Australia's National
Science Agency

State of bioplastics in Australia

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Executive summary

Growing concerns about the environmental impacts of plastic waste have fuelled an increase in the use of bioplastics. While definitions vary, bioplastics are characterised by unique properties that make them biobased, biodegradable and/or compostable. Biobased plastics can offer low-carbon, renewable alternatives to a wide range of conventional plastics and decouple plastic from fossil fuels. Certified biodegradable and compostable plastics can offer solutions to plastics that commonly contaminate organics recycling streams, aid in transporting food waste to soil, and provide improved environmental outcomes in niche applications, such as in agricultural films and some packaging formats.

However, the adoption of bioplastics is not without challenges. The state of bioplastics in Australia presents a complex landscape characterised by a wide range of polymer types and applications, compounded by confusing terminology. The lack of clear standardised labelling for bioplastics and other materials has led to consumer confusion, resulting in contamination across recycling and composting streams, and leading many bioplastics to end up in landfill.

This report provides an overview of the Australian bioplastics system, identifies materials flow from feedstocks to end-of-life, highlights lost value within the sector, and prioritises interventions and opportunities to enhance circular outcomes.

Material flow analysis

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. An MFA was completed and provided valuable insights into bioplastics consumption in Australia across four distinct phases. The overall findings of the MFA indicate that polylactic acid (PLA) dominates the Australian bioplastics market and is predominantly used in food service ware, the majority of which ends up in landfill, highlighting the need for improved waste management and recycling infrastructure. The investigation into raw materials used for bioplastics production in Australia highlighted prevalent sources such as sugarcane, corn sugar, and starches for PLA, bio-polyethylene (BioPE), and polyhydroxyalkanoates (PHA) manufacturing. Notably, PLA production primarily relies on corn sugar as its raw material, while BioPE is exclusively produced from sugarcane. PHA production involves using organic wastes, cane, and beet sugars.

The study found that most bioplastics in Australia are imported, primarily from Thailand (PLA) and Brazil (BioPE). However, quantifying raw material-to-polymer conversion rates posed a challenge due to insufficient data, especially for multiple raw material inputs. Conversion rates, such as 2-to-1 for corn sugar to PLA and 4-to-1 for cane and beet sugars to PHA, were established. The conversion process generates by-products; however, manufacturers confirm these can be repurposed for other products. End-of-life outcomes showed that most bioplastics end up in landfill due to challenges with recycling or composting. Food service ware is largely landfilled with the exception of some composting activities in South Australia.

Insights from Australia's bioplastics system

Research for this report included 10 in-depth interviews and two industry workshops with a diverse cohort of key stakeholders from across the Australian bioplastics value chain. These interactions focused on understanding the current use of bioplastics in Australia. Discussions examined the challenges and opportunities inherent in establishing a circular economy for bioplastics, and stakeholders explored and identified key enablers for realising such an economy in Australia. The insights gleaned from these interviews and workshops serve as a foundation for the recommendations and findings presented in this report.

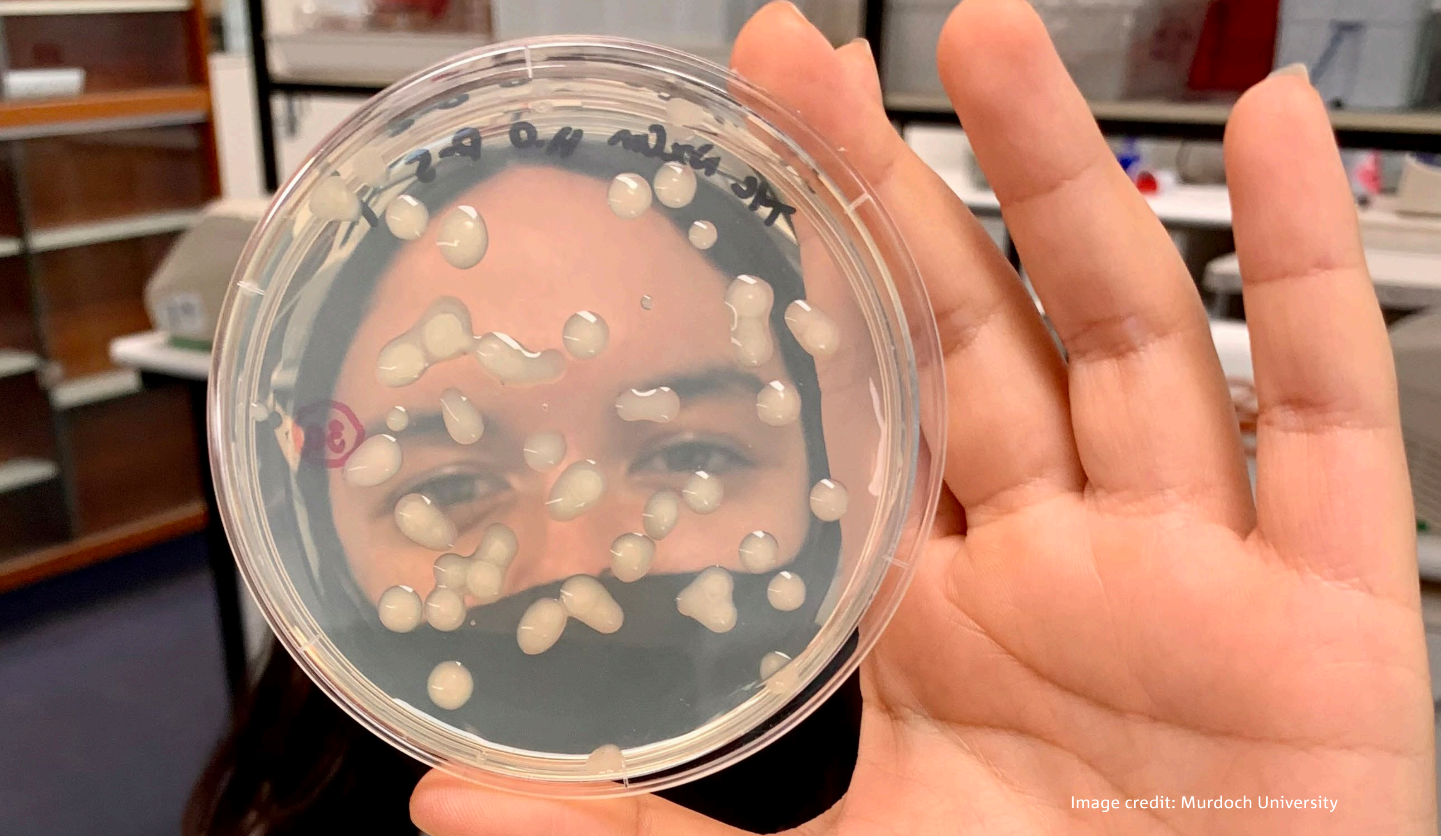


Image credit: Murdoch University

Challenges for bioplastics

Our report identifies key challenges to achieving a system based approach determining the future of bioplastics, including end-of-life management, labelling and certification, regulation, costs, knowledge gaps, trust, awareness, and environmental risks.

End-of-life management	End-of-life management emerged as a complex challenge, with insufficient infrastructure for bioplastics' disposal and recycling being a significant barrier. A lack of coordination and collaboration exacerbates this issue, necessitating investment and a coordinated approach for effective end-of-life management.
Regulation and certification	Clear labelling, certification, and effective regulation are major obstacles hindering the establishment of a circular economy for bioplastics. Consumer confusion is a result of inadequate standards and misleading practices, underscoring the need for improved certification and labelling practices, along with stronger regulatory oversight to counter greenwashing.
Properties and performance	Ensuring the properties and performance of various bioplastic types for appropriate applications is crucial. The balance between compostability and functionality, as well as the viability of bioplastics for specific uses, requires industry-wide collaboration and informed decision-making.
Knowledge, trust, and awareness	A lack of consumer understanding and trust in bioplastics' characteristics, use, and disposal hinders their effective adoption. A focus on consumer education, transparent information sharing, and consistent labelling is essential to address these challenges.
Feedstocks and nature-related risks	While bioplastics offer environmental benefits, they also pose risks related to feedstock sourcing and production processes. Sustainable sourcing, responsible agricultural practices, and mitigating environmental impacts are critical considerations in promoting bioplastics as a more environmentally friendly alternative.

Opportunities for bioplastics

We also present several opportunities to shape the future of bioplastics in Australia. These include PHA as a promising polymer of interest; the potential of bioplastics to further combat food waste; sector-specific applications in agriculture, horticulture, and marine activities; and industry 4.0 technologies that can support the transition to a circular economy for bioplastics.

Niche applications	Bioplastics present a unique potential to address environmental concerns in niche sectors like horticulture, agriculture, and biomedicine. They can replace conventional plastics in these sectors, offering solutions that biodegrade under specific conditions, reducing plastic waste and ecosystem harm.
Combating food waste	Incorporating bioplastic bin liners into the Food Organics and Garden Organics (FOGO) system offers an opportunity to significantly reduce food waste. These liners, derived from renewable resources, can facilitate effective organic waste management, reducing greenhouse gas emissions from landfills and enriching soils.
Polyhydroxyalkanoates (PHA)	PHA, a family of biodegradable polymers, holds promise for commercial viability. With its ability to break down in various environments, PHA can be used in single-use packaging and disposable products. Australian innovators like Uluu are leading the charge in leveraging PHA's potential.
Local manufacturing	While opinions on local bioplastic manufacturing vary, the potential exists to use agricultural and forestry by-products or explore emerging industries like seaweed for production. However, international investments in bioplastics manufacturing are a notable consideration.
Chemical recycling	Advanced chemical recycling offers an innovative solution for bioplastics' end-of-life management. This technology, employed by companies like APR Plastics and Licella, can convert bioplastics into valuable biofuels and biochemicals, promoting a circular economy approach and reducing waste.
Biobased and renewable content targets	Setting targets for incorporating biobased and renewable materials in packaging can incentivise the use of sustainable resources, reducing reliance on fossil fuel-based plastics and promoting sustainable packaging materials.
Clear definitions and labelling	Establishing clear definitions and standardised labelling for bioplastics is crucial for effective communication and education. Biodegradable bioplastics should be required to meet compostable standards, and claims should only be made for certified products, adopting official Seedling logos, and applying the Australasian Recycling Label to inform consumers.
Industry 4.0 technologies	The integration of Industry 4.0 technologies such as IoT, AI, and big data analytics can enhance resource efficiency, reduce waste, and improve end-of-life processes in the bioplastics industry. Real-time monitoring and tracking inputs and materials across the supply chain, optimised manufacturing, and data-driven insights can drive a more sustainable approach to bioplastics.

Finally, our report identifies key enablers to achieving a circular economy for bioplastics, including system-wide collaboration, standardisation, supporting regulation, harmonisation with end-of-life management, research, data collection, communication, and investment.

Introduction

Need for change

Since 2019, the amount of materials flowing through the global economy has exceeded 100 billion tonnes each year.[1] Yet, of all the materials we use across the globe – for sectors from food to manufacturing and mobility – only 8.6% is recirculated back into the system.[2] The circular economy model provides a powerful solution to the environmental challenges brought on by escalating waste. By prioritising regenerative materials, focusing on using materials more efficiently, extending product lifetimes, and using waste as a resource, we have the opportunity to support global efforts towards keeping the global temperature rise below 1.5-degree above pre-industrial levels, as per the Paris Agreement, within the next decade.[1]

During the 2020–21 financial year, Australia generated an estimated 75.8 million tonnes (Mt) of waste, 2.6 Mt of which was plastic.[3] Plastics are a notoriously linear material; of the more than 380 Mt produced annually, some reports state that more than 50% is used for single-use items.[4] Australia recovers only 13% of the plastic used annually through recycling initiatives, which is the lowest recovery rate among all waste streams in the country.[5] In recent years, the global plastics landscape has undergone rapid evolution. This evolution is driven by mounting public concern over plastic waste and pollution; global policy change, such as China's National Sword Policy and the Basel Convention;[6] and initiatives such as the Ellen MacArthur Foundation's New Plastics Economy Global Commitment,[7] and the United Nations-led global treaty for plastic pollution.[8] Governments, major corporations, and non-governmental organisations (NGOs) are increasingly committing to creating a circular economy for plastics.

A focus on bioplastics

As organisations seek alternatives to conventional plastics, bioplastics use has increased.[9] Bioplastics can be derived from renewable, biologically based (termed biobased) feedstocks such as sugarcane. They can decouple plastics from fossil-based sources and result in lower carbon emissions, making for an attractive alternative to conventional plastics. In addition, innovative applications of biodegradable bioplastics can solve industry challenges in agriculture, horticulture, and biomedicine. Within these industries, examples of bioplastics improving overall circular outcomes already exist.

While some bioplastics are derived from renewable sources and have the potential to solve an array of challenges, they are not without their own complexities. Many different types of bioplastics are manufactured using a variety of methods and feedstocks – and without labelling standards – which can cause confusion for consumers. This can lead to contamination across recycling and composting streams and has resulted in a system where bioplastics largely end up in landfill. In landfill, biodegradable bioplastics can break down in anaerobic conditions resulting in methane emissions, which negatively contributes to climate change, wastes resources, and does not achieve circularity.

Despite these challenges, bioplastics present the opportunity to develop innovative materials with better functionality, solve specific environmental challenges, and raise awareness about the environmental issues of conventional plastics, including their impact on climate change. Globally, bioplastics production capacity is set to increase from 2.11 Mt in 2019 to approximately 2.43 Mt in 2024 (representing a 15% increase by weight).[10] However, the uptake of bioplastics is currently limited by high production costs, which impair their price competitiveness relative to their fossil-based counterparts.

Taking a circular economy approach

The concept of a circular economy has gained considerable attention worldwide as a response to the environmental challenges posed by our linear consumption patterns. In a circular economy, resources are used efficiently, waste is minimised, and materials are kept in continuous circulation. This shift away from the traditional 'take-make-waste' model requires innovative approaches, such as the adoption of bioplastics. However, for Australia to effectively embrace the principles of a circular economy, it is crucial to gain a deeper understanding of the role and potential of bioplastics and establish clear standards and regulatory guidelines to ensure their beneficial adoption.

It is important to note that bioplastics are still plastics and, as with conventional plastics, a circular economy approach to their use is required. Australia, like many other nations, is in the early stages of transitioning to a circular economy. While bioplastics offer considerable potential, the current lack of consistent definitions, standards, and labelling practices related to their use is leading to confusion among consumers, policymakers, and businesses. The absence of clear guidelines, based on Life-Cycle Analysis (LCA) to assess the environmental impacts of all options, impedes their effective implementation and adoption. To accelerate the transition to a circular economy and end plastic waste, it is important for Australia to gain a comprehensive understanding of the current state of bioplastics and provide clarity and guidance to all stakeholders involved.

Aims of this report

This report aims to achieve the following:

- Provide an overview of the Australian bioplastics system.
- Identify how key bioplastics flow from feedstocks through to end-of-life.
- Identify opportunities to enhance circular outcomes.
- Identify barriers to adoption of circular opportunities and enablers to overcoming these barriers in Australia.
- Provide a vision for the future of bioplastics and recommendations.

