportunities for paper

Table 4.3 summarises the range of possible opportunities that in combination could decrease residual wastepaper and increase the circularity of paper, paperboard, and paper products.

Table 4.3: Opportunities for paper in the circular economy

CIRCULAR ECONOMY STAGE	OPPORTUNITIES
Avoidance	• Digitise information – the 'paperless' office • Eliminate unnecessary packaging and ordering of 'extras' • Substitute disposable paper products with reusable products (e.g. reusable cups)
Design	• Design eco-friendly packaging: - Simplify packaging design to avoid composite materials - Replace problematic paper coatings with biodegradable options - Remove hazardous inks from paper products • Incorporate consistent labelling to facilitate recycling and reuse
Consumption	• Educate users of paper how preserve and recover the value of paper • Reduce the application of difficult-to-recycle 'stickies'
Collection	• Encourage multiple-bin systems for separation at source for kerbside recycling • Implement dedicated collection of polymer-coated paper products (and other coated-paper products) • Develop multi-unit development solutions • Improve collection at public events, stadiums, and food courts • Improve consumer recycling behaviour
Sorting	• Invest in infrastructure to achieve sorting best practice • Invest in systems dedicated to improving quality of collected paper and sorting
Recycling and Manufacturing	• Support opportunities for increased production and end markets for packaging and industrial paper products (e.g. corrugated cardboard boxes) and opportunities for procurement of recycled office and printing paper • Increase the amount of recyclate in a variety of products such as hygiene and tissue products, moulded-fibre products, pet-care products, and building and construction materials; and grow these markets • Support opportunities to export recovered paper pulp • Invest in and develop recycling infrastructure • Invest in technologies for paper unable to be re-manufactured: Organic reprocessing and composting for paper-production waste and wastepaper at end of life; and waste to energy technology

4.4 The road forward

Figure 4.6 shows the future paper flows through all the circular economy stages and depicts a more circular outcome than estimated 2020 flows (Figure 4.3), particularly with reduced waste going to landfill, a small decrease in virgin input and imports, increased paper recycled, and increased fibre used in construction, composting, and waste to energy. The 2030 consumption estimate is based on a stagnant industry outlook and 5-year market trend (IBISWorld, 2019b), and the outflows based on the National Waste Policy target of 80% recovery rate by 2030.

A summary of expected future outcomes are shown in Figure 4.7 for 2022, 2025, and 2030. Key activities that underpin outcome opportunities are also listed. A code has been entered at the start of each key activity in Figure 6 to indicate the relevant actor(s) responsible for that activity: G = government, I = industry, R = research, and C = community. As we would expect, most activities are either government or industry led, or some combination of the two. Community rarely features in this role as communities are generally beneficiaries of activities and outcomes rather than drivers of activities.

2022

The short-term activities are extensive and used to lay the groundwork for establishing future improvements in circularity outcomes. The focus will be in four key areas:

- Decreasing contamination of paper in recycled kerbside collection primarily through source separation and dedicated collection systems for problem contaminants such as glass, batteries, textiles, nappies and organics; packaging eco-design and labelling; and consumer education with consistent messaging.
- Improving sorting outcomes through upgrading MRFs and reviewing industry standards
- Growing end markets through increased demand for products with recycled content using procurement guidelines and education and supporting lower operating costs of manufacturers. Addressing end market solutions for low quality mixed paper through research and innovation.
- Identifying and establishing solutions for regional Australia through developing collaborations and investing in research to test and commercialise innovative approaches

2025

The mid term is used to consolidate work commenced earlier and to extend the activities for growing end markets by implementing certification processes for recycled content, and the use of targets and monitoring to ensure effectiveness of procurement policies and plans. Data systems and metrics in place to support decision making and progressing the piloting and commercialisation of regional solutions. The mid term will also see a focus on developing SME capability to participate in the circular economy supply chain.

2030

The longer term will see a continuation of the earlier strategies, but with an emphasis on embedding circular economy thinking into industry practices through continual building of industry knowledge and capability, and completion of life cycle assessments of products for informed decision making and improved outcomes. Similarly, ongoing education and support to inculcate sustainable consumption routines into procurement and use of paper including waste avoidance, reuse, and repair of paper products and substituting disposable products with reusable products. Support for ongoing research and innovation will continue to see Australian solutions for improving the circularity of paper delivering economic and environmental benefits to Australian cities and regions.

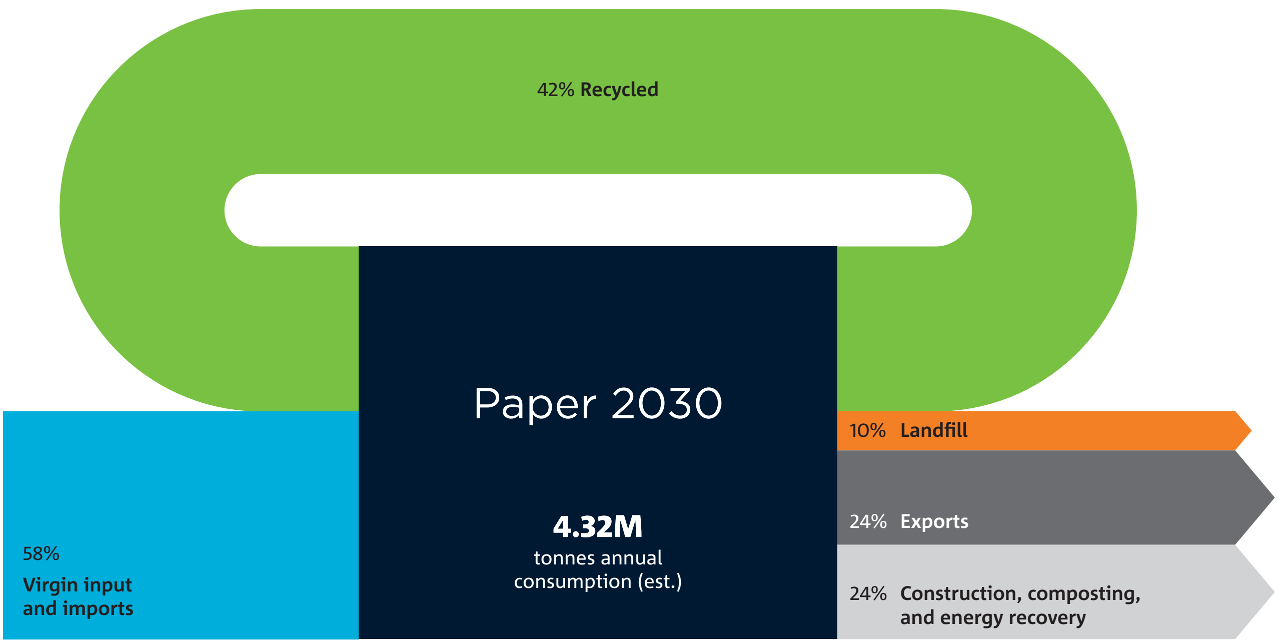


Figure 4.6 Sankey diagram of estimated paper flows for Australia in 2030

2022

Key outcomes:

Reduced contamination of paper in kerbside recycled collection

Improved sorting outcomes for mixed paper at MRFs

Packaging design supports recyclability and longevity of recovered fibre

Increased domestic demand and end markets for recovered paper products

Regional solutions for recycling and reprocessing fibre identified

Harmonisation of messages across jurisdictions

Harmonisation of standards across Australia

Solutions for reprocessing 380 kt mixed paper post-ban identified

Improved operating conditions for manufacturing in Australia

Key activities:

G/I/C: Institute source separation and collection of kerbside recyclables into single streams of paper, glass, organics and plastic

G/I: Expand collection systems for contaminants e.g. batteries, nappies, textiles

G/I/R: Establish consistent messaging about recycling across jurisdictions, including ARL labelling

G: Educate households and businesses on how to source separate and how to retain the value of paper fibre during use.

G/I: Investment in upgrading MRF sorting technology

G/I/R/C: Develop collaborations for solving regional recycling solutions

I: Increased engagement by brand owners in product stewardship of paper packaging

I: Deigning out difficult to recycle packaging

I/R: Develop solutions for polymer coated paper board

G: All levels of government adopt favourable procurement policy for recycled paper products

G/I: Investment in research and innovation to Identify possible additional end market solutions for low quality mixed paper

G: Policy and initiatives to lower operating costs of Australian manufacturing

2025

Key outcomes:

100% of packaging to be reusable, recyclable or compostable

70% average resource recovery rate for paper

50% average recycled content (post-consumer recyclate) across packaging

Data improved and metrics developed for accurately measuring paper flows through the supply chain

Harmonisation of targets across Australia

Reduced paper going to landfill from the general waste

Reduced loss of recovered paper fibre going to landfill

Food courts, takeaway food, and major events not generating fibre loss to landfill

Recovered paper manufacturing increasing its output to meet increased market demand

Key activities:

G: Certification and standardisation processes implemented for recycled content of products

G: Monitoring of effectiveness of procurement policies for recycled paper products

G/I: Continued investment in collection and sorting infrastructure

G/I/R/C: Development and pilot of regional and niche business models for paper recovery and remanufacturing

G/I/R: Solutions for low quality mixed paper tested and ready for commercialisation

G/I/R: Data systems and metrics identified and implemented

I: Designers and brand managers designing packaging comprising one product stream – no composite packaging

G: Continued education campaigns to maintain improved source separation and the recoverability of paper fibre

G/I: SME education and programs to build SME capability to implement circular economy plans to achieve sustainability targets developed for their business

2030

Key outcomes:

All hard to recycle packaging is obsolete

80% average resource recovery rate for paper

Decision making for product choices based on LCA information

SMEs reaching sustainability targets for waste reduction, resource recovery, and participation in the circular economy

Total paper fibre loss in the general waste bin reduced to 10% per person

10% paper fibre going to landfill

Energy recovery technology implemented for residual paper unable to be recycled

Australian innovation in manufacturing options for low quality paper used internationally

Regional Australia benefiting economically, socially, and environmentally through improved circularity of paper

Key activities:

G/I/R: Completion of LCA of products to support informed decision making about substitution products and improved outcomes in the supply chain

G: Ongoing incentives and education programs for building SME capability for implementation of resource recovery activities within their business and participation in the local circular economy

G: Ongoing education of the Australian public to maintain world leading recovery rates and recyclability of paper fibre

G/I/R: Continued support and investment into research and innovation hubs to improve the circularity of paper fibre

Figure 4.7 Key outcomes and activities for a circular economy for paper by 2022, 2025 and 2030. (Actors: G = government, I = industry, R = research and C = community).

5 Tyres

In 2018–19, **465 kt of tyres reached their end of life** in Australia.

All tyres are imported to Australia as there is **no tyre manufacturing in Australia**; but retreading of truck tyres is still practiced in some jurisdictions.

In 2018–19, **55% of Australian used tyres were exported**, 31% disposed of and only 14% processed for domestic recycling and energy use.

Most used truck and passenger tyres are exported, and the bulk of off-the-road tyres are disposed on-site.

The **main recycling options** for used tyres have been the production of shred, rubber crumb, granules and buffings, retreading and the use of tyres for civil engineering projects.

Key challenges

- Voluntary instead of mandatory and regulated tyre stewardship scheme
- Lack of import levies for some tyre imports
- Lack of quality standards for imported tyres
- Inconsistent policies, regulations and permitting
- Disposal fees that are inconsistent and non-transparent to consumers
- Long transport distances and disconnected supply chains
- Incomplete tracking of tyre transportation and export, and lack of transparency on sustainability and safety of exported material use
- High infrastructure costs for recycling, lack of available funding and slow permitting of tyre recyclers
- Unaudited operators and an unlevel playing field
- Lack of consistent standards and specifications for tyre-derived products and fuels
- Competition of domestic tyre-derived products with subsidised imports and other products
- Lack of knowledge and a preference for business as usual

Key opportunities

- **Avoidance:** Avoid tyre use by supporting distance work and replacing tyre-based transport with other transport modes.
- **Design:** Design tyres that require less materials, are more durable and easily remanufactured, recycled or safely used as fuel; and manufacture tyres from bio-derived renewable materials.
- **Consumption:** Reduce tyre consumption through promotion of public transport, carpooling, taxis, ride-sharing services, and light transport vehicles which have small tyres.
- **Collection, transport and tracking:** Improve collection, transport and tracking of tyres through implementation of collection systems for all families of tyres, reverse logistics to minimise transport costs and online tracking to ensure chain of custody.
- **Remanufacturing and reuse:** Increase retreading of used tyres and remanufacturing tyres for alternative uses (e.g. in civil engineering).
- **Recycling:** Increase recycling and energy recovery use of used tyres through mechanical and thermochemical processing.
- **Use of recyclates:** Increase the use of tyre-derived recyclates for civil engineering uses (e.g. road and rail works), surfaces, seals, moulded products, explosives, plastics and cement manufacturing, and the use of tyre shred, tyre-derived oil, syngas and steam as energy.

5.1 Overview of global and Australian landscape

Tyres are essential for transporting people, animals, raw materials and goods by vehicle and air transport. Passenger car tyres account for the majority of tyre production. Tyres are also used for utility vehicles, trucks, off-road vehicles, such as agricultural, civil engineering, industrial, mining and airplanes as well as motorcycles and bicycles (Schulman, 2019).

The composition of tyres varies depending on the use (e.g. vehicle, plane) and the environment (e.g. temperature, road quality) (Bockstal et al., 2019). Natural and artificial rubbers are a major part of tyres and their proportions depend on the type of tyres. Carbon black contributes to mechanical reinforcement and protects against abrasion. Metals act as reinforcing materials. In lighter tyres, metals are increasingly substituted with textiles, such as rayon, nylon and polyester, whereas truck tyres have fewer textiles because of their reinforcement needs. Other tyre components include vulcanisation agents and additives (Bockstal et al., 2019).

Global tyre production has doubled during the last decade (Schulman, 2019), and tyre demand was estimated to reach 3 billion units in 2019 (Bockstal et al., 2019). The growth has been largest in areas where motorisation is occurring fastest, namely Asia, Oceania and the Middle East (141% between 2005 to 2015), followed by Central and South America (60%) and Russia and non-EU/European Free Trade Association countries (59%) (OICA, 2019). The average global motorisation rate in 2015 was 182 vehicles per 1,000 inhabitants, whereas the Australian rate was 718 vehicles per 1,000 inhabitants (OICA, 2019). According to a report by the World Business Council for Sustainable Development, annual generation of end-of-life (EOL) tyres was approximately one billion units in 2008 (World Business Council for Sustainable Development, 2008). By now, generation has likely at least doubled with the increasing rate of global tyre production.

5.1.1 Tyre waste in Australia

Australian new tyre imports were 543 kt in 2018–19. Approximately 41% (by weight) of tyres sold in 2018–19 were passenger tyres, 36% truck tyres, and 23% off-the-road (OTR) tyres (e.g. those used on mining, heavy industry and other unregistered OTR applications) (Randell et al., 2020). All these tyres were imported as tyres have not been manufactured in Australia since 2010 (Randell et al., 2020). Only 26% (140 kt) of tyre imports attracted levies in 2018–19, as only tyres imported by the members of the voluntary Tyre Stewardship Australia (TSA) scheme are subject to the National Tyre Product Stewardship Scheme levy upon sale and no OTR tyre imports were levied (Randell et al., 2020). Tyre consumption in Australia is expected to increase at a rate of 1.5% per year till 2025 (Randell et al., 2020).

