

The Recycled Plastics Market: Global Analysis and Trends

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Executive summary

1.1 Goal of study

The goal behind this work is to provide a comprehensive and authoritative analysis on the plastics recycling industry to assist with the future identification of R&D opportunities to overcome market challenges and support growth.

1.2 Scope of study

This industry analysis draws on expert opinion sourced from key stakeholder interviews (n = 10), independent intellectual property (IP) landscape studies and CSIRO authored and independent market analysis reports into the plastic recycling industry. A comprehensive range of stakeholder groups were consulted in accordance with the ethical standards of the CSIRO Social Science and Interdisciplinary Human Research Ethics Committee (CSSHREC). These spanned representatives from Industry (FNQ Plastics), NGOs (Tangaroa Blue Foundation), recycling and resource management consultants (Nextek Pty Ltd), national bodies representing the plastic manufacturing industry (Chemistry Australia and Vinyl Council Australia), State Government (Queensland Department of Environmental and Heritage Protection) and a number of relevant scientists and market researchers within the CSIRO. Views have been conglomerated to provide a narrative on:

- Market forecasts
- Market growth sectors
- IP landscape & network analysis
- Investment trends
- Market influences
- Major system/technological gaps
- Market drivers/challenges
- Likely growth strategies
- Key factors for success
- Outlook for the industry

1.3 Market landscape

The growth in demand for plastic products and packaging, and rising environment concerns, are the main drivers for plastic recycling. This will translate into strong growth for the industry, with estimates of compound annual growth rates (CAGRs) between 5.00% and 6.80% between 2018 to 2026^{2, 3}. The market in 2017 is valued at US\$34.8 billion³, with some analysts predicting a larger market with a value of US\$66.9 billion by 2025⁴.

Expected growth is likely to positively impact all major end-uses and plastic resin-types. The market can be segmented into three major end-users: packaging accounting for 69% of the market, construction accounting for 14%, and automotive accounting for 8%^{2, 3}. The global recycled plastic market is dominated by four major plastic resin types, namely PET, accounting for 55% of the market, HDPE accounting for 33%, and PP and LDPE both accounting for 4%^{2, 3}.

The plastic recycling industry is generally characterised by a low concentration of players in each region, many of these being local, rather than multinational. There is also a trend towards companies that exhibit multiple capabilities across the supply chain or across materials.

1.4 IP landscape analysis

There is a clear intensity in patent filing in recent years with ~50% of patents having been filed in the 5 years to 2016. This is consistent with overall industry growth, but may also indicate growing R&D competition in the space.

Asia currently dominates the IP landscape, representing ~70% of all patents files. This is consistent with Asia being the largest producer of plastic materials, driving the need for improved recycling technologies.

Beyond generic polymer patents, filing in between 2006-2016 dominated by PET, PP and PS technologies. Of the three, PET accounts for the largest number at 188, conferring with the observation that this resin makes up a 60% market share. A future shift towards the use of PP (111 filings) and PS (100 filings) may also be predicted given that these resins appear to be overrepresented in recent filings.

Patent filings by market sector appear to follow similar trends to those observed in market value by end user, with the largest market sector of packaging providing 40% of the patents filed in the last 10 years. Further stratification of these results show that PET use in packaging far outweighs the number of patents in any other category in the last 10 years, with 64 patent filings. Of these, 51 disclose the use of bottles, consistent with the observation that this is one of the most commonly recycled products.

Dow Global Technologies is ranked as the highest patent filing company, with 27 patents in the last 10 years as identified in the Quid patent scoping study undertaken as part of this report. This is followed by SABIC Global Technologies with 24 patents and Resinate Materials Group with 19. The majority of the top cited patents for the top 10 companies appears to be in the polyethylene and polyol areas. The diversity in these companies, and their large industry dominance, indicates there could be strong competition in the R&D space.

IP landscape network analysis revealed that plastic waste management appears most central to the overall landscape, consistent with the drivers identified for plastic recycling. Storage and waste management systems (8.2%), containers and packaging solutions (7.7%), films, coatings, and packaging (6.0%) and bottle recycling (5.3%) are common themes associated with sources and applications of recycled plastics identified, especially in packaging. Analysis of a subsection of plastic recycling start-ups show an emergence in both plastic recycling speciality areas as well as those beyond just plastics, developing broader recycling systems and centres.

Investment in start-up companies is dominated by Waste Connections, Inc., who has received 1.3 billion in investment, over 40 times that of the next closest company, ECO2 Plastics, Inc. Highly vertically integrated companies appear to dominate the the list of top 10 start-up companies by investment level, and include Waste Connections, Inc., SAS APR2, Plas Recycle Ltd, Horizon Waste Services of Arizona, and Total Recycling Services Limited. This indicates there are, or recently were, opportunities throughout the supply chain to create value in plastic recycling.