Approach

To address these aims, a range of methods were implemented. A comprehensive literature review was conducted to establish the definition of bioplastics within the Australian context. The review also aimed to identify ongoing initiatives and activities that are shaping the future of bioplastics, specifically focusing on developments within Australia. Furthermore, a series of 10 interviews and two workshops were conducted during 2023; these involved approximately 60 participants, representing a diverse cohort of key stakeholders within Australia's bioplastics system. They included bioplastics manufacturers, finished goods providers, retailers, industry peak bodies, NGOs, researchers, and policy makers, as well as representatives from waste and resource recovery sectors.

Engagement and acknowledgements

A significant aspect of our methodology and project effort involves engaging stakeholders. These interactions are invaluable in driving change, with this document serving merely as a record of the process. We acknowledge the contribution of the following stakeholders in our discussions and workshops, whose insight and opinions helped shape this report.

NAME	WEBSITE	SECTOR
TotalEnergies Corbion	https://www.totalenergies-corbion.com	Bioplastics manufacturing
Uluu	https://www.uluu.com.au	Bioplastics manufacturing
BioPak	https://www.biopak.com/au	Compostable packaging products
TIPA Corporation	https://tipa-corp.com	Bioplastics manufacturing
Pact Group	https://pactgroup.com	Packaging manufacturing
Cardia Bioplastics	https://www.cardiabioplastics.com	Bioplastics manufacturing
Coles	https://www.coles.com.au	Retail
ARC Training Centre	https://www.arc.gov.au	Government
Australasian Bioplastics Association (ABA)	https://bioplastics.org.au	Peak industry body for bioplastics
Australian Council of Recycling (ACOR)	https://acor.org.au	Peak industry body for recycling
Australian Institute of Packaging (AIP)	http://aipack.com.au	Peak industry body for packaging education and training
Australian Packaging Covenant Organisation (APCO)	https://apco.org.au	NGO
National Retail Association (NRA)	https://www.nationalretail.org.au	NGO
Australian Food and Grocery Council (AFGC)	https://www.afgc.org.au	Peak industry body for food and grocery products
Australian Competition and Consumer Commission (ACCC)	https://www.productsafety.gov.au	Government
Waste Management and Resource Recovery Association Australia (WMRR)	https://www.wmrr.asn.au	Peak industry body for waste and resource recovery
World Wildlife Fund (WWF)	https://wwf.org.au	NGO
Planet Ark	https://planetark.org	NGO
Visy	https://www.visy.com	Recycling
Goterra	https://goterra.au	Waste management infrastructure
NSW Environment Protection Authority (EPA)	https://www.epa.nsw.gov.au	Government
Green Industries SA	https://www.greenindustries.sa.gov.au	Government
Local Government NSW (LGNSW)	https://www.lgnsw.org.au	Government
Department of Energy, Environment and Climate Action (DEECA)	https://www.deeca.vic.gov.au	Government
Department of Climate Change, Energy, the Environment and Water (DCCEEW)	https://www.dcceew.gov.au	Government

The CSIRO engaged KPMG to undertake the current state analysis, facilitate stakeholder consultations, and create the material flow analysis that informed this report.

Part 1: What are bioplastics?

Defining bioplastics

The term ‘bioplastics’ is used broadly to describe a variety of different materials; a universal and agreed-upon definition does not yet exist. The interchanging terminology is one of the issues facing the industry, as terminology differences are confusing and misleading for consumers, regulators, and producers alike. Two of the most used definitions for bioplastics come from the International Union of Pure and Applied Chemistry (IUPAC) and Bioplastics Europe.

IUPAC defines bioplastic as a ‘biobased polymer derived from the biomass or issued from monomers derived from the biomass and which, at some stage in its processing into finished products, can be shaped by flow.’ Within this definition, IUPAC notes that ‘bioplastic’ is generally used to describe polymers that are not derived from fossil resources but discourages use of the term, preferring the expression ‘biobased polymer’. This, however, is not the common definition used by bioplastics industry bodies.

The definition from Bioplastics Europe is commonly referred to by industry and defines bioplastics as plastic materials which are either biobased, biodegradable, or both.[11] This definition encompasses plastics that have biobased and/or biodegradable characteristics, whereas the IUPAC definition encompasses only biobased plastics.

In the European Union’s policy framework on biobased, biodegradable, and compostable plastics, the European Commission recommends: ‘To fight greenwashing and avoid misleading consumers, generic claims on plastic products such as “bioplastics” and “biobased” should not be made… In order to avoid misleading consumers, claims should only refer to the exact and measurable share of biobased plastic content in the product, stating, for instance, that the “product contains 50% biobased plastic content”.’ Instead of using the term ‘bioplastics’, the Commission recommends more specificity and defining bioplastics based on their characteristics of being biobased, biodegradable or compostable**.** Addressing the confusion of undefined ‘bio’ claims is an issue the industry will have to tackle as it develops.

For the purpose of this report, the term ‘bioplastic’ has been used in favour of ‘biobased polymer’, as the report discusses both biobased and biodegradable polymers, both of which are encompassed by the term ‘bioplastic’ under industry definitions. Moving forward, a consistent, standardised definition should be adopted in Australia for clarity for consumers, producers, and regulators, and to avoid greenwashing.

Image credit: Pixabay

Characteristics of bioplastics

A biobased bioplastic derives some or all its carbon from a renewable plant or animal source, while biodegradable plastics degrade into carbon dioxide (CO_2), methane (CH_4), and water (H_2O) through biological action in specific environments and timescales, such as composting. Biodegradability and biobased content are two separate characteristics of bioplastics and can exist either together or independently (demonstrated in Figure 1).

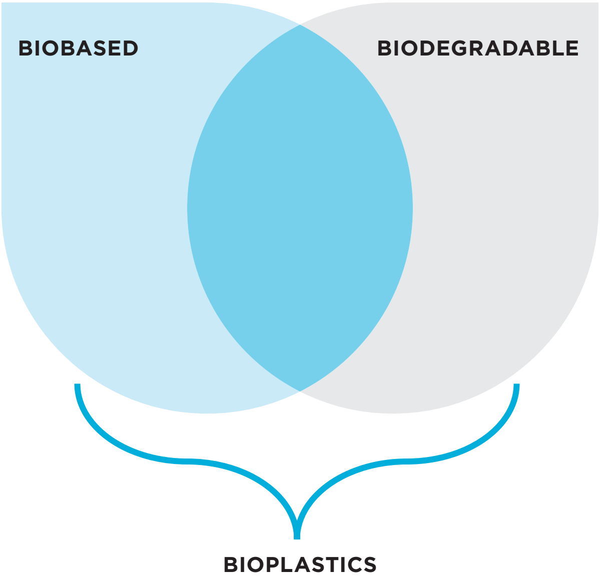
Biobased

Biobased polymers are materials which are produced at least partially from renewable biomass feedstocks, which can include plants, trees, and materials derived from organic waste. The most common biomass feedstocks are carbohydrate-rich food plants such as corn and sugarcane.[5] Biobased bioplastics can be produced entirely from biomass feedstocks or may contain only some components derived from biomass, such as the polymer, filler, or additive. Bioplastics made from biobased polymers can have the same properties and characteristics as fossil-based polymers and do not necessarily biodegrade. Biobased bioplastics can reduce the dependency on fossil resources, resulting in lower emissions of greenhouse gas. Bioplastics can be fully or partially made from biobased feedstocks.

Biodegradable

Biodegradable materials are materials that can be completely assimilated into natural substances, including water, carbon dioxide, and others, by naturally occurring organisms. Biodegradable plastics cannot release toxic chemicals to the environment when they degrade. The property of being biodegradable does not depend on the feedstock of a material but is linked to its chemical structure, and therefore biodegradable plastics may be produced from fossil-based or biobased feedstocks. The term 'biodegradable' is used broadly in waste management to describe materials that will degrade either in composting conditions or the environment. The main difference is compostable materials will degrade within a set time in managed composting conditions that are optimised to accelerate the action of the microorganisms and the enzymes responsible for the biodegradation and production of biomass.

Compostable products require microorganisms, humidity, and heat to yield a finished compost product (carbon dioxide, water, inorganic compounds, and biomass). Claims of compostability should only be made where a product has been certified compostable by accredited third parties to a recognised standard, such as Australian standards AS 4736-2006 (industrial compostable) and AS 5810-2010 (home compostable). These standards are discussed in section 1.5.



A material or product that is either in full or in part derived from biomass (e.g., plants such as corn, seaweed, sugarcane or cellulose).

Biodegradable plastics can be derived from both biobased and fossil-based feedstocks. Biodegradable means a material can be converted into natural substances including water, carbon dioxide and others by naturally occurring organisms.

Figure 1 – Defining bioplastics. Adapted from the Australasian Bioplastics Association (ABA).

Plastics that biodegrade in the environment must do so in unmanaged conditions that are less optimal for the microorganisms to assimilate them. A biodegradable statement must always be associated with the environment in which it may occur. There are generally three classifications for environmentally biodegradable plastics: soil-, marine- and water-biodegradable. In Australia, only the soil-biodegradable standard is accredited to ISO 23517, but other certifications (e.g., TÜV OK biodegradable SOIL, TÜV OK biodegradable WATER, and TÜV OK biodegradable MARINE) exist. Further details are available in section 1.5.3. Compostable plastics do not necessarily degrade in the environment or do so slowly, but environment biodegradable plastics are often also compostable.

It's important to note that a certified compostable bioplastic resin may lose its ability to biodegrade when compounded with other materials to create a final product. The thickness of the manufactured product or the additives may affect the biodegradation rate, so if not certified compostable as a finished product, it should not be promoted as such. Further details on labelling and certification can be found in section 1.5.3.

1.1 The types of bioplastics

As presented in the previous section, bioplastics are either biodegradable or biobased, or both. However, these categories are not exclusive, and there can be crossover between the different categories as highlighted in Figure 2. There are three basic polymer groups within the bioplastic realm: fossil-based biodegradable polymers, biobased biodegradable polymers, and biobased non-biodegradable polymers.

Biobased non-biodegradable

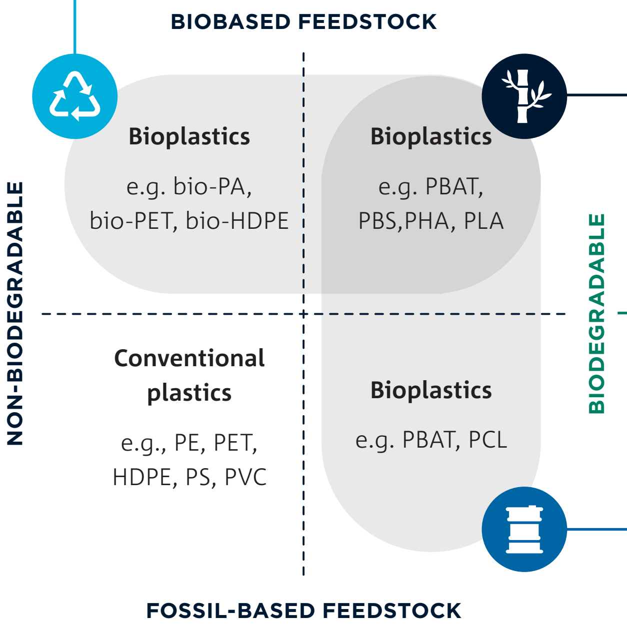
Bioplastics can be non-biodegradable but still derived from biobased feedstocks.

Biobased non-biodegradable bioplastics can be used to manufacture products that are suitable for plastic recycling processes, as they are chemically identical to conventional fossil-based plastics.

These products are increasingly emerging on the market as a renewable solution to virgin fossil-fuel inputs.

Biobased biodegradable

Biobased biodegradable refers to bioplastics that are derived from biobased feedstock and that completely biodegrade into natural substances either in composting conditions or in the environment.



Certified compostable

Compostable is used to describe a product that can biodegrade into non-toxic, natural elements within a set timeframe and specified composting conditions. Both fossil-based and biobased bioplastics may be certified compostable. Claims of compostability should only be made where a product has been certified compostable to a recognised standard such as Australian standards AS 4736-2006 or AS 5810-2010.

Fossil-based biodegradable

Fossil-based biodegradable plastics are a comparatively small group. Materials such as PBAT and PCL belong in this category. These biodegradable plastics are currently predominately produced using fossil-based feedstock. However, biobased versions of these materials are also being developed.

The use of the term bioplastic for fossil-based biodegradable bioplastics is controversial, owing to the potential confusion with biobased materials from biomass feedstocks.

Figure 2 – The types of bioplastics. Adapted from Bioplastics Europe.[9]

1.2 Overview of the bioplastics value chain

Figure 3 outlines the key stages in the bioplastics value chain, including feedstocks, material manufacturing, production and use of final products, and end-of-life management. This chapter explores each of these stages in greater detail.

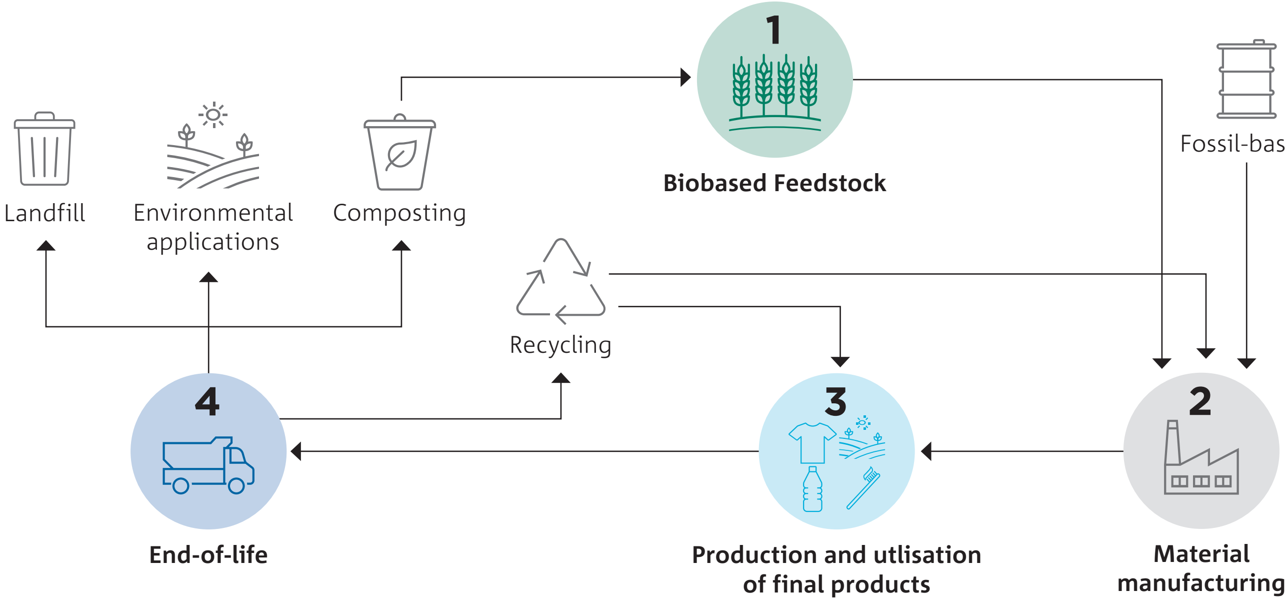


Figure 3 – The bioplastics value chain. Adapted from European Bioplastics.[10]

1.2.1 Feedstocks

Bioplastics can be manufactured from a wide variety of feedstocks, which may be biobased or fossil-based, as displayed in Table 1.