Average tyre lifespans have been estimated to be 3.4 years for passenger tyres, 1.5 years for truck tyres and 1 year for OTR tyres (Hyder, 2015). The generation of EOL tyres is determined by rates of consumption and the average lifespan of tyres. Australians generate 56 million EOL tyres annually (VAGO, 2019), totalling 465 kt in 2018–19 (Randell et al., 2020). This does not include tyre wear losses, which are estimated to be 15% of tyre weight and dispersed as tyre dust to the environment (O'Farrell, 2019). EOL tyre generation in Australian jurisdictions is shown in Figure 5.1. Australian EOL tyres contain 27.5% steel, 21.5% natural rubber, 17.6% synthetic rubber, 10.8% carbon black, 10.8% silica, 1.5% nylon, 1.5% polyester, 1.5% zinc oxide, 0.86% sulphur and other additives (O'Farrell, 2019). Used tyre arisings are estimated to increase to 490 kt by 2025 (Randell et al., 2020).

The fates of used passenger, truck and OTR tyres in Australia in 2018–19 are shown in Figure 5.2. Export was the dominant fate for passenger and truck tyres, whereas most OTR tyres were not captured for value recovery. The share of domestic recycling was 14% in 2018–19 (Randell et al., 2020). The key destinations for exports have been India, Malaysia and South Korea. However, the destination countries for over half of tyre exports were not identifiable in Australian customs export data (O'Farrell, 2019). According to interviewed stakeholders this was due to false export declarations, for example being labelled as 'rubber blocks' instead of 'baled tyres'. The major end uses for exported tyres were fuel applications, such as pyrolysis, furnaces, industrial and cement kilns and electricity generation (O'Farrell, 2019).

The fate of 206 kt of used tyres managed within Australia (i.e. excluding 258.9 kt of exports) in 2018–19 is shown in Figure 5.3. Recycling represented 30.9% of domestic tyre fate in 2018–19, with 32.9 kt used as crumbs, granules and buffings, 26.4 kt as casings and seconds, 3.1 kt for civil engineering uses and 1.3 kt for pyrolysis. The dominant domestic fate was on-site disposal for OTR tyres, landfill for passenger tyres, and crumbs, granules, buffings, casings and seconds for truck tyres (Randell et al., 2020). The overall tyre flows in Australia in 2018–19 are shown in Figure 5.4 (data from Randell et al., 2020).

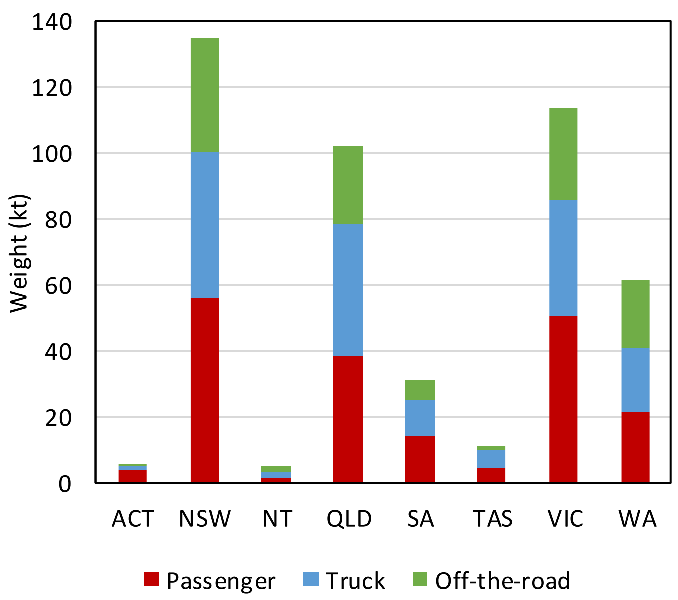


Figure 5.1: Used tyre arisings in Australian jurisdictions by tyre type in 2018–19

Source: data obtained from Randell et al., 2020

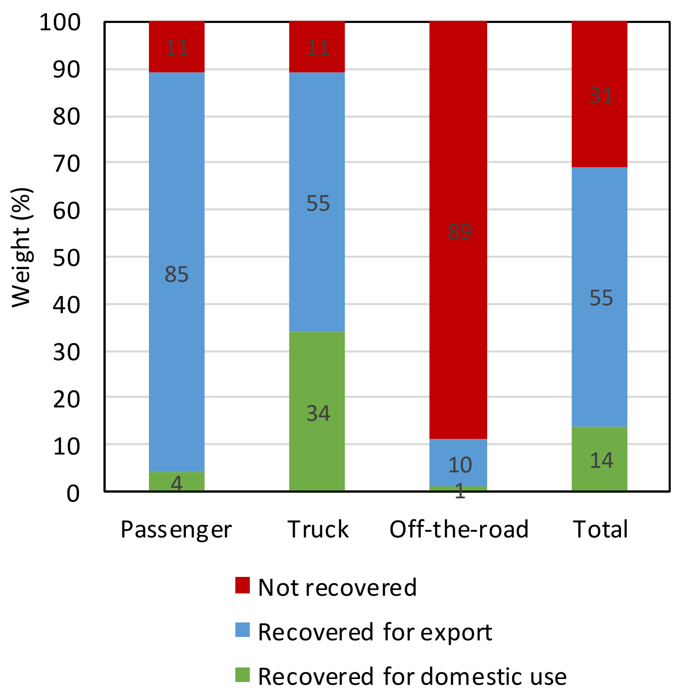


Figure 5.2: Percentage of Australian end-of-life tyres ending in landfill, export and domestic recycling by tyre type in 2018–19

Source: data obtained from Randell et al., 2020

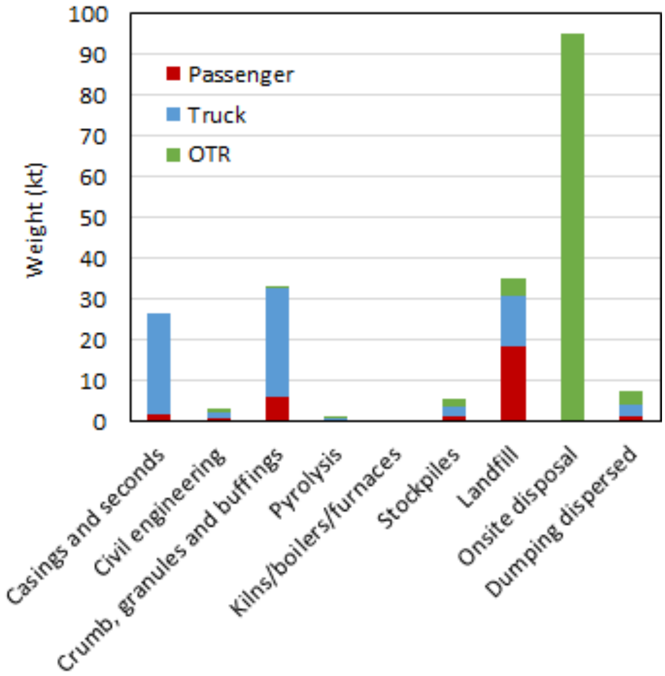


Figure 5.3: Fate of Australian tyres disposed of or processed domestically by tyre type in 2018–19

Source: data obtained from Randell et al., 2020

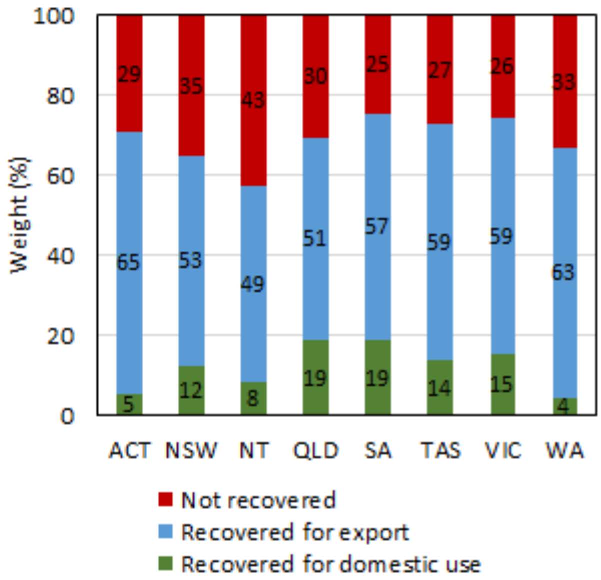


Figure 5.5: The fate of tyres in Australian jurisdictions in 2018–19

Source: data obtained from Randell et al., 2020

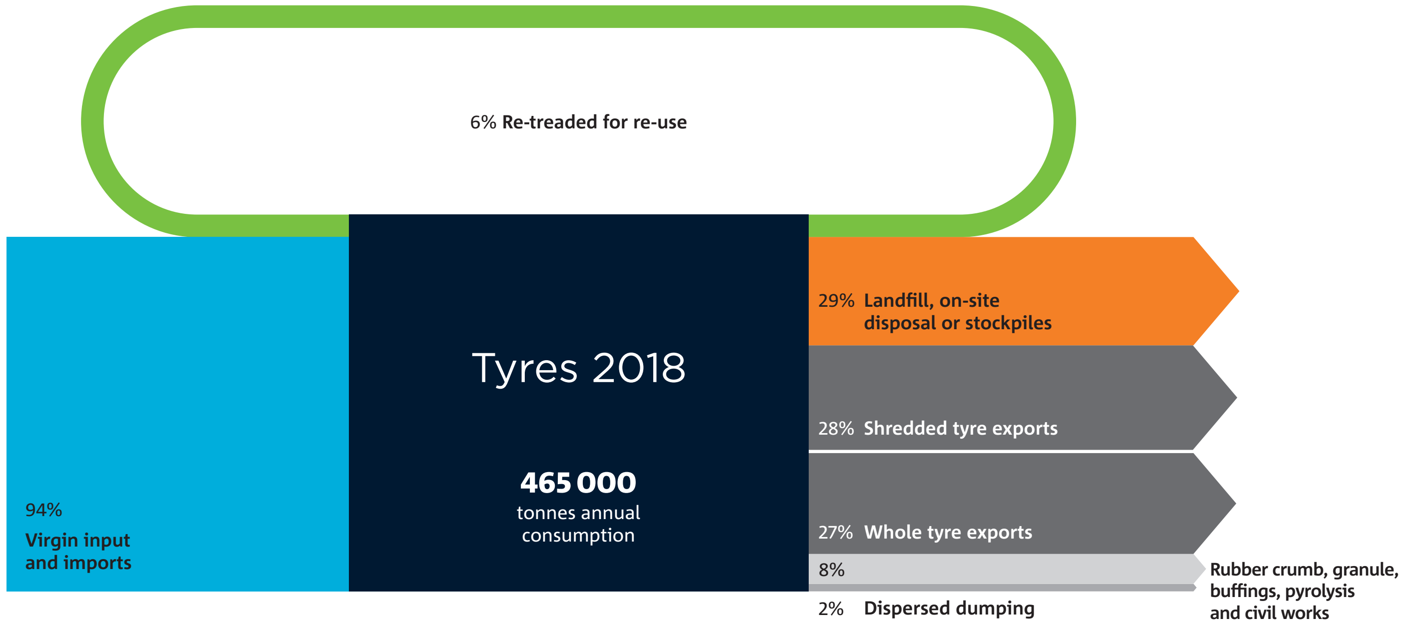


Figure 5.4: Sankey diagram of tyre flows in Australia in 2018–19

Source: data from Randell et al., 2020

Each Australian state and territory has different conditions for tyre recovery, depending on the regulatory framework, demand from consumers, proximity to international ports and population density (Genever et al., 2017). In 2018–19, the share of domestic recycling was highest in Queensland (QLD) and South Australia (SA) (19%), followed by Victoria (VIC) (15%), Tasmania (TAS) (14%), New South Wales (NSW) (12%), Northern Territory (NT) (8%), Australian Capital Territory (ACT) (5%) and Western Australia (WA) (4%) (Figure 5.5) (Randell et al., 2020).

Table 5.1: Capabilities for used-tyre processing and manufacturing of tyre-derived products and fuels in Australian jurisdictions indicated with blue colour

PRODUCTS	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Casings and seconds	■	■	■	■	■	■	■	■
Baling		■	■	■	■		■	■
Civil engineering		■		■	■		■	■
Shredding		■		■	■	■	■	■
Crumb, granules, buffings		■		■	■		■	
Steel		■		■	■		■	■
Nylon/rayon fabric		■		■	■		■	■
Chemical processing for syngas, carbon black/char and fuel oil		■ *		■			■ *	■ *

*As of 2020, not yet conducted at commercial scale

Source: adapted from Genever et al., 2017 and Randell et al., 2020

The capabilities for used-tyre processing and manufacturing of tyre-derived products and fuels in various Australian jurisdictions are shown in Table 5.1. According to National Market Development Strategy (Genever et al., 2017), tyre-baling capacity exists in all jurisdictions except for Tasmania and the ACT, whereas shredding capability exists in all jurisdictions except for the Northern Territory and the ACT. Steel and fabric recovery processes exist in all jurisdictions except for Tasmania, the Northern Territory and the ACT. Chemical processes for syngas, carbon black/char and fuel oil production have been established in Queensland, NSW, Victoria and Western Australia (Genever et al., 2017), of which notable quantities are only processed in Queensland (Randell et al., 2020). Crumb rubber, granule and/or buffings are produced in NSW, Queensland, South Australia and Victoria (Randell et al., 2020).

Australian Tyre Recycling Association

The Australian Tyre Recycling Association (ATRA) was established in 2003 to represent the interests of the legitimate and sustainable used-tyre collection and recycling sector in Australia. ATRA serves the tyre-recycling industry in an advocacy role with the public, government and associated stakeholders, and promotes the use of recycled rubber in a range of consumer and industrial products. All ATRA members are subject to operational audits by ATRA's independent audit firm. ATRA's constitution prohibits the export of whole baled tyres due to concerns for the environment and human health. ATRA members recycle over 20 million used tyre units per year, which represents approximately 95% of Australia's used-tyre recycling activity (ATRA, 2019).

National Tyre Product Stewardship Scheme and Tyre Stewardship Australia

The **National Tyre Product Stewardship Scheme** was established in 2014 (Commonwealth of Australia, 2014). The scheme provides a government-supported industry framework, authorised by the Australian Competition and Consumer Commission, to reduce the environmental, health and safety impacts of EOL tyres in Australia (Tyre Stewardship Australia, 2019). The objectives of the scheme are (Tyre Stewardship Australia, 2020):

- to increase resource recovery and minimise environmental and human health risks associated with used tyres in Australia
- to develop Australia's tyre recycling industry and markets for tyre-derived products.

Tyre Stewardship Australia (TSA) is a not-for-profit company established in 2014 to implement the National Tyre Product Stewardship Scheme (Genever et al., 2017). TSA accredits participants, including tyre retailers, collectors, recyclers and manufacturers who commit to support the objectives of the scheme. Additionally, TSA funds market-development initiatives, such as research, development and commercialisation of new uses for used tyres and helps to drive the transformation of used tyres into useful commodities (Tyre Stewardship Australia, 2020).