Overall, there have been a high number of exit events and acquisitions in the plastic recycling market, typically characteristic of growth. Within these, recycling systems appear to lead in volume for the sector, but industrial waste management has displayed the steepest growth of 36% between 2013 and 2016. Residential recycling has by far attracted the largest investment, over 59% of that in this space. This may have been driven somewhat by increased government legislation that encourages diversion of waste from landfill.

1.5 Macroeconomic analysis: PESTLE framework

Political influences in Australia

- **Policies driving collection rather than recycling:** Stakeholders noted that current policies favour the collection of plastic waste, rather than addressing other levels in the supply chain to ensure this is redirected into recycled products. Often results in waste stockpiles or offshore export.
- **Lack of universal waste management legislation:** Several participants in this study noted significant variance between states, meaning that businesses often do not have access to national waste volumes or the ability to replicate approaches across state borders.
- **Low uptake rates for Product Stewardship Programs:** Interviews reinforced that while programs provide needed industry flexibility, they often suffer from low uptake due to voluntary nature.
- **Growing Government concern for threat that plastic poses to marine environment:** Participants cited state and federal inquiries into the issue, and resultant abatement plans as evidence.

Political influences internationally

- **Europe is seen as a forerunner in plastic waste management.** Interviews reinforced that this is a result of strong regulation and incentives to drive alternatives with an emphasis on circular economies. Also, that there were high recycling rates and use of energy from waste methods to utilise plastic waste that is unsuitable for recycling.
- **China and India are rapidly overhauling waste management processes,** but current emphasis is on low-tech, laborious solutions.
- **UN has identified marine plastics as a key global threat.** Multiple programs in place to reduce entry of plastics into marine environment, and looking at marine plastics as a potential feedstock for recycling.

Economic influences in Australia

- **Container deposit schemes will challenge current PET collection and recycling business models**
 - Will require diversification of focus resins.
- **Costs of transport and/or labor** – can either prohibit collection of waste or force a switch to offshore processing.

Economic influences internationally

- **Cost of virgin materials versus recycled plastic waste streams** – tied to oil and plastic prices.
 - Can be offset by producing higher value products or lower value with endless feedstock.
- **High purity waste streams have higher value** – avoids costs of sorting and issues with contamination.
- **Incentivising recycling** – high costs of landfill disposal favors recycling of waste at end of life.
- **Energy from waste** – additional cost recovery stream for low value waste streams.

Social influences in Australia

- **Growing public interest in reducing environmental footprint associated with plastic products**
 - Stakeholders reported a shift in consumer habits to more environmentally friendly practices
 - High uptake in curbside recycling programs but consumer confusion can result in high contamination rates
- **Industry responding with social license measures** to offset consumer concerns

Social influences internationally

- **Growing public interest in reducing environmental footprint associated with plastic products**
 - Interview results reported a shift in consumer habits to more environmentally friendly practices
- **Industry responding with social license measures to offset consumer concerns**
 - Multinationals setting ambitious sustainability targets and adopting more circular economy approaches (e.g. Nike, DELL, P&G, Adidas and Target)
 - Higher rates of recycled plastic use in automotive industry due to increased consumer acceptance and downstream effects of EU legislature (e.g. Ford, Crysler, GM, Nissan and Toyota)

Technological influences

System Gaps:

- **Cost effective collection of waste**
- **Maximising the volume, usability and value of waste collected**
- **Maximising value of products produced**

Resin specific gaps:

- **PET** – collection volume and quality, contaminated/mixed waste streams, multilayered packaging, removal of pigments
- **HDPE** – sorting and separation based on application

- **PVC** – sorting and separation based on type, contamination of other waste streams with PVC, recycling via chlorine recovery. Polyethylene and other polymers contamination of PVC (in sectors (eg healthcare) where PVC accounts for about 30% of polymer stream).
- **LDPE** – cost of collection, sorting and processing filmic plastics
- **PP** – cost of collection for extended polystyrene
- **Nylons** – low recycling rates, multilayers structures

Legal influences in Australia

- National Industrial Chemicals Notification and Assessment Scheme (NICNAS) has greater flexibility than European equivalent to recognise differing economy in Australia.
- Taking EU as an example, stakeholders indicated that Australia will need increased regulation to incentivise plastic recycling to see a large-scale industry shift

Legal influences internationally

- Stakeholders identified the EU as a gold standard for increased regulation driving industry transition to increase both recovery and recycling rates for plastics, although some argue that this creates a slow and overly conservative environment
- Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation is assessment of recycle and 'legacy additives', which has significantly impeded recycling.