Table 1 – Bioplastic feedstocks.[10]

EXAMPLES OF BIOPLASTIC FEEDSTOCKS	
Sugarcane	Feathers
Corn	Algae
Soybeans	Wood
Canola	Natural gas (methane)
Castor beans	Oil (petroleum)
Used cooking oil	Organic waste

Feedstocks used for biobased polymers are categorised as follows:

- **First generation** – Substances retrieved from plants that are otherwise used in the food sector, including rice, sorghum, soy, beet, corn, palm, barley, sugarcane, wheat, and potatoes.
- **Second generation** – Lignocellulosic feedstocks gained from non-food crops or as by-products from the cultivation of food crops such as non-edible biowaste products like potato peels, sugar bagasse, and cooking oil wastes.
- **Third generation** – The most innovative forms of feedstock extractions from a range of substrates like whey, industrial and municipal waste, seaweed, or algae.

Traditionally, fossil-based feedstocks have been used to produce conventional plastics such as polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC) and polyethylene terephthalate (PET), as well as several fossil-based biodegradable polymers such as polybutylene adipate-co-terephthalate (PBAT) and polyvinyl alcohol (PVA).[12]

Feedstock considerations

Potential competition between the production of biobased bioplastics and agricultural production was explored in our research.[13] European Bioplastics reports that, in the foreseeable future, bioplastics production is projected to use less than 0.06% of global agricultural land, indicating no significant competition with food production.[14] However, a Greenpeace report noted the importance of considering the geographic distribution and concentration of land used for bioplastics production.[15] Additionally, bioplastics production requires considerable use of fresh water for crop cultivation, e.g., corn farming for PLA production.[16] Research and innovation into improving the commercial viability of second- and third-generation feedstocks is ongoing, specifically to establish processes to convert agricultural wastes such as forestry by-products, wheat straw, and sugarcane bagasse. These agricultural wastes are typically inexpensive but require additional pre-treatment steps to liberate fermentable cellulose and hemicellulose sugars from protective, phenolic, crosslinked lignin polymer networks.[17]

1.2.2 Polymer manufacturing

Similar to traditional oil refineries, biorefineries convert biobased feedstocks into chemicals and fuels to be used for bioplastic production.[108] Manufacturing processes of bioplastics polymers can vary depending on the specific type being produced. Primary methods of producing biobased bioplastics include:

1. Polymerisation of biobased monomers, which involves joining monomers produced from natural resources to form polymer chains.
2. Modification of naturally occurring polymers, which involves using natural polymers such as cellulose, which forms cellulosics.
3. Extraction of polymers from microorganisms,[18] which can involve using bacteria to synthesise and accumulate biopolymers.

Table 2 lists several primary biobased polymers grouped by their production process and followed by a brief description of their synthesis.

Table 2 – Biobased polymers grouped by production route with a brief description of their synthesis.[13]

POLYMER	TECHNOLOGY OVERVIEW	ROUTE
Polylactic acid (PLA)	PLA is synthesised through a polymerisation process involving lactic acid monomers. The lactic acid is then polymerised into PLA chains through a process called condensation polymerisation.	1
Polybutylene succinate (PBS)	PBS is synthesised through a polymerisation process involving succinic acid and 1,4-butanediol as the main monomers, which combine under specific conditions to form PBS polymer chains.	
Polyurethanes (PU)	Polyols obtained from plant oils are reacted with isocyanates or bio-isocyanates to produce polyurethane (PU).	
Polyamides (PA)	Diacids derived from castor oil are reacted with a diamine to produce PAs. A typical pair is sebacic acid and decamethylene diamine (obtained from the acid).	
Polyethylene (PE)	Polyethylene is synthesised through the polymerisation of ethylene monomers. In the case of bio-polyethylene (BioPE), ethylene is produced from the plant-derived feedstocks through processes like fermentation or gasification.	
Thermoplastic starch blends	Typically obtained by gelatinisation of starch (from corn, cassava, etc.) followed by casting or by extrusion of starch pellets and plasticisers.	2
Cellulose acetate	Cellulose from wood pulp is converted to a triacetate form which is then hydrolysed to cellulose acetate.	
Regenerated cellulose	Cellulose is converted to a soluble form then regenerated to obtain a film (cellophane) or a fibre (rayon).	
Polyhydroxyalkanoates (PHA)	PHAs are synthesised by bacteria through a fermentation process that involves the accumulation of these polymers as energy and carbon storage materials. Polyhydroxybutyrate (PHB) was the first to be discovered.	3

1.2.3 Production and use of final products

Although bioplastics are commonly associated with packaging, they are used in various applications and sectors, from agriculture to automotive. Figures from European Bioplastics showed that the global bioplastic market in 2022 included several categories, with the three largest being flexible packaging at 695,600 tonnes, rigid packaging at 376,100 tonnes, and fibres at 328,900 tonnes. Other major markets included consumer goods at 312,400 tonnes, automotive and transport at 159,000 tonnes, and agriculture and horticulture at 97,400 tonnes. This report will explore these applications and markets in subsequent chapters.

1.2.4 End-of-life

Bioplastics' end-of-life phase starts at the point of disposal by a customer (either a consumer or business) and involves various end routes, including reuse of the product without any structural changes (i.e., lifetime extension); remanufacturing where a discarded, non-functional, or traded-in product is restored to like-new condition; recycling, which involves the collection and treatment of waste products for use as raw material in the manufacture of the same or similar ones; incineration, where combustible wastes are burned and changed into gases (with or without energy recovery); dumping waste underground or landfill; and emission or leakage into the environment.

In a circular economy, plastics would be derived exclusively from recycled sources or, where unfeasible, renewable sources. The current reality deviates significantly from this ideal, with most plastics following a linear lifecycle. Globally, although many bioplastic types are designed for recycling or composting, limitations in current infrastructure for both collection and treatment, along with gaps in consumer understanding and environmental regulation, hinder their processing, which often results in their disposal in landfill. In the 2022 National Waste Report for Australia, bioplastics were included within the broader plastics category.[5] Australians discard 2.9 Mt of plastic waste annually with only 13% being recovered for recycling and the remaining 87% sent to landfill;[19] composting as an end-of-life treatment is not mentioned in these figures. Australia's waste system will be reviewed in greater detail in part 2 of this report.

It is important to note the difference between *intended* end-of-life versus *actual* end-of-life management. The intended end-of-life management of bioplastics depends on their specific properties. Biodegradable biopolymers may be processed through methods such as composting, biological degradation, anaerobic digestion, or soil burial; some can also be mechanically recycled. Conversely, non-biodegradable biopolymers can be recycled mechanically like conventional plastics. Chemical recycling presents an alternative to mechanical recycling.

Table 3 outlines current end-of-life management options for bioplastics.

Table 3 – Intended end-of-life for bioplastics.[22]

INTENDED END-OF-LIFE MANAGEMENT	DESCRIPTION
Biodegradation and composting	Microorganisms break down biodegradable biopolymers into natural substances such as water, carbon dioxide, and methane. Composting achieves this within a specific timeframe and under pre-decided environmental conditions to create nutrient-rich soil amendments for agricultural use. The conditions for compostable and biodegradable do not require the creation of nutrients as part of the process, but they need to demonstrate a lack of toxicity in the creation of biomass. The material when composted will actually contribute positively to the growth of feedstock.
Anaerobic digestion	Anaerobic digestion is a process in which microorganisms break down organic matter in the absence of oxygen. This process produces biogas, which may be captured and used as a renewable energy source. Anaerobic digestion is often used to process biowaste from households and commercial sources. Organic waste is ideally connected with a subsequent composting step.
Mechanical recycling	Plastics are sorted by polymer type and mechanically shredded, washed, and melted to be remoulded into new forms. Drop-in biobased bioplastics such as BioPE can be recycled alongside their conventional counterparts, as they are chemically identical.
Chemical recycling	Chemical recycling presents an alternative to mechanical recycling and has the potential to create high-quality polymers from waste. Materials are depolymerised into their monomeric subunits, which can then undergo controlled polymerisation mechanisms to create high-quality polymers.
Landfill	A landfill is a designated area where waste materials are deposited and buried in the ground. In Australia, 45% of all generated waste is directed to landfill.[20] It is a common method of waste disposal for solid waste and also the primary method for plastic waste disposal.
Other	Biological and enzymatic degradation, incineration, degradation for specific environmental applications; e.g., soil or marine.

1.2.5 Advantages and disadvantages of bioplastics

Bioplastics present a promising solution to many environmental challenges, including reducing fossil fuel dependency, mitigating plastic pollution, and optimising material circulation. However, bioplastics also present certain challenges, such as high production costs and the need for dedicated infrastructure. Table 4 outlines key advantages and disadvantages to bioplastics adoption.

Table 4 – Advantages and disadvantages of bioplastics adoption.[21]

		BIOBASED	BIODEGRADABLE
Advantages	Reduces fossil fuel dependency by utilising renewable resources.	✓	
	Can replace existing plastics with biobased counterparts, such as drop-in plastics with the same functional properties.	✓	
	Can offer climate-related benefits by reducing global warming potential.	✓	
	Can be used to transport food waste to soil (e.g., caddy liners) and used in products that commonly contaminate food waste streams (e.g., teabags).		✓
	Contributes to anaerobic digestion, producing significant energy and optimising the carbon-to-nitrogen ratio.		✓
	Can potentially mitigate plastic pollution by replacing non-degradable plastics in environmental leakage-prone products (e.g., agriculture).		✓
	Innovative film/barrier applications may improve the end-of-life outcomes for some packaging formats.	✓	✓
	Wide range of polymer types with a variety of properties that may be applied in applications across industries to improve environmental outcomes (e.g., biomedicine, agriculture, horticulture etc.).	✓	✓
Disadvantages	High production costs and possible lower performance compared to conventional plastics.	✓	✓
	Early stages of commercialisation with limited technologies and low conversion ratios for some polymer types.	✓	✓
	Insufficient market volume to justify major investments or redesign of production and waste management infrastructure.		✓
	Primary feedstocks may compete with the biofuel and food industry.	✓	
	May contaminate existing mechanical recycling streams with biodegradable plastics.		✓
	Potential GHG emissions from landfilling biodegradable plastics.		✓
	Lack of dedicated composting and recycling infrastructure and logistics.		✓
	Uncertainty regarding biodegradability in different open environments.		✓
	Lack of consumer understanding for materials at end-of-life.	✓	✓
	Environmental impacts e.g., biodiversity loss (ecosystems and soil), emissions and waste associated with manufacturing and leakage to the environment.	✓	
	Barrier properties may be limited and not meet the functional requirements for some packaging formats.		✓

1.3 Bioplastic polymers

Bioplastics are not just one single material. They comprise a whole family of materials with different properties, applications, and end-of-life management processes. This study investigates the following six common bioplastic types in greater detail: PLA, Starch blends, PHA, PA, PE, and PBAT. These have been selected based on market share and their potential for improved environmental outcomes. Table 5 outlines key properties, including feedstocks, applications, end-of-life treatment, environmental considerations and markets. Refer to Appendix 1 for greater detail on each biopolymer.

Table 5 – Key properties of various bioplastic polymers.

POLYMER TYPE	FEEDSTOCK AND CONVERSION	APPLICATION	END-OF-LIFE MANAGEMENT	ENVIRONMENTAL CONSIDERATIONS	GLOBAL MARKET SHARE
PLA	The most common feedstocks used for PLA include corn, sugarcane, corn stover (stems, husks, and leaves), cassava root.	Packaging Food service ware Coatings 3D printing Textiles Medical implants Agriculture	**Mechanical recycling** - PLA can be recovered for mechanical recycling; however, due to its prevalence in low volumes, it is not separated in post-consumer waste streams. **Industrial composting** - Depending on the application, PLA can be composted under commercial composting conditions. To ensure PLA products are suitable for compost, it is essential to use a certified compostable PLA resin and have the final products undergo their own compostability testing. **Home composting** - Depending on the application, PLA can be composted at home. However, achieving certification for home composting biodegradation is challenging due to the inefficiencies of home composting systems compared with commercial operations. **Landfill** - Landfill is a common waste treatment for PLA but is not ideal waste for this type of material and should be avoided.	Environmental impacts will differ depending on the feedstock used to produce the PLA. Sugarcane is the most efficient feedstock for producing PLA, and as such has the lowest emissions and non-renewable energy demand due to its high productivity yields. Alternatively, land requirements for use of corn stover are lower than those of sugarcane or corn. On average, PLA saves approximately 66% of the energy required to produce conventional plastics. Through natural conversion, PLA emits 2.8 kg CO_2 kg^{-1} throughout its lifecycle.	20.7%
Starch blends	The most common feedstocks used are potato, corn and wheat starch, side stream starch from potato processing (and/or grain, root, or seed flour-based resources), and starch reclaimed from wastewater. Starch-based bioplastics are complex blends of starch with compostable plastics such as PLA, PBAT, PBS, PCL and PHAs.	Packaging Packing peanuts Food service ware Coatings and films Pharmaceuticals	Composting Landfill Environmental degradation (e.g., soil)	Starch plastics have been shown to enable reductions in greenhouse gas (GHG) emissions and non-renewable energy use. However, they have higher eutrophication potential (overabundance of nutrients in water, primarily nitrogen and phosphorus) and require more agricultural land use compared to common fossil-based plastics. The potential GHG emissions savings are influenced by the composition of the plastic. Some grades can offer an 85% reduction, while others can offer an 80% increase compared to their fossil-based counterpart.	17.9%

POLYMER TYPE	FEEDSTOCK AND CONVERSION	APPLICATION	END-OF-LIFE MANAGEMENT	ENVIRONMENTAL CONSIDERATIONS	GLOBAL MARKET SHARE
PHA	The most common feedstocks used for PHA include corn, sugar, and vegetable oils. Today, many PHA-producing start-ups are working with innovative technologies that use wastewater streams, plastic waste, renewable methane, and carbon dioxide as feedstock.	Depending on type and grade, PHA can be used for injection moulding, extrusion, thermoforming, foam, non-wovens, fibres, 3D-printing, paper and fertiliser coating, glues, adhesives, as additive for reinforcement or plasticisation, or as building block for thermosets in paints and foams. The main markets where PHAs have already achieved some degree of penetration are packaging, food service, agriculture, and medical products.	Most PHA types degrade faster than PLA, which makes them attractive for applications in which biodegradation is desired. Among the advantages of PHA is the relatively high degradation rate in marine environments. After one year in a marine environment at 30° C, PLA biodegrades by approx. 8%, while PHBV (a type of PHA) degrades by approx. 80%. Additionally, PHA can be (in theory) mechanically recycled, though no material recycling facilities in Australia are currently set up to recycle PHA. Different PHA types are better suited to the mechanical recycling process, with PHB properties significantly reduced after two processing cycles, while PHBV maintains its tensile strength after seven processing cycles. PHA can also be biologically recycled under both aerobic and anaerobic conditions. As such, they can be suitably treated both by compositing and by anaerobic digestion. However, further research is needed on the degradation of PHA under aerobic conditions through composting.	Carbon dioxide and methane can be used as feedstocks to produce PHA, helping reduce greenhouse gases in the atmosphere. As PHAs are 100% biodegradable, PHA materials won't turn into microplastics which lower the uptake and storage of carbon dioxide in our oceans.	3.9%
BioPA	The most common feedstocks used for BioPA are vegetable oils, castor plants and oil, sugarcane, sugar beet, and starch.	PA bioplastics exhibit high heat resistance, stiffness, and mechanical stability, making them suitable for a range of applications across various industries. BioPA is often used for technical parts (in the transport and automotive industry), textiles, and regular consumption goods. BioPA is also used in the sport and leisure industries, primarily in injection moulding. As such, it is also used in 3D printing.	There is limited information available regarding end-of-life management options for BioPA. Supplier Technoform claims that their BioPA has unlimited recyclability. Fossil-based PAs such as nylon can be mechanically and chemically recycled; however, their collection is limited.	The environmental impacts of BioPA are unclear, though specific manufacturers have made claims regarding their products. Technoform claims that their BioPA production reduces carbon dioxide consumption during profile production by 62% and fossil-fuel energy consumption by 23%. It is important to note that this claim did not make explicit the basis for these comparisons; however, we have assumed that the comparison is made with conventional PA. Another manufacturer, Roboze, claims their BioPA is produced with 60% lower carbon emissions than conventional PA.	11.1%