Regulatory framework

EOL tyre management and resource recovery are influenced by several international and national policies. Key international regulatory frameworks are the Basel Convention and the OECD Council Decision 2001 on the Control of Transboundary Movements of Wastes Destined for Recovery Operations. Australian national regulatory frameworks include the Customs Act 1901, Hazardous Waste (Regulation of Exports and Imports) Act 1989, National Environment Protection (Movement of Controlled Waste between States and Territories) Measure 1998, National Waste Policy 2018, Product Stewardship Act 2011, Waste export ban 2019 and National Waste Policy Action Plan 2019.

Policy and regulation for waste management, including used tyres, has been mostly devolved down to state and territory governments. The state and territory-level governance instruments vary widely, which is a big problem for transboundary tyre movements. These instruments include acts, regulations and/or guidelines for tyre storage, fire safety of tyres, tyre transportation, tracking, disposal, reuse, recycling and energy recovery (Table 5.2).

Table 5.2: Existence of enabling acts, regulations and/or guidelines for used-tyre management across Australian jurisdictions indicated with blue colour

REGULATION	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Tyre storage	■	■	■	■	■	■	■	■
Fire safety of tyres		■		■	■		■	
Tyre transport	■	■	■	■	■	■		■
Tyre tracking		■		■	■	■		■
Tyre disposal	■	■	■	■	■	■	■	■
Tyre landfill levies	■	■		■	■		■	■
Tyre reuse		■			■			
Tyre recycling	■	■	■	■	■	■		■
Energy recovery from tyres		■			■		■	■

Source: data from Randell et al., 2020

5.2 Summary of key challenges for tyres

The management of used tyres presents both a persistent challenge and a resource-recovery opportunity (Genever et al., 2017). If not properly managed, EOL tyres can cause significant risks to human health and the environment.

Tyres are highly resistant to biodegradation and photochemical decomposition (Sienkiewicz et al., 2012). Whole tyres pose a considerable fire hazard when stockpiled and result in high costs and liabilities (Fattal et al., 2016; VAGO, 2019). If ignited, tyre stockpiles are difficult to extinguish (VAGO, 2019). When burned, tyres produce thick and toxic smoke that is dangerous when inhaled. Moreover, the runoff produced during firefighting activities can carry pollutants to surface water and groundwater (Genever et al., 2017).

Stockpiled whole tyres can also attract pests, such as rats, and retain water which creates a habitat for mosquitos (Bockstal et al., 2019). There are also concerns about tyre-derived microplastics entering food chains (Pickin, 2018). Moreover, some interviewed stakeholders expressed concerns about the safety of people handling baled and other tyres in overseas destinations.

Figure 6 shows a summary of some of the major challenges raised during the interview process relevant to the circular economy of tyres in light of the upcoming waste export ban.

To address the challenges facing the tyre industry, it will be necessary to improve the circular economy for tyres. Enabling actions from a range of actors are specifically addressed in Chapter 6.

1. Voluntary instead of mandatory and regulated Tyre Stewardship Scheme	Voluntary Tyre Stewardship Scheme does not capture all operators which leads to an unlevel playing field and insufficient funds to support the recycling of used tyres.
2. Lack of import levies for some tyre imports	Some imported tyres are not subject to import levies, which undermines producer responsibility and decreases viability of tyre recycling industry.
3. Lack of quality standards for imported tyres	A lack of control over the quality of imported tyres results in low-quality and non-retreadable tyres entering Australia's supply chain and reduces the potential for domestic tyre retreading and reuse.
4. Inconsistent policies, regulations and permitting	Inconsistent policies, regulations and permitting (e.g. on-site disposal of OTR tyres) leads to tyre waste landfilling, illegal stockpiling and on-site disposal of used tyres and reduces the capture of tyres for value recovery.
5. Inconsistent and non-transparent disposal fees for used tyres	Inconsistency and non-transparency of disposal fees lead to an unlevel playing field, undervaluing of tyres as a resource and insufficient portion of the fees going to tyre recyclers.
6. Long transport distances and disconnected supply chains	Long transport distances and disconnected supply chains hinder the capturing of tyres for value recovery.
7. Incomplete tracking of tyre transportation and export	Incomplete tracking of tyre transports leads to illegal stockpiling, dumping and exports and lack of transparency on the sustainability and safety of exported material use.
8. High infrastructure costs, lack of available funding and slow permitting of tyre recyclers	High infrastructure costs, lack of available funding and slow permitting hinder the building of tyre recycling capacity in Australia.
9. Unaudited operators	Some tyre operators have not been audited and accredited, which decreases accountability and leads to an unlevel playing field.
10. Lack of consistent standards and specifications for tyre-derived products and fuels	Lack of consistent standards and specifications for tyre-derived products and fuels across Australian jurisdictions discourages tyre recyclers and slows down the uptake of recycled products due to risk avoidance.
11. Competition of domestic tyre-derived products with subsidised imports and other products	Tyre-derived products need to compete with subsidised imports and products that are typically produced at much larger scale reducing market demand of domestic recycled products.
12. Lack of knowledge and preference for business as usual	Lack of knowledge on the benefits of using tyre-derived products and fuels and the preference for business as usual decrease commitment and slow down value recovery and recyclate uptake.

Figure 5.6: Summary of key challenges for tyres

5.3 Opportunities for circularity

This section highlights the opportunities across the circular economy system by breaking these into the following stages: avoidance, design, consumption, collection, transport and tracking, remanufacturing and reuse, recycling and recyclate use.

Figure 5.7: Examples of ways to avoid and minimise the use of tyres

5.3.1 Avoidance

Although tyres are an essential part of the transportation of people, animals, raw materials and goods, there are several ways to avoid the use of tyres. Distance work and replacing face-to-face meetings with virtual ones can help reduce the need for transport. Tyre-based vehicle transport can also to some extent be replaced with other transportation forms such as rail-based trams, metros and trains (Figure 5.7).

Investment in fast internet infrastructure and technologies for online meeting can reduce the need for people to travel for meetings and thus avoid the use of tyres. Similarly, investment in non-tyre-based transport infrastructure, such as a rail-based transport network, can decrease the reliance on tyre-based vehicle transport that generates EOL tyres while also decreasing carbon emissions. Education can impact the choices people make in their everyday lives and thus help with avoidance of EOL tyre generation. For example, education can equip people to use virtual meeting technologies and encourage them to minimise tyre-based vehicle use.

Governance instruments can support the avoidance of tyre use by allowing distance work and implementing targets to replace face-to-face meetings with virtual ones. Government can also set targets for the accessibility to non-tyre-based transport modes. The markets for enabling technologies for EOL tyre avoidance can be developed by government procurement of fast internet and virtual meeting technologies and promotion of non-tyre-based transport in infrastructure planning and procurement. Investment in research, development and innovation can also support the identification of further pathways for avoiding EOL tyre generation.

5.3.2 Design

The design of tyres can influence their lifespan, the ease of repair and the possibilities for reuse, recycling and energy recovery from used tyres. The development of tyres that require less materials, have higher tread wear resistance (Volodina et al., 2001) and are not easily punctured can help reduce EOL tyre generation (Figure 5.8). Many ingredients that improve the longevity and resistance to abrasion during on-road life, also contribute to the effectiveness of recycled tyre materials in down-stream products and applications (Shulman, 2019). Moreover, the use of biologically produced renewable chemicals, such as isoprene, can reduce the reliance on petrochemicals in rubber production and tyre manufacturing (Hayden, 2011). However, further research is needed to make bio-derived tyres a mainstream product.

Figure 5.8: Designing tyres that require less material, have a higher tread wear resistance and are not easily punctured can help to reduce end-of-life tyre generation

Design can also affect repairability and remanufacture of tyres for reuse, whether the materials in tyres can be separated easily for recycling and whether tyres are safe to use as a fuel. Design is also a key element of research and development for new ways of recycling tyres. As there is no tyre manufacturing in Australia, all tyres used in Australia need to be imported. Hence the ability to influence tyre designs used in Australia is somewhat limited. However, international collaboration and governance instruments, such as minimum quality standards for imported tyres and banning the import of poor-quality tyres may help to influence tyre designs towards more durable tyres and tyres that can be retreaded. Investment in research and evaluation of the durability and recyclability of various tyre designs could inform the development of such governance instruments.

Investment in infrastructure for innovation parks that bring together research organisations and industry partners can fast track the technology readiness of new innovations. Moreover, investing in infrastructure for business incubators can help start-ups to increase the market readiness of new tyre-derived products (TDPs) and tyre-derived fuels (TDFs). Design can also play a role in the market development of the tyre-recycling sector. An example of this would be the development of new market models, where tyres are leased instead of sold. This could potentially ensure that tyres (e.g. OTR tyres) would be returned for recycling instead of disposed on site. The design and use of eco-labels for tyres could also encourage the use of more durable and recyclable tyres.

5.3.3 Consumption

Correct tyre pressure and tyre rotation can reduce tyre wear and thus postpone EOL tyre generation. Choosing carpooling or public instead of private transport reduces the number of private vehicles on the roads and thus need for passenger tyres. The ownership of passenger cars may also be reduced through car rental and the use of taxis or ride-sharing services (Figure 5.9).

Infrastructure investment in self-service stations for checking and adjusting tyre pressures and rotating tyres provide opportunities for reducing tyre wear and thereby increase the lifespan of tyres. Moreover, investment in public transport infrastructure and light transport vehicle options reduce the number or size of tyres needed and hence EOL tyre generation.

Education can increase consumer awareness on the importance and impact of using correct tyre pressures and rotating tyres in vehicles to reduce tyre wear. Moreover, education campaigns could be organised to promote public transport, car share and light transport options, such as cycling to reduce the number of private vehicles.

Targets for public transport accessibility is an example of a governance instrument that can support the reduction of tyre consumption by decreasing the reliance of households on private vehicles. Government procurement practices can facilitate reduced tyre consumption (e.g. by mandating that tyre replacements in fleet vehicles are based on actual wear instead of tyre age). Procurement can also promote public transport to reduce the number of tyres.

Investment in the research and development of more durable tyres that minimise tyre wear under Australian conditions can reduce tyre consumption and thereby EOL tyre generation. Moreover, investment in the development of innovations, such as phone applications, that allow flexible car sharing can also reduce tyre consumption.

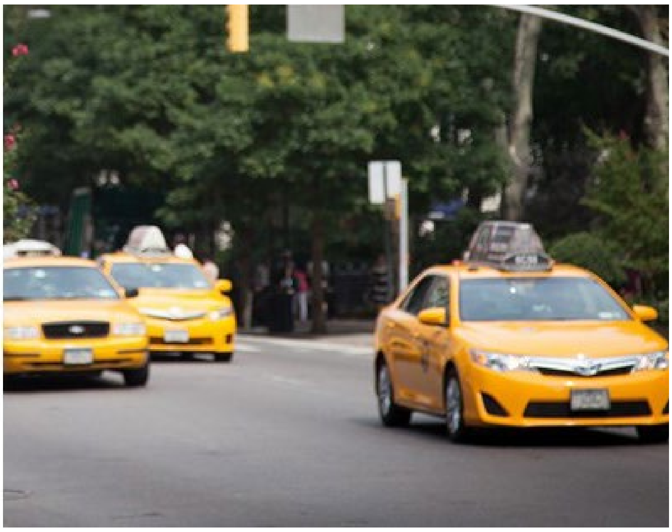


Figure 5.9: Choosing public transport or taxis over passenger cars can help reduce the consumption of tyres and thus end-of-life tyre generation

5.3.4 Collection, transport and tracking

Collection of used tyres is essential for efficient value recovery (Figure 5.10). A disposal or recycling fee is normally collected by tyre retailers when EOL tyres are returned. Interviewed stakeholders expressed concerns that the disposal fees vary widely and are not transparent to consumers, and only a small portion of the fees are directed to tyre recycling activities. In 2019, disposal fees for passenger tyres were $1–6 per unit or $125–750 per tonne, for truck tyres $5–20 per unit or $125–500 per tonne and for OTR tyres $165–600 per tonne depending on the location (e.g. metro, regional or rural area) (Randell et al., 2020).

Mandatory, consistent, transparent and increased recycling fees should be included in the price consumers pay for new tyres to cover the true recycling costs, provide a level field for operators and achieve consumer accountability for tyres. A consistent, higher portion of the recycling fee should be mandated to go to recyclers (e.g. a sliding scale with more paid to those processors that achieve a better environmental outcome of value-added products). The value of used tyres as a resource could be emphasised with a small, consistent and transparent refund to customers for returned used tyres, similar to the refund schemes used for other products (e.g. CDSs for bottles and cans in some jurisdictions). This would encourage consumers to return tyres for recycling and discourage illegal dumping. The capture of tyres for collection could be further increased by banning landfill and on-site disposal, stockpiling and dumping of whole tyres.

Further opportunities need to be developed for the capture of OTR tyres for value recovery. Alternative market models may be able to address some of these challenges. For example, leasing of OTR tyres could increase the return of tyres for recycling. Also, if tyre collectors were paid only when they bring tyres to a legitimate recycler, they would be less likely to dump tyres illegally.

Adoption of technology that enables automated weighing, loading and unloading of tyres reduces risks related to manual handling of EOL tyres and ensures a chain of custody. Similarly, covered storage facilities minimise the build-up of rainwater in used tyres and hence risks related to spreading of diseases carried by mosquitos.

Used-tyre **transportation** logistics can be optimised through tools such as the Transport Network Strategic Investment Tool (TraNSIT) which helps to minimise transport distances and hence costs (CSIRO, 2019). Transport costs can also be reduced through market platforms that support reverse logistics and collaboration between companies that transport goods to remote locations. Moreover, modular size reduction/processing units that can be taken to EOL tyre generation sites can help to reduce tyre volumes, and hence increase transportation efficiency. Transport distances could also be considered in the calculation of the support provided by the federal government to state and local governments for waste management to make tyre recycling more feasible in remote locations.

Figure 5.10: Efficient end-of-life tyre collection schemes, transport logistics and tracking systems are essential for enabling value recovery and reducing illegal dumping and export

Accurate **tracking** of collected, transported and exported tyres is important for monitoring the fate of tyres, reducing illegal dumping and export, and ensuring that tyres are handled in a sustainable and safe way both in Australia and overseas. Electronic, GPS-based tracking systems can help with online tracking of tyre movements. Mandatory online tracking of tyres should be implemented across Australian jurisdictions and globally to ensure consistent coding, zero balance reporting by all operators and reliable data collection. Permits should be renewed only for operators who can demonstrate zero balance tyre tracking and reporting, where all tyre flows are accounted for.

There should also be harmonised and compulsory auditing and accreditation of all tyre operators in Australia and overseas to ensure that their facilities and business processes are environmentally sustainable and not causing risks to human health. TSA has developed a global platform to verify the final disposition of EOL tyres to mitigate against the exploitation of workers (Tyre Stewardship Australia, 2020).

5.3.5 Remanufacturing and reuse

Remanufacturing rebuilds a product to specifications of the original or new manufactured product using a combination of used, repaired and new parts. It requires the repair or replacement of damaged or worn out components that affect the performance or the expected life of the whole product. In the case of tyres, remanufacturing includes retreading of used tyres by replacing the outer tread on used tyres.