Environmental influences

- **Increasing volume and long legacy of plastics** in the environment leads to ecological, economic and health impacts
- **Impact of growing microplastics problem** - No way to remove and they have ability to move up through the food chain to cause human exposure
- **Depletion of virgin resources** - for low value, single-use items
- **Impact of toxic additives** in plastics – e.g. plasticisers and flame retardants that are potentially released during degradation
- **Increasing waste disposal requirements** – landfill sites often stretched beyond capacity
 - Resulted in increase in domestic burning of waste & exposure to toxic derivatives
 - Human mortalities from unsafe landfill disposal
- **Impact of degradable plastics** – designed to combat issue of plastic entering environment.
 - Ambient conditions may not be sufficient to completely degrade plastic and hence compound the microplastic problem
 - Contaminate recyclable plastic waste streams, reducing value and performance

1.6 Microeconomic analysis: Thompson and Strickland's Seven Strategic Questions

Question 1: Dominant economic features

Continued growth is predicted for the market overall – CAGR of 7.9% predicted over next decade, driven by rising environmental concerns, waste management problems and increasing demand for recycled plastic items. Continued growth is expected across all major sectors, major resin types and across all regions.

Question 2: Competitive forces

Five force analysis revealed the power of suppliers and threat of market entry to be the dominant forces on the industry. This is due to the fact that there are few recycled plastic processors compared to buyers, and that as the market is in the developing stage, there are multiple promising entry points given technology efficiency or penetration improvements.

Question 3: Forces driving change

The highest impact market drivers identified are growing environmental concerns and sustainability goals, an increase in rate of plastic recycling, emerging opportunities and growing demand for recycled products and increased regulation and government support. The highest impact market challenges appears to be inefficient waste segregation and waste management problems.

Question 4: Market positions

- **Price leader** – Recycled plastics are a widely traded commodity globally. India, China and Hong Kong are considered the cheapest sources, and other regions will have to match these prices to remain competitive.
 - R&D opportunity → Technologies to increase value of recycled plastics through improved sorting (reduces contamination) or new methods that make use of low value/underutilised feedstocks
- **Backward integration** – Cost advantage if large manufacturers backward integrate to plastic manufacturing units
 - R&D opportunity → Technologies to transition to a more vertically integrated position
- **Quality** – Virgin resins compete aggressively on price and quality/consistency when compared with recycled resins.
 - R&D opportunity → Technologies for higher quality recycled resins to compete with virgin resins.
- **Proximity of supplier** – Recycled plastics should be readily available to consumers in required quantities.

Question 5: Likely strategies

- **International player growth** – Organically as well as through acquiring regional or local players.
- **Small player growth** – Small players are best positioned for rivalry by focusing on end-user requirements.
- **Technological innovations and new product development** – Advances are likely to intensify competition. Also relevant to low recycling rates, which are partly due to technological issues. Opportunities to improve efficiency and effectiveness of plastic recycling.
- **Integrating down the supply chain** – Virgin resin suppliers may choose to integrate down the chain and adapt recycled resins as part of their portfolio.
- **Integrating up the supply chain** – Brand owners/converters may integrate up the chain to take responsibility for recycled resin quality used in their products.

Question 6: Key factors for future success

- **Technology and manufacturing** – To overcome inefficiency in sorting and to remove contaminating materials. Quality of recycled plastic is rated as the key parameter for procurement, so technological advancements that deliver high quality plastic are an advantage.
- **Distribution** – Recycled plastics are predominantly supplied directly from manufacturer to end-user, subverting any need for a trader or distributor, thereby increasing profitability for manufacturers.
- **Marketing** – Presenting a closed-loop or circular economy image is a promising strategy for attracting customers and suppliers.
- **Skills and capability** – Largest markets are driven by availability of advanced technologies and skilled workforce. Innovative business models should also be explored through R&D.
- **Government regulation** – Clear and supportive government targets for the collection and recycling of plastics coupled with strong and uniform environmental standards on waste. This will include positive incentives for businesses in this sector such as tax relief, R&D support, and innovation support.

Question 7: Outlook for industry

Strong positive growth is expected in Plastic Recycling markets. Increases in demand across the segments will spur growth in packaging, construction and automotive industries. In addition, environmental concerns and regulations are expected to be strong positive drivers for growth in this industry.

Business opportunities for R&D exist because technological barriers are limiting recycling rates, efficiency and safety in the industry. Business opportunities also exist in redefining business models, to increase penetration, and offer more value added services (especially across the value chain).

1.7 Conclusion

The key economic factor that governs the plastic recycling industry concerns the cost and quality competitiveness of recycled resins when compared with virgin materials. While this is often tied to oil and plastic commodity prices, this can be offset by the development of technologies that maximise the volume, usability, purity, quality and value of waste collected, or redirection of material to other streams such as energy from waste.

A large driver of growth in the industry stems from growing public interest in reducing the environmental footprint of plastic products. As a result, large multinationals are beginning to set ambitious sustainability targets, and adopting more circular economy approaches. Companies are hence showing an increased interest in new technologies that allow them to use recycled plastics in their consumer products, particularly for more problematic waste materials such as marine plastics.