POLYMER TYPE	FEEDSTOCK AND CONVERSION	APPLICATION	END-OF-LIFE MANAGEMENT	ENVIRONMENTAL CONSIDERATIONS	GLOBAL MARKET SHARE
BioPE	Typical feedstocks used for BioPE include sugarcane, sugar beet, lignocellulosic crops and waste, and starch crops such as maize and wheat.	BioPE can be used in the same applications as its conventional counterpart. Some common applications for PE include food packaging, agricultural use, and industrial use. PE also has applications across toy manufacturing, cosmetics, and personal care.	As a biobased equivalent of conventional PE, BioPE can be recycled in the same way as PE. As such, BioPE can be integrated into already formed waste streams and does not require separate waste infrastructure. A study conducted indicated that recycling of BioPE in conventional recycling (alongside fossil-based PE) did not lower the quality of the recylates.	Land use, human health and biodiversity must be considered due to the use of first-generation feedstocks. BioPE results in significant GHG emissions reduction when compared with its conventional counterpart. The typical emissions profile of BioPE is around 0.75 kg CO_2-eq per kg polyethylene, which is 140% lower than the production of fossil-based PE. Additional, BioPE reduces non-renewable energy usage by approximately 65%.	14.8%
PBAT	Feedstocks for PBAT may be biobased or fossil-based or a combination of both. The main feedstocks for PBAT are petrochemicals and castor plant.	PBAT has similar properties to LDPE, and as such can be used as an alternative for this product. PBAT is designed for film extrusion and extrusion coating, and as such has common applications across several industries for different film requirements. One such application is use in agricultural mulch films, where PBAT can degrade in soil over a period of >9 months.	In commercial composting, PBAT biodegrades within 2-3 months. PBAT is also commonly used in agricultural films where it can degrade in soil over a period of >9months.	Although PBAT can biodegrade and be compostable, it still has an impact on the environment if not disposed of properly. The composting process also requires specific conditions to break down the material effectively and will depend on how the polymer is used in the finished product.	4.5%

1.4 Global market snapshot

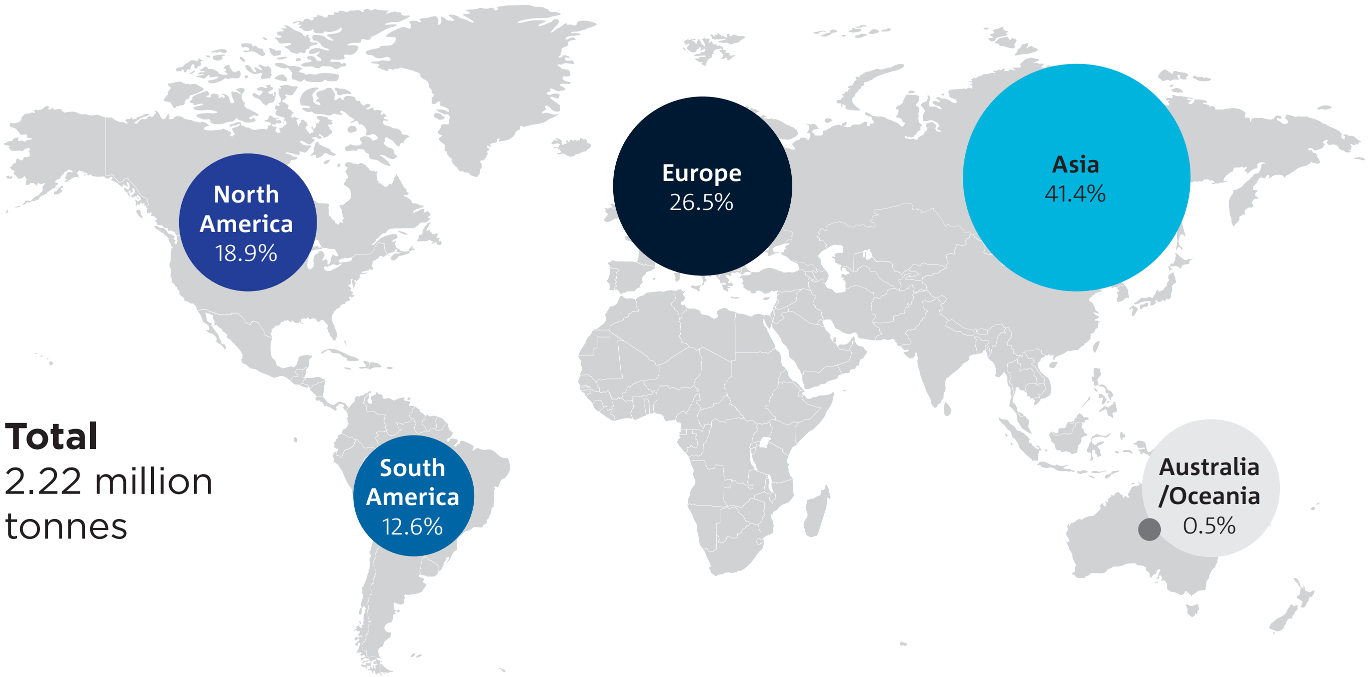


Figure 4 – Global production capacities by region.[10]

The annual worldwide production of biobased bioplastics using 100% renewable feedstocks is currently around 2 Mt, with biodegradable plastic accounting for two-thirds of that amount.[22] When also including partially biobased polymers, global production was 4.4 Mt in 2023 and it is expected to reach over 10 Mt in 2028.[23] In contrast, the annual production of fossil-based plastic is over 380 Mt per year.[24]

Owing to similar expected fossil-based plastic growth, the global market share of bioplastics is expected to remain low at 2%, with a compound annual growth rate of 4%. In Europe, the annual growth rate of biobased bioplastics is expected to be 10%, driven by upcoming regulations and increased demand for sustainable products. If bioplastics were subsidised and politically supported in a similar way to biofuels, the global growth rate could reach 10-20% annually.

Examples of bioplastics already on the market produced by companies in Europe, the USA, and Asia include Ecoflex® and Ecovio® manufactured by BASF (Germany), the Luminy® PLA portfolio by TotalEnergies Corbion (Netherlands), Ingeo™ by NatureWorks LLC (USA), CJ PHACT by CJ CheilJedang (Korea), Mater-Bi by Novamont (Italy), and PHA-based bio-polymers by Tianjin Guoyun (China).[25] Figure 4 shows the global production capacities by continent in 2022; Asia holds 41.4% of the market followed by Europe at 26.5%.

The largest market for bioplastics is flexible and rigid packaging, fibres, and consumer goods (see Figure 5). Growth in these markets is expected to continue due to potential investors seeking better environmental, social, and governance outcomes. Investment in and scaling of bioplastic technologies remain high-risk businesses due to uncertain demand, high prices, and undefined end-of-life management.

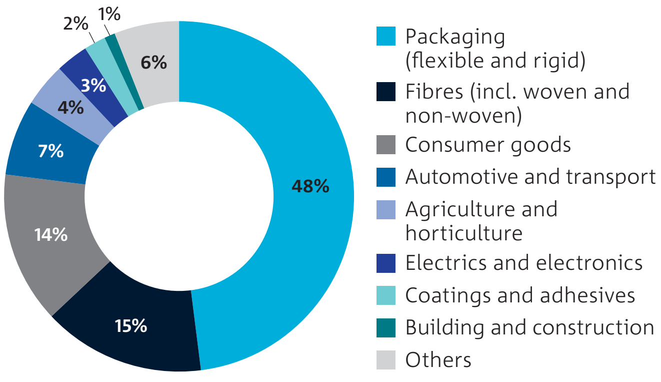


Figure 5 – Global production of bioplastics in 2022 by material type.[10]

1.5 Local and global regulatory landscape and standards

1.5.1 Local regulatory landscape and standards

Australia is increasingly committing to a circular economy. In 2022, the Federal Government committed to an ambitious target of transitioning towards a circular economy by 2030. On 9 June 2023 at the Environment Ministers Meeting, ministers met with a renewed purpose to work together to achieve a ‘nature positive Australia’ to leave the environment better off for future generations.[26]

Within their commitments, ministers agreed the need to ‘shift Australia toward a safer, circular economy by putting in place a new packaging regulatory scheme that will, for the first time, develop mandatory packaging design obligations, so packaging is designed to minimise waste and be recovered, reused, recycled, and reprocessed’.[27] For the first time, Australia will mandate obligations for packaging design as part of a new packaging regulatory scheme based on international best practice and make industry responsible for the packaging they place on the market. This scheme will also regulate to remove harmful chemicals and other contaminants in packaging. To support food waste recycling, ministers agreed that a timeline will be set to remove contaminants from compostable food packaging. They also agreed on developing a national roadmap for staged improvements to the harmonisation of kerbside collections, considering circumstances of metropolitan, regional, and remote communities for ministers to consider in 2024.

These commitments send clear signals to industry that outcomes for a regenerative circular economy are a priority.

Single-use plastic bans relevant to bioplastics

In addition to the regulations above, as part of the National Plastics Plan 2021, a range of single-use plastic bans have been implemented in Australia.[28] Each state is tackling this situation differently; some states’ bans are inclusive of PLA and some exclusive, increasing confusion for consumers using these products. Figure 6 below shows some of the different laws relating to single-use plastic and highlights the complexity of regulation across the country.

WA

Banned: disposable plastic cups or plastic glasses of any kind used for cold drinks, disposable paper cups which have any form of plastic or bioplastic, disposable cups made purely from compostable plastic (PLA), unlidded bowls/containers/straws (includes PLA coated paperboard products without lids)

Exempt: disposable plastic cups used for hot drinks, containers used for food, PLA cups with a lid, certified compostable paperboard bowls lined with PLA, PLA clear bowls with a lid, lidded containers including PLA, large serving ware (platters), compostable utility/barrier bags

NT

Exempt: compostable AS4736 bags

QLD

Banned: un lidded PLA bowls and containers

Exempt: PLA straws and cutlery, lidded bowls certified compostable (home or industrial), PLA coated paperboard, compostable utility/barrier bags (bin liners, dog bags)

SA

Banned: PLA straws

Exempt: PLA bowls and line paper cups, compostable bags AS4736

VIC

Banned: PLA straws

Exempt: PLA cups, containers, lined cups, lined paperboard containers, compostable utility/barrier bags

NSW

Banned: PLA straws, containers or bowls without spill-proof lids

Exempt: PLA containers or bowels designed to be used with spill-proof lid (must be sold with lid), PLA cups and PLA lined paper cups, compostable utility bags/barrier bags

ACT

Banned: PLA cutlery and stirrers

Exempt: PLA bioplastic is an acceptable replacement product for expanded polystyrene. Compostable AS4736 bags exempt

TAS

Exempt: PLA products and compostable bags (home or industrial certified)

Figure 6 – Australian State-based regulations on single-use plastics to be implemented 2023-2026.

1.5.2 Global regulatory landscape and standards

Governments and international bodies are increasingly prioritising circular economy principles. The United Nations (UN) recognised plastic pollution as a priority during its 73rd Session in 2018–2019. In response, 187 UN-member nations amended the directives of the Basel Convention in 2019 to include plastic waste, introducing new transparency and regulatory requirements.[29]

Collaborative efforts between the United Nations Industrial Development Organization, G20 nations, and the Plastic Waste Partnership are underway to implement circular economy measures. These initiatives encompass various stages of the plastic life cycle, including selective plastic bans, clear labelling standards, consumer engagement in waste management, and financial incentives for renewable resources and chemical recycling.[30]

Regarding bioplastics, the Basel Convention's Open-ended Working Group recommends that nations define and standardise the identification of bio(degradable) plastics, improve the economic and ecological competitiveness of bioplastic production processes compared to fossil-based plastics, and develop universal techno-economic analysis methodologies to assess the environmental benefits of bioplastics.[31]

The Ellen MacArthur Foundation is advocating for the creation of a UN treaty that incorporates legally binding global rules and comprehensive circular economy measures.[32] This treaty presents a unique opportunity to bring about significant changes in systems and effectively address the issue of plastic pollution. The Foundation emphasises the importance of legally binding rules in stimulating investment and innovation necessary for driving global change. The Foundation suggests prioritising plastic packaging initially, as it constitutes approximately 40% of total plastic waste and is more likely to end up in the environment.

In the USA, the current (Democratic) administration is committed to environmentally and climate-focused policies, including clean energy technologies and addressing ocean plastics.[33] The Break Free From Plastic Pollution Act, introduced in the House of Representatives in February 2020, aims to limit single-use items and non-recyclables by establishing a tax on carry-out bags and holding plastic producers accountable for collecting and recycling their products. The bill also prohibits the export of plastic waste to non-OECD countries.[34]

China, the world's largest producer of single-use plastics, announced a ban on non-recyclables other than degradable bioplastics by 2025 in 2020.[35] This has led Chinese manufacturers to increase production capacities for PLA, PBAT, and PBS, which may impact global market prices for these polymers. Other countries like Japan, Malaysia, Singapore, and South Korea have implemented financial subsidies for bioplastics.[36]

The European Union (EU) has introduced several plastics policies within the framework of the European Green Deal and Circular Economy Action Plan. One of the goals is to achieve a recycling target of 50% for plastic packaging by 2030. As of January 2021, certain single-use plastic items and oxo-degradable plastics have been banned for sale in the EU. The EU is also restricting low-grade plastic waste exports outside its borders and implementing a tax on non-recycled plastic to encourage the adoption of recyclable, reusable, or compostable materials. Extended Producer Responsibility (EPR) schemes, currently limited to packaging materials, need to be expanded to other plastic-intensive industries, and their implementation and definitions require improvement. The EU is developing a regulatory framework for bioplastics to prevent false sustainability claims and plans to revise and harmonise existing standards for more realistic biodegradation testing.

1.5.3 Labelling and certification

Plastic products are often labelled to indicate their chemical composition and whether they are recyclable, biobased, and/or biodegradable, including the conditions under which they biodegrade. The Australian Competition and Consumer Commission (ACCC) recently published draft guidance to improve the integrity of environmental and sustainability claims made by businesses and protect consumers from greenwashing.[37]

Identification labels

The most common labels on plastic products are the plastic resin identification codes which identify the polymer but provide no information on the recyclability. The older version of these labels – the 'chasing arrows' – still appears on products, and many consumers still falsely believe that products with these labels are recyclable. Biobased bioplastics such as PLA are currently labelled as '7' ('Other').