Retreading reduces tyre costs per km and consumption of oil and energy in manufacturing as compared to new tyres, thus decreasing CO_2 emissions and ecological footprint and ensuring the efficient use of resources (Bandag, 2019). Australia's current retreading capacity has been estimated to be 32 kt, of which 24 kt has been in use (Gonzalez and Hughes, 2019). Infrastructure exists for retreading truck casings in most Australian capital cities, and there is casings market demand in Asia and Africa. However, the domestic market for passenger-tyre retreading has declined as consumers are moving away from passenger-tyre retreads (O'Farrell, 2019).

The import of cheap, less-durable tyres has decreased tyre retreading in Australia, as people often default to buying new cheap tyres instead of retreading old ones. Implementing minimum quality standards for imported tyres, financial incentives (e.g. rebates or lower recycling fees) and procurement policies for the use of retreaded tyres could potentially reinvigorate tyre retreading in Australia. If the export of whole tyres for retreading is allowed, permit requirements for exporters should include showing proof that tyres are shipped to an accredited retreading facility.

Reuse refers to the use of tyres for the purpose for which they were originally made, including use as retreaded tyres and second-hand tyres. The structure of tyres can also be used to manufacture new products such water tanks, floating devices for reducing evaporation from water storage dams and modules used in civil-engineering projects.

5.3.6 Recycling

Recycling transforms used tyres into a raw material that will be reintegrated into the economic stream as a resource in substitution for virgin resources, thereby reducing the need of virgin materials, energy usage and pollution. In the case of used tyres, recycling includes the modification of used tyres for civil-engineering applications and the manufacturing of TDPs. Whole tyres and TDPs can also be used directly as a fuel substitute or as a feedstock for the production of TDFs.

Mechanical processing uses a series of shredders, screens and granulators to reduce particle size, separate materials and manufacture various products without significantly changing the chemical structure of the material. Initial size reduction is often done at ambient temperature, whereas low-temperature cryogenic processing can be used to produce finer particles and remove metals and textiles (Schulman, 2019). The major products from mechanical processing include tyre shred (50–150 mm), rubber granules (2–15 mm), buffings (<2 mm), crumb rubber (<1 mm), steel, nylon and polyester fabrics (Genever et al., 2017).

Australia's total shredding capacity has been estimated to be approximately 299 kt, but the utilisation has been only approximately 187 kt. Crumbing capacity has been estimated to be 58.5 kt of which 39.5 kt has been estimated to be in use (Gonzalez and Hughes, 2019). A key barrier to further recycling has been the distance of processing facilities from the location of EOL tyre generation as tyre processing capacity varies widely across Australian jurisdictions.

Chemical processing changes the chemical structure of the material. Pyrolysis and gasification are examples of thermochemical processes which utilise elevated temperature to change the chemical composition. During pyrolysis, used tyres are thermally decomposed in the absence of oxygen, whereas gasification is conducted with a controlled amount of oxygen and/or steam to prevent combustion.

Thermochemical processing generates various products, such as syngas, oil, steam, steel and carbon black or char (Genever et al., 2017). Although pyrolysis has been used in some countries that import Australian EOL tyres, industry bodies have questioned the cost effectiveness of pyrolysis in Australia. Some interviewed stakeholders reported that pyrolysis was not a commercially viable option due to transport costs, sourcing a continuous supply of feedstock, strict environmental legislation and under-developed markets for end products.

The **recycling of fibres** from used tyres is still very low. Steel fibres recovered from used tyres can be used as reinforcement in concrete (Aiello et al., 2009) and textile fibres can increase the stability of bitumen used in asphalt (Bartl et al., 2005). Possible other tyre-derived materials include silicon carbide (SiC) nanofibre/particle composites (with e-waste glass), activated carbon, carbon black and SiC/Si_3N_4 nanocomposites (UNSW, 2017).

The demand for virgin rubber can be decreased by reclaiming rubber from used tyres through **devulcanisation** using thermo-mechanical or mechano-chemical, microwave, ultrasonic or supercritical water or CO_2 processing. Devulcanising breaks carbon–sulfur linkages (Shulman, 2019) and allows the recovery of rubber with physico-chemical properties similar to those of virgin rubber, depending on the devulcanising process. The conventional devulcanisation processes can be modified to be more environmentally friendly and improved (e.g. in terms of devulcanising agents and operating conditions) (Bockstal et al., 2019). However, interviewed stakeholders indicated that the devulcanization processes are not yet economical and further research is needed to improve their feasibility.

Investment implications for increasing the circularity of tyres

Investment costs vary significantly depending on the type of processing facility for tyres. Based on stakeholder interviews, a processing facility for converting used tyres to construction material for civil engineering requires as little capital investment as $3M and could process approximately 22.5 kt of tyres per year. Shredding is the next attractive processing form for used tyres in terms of capital investment (operating cost and land acquisition cost not included). A shredding facility with an investment of $2.5M could enable the shredding of approximately 15 kt of used tyres per year. A tyre crumbing facility would have a capital investment cost of $3.7M and would allow nearly 8 kt of tyres to be crumbed each year. The current capital cost of a pyrolysis facility is approximately $30M for processing 18 kt of used tyres per annum. A marginal abatement cost curve for tyres based on one of each type of above-mentioned processing facilities is shown in Figure 5.11. The cumulative weight of used tyres abated (i.e. not going to landfills) in a year would be almost 70 kt, and the total investment cost $40M. Construction of more facilities would increase the cumulative weight of used tyres abated and the investment cost. On average, the investment cost to process used tyres is $133/t for construction, $160/t for shredding, $480/t for crumbing and $1,660/t for pyrolysis. In terms of **employment**, tyre baling typically employs 0.2 people/kt of tyres processed annually. In comparison, shredding, crumbing and retreading employed 0.4, 1.2 and 10.4 people/kt, respectively (Gonzalez and Hughes, 2019). Based on the interviews, the use of tyres for civil engineering could employ 6-7 people/kt and pyrolysis 1-2 people/kt.

The **profits or losses** from used tyre recycling vary significantly depending on the process used and the fate of the used tyres (Randell et al., 2020). Restrictions in India on pyrolysis processes and major trade disruptions due to COVID-19 have also caused market fluctuations in the past year. The market of baled tyres has been very volatile. In 2019, baling and transporting used tyres to a port for export could provide $30/t or result in a loss of $20/t. The loss from tyre shredding ranged $70-100/t, $100/t and $180/t for passenger, truck and OTR tyres, respectively. Granule, buffings and crumb production resulted in a loss of $500/t, $500/t and $400-600, respectively when the products were sold for approximately $600/t, $700/t and $400-650/t, respectively. For comparison, disposal of tyres to landfills in jurisdictions where it was still allowed costed $600-1,900/t. The used tyre processing financials will change upon the implementation of the export ban for used whole and baled tyres in 2021. Unless tyre recycling fees are increased to support tyre processing and recycling, the risk for stockpiling and dumping of tyres increases (Randell et al., 2020).

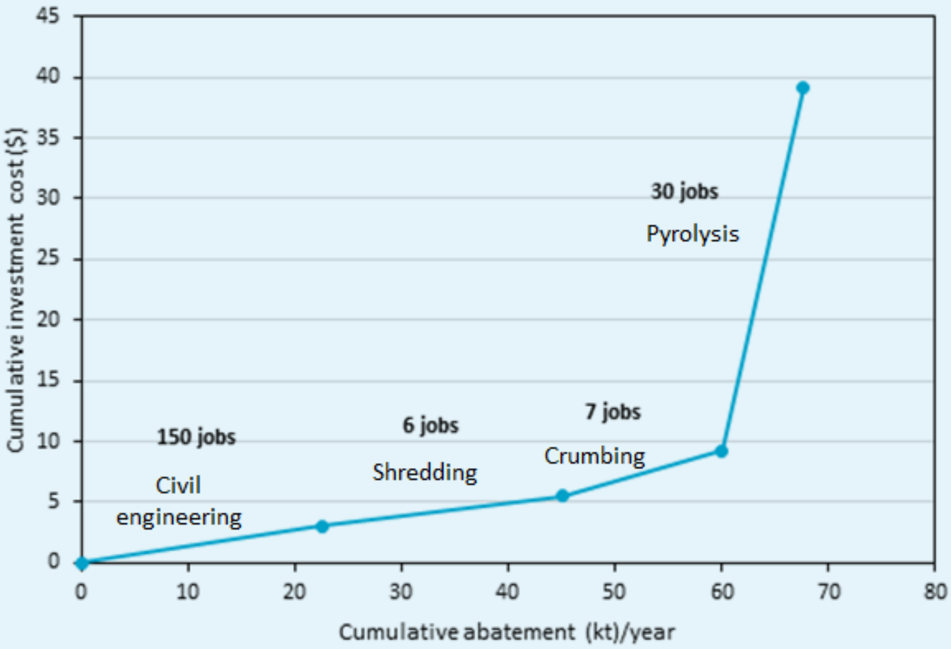


Figure 5.11: Cumulative investment cost and used tyre abatement per year if one facility is constructed for civil engineering, shredding, crumbing and pyrolysis.

5.3.7 Use of recyclates

Tyre-derived products and fuels can be used for a wide range of applications, examples of which are listed in Table 5.3. The structure of tyre casings or baled tyres can be used to provide strength in various civil-engineering applications, such as safety barriers, retaining walls, water-retention basins and soil stabilisation/erosion control (Genever et al., 2017; Bockstal et al., 2019). Steel fibres recovered through mechanical processing can also serve as reinforcement in concrete (Pilakoutas et al., 2004). Tyre-derived rubber products are good for protecting against impact and improving the durability of various surfaces, whereas tyre shred can increase gas and water permeability in engineering applications (Genever et al., 2017). The Australian Road Research Board (ARRB) has conducted research into the use of crumb rubber in road surfaces (ARRB, 2020), and is developing a national standard.

Tyre shred can also be used as an alternative energy source to replace fossil fuels such as gas, coal and oil in industrial applications such as cement kilns and electricity and heat generation. The energy content of tyres is higher than that of brown coal and black coal, but lower than that of fuel oil and natural gas per tonne of fuel. The use on 1 tonne of tyre shred would replace 3.02 tonnes of brown coal, 1.14 tonnes of black coal, 780 L of fuel oil or 784 m^3 of natural gas, and reduce CO_2 emissions by 40%, 35% or 24% when replacing brown coal, black coal or fuel oil, respectively (Kelman, 2017). The strong international demand for TDFs has somewhat limited the domestic consumption of recyclates from tyre processing (Genever et al., 2017).

Table 5.3: Examples of uses for tyre-derived products and fuels

TYPE OF PROCESSING	TYRE-DERIVED PRODUCT	USES
Mechanical	Tyre casings and baled tyres	• Civil-engineering applications: safety barriers, retaining walls, water retention basins, artificial reefs, fluvial reinforcement, sound barriers, landfill engineering, seismic isolation, soil stabilisation/erosion control
	Tyre shred	• Fuel in cement kilns, pulp and paper facilities and other industrial boilers • Civil-engineering projects: lightweight fill or backfill to improve drainage, insulation or compaction properties around water pipes and sewers, fences or buildings, and in landfill construction as backfill in gas venting and leachate collection systems and as daily covers
	Rubber granules	• Soft-fall surfaces, synthetic sport fields, playground bases, athletic tracks, solid wheels, animal mattresses
	Rubber buffings	• Soft and equestrian surfaces, paving blocks, roofing or carpet underlays, rubber matting, moulded products such as furniture, posts, fences, bollards
	Rubber crumb	• Rubber-modified spray seals and other sealants, binders, glues, adhesives, polymers, elastomers, coatings • Road surfacing, rubberised concrete in roads and rail sector, rubberised lightweight concrete, bitumen crumb rubber asphalt • Playground and soft-fall applications • Explosives • Plastics production
	Textile	• Increase the stability of bitumen used in asphalt • Fuel production
Physical/ chemical	Steel	• Melting and reforming into steel billet to use for producing rods, bars and wire • Use of steel fibres as reinforcement in concrete
Chemical	Syngas	• Combusted to generate electricity
	Oil	• Low-grade ship oil, bunker oil • Further refined into higher-quality diesel products and explosives
	Steam	• Heating or electricity generation
	Carbon black/char	• Manufacturing new tyres and as a colour pigment in paints and plastics • Nanocomposites • Activation to produce activated carbon for gold recovery and as a purification agent for water, wastewater and gas • Soil additive to improve moisture retention

Syngas and steam from thermochemical tyre processing can be used for electricity generation and oil as low-grade ship oil or further refined into higher-quality diesel products. Carbon black generated in thermochemical processing can be used as a pigment or feedstock for nanocomposites (Rajarao et al., 2015; Genever et al., 2017). Lower-grade char can be activated for use as activated-carbon sorbent used in gold extraction, electrode material (Antoniou et al., 2014) or soil amendment to retain moisture (Genever et al., 2017).

In the National Market Development Strategy for Used Tyres, Genever et al. (2017) estimated potential market sizes for various tyre-derived products (Figure 5.12). In the short and medium term, the biggest opportunities for Australia are the use of crumb rubber in spray seals, binders, glues, adhesives, playground and soft-fall applications.

In the long term, largest growth is expected in the use of tyre-derived shred as lightweight fill and tyre-derived drainage aggregate, and oil and carbon from tyre pyrolysis followed by the use of crumb rubber in explosives.

Other growth areas are expected to be rubberised structural concrete in the road and rail sector, rubberised lightweight concrete, bitumen crumb rubber asphalt, whole tyres in civil works, use of crumb rubber in permeable pavements, and rubber products and vibration dampening in the rail sector. On the other hand, growth in the use of crumb rubber as infill in sport fields, in steelmaking, and the use of tyre-derived fuel in domestic cement kilns and electricity generation were estimated to have less growth opportunities (Genever et al., 2017). For example, Australian cement kilns already use other alternative energy sources.