The largest technological gaps that were identified involve the cost effective collection of waste, appropriate sorting technologies that allow the extraction of high quality waste streams for reprocessing, and processes that maximise the volume, usability and value of waste collected. Of interest are waste streams or resin types that currently suffer from low recycling rates due to contamination or issues with multilayered packaging.

Our results indicated that plastic products are associated with an array of environmental concerns, including the increasing volume and long legacy of plastics, the accumulation of marine and microplastics in the environment, increasing waste disposal requirements, and depletion of virgin resources and potential impact of toxic additives in plastics. Results from our stakeholder interviews indicated that growth of the plastic recycling industry has hence been driven by the increasing consumer focus on environmental issues and sustainability. This has translated into both a shift in preference towards global brand owners with sustainable processes, as well as political action from government to introduce legislation and policies that support plastic recycling measures.

An analysis of dominant competitive forces, and forces driving change, revealed strong cases for the development of innovative technologies that either increase efficiency or penetration of waste segregation and management. Strong market positions would also be delivered by R&D directed towards increasing the value of recycled plastics via reduced contamination, new processes for low value/underutilised feedstocks or processes that deliver higher quality recycled resins that are able to compete with virgin materials. Also technologies that help transition manufacturers to a more vertically integrated position.

This report provides strong evidence for numerous R&D opportunities that would assist the plastics recycling industry to overcome identified market challenges and support future growth. It is hence the recommendation of the authors that a further body of work be commissioned that involves in depth industry consultation to facilitate the crafting of an industry aligned R&D roadmap for the CSIRO.

2 Introduction

2.1 Goal of study

The goal behind this work is to provide a comprehensive and authoritative analysis on the plastics recycling industry to assist with the future identification of R&D opportunities to overcome market challenges and support growth. Such work will facilitate the future crafting of an industry aligned R&D roadmap for a research organisation.

2.2 Scope of study

This industry analysis draws on expert opinion sourced from key stakeholder interviews (n = 10), independent intellectual property (IP) landscape studies^{5,6} and CSIRO authored⁷ and independent^{1,2,4,8-11} market analysis reports into the plastic recycling industry. A comprehensive range of stakeholder groups were consulted in accordance with the ethical standards of the CSIRO Social Science and Interdisciplinary Human Research Ethics Committee (CSSHREC). These spanned representatives from Industry (FNQ Plastics), NGOs (Tangaroa Blue Foundation), recycling and resource management consultants (Nextek Pty Ltd), national bodies representing the plastic manufacturing industry (Chemistry Australia and Vinyl Council Australia), State Government (Queensland Department of Environmental and Heritage Protection) and a number of relevant scientists and market researchers within the CSIRO. Views have been conglomerated to provide a narrative on:

- Market forecasts
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- IP landscape & network analysis
- Investment trends
- Market influences
- Major system/technological gaps
- Market drivers/challenges
- Likely growth strategies
- Key factors for success
- Outlook for the industry

Here, we have defined industry analysis according to the PESTLE (political, economic, social, technological, legal and environmental, Figure 1) framework, providing a snapshot of the macro-environmental factors effecting the industry. Additionally, a microeconomic analysis was utilised according to Thompson and Strickland's seven strategic questions framework (Figure 2)¹².

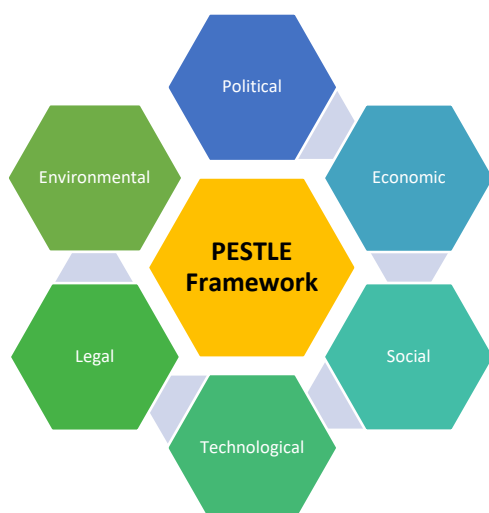


Figure 1. Macroeconomic PESTLE framework utilised in this study encompassing political, economic, social, technological, legal and environmental influences.

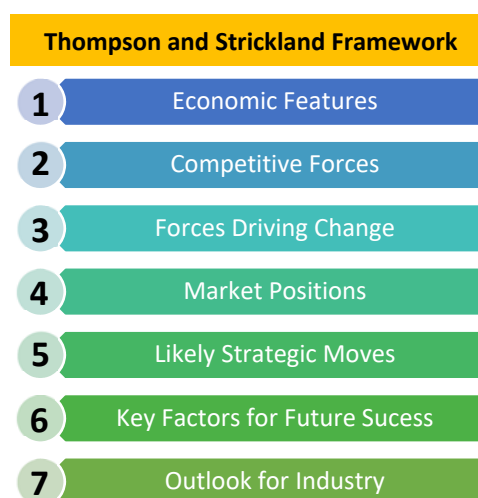


Figure 2. Microeconomic Thompson and Strickland framework used in this study encompassing seven strategic questions to understand industry competitive environments and key information for strategic planning.