Recycling-oriented labels

The Australian Recycling Label developed by the Australian Packaging Covenant Organisation aims to provide clear and concise information to help consumers make environmentally responsible choices when disposing of their packaging.

Globally, a range of recycling-oriented labels exist in attempt to guide consumers. The 'Green Dot' symbol used in the EU indicates that producers have paid an ERP fee to fund collection and recycling programs, but it does not guarantee that the product can be recycled. The UK's on-pack recycling label (OPRL) recommends whether consumers should dispose of plastic packaging components in trash or recycling bins based on the likelihood of successful collection, sorting, and reprocessing. DIN CERTCO, a German certification body, has introduced labels to certify the recyclability of plastic products based on the polymer and existing recycling infrastructure. The 'How2Recycle' logo in the United States is a standardised labelling system that communicates recycling instructions to the public. Additionally, certification labels for recycled content are being proposed.

Biobased content labels

Labels have also been developed to certify the biobased content in plastic products. The 'DIN-Geprüft biobased' label, granted by DIN CERTCO, and the 'OK biobased' label, granted by TÜV Austria, are certifications commonly used to indicate the biobased content of products. The US Department of Agriculture's BioPreferred® Program issues a label based on third-party analysis, while in Japan, the Japan BioPlastics Association issues biobased labels. These labels adhere to recognised standards such as EN 16640 (Europe), ISO 16620 (international), and ASTM D6866 (USA). The Australasian Bioplastics Association (ABA) offers certification of biobased content.

Compostability and biodegradability labels

The ABA administers a voluntary verification scheme for companies or individuals wishing to verify their claims of compliance with Australian standards AS 4736-2006 and AS 5810-2010. Figure 7 presents the logos for these two certifications.

Australian standard AS 4736-2006 relates specifically to biodegradable plastics suitable for composting and other microbial treatment. This standard refers to industrial composting and specifies requirements and procedures to determine the compostability of plastics, noting that this refers exclusively to biodegradable plastic shopping bags.[38] The standard requirements under AS 4736-2006 include:[39]

- Minimum of 90% biodegradation of plastic materials within 180 days in compost.
- Minimum of 90% of plastic materials should disintegrate into less than 2 mm pieces in compost within 12 weeks.
- No toxic effect of the resulting compost on plants and earthworms.
- Hazardous substances such as heavy metals should not be present above the allowed levels.
- Plastic materials should contain more than 50% organic materials.

Australian standard AS 5810-2020 is the additional standard (with the same requirements as above) for home-compostable biodegradable plastics. The requirements are the same as the 12 weeks mentioned above except the testing period is 12 months (due to differences in home and industrial composting).[40]

Figure 7 – Logos for AS 4736-2006, AS 5810-2010 and ISO 23517 administered by the Australasian Bioplastics Association (ABA).

The ABA has also launched a program for verifying compostable materials and products to the requirements of ISO 23517:2021. The 'Soil Biodegradable' logo (Figure 7) identifies and differentiates materials and products as biodegradable in soil. To be certified compostable and carry this logo, suitable biopolymer materials must undergo a stringent test regime described in ISO 23517, carried out by recognised independent accredited laboratories to the ISO 23517 standard.[41]

Globally, 'OK compost' and 'BPI Compostable' labels, along with the Seedling logo, are currently used to communicate industrial compostability. These are based on four tests specified in the standards EN 13432 and ASTM D6400:

- Biodegradation (90% of material is converted into carbon dioxide in inoculum derived from compost at 58° C after 6 months).
- Disintegration (90% of material is smaller than 2 mm after 3 months at 40–70° C, depending on the standard).
- Ecotoxicity (90% of regular plant growth in soil with plastic present).
- Heavy metal content (must not exceed a certain threshold).

TÜV Austria's 'OK biodegradable' certifications

TÜV Austria has also developed labels and certification procedures for different environments in which plastics may end up, including home composting, soil, water, and marine environments. Currently, only items certified under Australian composting standards are accepted for composting within Australia. The certifications are as follows:

- TÜV AUSTRIA OK biodegradable MARINE: Requires 90% biodegradation within a maximum of 6 months at a temperature of 30° C.

- TÜV AUSTRIA OK biodegradable WATER: Requires 90% biodegradation within a maximum of 56 days in fresh water at a temperature of 21° C.

- TÜV AUSTRIA OK biodegradable SOIL: Requires 90% biodegradation within a maximum of 2 years at a temperature of 25° C (certified by DIN Certco as 'DIN-Geprüft biodegradable in soil').

Part 2: Current state review

This chapter delves into the current state of bioplastics in Australia, providing an overview of their use and impact across the value chain. The current lifecycle of polyhydroxyalkanoates (PHA), polylactic acid (PLA), and bio-polyethylene (BioPE) has been examined through material flow analysis (MFA), which examines the pathway for these materials from feedstocks to end-of-life. Drawing from a combination of desktop research, 10 stakeholder interviews, and two system-wide workshops, this section presents a holistic view of the bioplastics landscape.

The stakeholder selection process ensured a diverse representation from various sectors involved in the bioplastics system, including government agencies, industry associations, bioplastics producers, manufacturers, retailers, waste management organisations, environmental NGOs, research institutions, and consumers.

2.1 Material flow analysis

2.1.1 What is material flow analysis?

MFA is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It can be used to keep track of bioplastic consumption within Australia by analysing the inputs, outputs, and transformations of bioplastics in the country. MFA can help identify inefficiencies, waste generation, and potential opportunities for improvement in the bioplastic lifecycle.

In the context of a circular economy, MFA can be used to track the flow of bioplastics from production to consumption and end-of-life management. This includes monitoring the recycling, recovery, and disposal of bioplastics, as well as identifying opportunities for reducing waste and improving resource efficiency.

2.1.2 Methodology

An MFA was conducted to examine the movement of bioplastics within the Australian system. The purpose of this analysis was to develop a model that tracks the flow of bioplastics from polymer production to end-of-life in Australia. The approach is based on the principle of mass conservation, where material inputs and outputs are balanced to enable the quantification and analysis of material flows.

Our analysis aimed to showcase the flow of bioplastic materials from polymer production to end-of-life, focusing on the following phases:

- **Phase 1** – Raw materials/feedstocks used for polymer production. Key question: What feedstock is used, and in what quantities, to produce the polymer?
- **Phase 2** – Production/import quantities of polymers. Key question: How much polymer is produced or imported into Australia?
- **Phase 3** – Use of polymers in goods (output of polymers). Key question: Once acquired, which products/sectors utilise the polymers?
- **Phase 4** – End-of-life outcomes for polymers. Key question: What end-of-life management options are used, and how much of each polymer is present in each waste stream?

For each phase:

- A desktop analysis was conducted, which included review of peer-reviewed literature, grey literature, and industry reports.
- Interviews with key stakeholders in the bioplastics industry were conducted to gain further insight into data; key assumptions were used as inputs into the MFA. Key stakeholders interviewed included manufacturers, producers, local government, researchers, and industry bodies.

It is important to note that limited Australian bioplastics studies exist with most studies predominately from Europe, the USA and Asia.

A Sankey diagram* (Figure 8) provides visualisation of how the materials flow in the Australian system.

In-scope polymers

The polymers selected for our MFA analysis were PLA, PHA, and BioPE. These polymer types were chosen due to their significant global production capacities and current investment in research and development, making them the most relevant for scaled market applications in the short term. PLA represents 20.7% of the global bioplastics production capacity (the maximum output that can be produced using available resources), with BioPE and PHA representing 14.8% and 3.9% respectively.

Main limitations

Data availability

- Available data is limited due to the small scale of the industry.
- While main scale use is PLA, there are large data gaps for BioPE and PHA, as they are yet to be used in large-scale applications in the Australian market.
- Lack of large-scale Australian production further exacerbates data limitations.
- Data collection lacks granularity at the polymer level; data is often categorised as 'bioplastics' without further breakdown.

Quantification

- Limited data makes accurate quantification difficult.
- Assumptions are required to quantify some aspects (see Appendix 3).
- Most products are imported in finished form, which further complicates quantification.
- Differentiating between BioPE and polyethylene (PE) presents challenges, as recyclers' collection data quantifies all PE (Bio-PE, low-density polyethylene (LDPE), high-density polyethylene (HDPE), etc.). This means there is an unknown make-up of biobased content within these quantities.

2.1.3 Sankey diagram*

Through the MFA completed (Figure 8), valuable insights into bioplastics consumption in Australia have been gained across four distinct phases. In the following sections, key findings and insights are presented on the current state of bioplastics use and potential areas for improvement and growth within the Australian market. The overall findings of the report indicate that PLA (Polylactic Acid) dominates the Australian bioplastics market. However, a concerning trend revealed that a significant portion of bioplastics in Australia ends up in landfill, highlighting the need for improved waste management and recycling infrastructure.

Phase 1: Raw materials/feedstock used for polymer production

In Phase 1, we examined the raw material inputs used to produce key bioplastics in Australia. We found that the most common raw materials used include sugarcane, corn sugar, and starches for PLA production. In Australia, there is one key supplier of PLA, which solely uses corn sugar as the raw material. Similarly, for BioPE production, there is one key supplier that exclusively uses sugarcane for Australia's BioPE production. Organic wastes and cane and beet sugars are used for PHA production in Australia. Due to limited data and low PHA consumption in Australia, it is difficult to determine the exact proportions of each input used in the annual production of PHA.

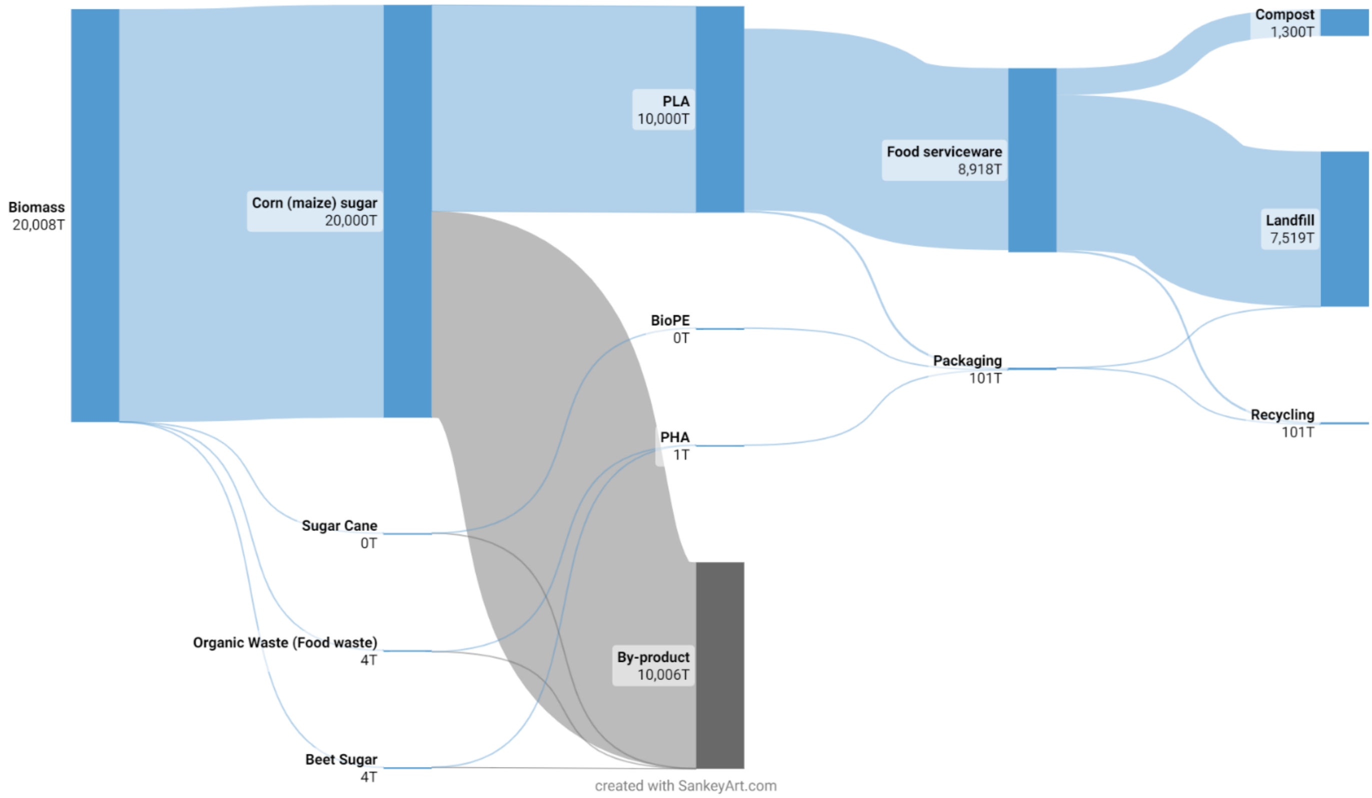


Figure 8 – Material flow analysis completed for PLA, PHA, and BioPE in Australia, demonstrating the flow of materials contained within bioplastics from feedstock to final consumer product. The width of the arrows is proportional to the quantity material flowing through the value chain.

Phase 2: Production/import quantities of polymers

In Phase 2, we examined the polymers produced or imported in Australia. We found that most polymers in Australia are imported from overseas, predominantly from Thailand for PLA and Brazil for BioPE. Limitations included determining the conversion rate of raw materials to bioplastic polymers, as there is limited data on the conversion rate, especially if multiple raw material inputs were used. It was determined to use a 2-to-1 conversion rate between corn sugar to PLA polymers and a 4-to-1 rate for cane and beet sugars to produce PHA. A 1-to-1 conversion rate from cane sugar to BioPE was used. Although the conversion rate does not use entire raw materials, manufacturers confirmed that the waste (e.g., excess corn sugar) is used for other products, which essentially creates a circular flow.

Phase 3: Use of polymers in goods (output of polymers)

In Phase 3 of our analysis, we discovered that most compostable bioplastic polymers are used within the food industry, particularly in food service ware; an estimated 8,000 tonnes of PLA is used in cutlery, cups, and coffee lids, and as a water barrier coating on paper cups. Compostable bioplastics are increasingly used in FOGO (Food Organics and Garden Organics) kitchen caddy bags. In agriculture, bioplastic material is used for mulch films, and according to one survey, the industry consumes approximately 7,300 tonnes of bioplastic.[42] However, 6,100 tonnes of this material consists of plant-based starches and the remaining 1,200 tonnes comprises a mixed composition of PLA, PBAT and starches; this complicates determining how much PLA is actually consumed by the industry.[39] In addition, bioplastics are used in 3D printing and biomedicine; however, the data available for these sectors in Australia is limited due to relatively low consumption levels.

Phase 4: End-of-life outcomes for polymers

In phase 4, we reviewed the end-of-life of bioplastic products and discovered that the majority ends up in landfill. This is primarily due to the mixed materials in food packaging, such as paper and bioplastics, which render them non-recyclable or compostable in most states, except for South Australia. Agriculture mulch films, on the other hand, are left to naturally degrade on fields. As BioPE bioplastics have a structure similar to polyethylene, it is the only bioplastic that can be recycled with other plastics.