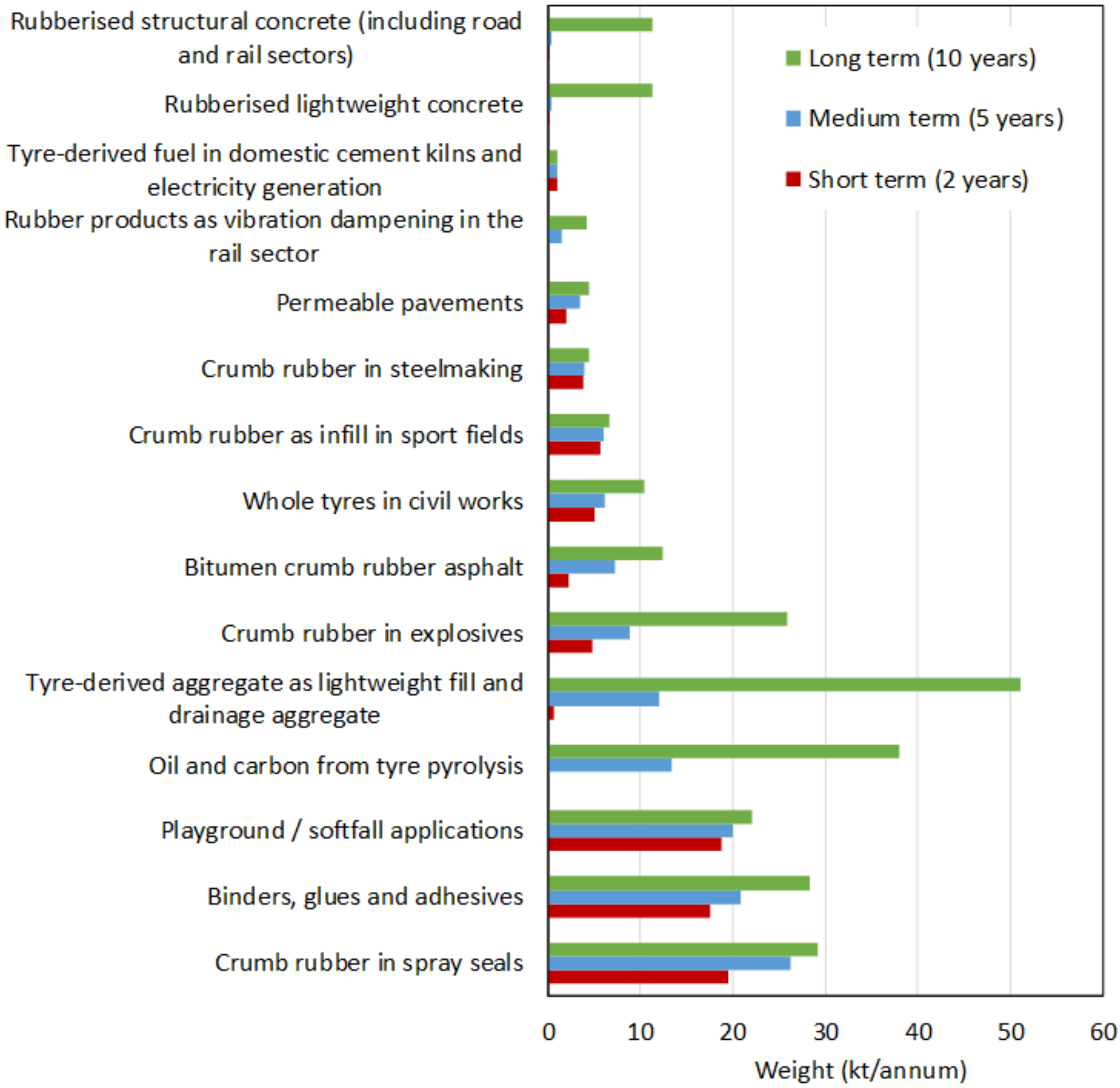


Figure 5.12: Potential market size of tyre-derived product opportunities

Source: data from Genever et al., 2017

5.3.8 Summary of opportunities for tyres

Key opportunities for EOL tyre avoidance, design, consumption, collection, transport, tracking, remanufacturing, reuse, recycling and energy recovery are listed in Table 5.4.

Table 5.4: Opportunities for tyres in the circular economy

STRATEGY	OPPORTUNITIES
Avoidance	• Implement distance work and replace face-to-face meetings with virtual ones • Replace tyre-based transport with other transportation forms where possible
Design	• Design tyres that require less materials, are more durable and easily remanufactured, recycled or safely used as fuel • Manufacture tyres from bio-derived renewable materials
Consumption	• Encourage public transport systems, carpooling, taxis, ride-sharing systems • Invest in light transport vehicles which have small tyres
Collection, transport and tracking	• Develop collection systems for all families of tyres (including e.g., OTR, motorcycle and bike tyres) • Reverse logistics to minimise transport costs • Develop software to optimise transport logistics • Implement online tyre tracking across the country and include exported tyres
Remanufacturing and reuse	• Retread tyres for reuse • Remanufacture used tyres to innovative alternative uses, such as water tanks, evaporation control devices and modules for civil engineering
Recycling	• Use tyre casings or tyre-bales for civil-engineering applications • Use mechanical processing of EOL tyres to produce shred, rubber granules, buffings and crumb, textile and steel • Use thermochemical processing of EOL tyres to syngas, oil, steel, carbon black and/or char
Use of recyclates	• Use tyre-derived products in civil engineering, surfaces, seals, moulded products, explosives and plastics • Use tyre shred, tyre-derived oil, syngas and steam as energy

5.4 The road forward – tyres

A possible future state of tyre flows for year 2030 is presented in Figure 5.13. Figure 5.14 shows a summary of key activities recommended for tyre management and expected outcomes for 2022, 2025 and 2030 time frames.

2022

In the first part of the transition, national mandatory and regulated or co-regulated tyre stewardship scheme will help to capture all tyre operators. Implementing minimum quality standards for imported tyres will ensure that tyres are more durable and can be retreaded.

Harmonising and mandating increased levies for all tyre imports, mandating consistent, transparent and increased recycling fees for tyres, and channelling a larger part of the fees to go to recyclers will help build tyre recycling capacity. Moreover, implementing a small refund to go to customers upon returning used tyres would emphasise the value of tyres as a resource.

Financial support for investing in processing infrastructure and fast permitting of operators are important for increasing the capacity of tyre recycling and energy recovery. Investment is also needed to support research, innovation, demonstration and scale up of technologies, and testing the performance of TDPs and TDFs. This will provide the next wave of technologies and reduce perceived risk associated with using TDPs and TDFs. Education of all levels of government, tyre operators and consumers is also required to increase understanding and build commitment to recover value from tyres.

2025

In the second phase of the transition, harmonising policies, regulations and permitting for tyre management and recycling will provide a level playing field for operators across the country. Harmonised banning of dumping, stockpiling, landfill and on-site disposal of whole tyres and tyre-derived materials will help to increase the capture of tyres for value recovery.

Compulsory auditing and accreditation of all tyre retailers and operators will ensure compliance. Mandatory online tracking of tyres, TDPs and TDFs across the country and overseas to legitimate processing facilities will ensure chain of custody and improve data reliability.

Harmonising standards and specifications for TDPs and TDFs across Australian jurisdictions will increase the confidence for producing and using TDPs and TDFs. Procurement policies and financial incentives to encourage the use of retreaded tyres and TDPs and TDFs in relevant applications can further help to develop markets and increase uptake of retreaded tyres, TDPs and TDFs.

2030

In the third phase of the transition, investment in fast internet, virtual meeting technologies and non-tyre-based transport modes will reduce the reliance on tyres and used tyre arisings. International collaboration across the tyre value chain will be important for providing a level playing field across countries.

Investment in innovation parks and business incubators will support the generation of next-generation innovations and start-ups for tyre recycling and energy recovery. Investing in market platforms to enable reverse logistics and linking tyre recyclers to end users will help to optimise tyre transports and realise industrial ecology opportunities.

Support for setting up consortia or communities of practice for tyre operators will help to share best practise. Finally, commitment of all stakeholders to a more circular economy for tyres is required to achieve 100% of used tyres to be captured for value recovery.

A code has been entered at the start of each key activity in Figure 5.14 to indicate the relevant actor(s) responsible for that activity: G = government, I = industry, R = research, and C = community. As we would expect, most activities are either government or industry led, or some combination of the two. Community rarely features in this role as communities are generally beneficiaries of activities and outcomes rather than drivers of activities.

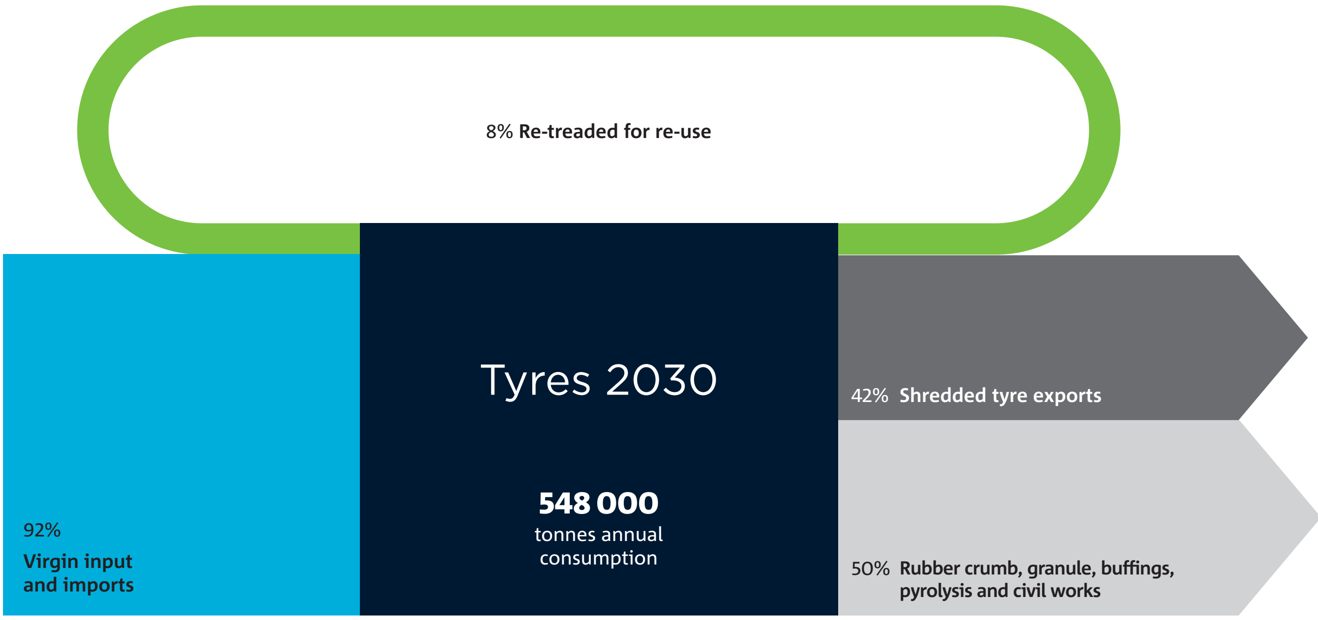


Figure 5.13: Sankey diagram of estimated tyre flows for Australia in 2030

Estimated flows are based on projected end-of-life tyre generation (extrapolated from 1.5% annual increase from O'Farrell, 2019) if all tyres are captured for value recovery, and existing shredding (Gonzalez and Hughes, 2019) and retreading capacity is fully utilised (Data received in conjunction with interviews), capacity to produce rubber crumb, granule and buffings and the use of tyres for civil works are increased to anticipated domestic market demand, pyrolysis capacity is increased to 30% of anticipated domestic market demand (extrapolated based on Genever et al., 2017), export of whole tyres is stopped and export of tyre shred is increased to compensate for part of stopped whole tyre export.

2022

Key outcomes:

All tyre operators captured under tyre stewardship scheme

Imported tyres more durable and suitable for retreading

Levies and recycling fees directed to building tyre recycling and energy recovery capacity, and tyres valued as a resource

Increased infrastructure capacity to recycle and recover energy from tyres

New innovations and technologies available for value recovery from tyres

Perceived risks associated with using TDPs and TDFs reduced

Increased understanding to support commitment for recovering value from tyres

Key activities:

G: Implement national mandatory and regulated or co-regulated tyre stewardship scheme

G: Implement minimum quality standards for imported tyres

G: Harmonise mandatory and increased levies for all tyre imports

G/I: Harmonise transparent and higher recycling fees to the price of new tyres, higher % of fee going to recyclers and consumers to receive a small refund when returning tyres for recycling

G/I: Invest in tyre processing infrastructure and implement fast permitting for operators

G/I/R: Invest in research, innovation, demonstration and scale up of tyre recycling and energy recovery technologies

G/I/R: Invest in testing the performance of TDP and TDF applications

G/I/R: Educate all levels of government, tyre operators and consumers

2025

Key outcomes:

Level playing field for tyre operators across the country

Capture of tyres for value recovery increased

All tyre retailers and tyre operators compliant, audited and accredited

All tyre, TDP and TDF transports captured with online tracking to ensure chain of custody and improve data reliability

Confidence for use of TDP and TDF increased

Markets developed and uptake increased for retreaded tyres, TDPs and TDFs

Key activities:

G: Harmonise policies, regulations and permitting for tyre management and recycling across the country

G: Harmonise banning of on-site disposal, dumping and landfilling of whole tyres and tyre-derived materials

G/I: Implement compulsory auditing and accreditation of all tyre retailers and tyre operators

G/I: Implement mandatory online tracking of tyre, TDP and TDF transports across the country and overseas to legitimate processing facilities

G/I: Harmonise standards and specifications for TDPs and TDFs across Australian jurisdictions

G/I: Implement procurement policies and financial incentives to encourage the use of tyre retreads; and minimum % of domestic TDPs and TDFs in relevant applications

2030

Key outcomes:

Reliance on tyre-based transport and used tyre arisings reduced

Level playing field through international collaboration

Next generation innovations available and start-ups for tyre recycling and energy recovery established

Tyre transports optimised and industrial ecology opportunities realised

Efficient sharing of best practices among tyre operators

100% of used tyres captured for value recovery

Key activities:

G/I: Invest in fast internet, virtual meeting technologies and non-tyre-based transport infrastructure

G/I: Collaborate internationally across tyre value chain

G/I/R: Invest in innovations that enable a more circular economy for tyres and innovation parks and business incubators

G/I/R: Invest in market platforms to enable reverse logistics and link tyre recyclers to end users

G/I/C: Support the set up consortia/community of practice for tyre operators

G/I/R/C: Commit to advance a more circular economy for tyres

Figure 5.14: Key outcomes and activities for a circular economy for tyres by 2022, 2025 and 2030. (Actors: G = government, I = industry, R = research and C = community).

6 Strategies for a circular economy transition of plastics, glass, paper, and tyres

This section presents strategies clustered into five key groups that address fundamental challenges limiting the circularity of plastics, glass, paper and tyres in Australia. Implementing these strategies will help unlock opportunities to drive a circular economy across each of the material streams. Figure 6.1 shows how these key strategies reflect improvements to product design, collection and sorting outcomes; reprocessing and recycling infrastructure; growing end markets for recycled products; providing consistency in governance and education; and achieving system-level changes to embed the circular economy approach in Australia.

IMPROVING PRODUCT DESIGN, COLLECTION, AND SORTING OUTCOMES	BUILDING CAPACITY FOR REPROCESSING AND MANUFACTURING OF RECYCLED PRODUCTS NATIONALLY	MARKET DEVELOPMENT AND INNOVATION TO GROW THE CIRCULAR ECONOMY	HARMONISING STANDARDS, REGULATIONS, AND MESSAGING ACROSS JURISDICTIONS	ENABLING THE CIRCULAR ECONOMY VISION
Aim: Retain the quality and value of source materials and prevent material loss	**Aim: Increase national recycling infrastructure**	**Aim: Boost market demand for recycled products and develop innovative solutions**	**Aim: Provide consistency in governance, messaging, and education**	**Aim: Facilitate system-level changes that foster sustainable consumtpion and production**
Achieve cleaner material streams and improved systems for collection	Increase infrastructure capacity to reprocess plastics, paper and tyres	Grow markets for recycled products	Harmonise standards and governance mechanisms across jurisdictions	Implement system-level strategies to support industry participation in a circular economy and sustainable consumption practices
Maximise material recovery through improved sorting	Implement regional and niche recycling solutions	Innovate and design for the circular economy	Harmonise messaging to consumers, industry, and all levels of government	Build a broader committment to Australia’s circular economy

Figure 6.1: Strategies for unlocking the circular economy of plastics, glass, paper and tyres

Each key strategy has been developed in response to the challenges identified in previous sections and reflects a range of actions that combined will help deliver circular economy outcomes. These will facilitate increased resource recovery, increased use of recycled material, reduced use of virgin materials, and reduced disposal to landfill. Table 6.1 summarises the five key strategies and aims, and the underpinning sub-strategies and range of actions involved.