3 Plastic recycling overview

3.1 Plastic waste management definitions

The ISO 15270¹³ guidelines categorise the wide variety of plastics recovery strategies into two major classes, namely **materials recovery** and **energy recovery**. Both methods aim to reduce the quantity of end-of-life plastics being transferred into landfill and have been defined in the following sections.

Materials recovery

Materials recovery constitutes material-processing operations that include mechanical recycling, chemical (feedstock) recycling or biological (organic) recycling¹³. These methods aid in the conversion of waste plastic into lower or same grade plastic materials and/or starting materials.

3.1.1 MECHANICAL RECYCLING

Mechanical recycling is the dominant form of material recovery whereby plastic waste is processed into secondary raw material or products without significantly changing the chemical structure of the material¹³. Such processing readily lends itself to recycling thermoplastics such as PET, PE, PVC and PP, but is not applicable to thermoset polymers such as unsaturated polyesters or epoxy resins due to their permanent crosslinking during manufacture¹⁴.

Mechanical processing typically involves the following five stages of production as listed in Figure 3, adapted from Technavio, 2016¹:

1. **Collection:** Recycling facilities gather recyclable materials from municipal waste collections, specialised recycling bins and/or directly from industry.
2. **Sorting:** Collected plastic is sorted, typically manually, according to its plastic resin code, some optical sorting.
3. **Chipping:** Sorted plastics is passed through a chipper which consists of cylinder of blades that cut plastic down to a predetermined grill size.
4. **Washing:** Melted chips are washed to remove any contaminants (dirt, glue, paper labels, product remnants etc.). A wash is also typically performed using an alkaline, cationic detergent in water at elevated temperatures for short periods.
5. **Pelleting:** Cleaned and chipped plastic is put through an extruder which melts the chips and shapes them into pellets, ready for reuse into new items.



Figure 3. Overview of the plastic recycling process¹

3.1.2 CHEMICAL (FEEDSTOCK) RECYCLING

Chemical or feedstock recycling involves converting waste plastic into monomer starting materials or other raw materials by changing the chemical structure of the polymer¹³. This can be achieved by cracking, gasification or depolymerisation processes but excludes energy recovery or incineration.

3.1.3 BIOLOGICAL (ORGANIC) RECYCLING

Biological or organic recycling involves the microbiological treatment of biodegradable plastic material under aerobic (composting) or anaerobic (digestion) conditions. In the presence of oxygen this produces organic residues, carbon dioxide and water, while in the absence of oxygen, organic residues, methane, carbon dioxide and water^{13, 15}.

Note that based on UNEP definitions¹⁶, 'biodegradable' polymers are a distinct subset of 'degradable' polymers (Table 1), and that either class can in fact act to compound accumulation of microplastics in the environment if they do not degrade completely.

3.1.4 DEGRADATION OF PLASTICS

Table 1. Definitions associated with the degradation of plastics¹⁶

TERM	DEFINITION
Degradation	Partial or complete breakdown of a polymer as a result of UV radiation, oxygen attack, biological attack. Note that weathering-related degradation results in a loss of mechanical integrity, embrittlement, further degradation and fragmentation into microplastics, and is thought to significantly contribute to the build-up on microplastics in the environment¹⁶.
Biodegradation	Biological process of organic matter which is completely or partially converted to water CO ₂ /methane, energy and new biomass by microorganisms (bacteria or fungi).
Mineralisation	Defined in 2015 report as the complete breakdown of a polymer as a result of combined abiotic and microbial activity into CO ₂ , water, methane, hydrogen, ammonia and other simple organic compounds.
Biodegradable	Capable of being biodegraded
Compostable	Capable of being biodegraded at elevated temperatures in soil under specific conditions and timescale, usually only encountered in an industrial composter




Energy recovery





Energy recovery involves directly combusting waste plastic under controlled conditions to produce useful energy¹³. For example, a simple solid-waste incinerator can be utilised to produce hot water, steam and/or electricity from the combustion of waste plastic, or plastics may be liquefied to diesel fuel to power vehicles or power generators. There are, however, concerns that potentially hazardous substances present in the waste plastic may be released into the atmosphere during combustion, particularly if suitably high temperatures are not reached. As a result, energy recovery is typically less prevalent than mechanical processing to recycle plastics¹⁴. There is, however, expected to be significant growth in this area as technology improves, signified by the recent large investment into start-up companies focussed on new energy recovery approaches.