Note: During the stakeholder workshops, participants noted that quantifying polybutylene adipate terephthalate (PBAT) in Australia would be valuable due to its common use in agricultural films and FOGO/waste caddy bin liners. It is important to note that 9.8 million liner bags are currently in use in Australia. This information could contribute to a better understanding of bioplastic consumption and waste management in the country.

2.2 Stakeholder mapping

Table 6 below provides an overview of the key stakeholders involved in the Australian bioplastics system. This was developed through a combination of stakeholder consultations, including interviews and workshops, as well as desktop research. By engaging with stakeholders and through this research, a network of actors in the bioplastics value chain in Australia has been identified.

Table 6 – Key players and activities in Australia's bioplastics system identified by interview and workshop attendees.

APPLICATIONS/ USES	MANUFACT-URERS	INDUSTRY BODIES	FINISHED GOODS SUPPLIERS	WASTE AND RESOURCE RECOVERY	RESEARCH AND INNOVATION	NGOS	GOVERNMENT AND REGULATORY BODIES
Agriculture and horticulture	NatureWorks	Australasian Bioplastics Association (ABA) *Australian standards for compostable and biobased content*	BioPak	Visy	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Compost Connect	Australian Competition and Consumer Commission
Food service ware	TotalEnergies Corbion	Australian Council of Recycling (ACOR)	Great Wrap	Goterra	The ARC Training Centre for Bioplastics and Biocomposites	Planet Ark *Australian Circular Economy Hub*	State Environmental Protection Agencies
Packaging	Uluu	Australia Organics Recycling Association (AORA)	Cardia Bioplastics	Cleanaway	Universities Commonwealth Scientific and Industrial Research Organisation (CSIRO) CSIRO-Murdoch University Bioplastics Innovation Hub	Australian Marine Conservation Society	Department of Climate Change, Energy, Environment and Water (DCCEEW)
Food and grocery	Cardia Bioplastics	Australian Packaging Covenant Organisation (APCO) *Compostable packaging work stream* *National Packaging Targets* *Australasian Recycling Label (ARL)*	Source Separation Systems	Repurpose It	Ocean Impact Organisation	Plastic Free Foundation *Plastic Free July*	Sustainability Victoria
Caddy liners	Plantic Technologies	Australian Food and Grocery Council (AFGC) *National plastics recycling scheme*	Detpak	Sacyr	Cooperative Research Centres	World Wildlife Fund (WWF) Australia *Sustainability of Bioplastics in Australia Report*	Department of Energy, Environment and Climate Action (DEECA)

APPLICATIONS/ USES	MANUFACTURERS	INDUSTRY BODIES	FINISHED GOODS SUPPLIERS	WASTE AND RESOURCE RECOVERY	RESEARCH AND INNOVATION	NGOS	GOVERNMENT AND REGULATORY BODIES
Supermarket	BASF	Australian Institute of Packaging (AIP)	Pac Trading	Soilco	Twynam Investments	Tangaroa Blue Foundation	Recycling Victoria
Customers/end user	Tipa	National Retail Association (NRA) *Single-use plastic education campaign*	Huhtamaki	Green Eco Technologies	Stop Food Waste Australia	Boomerang Alliance	All local governments
Hygiene	Phantm	National Retail Association (NRA) *Single-use plastic education campaign*	Hero Packaging	Corio Waste Management	Australian Impact Investments	Ellen MacArthur Foundation	Federal Government
Retail	Kuraray	Overseas e.g. European Bioplastics, Biodegradable Products Institute (BPI), BBIA	Compost-a-Pak	WRITE Solutions	Victoria University	Waste and Resources Action Programme (WRAP)	Queensland Government
Controlled release applications	Hisun	Go!PHA	Glad	Jeffries Compost	CSIRO-Murdoch University Bioplastics Innovation Hub		Northern Territories Government
Biomedical	Source Separation Systems	ISO International Organisation for Standardisation	Biogone	Pete Soils	University of Technology Sydney Institute For Sustainable Futures		Tasmania Government
Entertainment venues		Alliance to End Plastic Waste	Amcor				Local councils
Quick service restaurants							Green Industries South Australia
Brisbane 2032 Olympics							
Clothing and textiles							
3D printing							

2.3 Challenges across the value chain

The interviews and workshops conducted as part of this review highlighted several key challenges across the bioplastics' value chain. Key themes identified were:

- End-of-life management.
- Regulation and certification.
- Bioplastic properties and performance.
- Knowledge, trust, and awareness.
- Feedstocks and nature-related risks.

2.3.1 End-of-life management

End-of-life management poses one of the most complex challenges for the use of bioplastics in Australia, and was the most frequently mentioned challenge by stakeholders during the workshops. Lack of infrastructure capable of supporting the bioplastics value chain was seen as the biggest barrier to widespread uptake, with a fragmented regulatory environment further exacerbating this challenge. Industry called for greater investment, coordination, and collaboration in this area to ensure Australia is able to effectively manage bioplastics at end-of-life.

The waste and resource recovery sector emphasised the importance of ensuring the presence of viable end markets for materials. Designing a product using compostable or recyclable bioplastics in the absence of markets for the recovered material can hinder recycling efforts and render these products economically unfeasible and destined for landfill. For a range of biopolymers used in Australia, volumes are so low that the economics of collecting and reprocessing them do not cover their market price. Location can also influence the viability of recovery, as transporting materials can affect the economic feasibility of recycling. Additionally, resource recovery in certain locations can be constrained by limited space and availability of suitable end markets. Participants from the resources recovery sector suggested that South Australia likely offers preferred conditions for composting bioplastics, including a historically motivated community, lower urban density that provides more space, and existing end markets for composted material.

Mechanical recycling

Currently, biopolymer types which have identical properties to their fossil-based counterparts, such as bio-polyethylene terephthalate (BioPET), can be recycled in existing recycling streams. As these are chemically identical, they are not recognised for their biobased qualities and are treated the same as conventional polymers. Finished goods suppliers struggle to inform consumers that products are bioderived, fearing they may increase confusion leading to contamination of organics recycling streams. Due to low volumes, mechanical recycling is currently not accessible for all bioplastic polymer types.

The risk of contaminating traditional recycling streams was raised in discussions with stakeholders, but industry participants did not consider it to be likely. They highlighted that current market volumes of bioplastics are relatively low, making it unlikely to significantly impact existing recycling activities, especially considering the abundance of multi-layered and non-recyclable materials already being used. Further research is needed to gain a better understanding of the impact that bioplastics might have on recycling streams if their usage were to increase to help identify appropriate mitigation strategies and potential solutions to future challenges.

Composting

In Australia, FOGO collection is limited to 30% of Australians, primarily in metropolitan areas. Among the councils that offer FOGO collection, most do not accept certified compostable plastics except for those in South Australia, where they are widely collected. However, some councils make exceptions for compostable bin liners, resulting in around 950 million liners used annually across the country. For instance, in New South Wales, regulations by the Environment Protection Authority allow only compostable plastic kitchen caddy liners that comply with Australian standard AS 4736-2006 in FOGO bins, while other compostable plastics and fibre-based packaging are prohibited.

Managing compostable plastics through the FOGO system faces several challenges. Certain composting facilities have shorter processing durations, leading to insufficient biodegradation. Additionally, low consumer awareness of compostable plastic certification and misleading product labelling increases the risk of contaminating FOGO waste with conventional or fragmentable plastics. As more local councils adopt the FOGO system, compost processors face an increased burden due to waste stream contamination. This highlights the overarching issue of consumer confusion regarding proper waste disposal, which is likely to persist as bioplastics gain more prominence in the market.

Stakeholders in workshops emphasised the need for uniform kerbside collection standards and stressed the importance of a national approach to reduce consumer confusion and enhance compliance. In the context of organics recycling, concerns were raised about contamination associated with the chemical composition of certain bioplastic products. This challenge is linked to regulation and certification, as there is a lack of regulation concerning the properties of polymers and how they interact with the environment during biodegradation or composting. If compost becomes contaminated with harmful chemicals like per- and polyfluoroalkyl substances (PFAS), it poses a risk of environmental contamination and negative impacts resulting from increased use of bioplastic products. Measures are being taken to phase out PFAS, with the Australian Packaging Covenant Organisation (APCO) publishing an *Action Plan to Phase Out PFAS in Fibre-Based Food Contact Packaging*.

2.3.2 Regulation and certification

The lack of clear labelling, certification, and effective regulation emerged as major obstacles to establishing a circular economy. Recognising the urgency, stakeholders emphasised that addressing labelling and certification challenges requires a collective effort from the entire system, rather than individual entities.

Labelling and certification

Labelling and certification emerged as a core challenge among stakeholders, with compostability and recyclability labels a key focus. Discussions highlighted the necessity of conducting public consumer behaviour surveys to understand the underlying heuristics and assess consumer comprehension of Australia's waste management system. Such insights are crucial for developing a streamlined labelling system that is easily comprehensible and applicable to all materials available in the market, not limited to bioplastics. The interviewed stakeholders referenced a potential to integrate the Australasian Recycling Label (ARL) into packaging with home and commercial composting icons that require products to be certified to a relevant Australasian standard. Industry participants expressed interest in scaling the use of biobased and recycled content labels and certification, but were apprehensive about further confusion this may cause.

Challenges were also raised regarding certification of bioplastics in Australia. There are currently voluntary programs available for certification of compostable bioplastics products in accordance with AS 4736-2006 and AS 5810-2010. For any business making claims of biodegradability or compostability, participants believed it should be mandatory to be certified to an Australasian standard. However, participants acknowledged a specific challenge regarding the high cost associated with this process, which requires certifying all final product formats, not just the raw materials. This poses a significant barrier to entry for businesses with multiple products.

Greenwashing

Greenwashing poses a significant concern for the bioplastics industry in Australia. Greenwashing refers to deceptive marketing or labelling practices that mislead consumers into believing a product is more environmentally friendly than it is. In the case of bioplastics, there is a risk that companies may overstate the environmental benefits of their products or use ambiguous terminology that confuses consumers. A 2023 World Wildlife Fund (WWF) Australia report prepared by the Institute of Sustainable Futures uncovered widespread greenwashing by analysing the sustainability claims of 26 bioplastic products from 14 companies involved in their production or sale.[43] The products assessed included plastic bags, food service ware, coffee pods, postage bags, loose packing fill, and balloons. A total of more than 160 individual claims were examined, revealing 29% were potentially misleading or could not be verified (24%). Misleading claims included statements regarding product disposal; the use of vague terms like 'green', 'earth friendly', and 'sustainable'; the labelling of products as 'biodegradable' when they are not compostable; the use of the term 'plastic-free'; and unverifiable assertions about feedstocks and carbon footprint.

The term 'biodegradable' was considered unhelpful by participants, with growing consensus that its use should be restricted to when it can be supported by accreditation or verification against a recognised standard. California and parts of the EU have already taken steps in this direction by implementing sanctions for the use of the term without substantiation. It is important to establish a certification process for biodegradable products rather than allowing unrestricted use of the term.

Participants believe the ACCC needs to play a more active role in regulating this matter. Stakeholders agreed that the industry suffers material damage due to the presence of counterfeit or falsely labelled products. Such products hinder trust in and wider adoption of genuinely beneficial products. Awareness and education campaigns were also seen as essential to empower individuals to make informed choices and recognise greenwashing.

On 18 November 2024, the committee was granted an extension of time for the report until 12 February 2025. The report will reference the following:

- the environmental and sustainability claims made by companies in industries including energy, vehicles, household products and appliances, food and drink packaging, cosmetics, clothing and footwear
- the impact of misleading environmental and sustainability claims on consumers
- domestic and international examples of regulating companies' environmental and sustainability claims
- advertising standards in relation to environmental and sustainability claims
- legislative options to protect consumers from greenwashing in Australia
- any other related matters.

2.3.3 Bioplastic properties and performance

During workshops, participants identified several challenges related to the properties and performance of different bioplastic polymer types and ensuring their use in appropriate applications. Consensus emerged that for bioplastics to effectively play a role in reducing waste, they must support activities further up the waste hierarchy and that can be reused. Emphasis was placed on ensuring that polymers possess properties that meet their required purpose and exhibit high performance compared to alternative materials. In packaging, safeguarding products was seen as a primary objective, as the environmental repercussions of product loss far outweigh those of packaging itself. It's important to note that while compostable bioplastics are designed to degrade, this attribute can sometimes compromise the packaging's overall effectiveness. Participants agreed that industry-wide knowledge and access to the right information about the different polymer types are required to make the right decisions and to support the effective use of bioplastics.

Industry also expressed confidence in the ability of biobased feedstocks to seamlessly replace fossil-based feedstocks for nearly all polymer types, particularly in the case of non-biodegradable plastics. The potential to substitute commonly recycled plastics with biobased polymers creates an opportunity to enhance environmental performance in various plastic applications. The main limiting factor for a transition to biobased non-biodegradable plastics was seen to be cost.

Other challenges included unintended consequences associated with use of first-generation feedstocks as well as lack in transparency across the supply chain, which will be discussed in subsequent chapters.

The cost of producing bioplastics compared to conventional fossil-based plastics was seen as a significant challenge. Raw materials used in bioplastics, derived from renewable resources, are generally more expensive to produce and process than fossil fuels used in traditional plastics. Additionally, the smaller production scale of bioplastics currently limits the economies of scale that can minimise costs. The technology and infrastructure required for bioplastics manufacturing also contribute to higher production costs, as specialised equipment and processes are required. Research and development efforts in the field of bioplastics further add to production expenses. Lastly, limited market demand and competition for bioplastics result in higher prices. At the time of this report, the production of bioplastics in Australia is not notable. The manufacturing costs are high, and the limited production of finished goods domestically, compared to the market's current scale, provides little motivation for local bioplastics' production to take place. Scalability was another key challenge highlighted during discussions, and one which will require investment and collaboration across sectors to be address. However, as technology advances, economies of scale are achieved, and more efficient production processes are developed, the cost disparity between bioplastics and traditional plastics is expected to decrease in the future.

2.3.4 Knowledge, trust and awareness

Confusion among consumers regarding bioplastics, single-use plastic products, labelling, and resource recovery is a prominent issue. At the root of this challenge lies a lack of understanding of the different types of bioplastics, how they are used, and how they can be disposed of appropriately. Due to the differing regulations and policies in Australia, consumers can become confused as to where and how they should dispose of biodegradable or compostable products, and whether they should do so in or outside of the home. While a program for labelling grocery food products exists to support consumers, labelling is not mandatory, and therefore is not uniformly applied across all products. Additionally, with the closure of REDcycle in Australia, accessibility to recycling for certain products has become limited for many consumers. It is important for consumers to understand proper disposal methods for both recycling and composting of bioplastics.

Establishing trust and transparency across the bioplastics value chain poses significant challenges. Questions surrounding feedstock origins, compostability, end-of-life management, and waste management hinder stakeholder confidence. To overcome these concerns, key focus areas should be greater transparency and traceability throughout the life cycle of bioplastics. This entails disclosing feedstock sourcing, labelling compostable materials accurately, and implementing robust tracking systems. Collaboration among stakeholders and consumer education are crucial in achieving transparency and encouraging responsible consumption and disposal.