Table 6.1: Summary of the circular economy strategies for plastics, glass, paper, and tyres

KEY STRATEGIES AND AIMS	UNDERPINNING SUB-STRATEGIES FOR PLASTICS, GLASS, PAPER, AND TYRES
1. **Improving product design, collection, and sorting outcomes** AIM: Retain the quality and value of source materials and prevent material loss	**Achieve cleaner material streams and improved systems for collection** Reduce contamination; improve source separation; eco-design of products; simplify packaging to one-material stream; have dedicated collection systems for materials that cause cross-contamination; use consistent messaging, consumer education; use of reverse logistics; and ban dumping, stockpiling, landfill and onsite disposal of tyres **Maximise material recovery through improved sorting** Upgrade MRFs through investment in improved technology and sorting processes; implement changes to industry standards and contractual arrangements; improve data collection
2. **Building capacity for reprocessing and manufacturing of recycled products nationally** AIM: Increase national recycling infrastructure	**Increase infrastructure capacity to reprocess plastics, paper, and tyres** Support strategic recycling infrastructure investment guided by state and territory infrastructure plans; streamline new infrastructure approval processes; support industry innovation in novel infrastructure **Implement regional and niche recycling solutions** Support local uses of recyclate; hub approaches with reverse logistics; industry and business precincts committed to circular economy approaches; microfactories; composting and waste-to-energy solutions
3. **Market development and innovation to grow the circular economy** AIM: Boost market demand for recycled products and develop innovative solutions	**Grow markets for recycled products** Government procurement of recycled products; guidelines for forward commitment procurement; enable a second life of tyres; research, education, and awareness raising of novel products; new product standards for Australian products made from recycled content **Innovate and design for the circular economy** Develop mission-oriented policy and coordinated, flexible innovation programs; design for circularity; develop novel solutions for niche problems
4. **Harmonisng standards, regulations, and messaging across jurisdictions** AIM: Provide consistency in governance, messaging, and education	**Harmonise standards and governance mechanisms across jurisdictions** Introduce and harmonise standards for collection and waste levies; harmonise policy for single-use plastic products; harmonise regulatory settings for tyre recycling; implement national standards for recycled materials used in construction and other applications; remove duplicated burden of compliance **Harmonise messaging to consumers, industry, and all levels of government** Ensure consistency in labelling, recycling instructions, and education messages; target households, commercial and government; promote sustainable purchasing, consumption and recycling routines; encourage waste avoidance and reuse behaviours
5. **Enabling the circular economy vision** AIM: Facilitate system-level changes that foster sustainable consumption and production	**Implement system-level strategies to support industry participation in a circular economy and sustainable consumption practices** Enable a smooth transition to a circular economy through grandfathering existing contracts; promote a culture of material responsibility; promote waste avoidance, and product reuse and repair including life-cycle assessments; enable end-to-end efficacy for resource recovery; enable broader participation in the circular economy supply chain **Build a broader commitment to Australia's circular economy** Develop national targets, data, and metrics for a circular economy; increase engagement with packaging product stewardship; link with international initiatives; build national manufacturing resilience to deal with system shocks; multi-tiered education to support a circular economy culture shift

6.1 Improving product design, collection, and sorting outcomes

6.1.1 Achieve cleaner material streams and improved systems for collection

Retaining and maintaining the quality of source materials so that products can be easily recycled and effectively reused in another product is a critical step in the circularity of plastic, glass, paper, and tyres. This includes decisions made at the time of product and packaging design, and the way the material is collected for recycling. It involves changes to industry infrastructure and technology through designing out problem materials, simplifying packaging to one-material stream, and changing collection systems to preserve high-value recyclables and to prevent contamination particularly through glass fines, batteries, electronic waste, nappies, textiles, food waste, and other organic waste.

Options such as multiple bins for source separation, container deposit schemes, and reduced compaction during kerbside collection would reduce contamination. Education programs, changes to industry standards and contracting, procurement policies that promote purchase of recyclable products, enforced labelling systems and other regulatory measures are also needed to support cleaner waste streams. Finally, innovation, particularly in food packaging and expansion of collection systems for dedicated materials, such as batteries, nappies, textiles, REDCycle, and high-value products such as cardboard, office paper, and hard plastic, will support ongoing improvements over time. Collection systems for specific situations such as multi-unit developments (MUDs) and education programs that are consistent in their messaging yet fit-for-purpose, including meeting the needs of culturally and linguistically diverse residents, are all required to improve the quality of collected materials and facilitate their recovery for reprocessing and ultimately reuse.

In the case of tyres, mandatory collection, and banning of dumping, stockpiling, landfill, and onsite disposal would improve recovery of used tyres. In addition, refund schemes, harmonised and transparent recycling fees, the use of reverse logistics for transport, and mandatory online tracking would also facilitate value recovery. Consistent regulations and education programs targeting the supply chain and end users would further promote improved collection outcomes.

6.1.2 Maximise material recovery through improved sorting

Optimising sorting processes in conjunction with cleaner waste streams will increase the quality and quantity of materials recovered from the co-mingled recyclables in municipal solid waste. Material recycling facilities (MRFs) across Australia have varying capacity and capability to sort co-mingled recyclables collected from the kerbside. Upgrading MRFs and achieving best practice outcomes will result in increased value from recovered materials and less recyclables going to landfill.

A range of actions are required to achieve higher-quality outcomes in sorting facilities. These include investment in improved technology and sorting processes, such as optical sorting, slowing throughput, increased manual sorting, and potential for a ‘positive sort’ to target desired recyclable products. In addition, changes to industry standards, and contractual arrangements that demand a higher-quality sorting outcome will facilitate improvements along with more robust data collection.

However, interview data indicated mixed views as to the relative value of investment in sorting compared to investment in improved collection systems including source separation supported by single-stream collection systems. The significant investment in scale and technology required to deliver a high-quality sorting outcome means fewer of these facilities exist and in limited (mostly Eastern) locations. Simpler collection strategies lead to more contaminated waste flows, more flows to landfill, or the need for transportation to complex sorting facilities. Alternatively, more complex collection modes allow for simpler and more distributed sorting options. Even so, if investment is made in improved sorting technology there are potentially still efficiency benefits to be realised through improving collections systems that enable source separation and reduce contamination.

6.2 Building capacity for reprocessing and manufacturing of recycled products nationally

6.2.1 Increase infrastructure capacity to reprocess plastics, paper, and tyres

There is an urgent need to increase Australia's domestic reprocessing capability for plastics, paper and tyres. Note that glass does not require additional infrastructure as the same furnaces that take virgin material to manufacture glass, can also take recycled cullet as input. These facilities currently have spare capacity to accept more recycled glass cullet as an input. The limiting steps for waste glass recovery are upstream of reprocessing. Contrastingly, plastics processing capacity must increase by at least 150% to process plastic waste that was exported in 2018–19.

Moreover, the current level of 12% recovery rate for plastics and 63% for paper must increase to meet the national target of 80% recovery by 2030. In addition, only 36% of used tyres (excluding export of whole or baled tyres) are processed for domestic or overseas recycling with the capacity to recycle tyres varying widely across Australia. Significant increases in recycling capacity are required for both the short term, to meet material export bans, and the long term to prevent loss of secondary materials from the Australian economy to landfill or through onsite disposal, stockpiling, or dumping.

Support strategic recycling infrastructure investment guided by state and territory infrastructure plans

Infrastructure needs should be supported by clear state and territory government infrastructure plans to match increased demand trends with local government strategies and private industry investment. There is lack of clarity in some states over what waste infrastructure is needed, mostly attributable to plans yet to be published and states at different stages of their infrastructure planning. Local councils are responsible for determining infrastructure needs for their regions and often own and operate landfills, MRFs and transfer stations. Council decisions and industry investment should be compatible with state government infrastructure plans and greater coordination on recycling infrastructure between state and local government is needed. Specific examples of infrastructure needs are investment in paper reprocessing capacity particularly in Western Australia, plastic recycling capacity particularly to produce hot-wash flake and rPET, infrastructure to process low-value mixed plastics and paper, and infrastructure to produce crumb, rubber, granules and buffings from used tyres.

National data on material recycling infrastructure might benefit from being compiled into an accessible, dynamic, real-time and updatable system. Such data would support planning and investment decisions through identification of future gaps in infrastructure capacity. Local governments can support the establishment of resource-recovery facilities by allocating dedicated areas away from residential housing with recommended buffer zones and where recyclers can access and operate their materials in sufficient volumes.

Streamline new infrastructure approval processes

Companies indicated in the interviews that the years needed for approval for new recycling infrastructure projects represent a major cost to business. The need for streamlining approval process and requirements was also recognised in the COAG response strategy. The application process should be reviewed to remove any unnecessary delays to streamline and accelerate the infrastructure planning process. This is particularly important as Australia addresses the gap in plastics recycling infrastructure. In addition, addressing, managing and mitigating community concerns associated with the location of new waste management infrastructure is essential.

Support industry innovation in novel infrastructure

Federal, state and local governments can provide financial incentives for investing in recycling infrastructure and the Australian Government has demonstrated its support for plastics processing industry investment through various schemes and funding programs. In July 2020 the Morrison government commited dollar 190 million to a new Recycling Modernisation Fund to generate dollar 600 million of recycling investement and to drive a billion dolloar transformation of Australia's waste recycling capacity. Grants and funding that support development from proof of concept, pilot, through to first commercial plant are further required for infrastructure that processes materials, in the absence of energy generation. In addition, subsidies and support for industry operating expenses such as insurance and energy costs would indirectly assist recycling businesses to innovate. Private investment in novel infrastructure for feedstock recycling could be attracted through incentives (e.g. tax deductions) that are proportional to the investment necessary at industrial scale. For paper processing, there is a desire to investigate novel processing methods to create value-added products (COAG, 2020). Investment, innovation and lean manufacturing principles may also be applied to make existing infrastructure more efficient and improve their processing capacity.

6.2.2 Implement regional and niche recycling solutions

Regional Australia experiences difficulties in finding recycling solutions for plastic, glass, paper, and tyres because of a lack of accessible infrastructure and low recyclate volumes that limit the economic viability of traditional recycling options. However, opportunities exist to utilise a circular economy approach to help manage these difficulties by applying a regional-scale perspective, reverse logistics, and identifying cross-industry-sector solutions.

Support local uses of recyclate

Using the circular economy principle of local solutions for locally generated waste applies to regional communities where volumes of recycled materials may be low. In these instances, finding local uses to minimise any transport of recovered materials is necessary if diversion from landfill is to be achieved. Industrial precincts that incorporate a commitment to circular economy approaches could help leverage local solutions and building the capacity of local small and medium-sized enterprises (SMEs) to implement resource-recovery plans.

Hub approach

A hub approach to planning the location of any new reprocessing facility is one solution for regional Australia, using larger centres located at nodes of strategic transit corridors as the hub. Fostering collaboration among groups of local government areas or using existing functional groups such as Regional Organisation of Councils (ROCs) to partner together in co-designing solutions for plastic, glass, paper, and tyre recyclates would leverage the effectiveness of an individual local government. For example, a ROC could increase the volumes of potential procurement and use of recyclate in road base and create a viable business case for industry investment. In addition, the use of reverse logistics to maximise the efficiency of transport could be considered as another collaborative approach to managing long-distance issues common to regions.

Industry and business precincts committed to circular economy approaches

Industrial and business precincts that incorporate a focus on circular economy initiatives are being trialled in regions across Australia, for example Yarrabilba in South East Queensland and Wagga Wagga and Parkes in NSW. Such precincts are developing as greenfield sites with infrastructure to support circular economy solutions not only in waste management but also in the use of water and energy resources. Scope exists to extend processes for facilitating local material flows among the regions' various industries and to build capacity within local SMEs to implement resource-recovery plans. These precincts can also function as test beds for new ideas and innovative solutions for resource recovery and benefit from a champion, a long-term horizon, metrics for measuring impact, and collaboration with local councils and regional development networks.

Microfactories

Microfactories are possible solutions for waste management in remote regions and have been proposed as an alternative to traditional large-scale manufacturing sites. Microfactories are small decentralised systems that can be mobile and operate in regional sites, near to where waste is generated. Microfactories can also operate as pre-processing facilities where waste is initially processed to make transportation options more viable. Microfactories can be applied to a range of materials, including plastics and glass.

As possible solutions for low-volume materials, microfactories could be used to address challenges of specific industry sectors, such as hospitals, or provide solutions for high-value niche waste materials such as high calorific plastics from e-waste to produce high-end goods (Sahajwalla and Gaikwad, 2018). The mobile nature of microfactories could also be well suited to providing niche enterprise outcomes for local SMEs.

Composting and waste-to-energy solutions

Industrial organic composting solutions or anaerobic digestors could provide decentralised solutions for reprocessing compostable plastic and paper products in regional areas where there are vast distances to other recycling infrastructure. Such solutions are preferable to landfill and could become part of a regionally based circular economy where compost is used to fill mine voids and energy generated used in local agricultural industry activities. However, these end-of-life solutions should be used judiciously where no other solutions present beyond landfill.

6.3 Market development and innovation to grow the circular economy

6.3.1 Grow markets for recycled products

It is well recognised that Australia lacks market demand for products containing recycled content and this problem is consistent across plastic, glass, paper, and tyres. Recycled products may contain percentages of recycled material or be entirely recycled, or in the case of tyres remanufactured for reuse (retreading). Recycled products have a variety of markets such as civil and construction projects (e.g. roads, park benches, bollards, acoustic noise panels), agriculture and aquaculture (e.g. plastic film and structures). Where new recycled-content products look to displace or compete with existing virgin products, they can sometimes be at a disadvantage due to higher prices. A higher market price is often indicative of more expensive processed secondary materials, which in the case of plastic is unlikely to compete with cheap virgin materials. However, a higher price might be offset by lower maintenance costs, and this should also be considered during procurement processes. In some applications, such as tyres, the use of recyclates in manufacturing processes requires specific infrastructure when compared to traditional feedstocks and may require additional infrastructure to mitigate any environmental hazards, for example when using tyre-derived fuels. Five main strategies that improve demand for recycled products are discussed below.

Government procurement of recycled products

Government procurement can drive demand for recycled products and the federal government announced changes to their procurement guidelines during the National Plastic Summit, March 2020. All federal government agencies will need to consider environmental sustainability and recycled content as part of their procurement guidelines. This approach can also be adopted by state and territory governments by implementing guidelines to encourage recycled product procurement. State governments could also create large-scale markets for products by identifying 'sinkhole' projects for major infrastructure. These projects have the potential to purchase large quantities of recovered waste material such as plastic in railway sleepers or glass and tyres in road base. These actions require regulatory barriers to be removed and project guidelines to be updated to promote recycled content. Procurement should be tracked and reported to ensure policy changes are effective.

Local governments also have a key role in procuring recycled products. This approach is already occurring voluntarily, for example, in South Australia where nine councils signed a memorandum of understanding in 2019 to commit to the procurement of products with recycled content. This commences with the purchase of plastic material equivalent to 10% of the weight of plastic collected in their council region. This will increase to 50% over the next few years. This initiative was supported with a grant from the state government.