3.2 Plastic resin classifications

The sorting of plastics for recycling is guided by the ASTM International Resin Identification Coding System,¹⁷ which identifies the plastic resin from which the product is made. These symbols along with chemical structures, resin properties and typical applications have been summarised in Table 2, which is adapted from the American Chemistry Council Plastic Packaging Resins Document¹⁸.

Table 2. Major plastic resins¹⁸

RESIN CODE	NAME AND STRUCTURE	PROPERTIES	PRODUCT APPLICATIONS	PRODUCTS MADE WITH RECYCLED CONTENT
 PET	Polyethylene terephthalate (PET or PETE)	<ul style="list-style-type: none"> • Clear and optically smooth surfaces for oriented films • Excellent barrier for O₂, H₂O and CO₂ • High impact capability and shatter resistance • Excellent resistance to most solvents • Hot-filling capability 	Packaging <ul style="list-style-type: none"> • Plastic soft drink bottles • Food jars • Ovenable film and microwave trays Others <ul style="list-style-type: none"> • Textiles, carpet, films, engineering mouldings 	<ul style="list-style-type: none"> • Fibre for carpet, fleece jackets, comforter fill and tote bags • Containers for food, beverages (bottles) and non-food items • Films and sheets • Strapping
 HDPE	High density polyethylene (HDPE)	<ul style="list-style-type: none"> • Excellent resistance to most solvents • Higher tensile strength compared to other PE forms • Relatively stiff material with useful temperature capabilities 	Packaging <ul style="list-style-type: none"> • Plastic bottles for milk, juice, water and household cleaners • Retail and grocery bags • Cereal box liners Others <ul style="list-style-type: none"> • Injection moulding, extruded pipes, plastic wood composites, wire and cable covering 	<ul style="list-style-type: none"> • Bottles for non-food items such as personal care and household cleaners • Plastic lumber for outdoor decking, fencing and picnic tables • Pipe, floor tiles, buckets, crates, flow pots, garden edging, film and sheet, and recycling bins
 PVC	Polyvinyl chloride (PVC or vinyl)	<ul style="list-style-type: none"> • High impact strength, clarity and processing performance • Resistant to grease, oil and chemicals 	Packaging <ul style="list-style-type: none"> • Rigid: bottles, blister packs and clamshells • Flexible: medical and bedding bags, shrink wrap, deli wrap Others <ul style="list-style-type: none"> • Rigid: permanent framework, pipe, window frames, fencing, siding, railing • Flexible: medical products (blood bags, tubing), wire/cable insulation, carpet backing, coated fabrics and flooring 	<ul style="list-style-type: none"> • Windows, pipes, decking, fencing, panelling, gutters, carpet backing, floor tiles and mats, resilient flooring, mud flaps, cassette trays, electrical boxes, cables, traffic cones, garden hose and mobile home skirting • Packing, film and sheet and loose-leaf binders

RESIN CODE	NAME AND STRUCTURE	PROPERTIES	PRODUCT APPLICATIONS	PRODUCTS MADE WITH RECYCLED CONTENT
 LDPE	Low density polyethylene (LDPE)	<ul style="list-style-type: none"> • Excellent resistance to acids, bases and vegetable oils • Toughness, flexibility and relative transparency • Good for packaging that requires heat sealing 	Packaging <ul style="list-style-type: none"> • Bags for bread, dry cleaning, newspapers, frozen foods, fresh produce and household garbage • Shrink wrap and stretch film • Coatings for paper milk cartons and hot/cold beverage cups • Container lids • Squeezable bottles Others <ul style="list-style-type: none"> • Toys • Injection moulding, adhesives, sealants, wire/cable coverings 	<ul style="list-style-type: none"> • Shipping envelopes, garbage bin liners, floor tile, panelling, furniture, film and sheet, compost bins, garbage bins, landscape timber and outdoor lumber
 PP	Polypropylene (PP)	<ul style="list-style-type: none"> • Excellent optical clarity in biaxially oriented films and stretch blow moulded containers • Low moisture vapour transmission • Inertness towards acids, alkalis and most solvents 	Packaging <ul style="list-style-type: none"> • Containers for yoghurts, margarine, takeout meals • Medicine bottles • Bottle caps and closures Others <ul style="list-style-type: none"> • Fibres, appliances and consumer products • Durable applications such as automotive and carpeting 	<ul style="list-style-type: none"> • Automobile applications such as battery cases, signal lights, battery cables, brooms and brushes, ice scrapers, oil funnels, and bicycle racks • Garden rakes, storage bins, shipping pallets, sheeting, trays
 PS	Polystyrene (PS)	<ul style="list-style-type: none"> • Excellent moisture barrier for short shelf life products • Excellent optical clarity in general purpose form • Significant stiffness in both foamed and rigid forms • Low density and high stiffness in foamed applications • Low thermal conductivity and excellent insulation properties in foamed form 	Packaging <ul style="list-style-type: none"> • Food service items such as cups, plates, bowls, cutlery, hinged takeaway containers (clamshells), meat and poultry trays and rigid food containers (with foamed or non-foamed PS) • Protective foam for packaging delicate items • Packing peanuts (loose fill) • Compact disc cases Others <ul style="list-style-type: none"> • Agricultural trays, electronic housing, cable spools, building insulation, video cassette cartridges, coat hangers, medical products and toys 	<ul style="list-style-type: none"> • Thermal insulation, thermometers, light switch panes, vents, desk trays, rulers and license plate frames • Cameras or video cassette casings • Foamed foodservice applications such as egg shell cartons • Plastic moulding (i.e. wood replacement products) • Expandable polystyrene (EPS) foam protective packaging
 OTHER	Other Use of code indicates use of resin other than those listed above or is made of a mixture of resins	<ul style="list-style-type: none"> • Dependent on resin combination used 	<ul style="list-style-type: none"> • Large reusable water bottles, some citrus bottles • Oven-baking bags, barrier layers and custom packaging 	<ul style="list-style-type: none"> • Bottles and plastic lumber applications