2.3.5 Feedstocks and nature-related risks

Bioplastics derived from renewable sources can offer environmental advantages but also pose nature-related risks. When considered in first-generation feedstocks, these risks include deforestation and habitat destruction due to increased crop cultivation, the use of fertilisers and pesticides impacting water and soil, water scarcity from irrigation, resource-intensive manufacturing processes, and challenges in waste management. Shifting to bioplastics should consider sustainable sourcing, responsible agriculture, efficient manufacturing, proper waste disposal, and consumer education to mitigate these risks.

2.4 Opportunities

2.4.1 Niche applications

Bioplastics offer a unique opportunity to address environmental challenges in niche applications within Australia. In the horticultural and agricultural sectors, where the use of plastics is common for mulching, crop protection, and soil preservation, bioplastics that biodegrade under specific environmental conditions can provide a sustainable alternative. These bioplastics can break down into natural components, reducing the accumulation of plastic waste and potential harm to ecosystems.

Similarly, bioplastics can play a vital role in biomedical applications, for example as biocompatible materials for temporary implants or drug delivery systems that degrade harmlessly in the body. Additionally, using bioplastics as coatings or films in packaging can improve end-of-life outcomes by allowing for easier separation and recycling or composting. By adopting bioplastics in these niche applications, Australia can contribute to mitigating the environmental impact of specific sectors, reduce plastic waste, and promote a more sustainable and circular approach to materials use.

2.4.2 Combatting food waste

Australia has a significant opportunity to advance its efforts in reducing food waste by incorporating bioplastic bin liners in the FOGO system. FOGO programs aim to divert organic waste, including food scraps and garden trimmings, from landfill and instead use it for composting or energy generation. Bioplastic bin liners are derived from renewable resources and designed to biodegrade under specific conditions. They help contain and manage food waste – preventing odours, leakage, and contamination – while simultaneously facilitating organic waste's integration into composting or anaerobic digestion processes. This integration not only reduces greenhouse gas emissions from organic waste in landfills but also supports the production of nutrient-rich compost that can be used to enrich soils and promote sustainable agriculture. By embracing bioplastic bin liners within the FOGO system, Australia can enhance the effectiveness of FOGO initiatives, demonstrate its commitment to circular economy principles, mitigate environmental impacts, and foster a more sustainable approach to waste management.

2.4.3 PHA

During stakeholder interviews and workshops, participants identified polyhydroxyalkanoates (PHA) as a bioplastic polymer that has the potential to become more commercially viable, particularly in applications where rapid biodegradation is desirable. PHA is a family of biodegradable polymers produced by certain microorganisms under specific conditions. Stakeholders recognised PHA's ability to break down in various environments, including soil, freshwater, and marine ecosystems, making it suitable for applications such as single-use packaging and disposable products. The participants highlighted PHA's promising properties, including its versatility, durability, and compatibility with existing manufacturing processes.

Additionally, the renewable feedstocks and reduced carbon footprint associated with PHA production were seen as significant advantages, as well as its mechanical properties and lack of toxicity. Stakeholders acknowledged the need for further research and development to improve PHA's cost-effectiveness and scalability, but they expressed optimism about its potential to address the growing demand for sustainable alternatives to conventional plastics. Australian start-up Uluu has emerged as a key player in the development and commercialisation of PHA bioplastics, leveraging innovative technologies and sustainable practices to drive the adoption of this promising biopolymer in various industries.

2.4.4. Textile industry

The textile industry significantly impacts the global economy through its vast production of clothing and other products, contributing to synthetic polymer consumption and environmental concerns. With a market size exceeding 113 Mt in 2021, dominated by synthetic fibres, the industry faces challenges in waste management, pollution, and the need for sustainable practices. The shift towards biobased polymers, particularly biodegradable plastics like PLA and PHA, offers a potential solution. These materials, expected to increase in production capacity, provide an environmentally friendly alternative capable of replacing conventional plastics in textiles. PHAs and high-molecular-weight polyhydroxybutyrates (PHBs), in particular, show good mechanical properties and strength, allowing for the creation of fibres with high tensile strength suitable for various textile applications. Their biocompatibility and complete biodegradability by various microorganisms into harmless products (water and carbon dioxide) make PHAs suitable for eco-friendly textile applications. However, the significant production expenses of PHAs, which are currently higher than those of synthetic polymers, pose a major barrier to their widespread adoption. In addition, the incorporation of suitable additives and blending with other biopolymers needs to be studied to improve mechanical qualities. Further research and practical testing are needed to address the challenges and expand the use of PHAs in textiles effectively.

2.4.5 Local manufacturing

In terms of onshore manufacturing of bioplastics in Australia, opinions among interviewees and workshop participants varied. While some considered it a possibility, others deemed it highly unlikely. Those who saw potential emphasised Australia’s agricultural and forestry activities, suggesting that by-products from these sectors could be used to develop bioplastics. Additionally, they highlighted the opportunity to explore other streams such as food waste or emerging industries like seaweed to locally manufacture bioplastics. However, contrasting views pointed out the limited scope of this opportunity in Australia. They highlighted the absence of onshore manufacturing capabilities for finished bioplastic products and referred to international bioplastics manufacturers investing in production facilities located closer to feedstock sources and manufacturing hubs, particularly in the USA and Southeast Asia.

2.4.6 Chemical recycling

Advanced chemical recycling presents a significant opportunity for bioplastics in Australia, offering an innovative solution to address the challenges associated with their end-of-life management. Companies like APR Plastics and Licella are at the forefront of this technology, utilising a unique hydrothermal liquefaction process to convert bioplastics into valuable, high-quality biofuels and biochemicals. Unlike traditional mechanical recycling, which has limitations in terms of the types of bioplastics that can be processed, advanced chemical recycling can handle a broader range of bioplastic materials, including mixed and contaminated streams. This technology enables the recovery of the inherent energy and carbon stored in bioplastics, thereby creating a closed-loop system that maximises resources and reduces waste. By harnessing advanced chemical recycling, Australia can enhance the circularity of its bioplastics industry, fostering a more sustainable and efficient approach to plastic waste management while also supporting the development of a biobased economy.

It is important to note that while advanced chemical recycling offers opportunities for bioplastics and a wider range of materials, prioritising activities further up the waste hierarchy remains crucial. By combining advanced chemical recycling with upstream waste reduction and recycling strategies, Australia can achieve a more comprehensive and sustainable approach to managing its waste and resources.

2.4.7 Biobased and renewable content targets

Australia has a significant opportunity to adopt biobased and renewable content targets alongside recycling targets for packaging. By setting specific targets for the incorporation of biobased and renewable materials in packaging, Australia can incentivise the use of renewable feedstocks, such as plant-based polymers or bio-derived additives, in the production of packaging materials. This shift can reduce reliance on fossil fuel-based plastics, decrease greenhouse gas emissions, and promote the use of renewable resources. Additionally, coupling these targets with recycling goals encourages the development of a comprehensive approach to waste management. While recycling targets currently focus on diverting packaging waste from landfill and promoting the recycling infrastructure, biobased and renewable content targets promote the use of materials that have a lower environmental impact and can be sustainably sourced. By adopting both targets, Australia can promote a holistic approach to packaging sustainability, balancing resource conservation, waste reduction, and the use of renewable materials in a manner that aligns with its environmental goals.

2.4.8 Common definitions and clear labelling

Clear definitions and common terminology for bioplastics in Australia are essential for effective communication and education. With the wide range of polymer types, diverse feedstocks, and varying properties, it becomes challenging to convey accurate information about these sustainable materials. By establishing clear definitions and common terminology, we can support individuals, businesses, and policymakers with a shared understanding, facilitating clear communication and enabling effective education about the benefits, applications, and environmental implications of bioplastics.

Workshop participants in Australia called for improved labelling of bioplastic products to reduce confusion for businesses, consumers, and recyclers. They recommended:

- Using the term 'compostable' only for products certified to Australian standards and avoiding 'biodegradable' for non-certified compostable items. Mandating certification for compostable products could be considered.
- Standardising labelling with official Seedling logos for certified compostable products, discouraging other symbols. Detailed guidance on compostable product labelling could be developed with industry input.
- Applying the Australasian Recycling Label to non-compostable bioplastic products to inform consumers about appropriate disposal.
- Adopting reputable standards for the environmental impacts and responsible sourcing of biobased plastics, enabling more sustainable choices.

International examples from countries like France, Belgium, and California demonstrate how clear labelling regulations for bioplastics have been successfully implemented.[44] For instance, France restricts the use of 'compostable' labelling to products that can be industrially composted, while Belgium prohibits the use of the term 'biodegradable'. California similarly mandates compliance with relevant composting standards for products labelled as 'compostable' or 'home compostable'. At the moment, three certified labels are adopted in Australia for products that are 'compostable', 'home compostable', or 'soil biodegradable' (see section 1.5.3).

2.4.9 Industry 4.0 technologies

Industry 4.0 technologies are poised to play a pivotal role in supporting a circular economy for bioplastics in the future. With the integration of advanced digital technologies like the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, the bioplastics industry can enhance resource efficiency, reduce waste, and improve end-of-life processes. IoT sensors can enable real-time monitoring of bioplastic production, ensuring optimal usage of feedstocks and energy resources. AI algorithms can optimise manufacturing processes, minimising material waste and energy consumption. AI can also improve waste collection by sorting products by their materials using smart bins, minimising the contamination of recycling streams and ensuring the appropriate downstream processing of bioplastics. Additionally, big data analytics can provide valuable insights into the entire life cycle of bioplastics, enabling better decision-making and identifying opportunities for optimising processes and reducing waste. These technologies will enable greater traceability and transparency, facilitating the tracking of bioplastic materials across the supply chain, during their usage, and at end-of-life.

Appendix

Appendix A: Bioplastic polymers in detail

POLYLACTIC ACID (PLA)

Polylactic acid or polylactide (PLA) is the most widely used bioplastic accounting for 20.7% of global bioplastics production volumes.[45] PLA is both biobased and biodegradable.

Feedstocks and material manufacturing

PLA is derived from renewable biomass, with the main feedstocks coming from corn, sugarcane, corn stover (stems, husks, leaves), and cassava roots.[46]

PLA is produced from the fermentation of plant-derived carbohydrates. PLA is a polyester (polymer containing the ester group) made with two possible monomers or building blocks: lactic acid and lactide. Lactic acid can be produced by the bacterial fermentation of a carbohydrate source under controlled conditions. There are various PLA manufacturing processes, each at differing stages of maturity. The processes which are currently at full commercial application are azeotropic poly-condensation, ring-opening polymerisation, and acidification filtration.[47]

Key PLA biopolymers include Ingeo™ produced by NatureWorks LLC, as well as the Luminy® series of PLA resins produced by TotalEnergies Corbion (a 50/50 joint venture between TotalEnergies and Corbion).

Common applications

PLA has a wide range of applications spanning across several industries. Some common applications for PLA include:

- **Packaging and food service ware** – PLA bioplastic is commonly used for packaging applications, such as food packaging and containers, as well as food service ware like clamshells, cups, and cutlery.[48] A well-known example in Australia is PLA products by BioPak, which are designed for food service.
- **3D printing** – PLA bioplastic is a popular material used in 3D printing due to its low melting point, ease of use, and ability to produce detailed prints.
- **Textiles** – PLA bioplastic can be used to make eco-friendly textiles, such as clothing, bedding, and curtains. PLA-based fabrics are soft, breathable, and moisture-wicking.
- **Medical implants** – PLA bioplastic is used in medical applications, such as implants and sutures. Its biodegradability and compatibility with human tissue make it an ideal material for temporary medical devices.
- **Agriculture** – PLA bioplastic is used in agriculture for applications such as biodegradable mulch films and plant pots. These products can help reduce waste and environmental impact in the industry.

End-of-life

Recycling: PLA can be recovered for mechanical recycling; however, due to its prevalence in low volumes, it is not separated in post-consumer waste streams. In current plastic waste channels, distinguishing PLA from other polymers such as polyethylene terephthalate (PET) (used in water bottles) can be challenging. This can lead to contamination issues that adversely affect recycling. Globally, only post-industrial PLA scrap is recycled on an industrial scale. Near Infrared (NIR) sorting can be used to identify PLA in waste streams and sort it from other plastic types.[49]

Commercial composting: PLA can be composted under commercial composting conditions. Best practice for ensuring PLA products are suitable for compost is through the use of a certified compostable PLA resin, as well compostability testing for final products.

Home composting: Depending on the application, PLA can be composted at home. However, achieving certification for home composting biodegradation is challenging due to the inefficiencies of home composting systems compared with commercial operations. The value of compostable products like PLA lies in their diversion to composting facilities, which reduces materials entering waste or recovery streams. 2,312 tonnes of compostable PLA was consumed in Australia in 2020–2021.[50] A current data gap is to ascertain the quantity of the consumed PLA which was composted versus recycled or sent to landfill.

Landfill: Landfill is a common waste treatment for PLA, though it is not ideal for this type of material. Given there are more sustainable options for end-of-life use, disposing of PLA in landfill should be avoided.

Environmental considerations

Environmental impacts will differ depending on the feedstock used to produce the PLA. Sugarcane is the most efficient feedstock for producing PLA, and as such has the lowest emissions and non-renewable energy demand due to its high productivity yields. Alternatively, land requirements for use of corn stover are lower than those of sugarcane or corn. On average, PLA saves approximately 66% of the energy required to produce conventional plastics. Through natural conversion, PLA emits 2.8 kg CO_2 kg^{-1} throughout its lifecycle.[51]

STARCH BLENDS

Starch-based polymers form an important family of bioplastics on the market, and starch-based materials are attracting increasing interest across the plastics industry.[52]

Feedstocks

Common feedstocks used in starch-blend bioplastics are potato, corn, and wheat starch;[53] side stream starch from potato processing (as well as from grain-, root-, or seed-based flour resources);[54] and starch reclaimed from wastewater.[55]

Material manufacturing

Starch-based bioplastics are complex blends of starch with compostable plastics, such as polylactic acid (PLA), polybutylene adipate-co-terephthalate (PBAT), polybutylene succinate (PBS), polycaprolactone (PCL) and polyhydroxyalkanoates (PHA). Blending starch with plastics improves the water resistance, processing properties, and mechanical properties of the resulting blend.[56] In 2022, starch-blend bioplastics accounted for 17.9% of global bioplastics production.[57] Starch is a polysaccharide consisting of two main macromolecules: amylose and amylopectin. It is a suitable filler material because of its thermal stability and limited interference with the melt flow properties of most synthetic plastic materials. Blending starch with synthetic polymers increases their biodegradability, as starch is naturally degraded by microorganisms. This leaves behind a skeleton of synthetic polymers, which is more easily degraded by natural processes such as thermal oxidation and ultraviolet photo-degradation.[58]

To manufacture starch-based plastics, native starch must first be restructured to make it thermoplastic and melt-processable. This is achieved using plasticisers such as water, glycerine, or other polyols, or through thermomechanical processes. This results in the production of thermoplastic starch (TPS), which can be processed using standard equipment designed for other synthetic plastics. TPS can be blended and additivated to adjust its physical-mechanical properties, such as stiffness, strength, and water solubility.[59]

Additionally, starch blending can reduce the production costs of bioplastics, especially for PHA and PLA production.[60]

Novamont is a key manufacturer producing a biodegradable, starch-based product called Mater-Bi.