There are also options to increase adoption of recycled products by mandating targets. Procurement policies could for example be harmonised to mandate minimum percentages of recyclates in relevant applications (e.g. road and rail works), in a similar way that biofuels have been mandated in some states. However, this approach has a risk for perverse outcomes where products aren't locally available or are cost prohibitive for smaller councils. Moreover, 'forcing' councils to procure products they are not comfortable with may also result in risk-averse behaviours. Rather, state governments might take an incentive-based approach to encourage local governments or ROCs to partner together for recycled-product procurement. This approach means that market opportunities grow through 'working with the willing' to increase demand in civil projects for products made from recycled content. Procurement practices could also promote tyre replacements to be based on tyre wear instead of age to increase the life span of tyres used in government fleet vehicles.

Guidelines for forward commitment procurement

Forward commitment procurement is a public sector process for securing innovative goods and services that reduce perceived risk. It is a mechanism for the public sector to create space for private sector innovation for products that meet or exceed existing standards while also containing recycled content (Whyles et al., 2015). An example of forward commitment procurement in practice is from Geelong, Victoria, where a tender was put to market for a zero maintenance 100-year lifetime recreational bridge (City of Greater Geelong, 2020). It is a transparent process where products that are novel or first to market can be tested, monitored and verified within a procurement process that is clear about tender conditions. Forward commitment procurement provides clarity on the testing framework and standards required of an innovative product. This strategy can be employed by well-resourced, innovative local or state governments as part of their procurement plans.

Enable the second life of tyres

The domestic market for passenger-tyre retreading has declined as consumers are moving away from passenger-tyre retreads (O'Farrell, 2019). Education campaigns on the benefits of tyre retreading could potentially revive the retreading market in Australia. Tyre retailers and retreaders could also be informed on the available technologies and opportunities for retreading tyres. Investment in retreading infrastructure in each Australian jurisdiction could also increase the capacity for domestic retreading for both trucks and other vehicles and reduce the need for export of tyres to be retreaded overseas. Financial incentives in the form of grants or tax offsets can help industry with infrastructure investment, and rebates for using retreaded tyres would encourage consumption. Procurement policies could also help grow the retread market by mandating the use of retreads on government fleet vehicle tyres.

Research, education and awareness raising of novel products

Great variability exists across councils and companies for their acceptance of products with recycled content. Challenges include perceptions that recycled content is not of high quality, risks to health and safety, a lack of awareness of product performance and a lack of understanding of where to source products with recycled content. Research to understand concerns will support targeted information to overcome any misconceptions or prejudices that exist for recycled materials. Evidence provided by third-party laboratory or field trials is an important part of validating a product is fit for purpose. These data are necessary to counter risk-averse behaviour and business-as-usual purchasing approaches by providing confidence to uptake a recycled product and support education and market awareness of new products. Education that provides clear guidance on where recyclates can be safely used to ensure fit-for-purpose applications and the benefits of using recyclates would support wider adoption. Case studies on successful trials should be developed and shared nationally to increase awareness of product specifications and quality. Case studies on new products (e.g. moulded paper fibre in packaging or compostable products) support market awareness. Broader marketing and eco-labels can also help to increase the uptake of recycled products.

New product standards for Australian products made from recycled content

It is important to set expectations for the market for the quality and specifications for recycled-content products. Manufacturers of products made from recycled content would like to ensure they are not competing against lower-cost products manufactured offshore, derived from non-Australian waste. A standard for recycled products might work in combination with a campaign similar to 'Buy Australian Made', to support consumption of and preferences for Australian-manufactured products. Considerations for developing an Australian recycled-content standard might be:

- manufactured in Australia
- Australian-sourced waste material
- the percentage of post-consumer recycled content
- that the product is recyclable at end of life.

6.3.2 Innovate and design for the circular economy

Innovation has an important role in the transition to a circular economy. Innovation is described as a new or improved product or process made available internally for business use or externally for the market.

Mission-oriented policy and coordinated, flexible innovation programs

The challenge with a transition to a circular economy is that traditional policy approaches are less useful for addressing market transformation. Australia can learn from the UK through the application of mission-oriented policy. Missions are oriented to solve national challenges and stimulate collaborative innovation (Australian Government, 2020). The CSIRO research strategy includes a mission to End Plastic Waste with a goal of reducing plastic waste into the environment by 90% by 2025.

It is important that research systems and funding models are aligned and accelerated to support Australia's packaging-waste targets to 2025 and national waste targets to 2030. To that end, a model with an overarching coordination body and funding that allows smaller, nimble projects to proceed while also having an appropriate screening and reporting framework in place might be more appropriate for the challenges in resource recovery and reuse. Examples might be for APCO to coordinate plastics research beyond their remit of packaging and in the case of tyres for the TSA to coordinate research on tyre recycling. National coordination of research grants and initiatives aimed at addressing a circular economy for plastics, paper, glass and tyres helps to reduce duplication between jurisdictions. This can be achieved with greater collaboration between governments (Australian Government, 2020). Industry peak bodies also have a key role in coordinating collaboration across the supply chain and it is important that policy initiatives do not neglect or exclude Australian SMEs.

Design for circularity

Designing products or packaging for circularity sits at the heart of realising the circular economy. Design arguably has the greatest influence over a product moving from a linear to a circular economy. Peak bodies have a role to play in supporting companies to consider their design (e.g. the APCO PREP Tool), and in the case of tyres an audited labelling system being developed by the TSA. Design concepts also include:

- design for sustainability (e.g. bio-derived raw materials), durability, reusability and recyclability
- design for disassembly, design for environment, cradle-to-cradle design
- new business models for reuse
- development and access to design guides
- design solutions for problematic materials
- phase out single use products or non-recyclable products and packaging
- eco-labels to indicate sustainable designs.

Develop novel solutions for niche problems

Some ‘problem’ products require niche approaches. Multi-layer packaging is particularly challenging as it typically isn’t recyclable. This requires innovation to develop a recyclable solution or developing recycling processes to accept multi-layer packaging. An example of the latter is the plan to implement recycling technology for the multi-layer Tetra Pak packaging in Australia. Once implemented, Australia has opportunities to either take novel technologies into neighbouring countries or accept waste processing from those countries. Australia needs solutions for low-value mixed, or contaminated materials. Feedstock or chemical recycling or waste to energy are both viable options. Funding is required for further research and development of novel value recovery technologies, including investment to evaluate the performance and safety of new technologies, create standards accordingly, and to upscale and commercialise innovations. In the case of tyres, research into high-value applications, such as binders for roads and explosive-resistant buildings, has the potential to generate significant new sales for the tyre-recycling industry (National Waste and Recycling Taskforce, 2019).

6.4 Harmonising standards, regulations, and messaging across jurisdictions

6.4.1 Harmonise standards and governance mechanisms across jurisdictions

Whether it is consumers who want to know about how recyclable a product is, MRF operators expecting a certain quality of supply, or recyclers trying to comply with road construction material specifications, there is a need for consistency and clarity in governance, standards and education across all the stages of the circular economy.

Additionally, it would be useful to harmonise standards across jurisdictions to ease the burden of compliance for businesses, and disable waste and recycling problems being re-located rather than being addressed, for example, in the practice of re-locating stockpiles to deal with local regulatory limits or avoiding levies (see also recommendations and notes of The Australian Senate Environment and Communications References Committee (2018)).

There are genuine local differences in the capacity to treat waste and recover resources. Harmonisation does not mean the exact same *details* in standards. Common principles, intended outcomes, classifications, definitions and measurement of thresholds, can all enable cross-government and cross-jurisdiction coordination.

Introduce and harmonise standards for collection and waste levies

The standard of collection services is highly varied across businesses and local governments. Minimum and harmonised standards for collection would provide certainty in the sector and raise the quality of material to downstream stages and operators. This could also place more burden on local government and rate payers (LGNSW 2020) and needs to be used in tandem with the practice of seeking lowest-priced bidders for waste collection contracts, ensuring that best value is achieved for the whole recycling chain. This also addresses the reported perverse effect of the same contractor delivering different levels of services and having to treat the combined recyclable flows at the level of the lowest common denominator.

Related to this are the differentials in waste levies across jurisdictions that have created a levy avoidance industry, both legal and illegal, resulting in recyclable material ending up in landfill (Serpo and Read, 2019). A first step in addressing this would be a national coordination of waste levies removing inter-jurisdictional inconsistencies.

Harmonise policy for single-use plastic products

Each jurisdiction has a different approach to implementing single-use plastic policy. There are opportunities to harmonise policies and programs across states and territories to reduce confusion for households. Moreover, as Tasmania and Victoria are in the planning stages for their container deposit schemes (CDSs) there may be opportunities to look for harmonisation with existing schemes (e.g. in South Australia or NSW). The South Australian Government is leading national work regarding CDS harmonisation opportunities.

Harmonise regulatory settings for tyre recycling

The lack of consistent regulations, standards and specifications for tyre recycling across Australian jurisdictions hinders the growth of end markets and results in tyre loss either through illegal stockpiling, dumping, or export overseas. Harmonising regulations, policies and enforcement of tyre recycling including a national mandatory and regulated or co-regulated tyre stewardship scheme would support improved recycling outcomes. Ensuring all tyre imports attracted levies and that the cost of recycling is included in the purchase price of the product rather than being a cost at the end of the product's life would support the viability of the tyre recycling industry. Moreover, a mandatory tyre stewardship scheme and auditing would ensure all operators act in accordance with best practice. In addition, harmonising the standards and specifications for tyre-derived products (TDPs) and tyre-derived fuels (TDFs) across Australian jurisdictions would reduce perceived risks of recyclate use, increase uptake of TDPs and TDFs, and support improved safety and environmental outcomes.

National standards for recycled materials used in construction and other applications

Potential terminal use of recycled materials in the construction industry involves substantial volumes and this market could be expanded by paying specific attention to construction material standards. Although the needs are not the same as for recycled packaging (e.g. colour separation of glass), there are still specific standards to meet the engineering requirements of the construction industry and regulatory specifications. One obstacle to recycled material accessing road construction material markets is where performance criteria are met but the recycled material cannot be used because it does not meet prescribed specifications (Bond, 2020). National standards for recycled material in road construction are specific recommendations in COAG's response strategy to phasing out exports of waste plastic, paper, glass and tyres (Council of Australian Governments, 2020, pp25–26) companies and individuals all have a role in working to reduce waste where possible and making productive use of our waste as resources where we can't avoid itsgeneration.In August 2019 a decision was made by the Council of Australian Governments (COAG. Performance-based standards are used nationally in the Building Code of Australia and similar principles could be translated to the use of (non-standard) recycled materials.

Government and industry peak bodies can facilitate the harmonisation of standards and specifications that are based on minimum percentages of recycled content to boost the use of recyclates in various applications, such as road and rail works, and closely monitor achieving those targets for recycled content. Developing national specifications and standards would also reduce perceived risks associated with using recycled materials by providing specific conditions that need to be met in order to attain an approved level of performance and increase confidence for suppliers and consumers operating across jurisdictions. Specifications that prescribe material types, qualities and dimensions, could include requirements related to recyclates (National Waste and Recycling Taskforce, 2019).

Remove duplicated burden of compliance

The burden of compliance could be eased considerably, not by lowering standards but by coordinating them, removing duplication of compliance for recycled products so that standards and compliance are recognised across jurisdictions. From interviews with industry, other hindrances to entering the recycled-material market are compliance of recycling operations with environmental standards for waste handling and landfill; and burden of compliance to standards that move slower than the policy changes intended to enable the circular economy. For example, one-off grants[30] to encourage entry into the recycling sector are incommensurate with the cost of environmental compliance that conflates waste industries with resource recovery and takes many months or years to respond to.

30 See Recommendation 9: https://www.infrastructure.gov.au/department/ips/files/government-response-hor-building-up-moving-out-may-2020.pdf (accessed 14 July 2020)

6.4.2 Harmonise messaging to consumers, industry, and all levels of government

Harmonising messages to consumers through consistency in labelling, recycling instructions, and education messages will underpin effective behaviour change in household, commercial, and industry purchasing, consumption and recycling routines. This will help ensure reduced waste generation, cleaner recyclables are collected, more efficient sorting outcomes are achieved, and end markets for recycled products are sustained.

Even though some differences exist among jurisdictions there are sufficient improvements to be made in strengthening consumer purchasing choices and achieving more effective recycling behaviours that warrant a national or statewide consistency in messages. Opportunities for national awareness and education campaigns would leverage the effectiveness of social approaches to facilitate change and achieve national targets.

For example, messaging around the value of purchasing products in eco-designed packaging, how to correctly follow labels for recycling, how to prevent contamination of recyclables, how to present products for recycling, and how to purchase products with recycled content would all be beneficial. In addition, education about waste avoidance and different ways to reuse and repair products will encourage waste reduction. Furthermore, consistent messaging around targets and goals and feedback on target achievement will also support social processes for promoting behaviour change.

Education targeting the industry sector and end users of recyclates would also be beneficial, and utilising peak industry bodies for knowledge sharing and establishing communities of best practice would help promulgate a circular economy approach to business. Education is also required to prepare a skilled workforce for eco-design of products, recycling occupations, and manufacturing of recycled products using innovative technologies. The role of government at all levels is to facilitate the collaboration needed to harmonise messaging and roll out fit-for-purpose education programs across all jurisdictions.

6.5 Enabling the circular economy vision

6.5.1 Implement system-level strategies to support industry participation in a circular economy and sustainable consumption practices

Constraints and enablers for different parts of the circular economy are not always proximal. In other words, there may be key enablers or inhibitors upstream or downstream from a given stage. Some system-level considerations for both inside and outside the resource-recovery industry to improve resilience of the sector and broader participation in the circular economy are discussed below.

Enable a smooth transition to a circular economy through grandfathering existing contracts

One structural–institutional consideration is the usual duration of contracts that local government and business have with collection contractors. This is often 3–7 years (Allan, 2019) and, from interviews with industry and local government, usually greater than 5 years. Similar contract duration occurs in the stages between material recovery and consumers of recyclate. To avoid uncertainty in the sector, and opaque legal implications for local government, any policy intervention on the waste collection and resource-recovery sector with shorter time frames, needs to allow for grandfathering of existing contractual arrangements as part of a smooth transition to activities that align with a circular economy approach.

Promote a culture of material responsibility

Developing a culture of civic environmental responsibility has been an important feature in countries with higher recovery rates. For example, Germany progressively reduced allowed flows to landfill until 2005 when operators were banned from sending any untreated waste directly to landfill (Fischer, 2013). This process was difficult, but the cultural change has stuck, and the strategy has survived through several changes in government over more than 20 years. The long transition period to a challenging target allowed businesses to adjust but also engendered a national culture of responsibility for material recovery.

In Australia, recovery rates from MUDs are conspicuously low, and many residents do not fully understand what is and what is not recyclable due to the lack of a consistent and sustained approach to education (Victorian Auditor-General's Office, 2019). MUDS are an increasing proportion of the dwelling stock and any effective planning and policy interventions here will have increasing impact over time.