4 Market analysis

4.1 Market landscape

Market size and forecast

The growth in demand for plastic products and packaging, and rising environment concerns, are the most important drivers for Plastic Recycling.

Accelerating consumer plastic consumption over the last 50 years has seen the Global Plastic Product and Packaging Manufacturing industry grow to an estimated worth of \$514 billion in 2018¹⁹. Increased demand is largely due to the unsurpassed properties that plastics provide in consumer products, namely they are cheap, lightweight (and therefore easier to transport), durable, can be very resistant to chemicals, act as thermal and electrical insulators, and can be easily processed into a wide variety of products. The recyclability of plastic products is another demand driver given the environmental concerns of governments and consumers worldwide¹⁹.

Due to the durability of plastics, there is an increasing accumulation of end-of-life plastics in landfills and as waste litter in the environment, creating both waste-management issues and environmental damage¹⁴. In response, industry R&D over the next five years is predicted to focus on creating cost-effective, environmentally friendly plastic products¹⁹.

There is strong growth anticipated for the global plastics recycling market. Compound annual growth rates (CAGRs) are predicted to be between 5.00% and 6.80% for the years 2018 through to 2026^{2,3}. The total market in 2017 was valued at US\$34.8 billion³. Other sources anticipate larger growth of 7.9% and a bigger market by 2025, to be worth US\$66.9B⁴. The former more conservative estimate is however used.

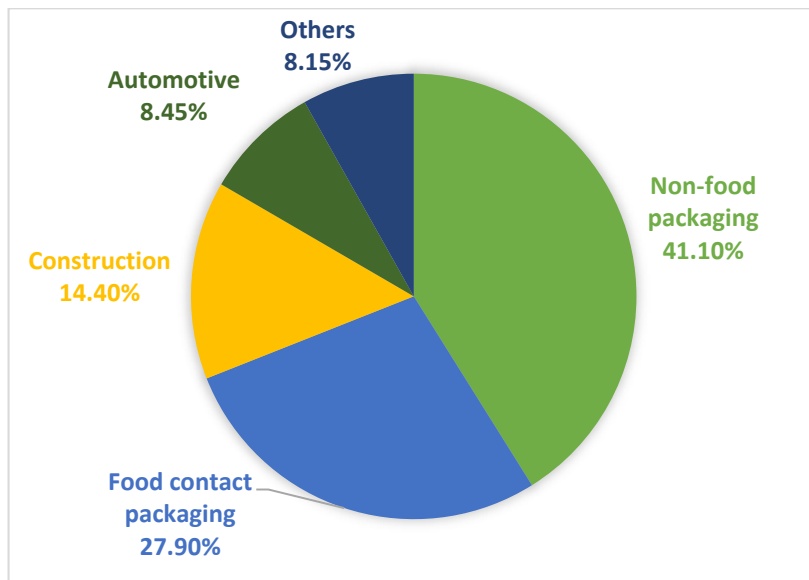
The strong growth is expected to positively impact all major segments and resin types. The market can be segmented into three major end-users, namely food and non-food packaging, construction, and automotive². Others include textile, industrial, agriculture and consumer goods³. The global recycled plastic market is dominated by four major plastic resin types, namely PET, HDPE, PP and LDPE.

Sources anticipate larger growth of 7.9%, and a bigger market by 2025, to be worth US\$66.9B

Market segmentation

4.1.1 GLOBAL RECYCLED PLASTICS BY END USER

The largest market segments for recycled plastic are non-food contact packaging, food contact packaging, construction and automotive (Figure 4²), packaging however dominates the market at 69%. Growth is expected for all segments due to population growth, and increasing demand for lightweight and sustainable materials.