Common applications

Starch-based plastics find different applications in the packaging, food, textile, and pharmaceutical industries.[61] Starch-blend bioplastics have applications across several industries, with further development into different applications ongoing. Key areas of use include:

- **Transport packaging** – Starch-blend bioplastics are often used as loose fill foams (packing peanuts) for transport packaging.
- **Food service ware packaging** – Starch-blend bioplastics are often used in cups, plates, cutlery, and films in food services packaging.[62]
- **Coatings and films** – As well as in coatings and films, starch-blend bioplastics are often used in both rigid and flexible packaging.[63]

Some applications of starch-blend plastics depend on the plastic type with which it is blended. Some examples of potential blend applications include:[64]

- PLA/starch for food packaging, electronic devices, membrane material for the chemical and automotive industries, textiles, and medical applications.
- PHB/starch for biomaterial in medical applications.
- PBSA/starch for antimicrobial packaging.
- PVA/starch for LDPE film replacement, water soluble laundry bags, biomedical applications, replacement of polystyrene foams, and packaging applications.

End-of-life

Depending on the type of starch used and their blend, starch-based polymers may be biodegradable, compostable, or disposed of in landfill.

Environmental considerations

Starch plastics have been shown to enable reductions in greenhouse gas (GHG) emissions and non-renewable energy use. However, they have higher eutrophication potential and require more agricultural land use compared to common fossil-based plastics. The potential GHG emissions savings are influenced by the composition of the plastic. Some grades can offer an 85% reduction, while others can offer an 80% increase compared to their fossil-based counterpart.[65] In a different study, PLA blends were compared to other fossil-based plastics such as LDPE. The study found that PLA blended with other biodegradable materials may have a higher global warming potential when compared to LDPE. This is a factor to consider in potential blends.[66]

Additives can account for up to 40% of GHG emissions associated with starch plastics. As such, the highest GHG savings are realised when components such at PBAT and PBS are minimised, while starch, natural fibres, and mineral fillers are maximised. Using reclaimed starch as opposed to virgin starch can also lead (in most instances) to modest decreases of up to 10% in non-renewable energy usage and GHG emissions, while also providing up to 60% reductions in eutrophication and agricultural land use.[67] When compared with virgin starch, blends using starch residues, such as waste from potato processing, have shown a reduction in eutrophication potential by up to 40%, agricultural land use by up to 60%, and GHG emissions and non-renewable energy usage by up to 10%.[68]

BIO-POLYETHYLENE (BIOPE)

Bio-polyethylene (BioPE) is biobased and non-biodegradable.[69]

Feedstocks

Typical feedstocks used for BioPE include sugarcane, sugar beet, lignocellulosic crops and waste, and starch crops such as maize and wheat.[70]

Material manufacturing

BioPE is produced from first-generation ethanol derived from food crops such as sugarcane.[71] BioPE is synthesised through the polymerisation of ethylene via different conditions of temperature and pressure and in the presence of various catalysts, which results in different PE types, such as high-density PE (HDPE), low-density PE (LDPE) and linear low-density PE (LLDPE).[72] Figure 9 depicts the process for ethanol to be produced from different feedstocks. Ethylene can be derived from the dehydration of ethanol from sugarcane, either by steam cracking of biomass or through the methanol-to-olefin route.[73] Bioethylene is also used to synthesise other polymers such as polystyrene (PS), rubbers, epoxy resins, polyvinyl chloride (PVC), and ethylene propylene diene monomer (EPDM) rubber. Resins synthetized from bioPE are also biobased, and constitute important possibilities for bio-ethylene utilization.

Manufacturing BioPE is not cost-competitive with that of its fossil-based counterpart, with 1 kg of BioPE costing approximately 30% more than one kilogram of fossil-based PE.[74]

Figure 9 – Production of ethanol for bioPE manufacturing.

1.3.3.3 Common applications

BioPE can be used in the same applications as its conventional counterpart. Some common applications for PE include food packaging, agricultural use, and industrial use. PE also has applications across toy manufacturing, cosmetics, and personal care.[75]

1.3.3.4 End-of-life

BioPE, as a biobased equivalent of conventional PE, can be recycled in the same way as conventional PE. BioPE is chemically identical to conventional PE. As such, BioPE can be integrated into already formed waste streams and does not require separate waste infrastructure. A study conducted indicated that recycling BioPE in conventional recycle streams (alongside fossil-based PE) did not lower the quality of the recylates.[76]

1.3.3.5 Environmental considerations

The environmental impacts of BioPE depend on its manufacturing process. Using biomass as a steam source for manufacturing can minimise GHG emissions in BioPE production. The impact of biobased polymers on human health and ecosystem quality can be up to two orders of magnitude higher.[65] This is mostly due to pesticide use, pre-harvesting burning practices, and land occupation. Improvements to the supply chain, like pesticide management and eliminating burning, can lessen the impact of biobased polymers.[77]

Feedstock use and sourcing also play a role in the environmental impacts associated with BioPE production. One such example is the difference in impacts associated with use of Brazilian versus Indian ethanol. The environmental impacts associated with the use of Brazilian ethanol are higher compared to Indian ethanol, attributed to factors such as the dampening effects of Indian ethanol, differences in sugarcane processing procedures, and the transportation of feedstocks.[78]

BioPE results in significant GHG emissions reduction when compared with its conventional counterpart. The typical emissions profile of BioPE is around 0.75 kg CO_2-eq per kg polyethylene, which is 140% lower than the production of fossil-based PE. Additional, BioPE reduces non-renewable energy usage by approximately 65%.[79]

BIO-POLYAMIDES (BIOPA)

Feedstocks

The most common feedstocks used for BioPA are vegetable oils,[80] castor plants and oil, sugarcane, sugar beet, and starch.[81]

Material manufacturing

Polyamide has multiple structural formulae, each of which has a separate method of production. Each method constitutes the synthesis of amide monomer from sources like castor oil or biomass.[82] Commercially available BioPAs are typically either based on sebacic acid or undecanoic acid, which can be derived from castor oil. The more common and commercially available PA derived from this biomolecule is polyamide 11 (PA11).[83]

Common applications

PA bioplastics exhibit high heat resistance, stiffness, and mechanical stability, making them suitable for a range of applications across various industries.[84] BioPA is often used for technical parts (in the transport and automotive industry),[85] textiles, and regular consumption goods. BioPA is also used in the sport and leisure industries, primarily in injection moulding.[86] As such, it is also used in 3D printing.[87]

End-of-life

There is limited information available regarding end-of-life management options for BioPA. Supplier Technoform claims that their BioPA has unlimited recyclability.[76] Fossil-based PAs such as nylon can be mechanically and chemically recycled; however, their collection is limited.

Environmental considerations

The environmental impacts of BioPA are unclear, though specific manufacturers have made claims regarding their products. Technoform claims that their BioPA production reduces carbon dioxide consumption during profile production by 62% and fossil-fuel energy consumption by 23%. It is important to note that this claim did not make explicit the basis for these comparisons; however, we have assumed that the comparison is made with conventional PA.[88] Another manufacturer, Roboze, claims their BioPA is produced with 60% lower carbon emissions than conventional PA.[89]

POLYBUTYLENE ADIPATE TEREPHTHALATE (PBAT)

Feedstocks

Polybutylene adipate-terephthalate (PBAT) is a biodegradable aromatic-aliphatic copolyester.

Feedstocks for PBAT may be biobased or fossil-based. Main feedstocks for PBAT are petrochemicals and castor plant.[90]

Material manufacturing

PBAT is both biodegradable[91] and fully compostable.[92] It can be produced by a polycondensation reaction of 1,4-Butanediol (BDO), polyarylate (PAT), and adipic acid (AA) using conventional polyester manufacturing technology and equipment. The synthesis of PBAT can be divided into three key processes: pre-mixing, pre-polymerisation, and final polymerisation.[93] As PBAT can be synthesised using conventional polyester manufacturing technology, it may be possible to obtain sufficient production capacity for PBAT within the short- to medium-term timeframe.[94]

For more than two decades, BASF have manufactured Ecoflex®, which is the most used PBAT-certified compostable polymer from fossil-based feedstock.[95]

Common applications

PBAT has similar properties to LDPE, and as such can be used as an alternative to this product.[96] PBAT is designed for film extrusion and extrusion coating,[97] and has common applications across a number of industries for different film requirements. One such application is agricultural mulch films,[98] where PBAT can degrade in soil over a period of >9 months.[99] PBAT is also used in compostable kitchen waste liner bags, packaging and wrapping films, and disposable tableware.[100] Certified compostable kitchen waste liners have been found to significantly increase the usage and capture rates of food waste, reaching up to 70% within a local government area.[101] PBAT is also used in the manufacture of medical products such as suture materials, wound dressings, and other medical devices.[102]

A challenge associated with the use of pure PBAT is the high production costs of the product versus its lower mechanical properties when compared to its conventional counterparts. As a result, the PBAT market is underdeveloped, and will only increase when production costs decrease or when further investment is made to improve properties of PBAT. One way of working around this is through blending low-cost materials (such as starch) and reinforcing materials (such as PLA) with PBAT to decrease the final price and improve the properties, while also maintaining the biodegradability of the composites.[103]

End-of-life

In commercial composting, PBAT biodegrades within 2-3 months.[104] PBAT is also commonly used in agricultural films where it can degrade in soil over a period of >9months.[105]

Environmental considerations

Although PBAT can biodegrade and be compostable, it still has an impact on the environment if not disposed of properly.
The composting process also requires specific conditions to break down the material effectively and will depend on how the polymer is used in the finished product.[106]

POLYHYDROXYALKANOATES (PHA)

PHAs are an emerging family of biodegradable aliphatic polyesters with a commercial market that is expected to reach annual volumes of >100,000 tonnes in the coming years.[107]

Feedstocks

PHA can be produced using a wide variety of feedstocks, including some exciting developments which will positively affect the environmental impact of the production of these materials.

Typical feedstocks include oil crops, lignocellulosic crops and residues, starch and sugar crops,[108] and sugar or fatty acid-rich wastes.[109] Oil crop feedstock yields higher amounts of PHA per mass than sugar feedstocks due to its higher carbon content.[110]

Developments in feedstocks used to produce PHA have been made, which can contribute to a more circular economy and reduce environmental impacts. Of five companies manufacturing PHA in Europe, three use sugar beet as a feedstock, one uses waste cooking oil, and one uses wastewater.[111] Additionally, Australian company Uluu has developed a PHA polymer that is manufactured using algae and seaweed.[112]

Material manufacturing

PHA is produced by fermenting natural raw material such as sugar or lipids. PHA can be produced by various bacteria, including *Pseudomonas* and *Ralstonia* strains, as well as algae.[113] First, microorganisms are fermented to grow the PHA biopolymer within their casing. Once the desired yield is reached, they are harvested from the fermentation broth to increase the concentration. The PHA is then extracted from the cells, which can be done physically or chemically depending on each production specifications. Finally, the lysate is extracted to form the bioplastic. PHA is often more adaptable and less elastic than other plastics, making it a much more versatile option to produce.

PHAs are typically extracted from cells using halogenated organic solvents, however research is being undertaken to develop more environmentally benign and solvent-free cell disruption methodologies.[114]

Common applications

PHAs are used in the packaging, food and chemical industries, and recent attention has shifted towards their use in agricultural applications.[115] PHA has also been used to replace petrochemical polymers in coatings and packaging, and has applications across the medical industry F.[116]

End-of-life

Most PHA types degrade faster than PLA, which makes them attractive for applications where biodegradation is desired.[117] Among the advantages of PHA is their relatively high degradation rate in marine environments. After one year in a marine environment at 30° C, PLA biodegrades by approx. 8%, while PHBV (a type of PHA) biodegrades by approx. 80%.[118] Additionally, PHA can be (in theory) mechanically recycled. Different PHA types are better suited to the mechanical recycling process, with PHB properties significantly reduced after two processing cycles, and PHBV maintaining its tensile strength after seven processing cycles.[119] PHA can be also biologically recycled under both aerobic and anaerobic conditions. As such, they can be suitably treated both by compositing and by anaerobic digestion. However, further research is needed on the degradation of PHA under aerobic conditions through composting.[120]

Environmental impacts

As with the other bioplastics discussed, the environmental impacts of the production and use of PHA is dependent on the type of feedstocks used. The lowest values found for carbon emissions and non-renewable energy demand were obtained for the production of PHA from sugarcane, owing to the high productivity yields of sugar and the credits assigned to the process for the energy surplus, generated from bagasse burn.[121] Additionally, most PHA types degrade faster than PLA, which makes them attractive for applications where biodegradation is desired.[122]

Appendix B: Useful resources

APCO National Compostable Packaging Strategy

The Australian Packaging Covenant Organisation (APCO) has taken steps to address compostable packaging through the development of a national compostable packaging strategy. They have established a working group tasked with implementing a roadmap to tackle the issue effectively. The strategy involves several key initiatives to drive positive outcomes for the use of compostable packaging. The proposed strategies to achieve these shifts are summarised below:

- **Packaging design and procurement**
- Strategy 1.1 – Phase out fragmentable plastic packaging.
- Strategy 1.2 – Educate the packaging value chain about appropriate use.
- Strategy 1.3 – Eliminate false or misleading claims.
- **Collection systems**
- Strategy 2.1 – Label for correct disposal.
- Strategy 2.2 – Minimise contamination inorganics collection services.
- Strategy 2.3 – Increase collection of organics from the food service sector.
- **Recycling end markets**
- Strategy 3.1 – Promote greater collaboration between the packaging and recovery sectors.
- Strategy 3.2 – Undertake processing trials for compostable packaging.

WWF Sustainability of Bioplastics in Australia Report

WWF Australia's No Plastics in Nature initiative is working to eliminate the leakage of plastic into the environment, build a circular economy for plastics, and drive global action to end plastic pollution. WWF commissioned the Institute for Sustainable Futures to examine risks and opportunities associated with bioplastics to assist policymakers in navigating and regulating this emerging class of materials.

The report outlines a growing global bioplastics market that requires responsible sourcing and proper end-of-life management.

Recommendations include phasing out problematic bioplastic products, improving labelling and feedstock standards, mandating certification for compostable products, acting against misleading claims, increasing awareness, improving end-of-life management options, conducting further research, and advocating for global regulations.

Appendix C: MFA Assumptions

Key Assumptions used in the production of MFA

Phase 1:

- Production of PLA uses 2 kg of feedstock to produce 1 kg of polymer.
- Insignificant amounts of BioPE currently used in Australia.
- PHA uses 4 kg of feedstock to produce 1 kg of polymer.

Phase 2:

- Estimated around 10,000 tonnes of PLA is imported into Australia per annum, particularly in food service ware with an estimated 8,000 tonnes of PLA used in items such as cutlery, cups, and coffee lids.
- The Australian Plastics Flows and Fates study identified around 9,600 tonnes of PLA bioplastic in the waste system.

Phase 4:

- Bioplastic present in compost, as identified by the Plastics Flows and Fates study, is food service ware products, as food contaminated products cannot be recycled.
- Remainder of food service ware products not in compost will flow to landfill, as they cannot be recycled.
- Very limited amount of non-contaminated food service ware will be recycled.

Note: Many assumptions have been made based on commercially sensitive figures provided by industry through stakeholder interview and workshops.

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