Enable end-to-end efficacy for resource recovery

A number of key issues were identified through the literature review, submissions to various government enquiries, and interviews conducted across the waste and resource-recovery sector. Supporting one part of the recycling sector does not mean there will be a contract for source-separated collection, a market for the recycled material, or regulatory acceptance of novel materials (e.g. for road construction). Actions are required at each stage of the circular economy cycle and it is important to recognise key synergies for these to be effective. Possible actions include the following:

- Improving the quality of collected material requires simultaneous implementation of product design that enables easy separation at source, standardised labelling on recyclability, and consumer education on labelling and separation-at-source behaviours. These have to work together and only result in more high-quality recovery if there are concurrently improved collection systems and greater capacity to re-process material.
- Burden of compliance can be addressed with material and cross-jurisdictional standards to improve certainty and reduce duplication (see also Section 6.4). This also has to work with key drivers of the market: government procurement of collection services and procurement planning, and increased capacity to supply compliant quality recycled material.
- For transport and logistics, the COAG Response Strategy (2020)companies and individuals all have a role in working to reduce waste where possible and making productive use of our waste as resources where we can't avoid itsgeneration.In August 2019 a decision was made by the Council of Australian Governments (COAG suggests targeted locations for additional recycling capacity, to reduce transport costs. This should work with state infrastructure plans and the small-scale, regional actions of Section 6.2.2, where there are opportunities to engage SMEs and region-specific markets for recycled products. It would also help to coordinate waste levies to discourage transfer of waste problems.

Enable broader participation in the circular economy supply chain

- The margins for resource recovery can be small, markets few and concentrated. Under such conditions, certainty of supply and end use for recovered materials is of a premium value. To enable this, there is a need for broad acceptance and participation of many sectors in the circular economy:
- reduce the risk to other business in adopting a circular economy approach, for example, support for innovation in product development that uses recycled materials as inputs
- build SME capability to develop resource-recovery plans and participation in a circular economy supply chain
- retaining quality and value in recycled material flows, enables a more distributed resource-recovery sector at smaller scales that are accessible to SMEs
- regional and niche solutions such as reuse mentioned in Section 6.2.2
- scaling up chemical or 'feedstock recycling' where waste plastic is depolymerised to monomers that can be used as feedstock into many different applications
- institutional changes to incentivise the circular economy. For example, recycled material for construction is often needed in large volumes over a short time period (~months) to effectively substitute for virgin material. Some state-level regulations restricting stockpiling are a friction to this market unless recyclers can work collectively or more stockpiling at 'clean' MRFs is possible
- investment in technology for virtual hubs that connect producers, collectors, transporters, recyclers and end users to enable timely information exchange, the identification of circular economy opportunities and facilitate efficient use of resources. An example of such a platform is ASPIRE, which intelligently matches businesses with potential remanufacturers, purchasers or recyclers of waste resources (ASPIRE, 2019; King et al., 2020).

Promote waste avoidance, and product reuse and repair

A fundamental premise to the circular economy is the avoidance and prevention of waste generation. This takes place not only during the production of a product where eliminating waste and reducing the use of natural resources such as water and energy is critical, but also, during the way a product is consumed. Substitution of a disposable product with an alternate reusable product, eliminating unnecessary transport, packaging and purchases, instituting a paperless office, and avoiding single-use products such as single-use glass and plastic are all ways to avoid waste generation. Public education and procurement guidelines and policies that stipulate waste reduction as a criterion for purchase and encourage product attributes such as product durability, and minimal packaging would encourage waste reduction. In addition, reuse and repair of products along with different models of consuming products such as through leasing and purchasing of second-hand goods, would also reduce waste generation and prolong the use of valuable materials. To ensure product substitution decisions and other changes to the consumption system don't inadvertently shift the problem to a less sustainable solution, undertaking comparative life-cycle assessments are recommended to ensure the best solution is identified.

6.5.2 Build a broader commitment to Australia's development of a circular economy

Further develop national targets, data, and metrics for a circular economy

Australia has clear targets within the National Waste Policy. Embedding those targets within state and territory policy and plans will support a coherent approach to sustainable waste management and resource-recovery solutions and a circular economy. However, metrics that are used to measure Australia's progress towards these targets are underdeveloped. While some progress has been made to establish circular economy metrics, there are no internationally agreed metrics that Australia might apply. An opportunity exists for Australia to develop a national set of circular economy metrics for plastics, paper and glass that connect concepts such as design and adoption of circular business models with macro-economic material flows through the supply chain, uptake of recycled products, and track Australia's progress towards an 80% resource-recovery rate. In addition, a focus on improving the quality and extent of waste data, data across the supply chain, and tracking of material flows across jurisdictions is necessary to provide an evidence base, for decision making and informing actions and initiatives including information to support business cases for new innovation and investment opportunities.

Increase industry engagement with packaging product stewardship

Interview feedback indicated that Australia's voluntary packaging product stewardship would benefit from mandatory involvement in order to realise the 2025 targets. This would reduce the problem of 'free rider' companies operating outside of the APCO 2025 targets, which jeopardises Australia's broader commitment to achieving resource efficiency and the circular economy. However, should APCO continue as a voluntary product stewardship initiative then there is a need for new initiatives that target participation by companies that are eligible to join, but choose not to. An example is to improve recruitment messaging to companies and build incentives and advantages for companies who are members of APCO.

Link with international initiatives

The issue of imported materials not being subject to APCO targets was raised as a concern by a number of interview participants. This is particularly an issue for plastics and paper where imported packaging may not be recyclable. There are challenges in monitoring imported packaging materials for consistency with APCO targets and the Australian Government is unlikely to take a regulatory approach to managing imported materials. Instead, imported packaging might be addressed thorough connection with international initiatives and organisations such as the Ellen MacArthur Foundation (EMF), The UK Plastics Pact, the UN Environment Programme, and the UN Sustainable Development Goals. Much of this coordination, particularly for plastics is via Australia's peak industry body, APCO who announced the ANZPAC Plastics Pact in March 2020. This arrangement connects Australian companies with the EMF and multinationals who service global supply chains. By connecting to international initiatives, Australian imports of packaging may benefit from regulation and initiatives in other countries, such as the UK 2022 tax on imports of non-recyclable packaging. Multinational brands delivering to the UK may also deliver to Australia and therefore Australian imported packaging may indirectly benefit from increased regulation for packaging in other markets.

Another reason to link to international initiatives is that waste challenges are shared and extend beyond Australian borders. This is particularly the case with addressing marine plastic pollution and therefore international coordination on efforts to combat marine waste is a priority. Australia can also provide regional leadership on innovation initiatives, for example, the Indonesia–Australia Systemic Innovation Lab on Marine Plastic Waste.

In the case of tyres, international research collaborations have addressed solutions for sustainable outcomes for the different stages of the tyre life cycle. For example, the World Business Council for Sustainable Development's Tire Industry Project is a global initiative undertaken by leading tyre-manufacturing companies that drives research on potential human health and environmental impacts of tyres throughout their life cycle. Together, Tire Industry Project member companies work towards sustainable solutions on topics such as sustainable natural rubber, tyre and road-wear particles, and end-of-life tyre management (World Business Council for Sustainable Development, 2020).

Build national manufacturing resilience

The experience of the COVID-19 global pandemic has been far reaching. It is important that Australia emerges with a more resilient and diverse economy including recognition of the essential service provided by the waste management and recycling sector. The record low cost of virgin plastics is disrupting global plastics recycling by making it uneconomic[31] to recycle, and similarly, global cardboard businesses have warned of a shortage[32] because of interruptions to kerbside recycling collection services. Such impacts could also be experienced in Australia, particularly effecting the Australian plastics recycling market as these companies also compete with virgin materials and international markets.

Building manufacturing reprocessing capability requires support for SMEs, and coordination of manufacturing, waste, and industry policy to bring about a supportive environment for investment into new business that reprocess materials. This is also necessary to move from a linear recycling mindset, to a circular economy. Investment in research and innovation are also essential to enable industrial ecology and a more circular economy.

Education to support a circular economy culture shift

A circular economy requires a shift in the way waste is valued as a resource and how material cycles can be made more circular. This warrants a multi-tiered education program that extends across all levels: primary, secondary, tertiary, adult (including university-level education) to support the circular economy. Moreover, education and developing capability in industry, particularly in SMEs, to undertake planning and implementation of circular economy initiatives would support such a shift. Government programs and involvement of industry peak bodies would be instrumental in brokering new learnings and knowledge and building this type of capability for embedding a circular economy.

31 https://packagingeurope.com/european-plastics-recycling-industry-warns-of-shut-down/ (accessed 14 July 2020)

32 https://packagingeurope.com/european-industry-organisations-warn-of-cardboard-shortage/ (accessed 14 July 2020)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Concluding remarks

This industry and innovation roadmap is the result of an in-depth review of existing knowledge and engagement with industry and government stakeholders in Australia to identify a way forward for unlocking the potential of a circular economy for four waste materials – plastic, glass, paper and tyres. It identifies opportunities for increased circularity in the material supply chains of these materials starting with the substituting and phasing out materials that have no clear path for recycling and the redesigning of materials, products and processes to enable reuse and recycling. In the process, the research team, together with stakeholders, have focused on such opportunities that can be implemented in the Australian economic context and are supported by the existing economic and governance arrangements.

The objective of the roadmap was to address the short-term needs of the upcoming waste export ban, including the creation of infrastructure and markets for increased domestic processing of waste, and the long-term opportunities for new industries and business models based on circularity. The main advantage of the circular economy concept is that it is a genuinely economic framework. It helps identify economic opportunities based on research and development and innovative approaches, achieving significant and sometimes very large environmental co-benefits of resource conservation, resource productivity and waste minimisation. The fact that the circular economy aligns economic and environmental objectives has made it a powerful tool, now employed in many parts of the world. It is a process driven by industry and the innovation system and supported by policy.

In the roadmap we have identified a way forward for reducing the amount of plastic, glass, paper and tyres that ends up in landfill or leaks to the environment that is achieved through a strategy implemented over the next decade. The roadmap includes five main elements which align practical opportunities to improved governance. The five key clusters of strategies include

- retaining the quality of materials at all stages of the material supply chain, from cradle to grave
- upscaling and innovating recycling technologies and enabling the digital and technological innovations required for waste minimisation and increased circularity
- boosting market development and creating demand for secondary materials
- achieving nationally consistent governance through shared institutions and national standards
- enabling the circular economy vision in industry, government and the community at large.

Retain quality of materials

From the viewpoint of creating a circular economy, it is important to keep materials in circulation for longer and more often. This allows replacing additional needs for virgin materials with secondary materials and helps resource conservation, it also reduces waste going to landfill and allows value-adding to the same material multiple times. It requires avoiding the mixing of materials from design to collection and creating products that can easily be disassembled, collected, sorted, and graded by quality. Improving the quality of materials throughout the life cycle, and avoiding contamination, helps avoid material loss and secures clean feedstock for recycling and high-quality secondary materials.

Upscale and innovate recycling technologies

While there are many medium-term to long-term opportunities for new materials, products and processes that avoid unsustainable material supply chains, there is an immediate need to grow the national recycling capability in Australia to manage compounding amounts of waste materials and stockpiles. There is a need to increase the recycling infrastructure for plastics, glass, paper and tyres through strategic investment by industry in alignment with public investment by federal and state government programs. Building the Australian recycling infrastructure will benefit from streamlined approval processes for new facilities and science–industry collaboration, which will ensure that innovation can be readily implemented.

Depending on their size, recycling facilities will depend on a continuous quantity and quality of waste materials and there will be an opportunity to create regional facilities that can support regional economic development whilst attaining waste reduction objectives. Regional recycling facilities will enable local uses of recyclate, will create waste and recycling hubs with reverse logistics, and can aim towards industry and business precincts committed to circular economy approaches. There are good examples of microfactories, composting facilities and waste-to-energy solutions that can operate at a smaller scale and can contribute to regional, local and community-based solutions, especially in places where transport infrastructure is an important constraint.

Boost market development and demand for secondary materials

The growing supply of secondary materials from domestic recycling facilities will require growth in markets for these materials – for reuse either in manufacturing or construction – to make the supply chains truly circular. In many circumstances, this market development will benefit from changes in product standards made to accommodate the use of secondary materials. There is a role for government procurement to drive market demand for recyclables. Industry can contribute through forward commitment procurement with the large potential in the construction industry to absorb substantial amounts of secondary materials. A focus on manufacturing may also help reviving the Australian manufacturing industry and can create employment and revenue.

An important aspect of developing markets is innovation and design for the circular economy. Such an approach will benefit from a coordinated effort by the Australian innovation system. Design innovation programs that can be operated by government could bring together science and industry and allow for shorter paths to implementation for new technologies and business models. Experimentation will play a role in designing new materials, products and processes, and creating new market demand for such products.

Nationally consistent governance (institutions and standards)

Unlocking the potential of the circular economy and transitioning from the current take–make–dispose economic model to circular material supply chains will benefit from and be enabled by nationally consistent expectations and rules and an even economic context that creates favourable conditions for industry participation in the circular economy. Harmonising standards and governance mechanisms can be achieved by the different jurisdictions working together with the Australian Government taking the lead.

Harmonisation will include common standards for collection and waste levies, harmonised policy for single-use plastic products, harmonised regulatory settings for tyre recycling and a national standard for recycled materials used in construction and other applications. Well-designed policy guidance and governance mechanisms will remove duplication of effort and bring about a shifting of burdens and responsibilities. A nationally uniform set of rules will help reduce the burden of compliance for industry participants.

Consistency in labelling, recycling instructions, and messaging for households and for commercial and government purchasing will complement government efforts to facilitate the circular economy transition in Australia. This will help develop practices and routines in private and corporate consumers to engage in waste avoidance and reuse behaviours.

Enable the circular economy vision

The circular economy needs to become a national project, built on policy and investment priorities that support industry participation and sustainable consumption practices. Policy, governance mechanisms and incentives that support circularity and sustainable materials management will need to work hand in hand with infrastructure investment and research and development to create new opportunities in the circular economy. The success of a circular economy will crucially depend on the capacity for innovation and experimentation, the ability to develop new skills and train or retrain existing employees, and the scope for changing consumer expectations.

Industry and government stakeholders agree that it will be important to build a broad commitment to Australia's circular economy. The transition will benefit from developing national targets, data, and metrics for a circular economy to measure progress, by increasing engagement with packaging product stewardship and from linking with international initiatives. By embracing the circular economy, Australia can build national manufacturing resilience to deal with system shocks and provide multi-tiered education to support a circular economy shift in investment, expectations and practice that will support Australia's next wave of innovation and industrial and manufacturing growth.

Research and development

Research and development will be required to support this strategy, generating the next wave of innovation for creating wealth from waste. Industry and the innovation community will need to work together to address the needs of a circular economy and enable innovative approaches to become the new best practice in industry, in government and in guiding responsible consumption. CSIRO will use its core position in the Australian innovation system to act as a catalyst for creating the next wave of innovation with industry, to support a transition to a circular economy and to unlock the environmental and economic benefits that come with that transition.

Metrics, data and indicators

Understanding the progress of the circular economy in Australia will require new metrics, data and indicators that allow us to measure policy effectiveness and industry and community success in increasing the circularity of material flows. The metrics and indicators will address all aspects of the circular economy, which include the energy sector and technical and biological material supply chains. The measures need to cover materials that are managed domestically and products that are imported to Australia, allowing for a production and footprint perspective on circularity. Comprehensive datasets and indicators need to be made available for industry, local communities, state and federal governments. This will allow us to measure Australia's progress on its way to a circular economy, creating the technologies and business models that will underpin the economic prosperity and environmental sustainability of our future.

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