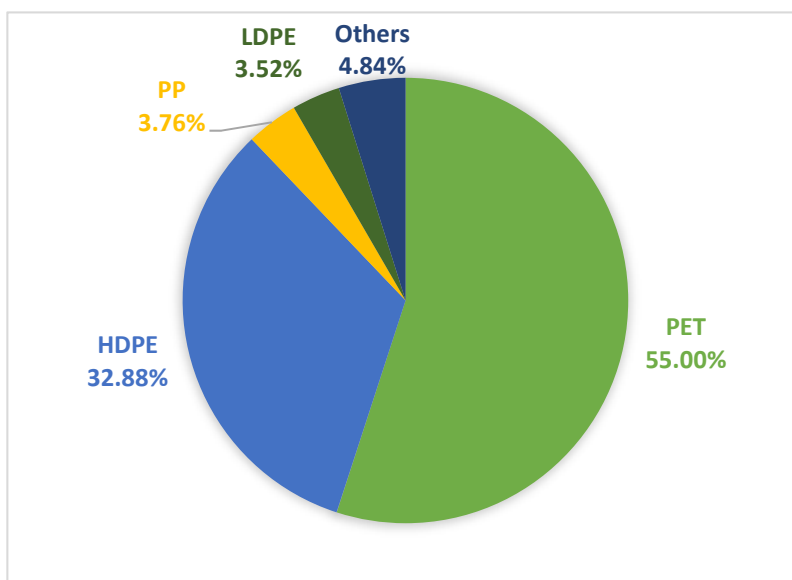


Packaging dominates the market at 69%

Figure 4. Global end user in 2017 ²

4.1.2 GLOBAL RECYCLED PLASTICS BY TYPE

The global recycled plastics market is dominated by four major plastic resin types, namely PET, HDPE, PP and LDPE (Figure 5 ²). The largest of these segments is PET, with a 2017 market share of 55%. PET is commonly used in the manufacture of containers and bottles, used for packaging foods and other consumer goods. Often legislation and recourse protection schemes serve to encourage growth in PET recycling markets by providing grants and other incentives. Increased demand for recycled PET products is likely to emerge from developing countries, including China and India, attributable to rising environmental concerns and the shift towards PET bottle packaging².



PET accounts for 57% of resins

Figure 5. Global market by type in 2017 ²

There will be increasing demand for HDPE in part driven by a developing market in China and India as living conditions improve, as well as increased demand for HDPE pipes and cables with the rapid growth of industries in the region. There is will also be significant growth in the HDPE recycling market due to increased consumption of milk bottles, jars, water bottles and detergent bottles. The growth of the market is also greatly supported by the fact that it is more cost efficient to manufacture a product from recycled HDPE than from virgin resin.

Major domestic and overseas companies

The Plastic Recycling industry is generally characterised by a low concentration of players in each region, that is, each region tends to have numerous players to serve local needs. Many of these players are local, rather than multinational, and exhibit multiple capabilities across the supply chain or across materials. There are however many players who also specialise in plastic recycling, or manufacturing using recycled plastic. An overview of the major domestic and overseas plastic recycling companies have been provided in Table 3 and Table 4⁷. This list is not exhaustive, but has been selected based on size of company and influence in the region, as well as those who have attracted investment funding in recent times. A more comprehensive listing of both domestic and international companies has been provided as a searchable and filterable database entitled ‘Plastic Recycling Stakeholder Identification’ attached to this report.

Table 3. Major domestic plastic recycling and waste recovery companies⁷

COMPANY NAME	TYPE	DESCRIPTION
Astron Plastics	Plastic waste processing	<p>Astron has been at the forefront of plastic recycling for over 30 years and continues to be a market leader in converting plastic scrap into recycled plastic resin, AS4702 underground cable covers and recycled slip sheets. Astron has recycling and manufacturing facilities in Melbourne, Sydney, Brisbane, Auckland and Christchurch. All facilities actively process plastic waste. Astron specialises in producing recycled HDPE, LDPE and Polypropylene. Astron New Zealand operate under ISO 9001. Astron Australia operate under a certificate of conformance from TUV Rheinland (a recognised global leader in manufacturing conformance to Australian Standards) for its AS4702 cable cover.</p> <p>Astron has plastic waste processing facilities in Sydney, Melbourne and Auckland and supplies through a vast distribution network covering all states and territories in Australia and New Zealand.</p>
Baxvis Pty Ltd (Bought by Transpacific Baxter Pty Ltd)	Waste processing	<p>Baxvis Pty, Ltd. operates as a commercial and industrial, and construction and demolition waste recycling facility. It recovers recyclable waste materials, such as cardboard, paper, and plastic. The company was founded in 2005 and is based in Australia. Baxvis Pty, Ltd. operates as a subsidiary of Baxter Group, Ltd.</p>
Bingo Holdings Pty Ltd/Bingo Industries Limited	Waste management, collection and processing	<p>Bingo Holdings Pty Ltd. provides waste management solutions for household, business, construction, and industrial sectors in Australia. It offers skip bins, including chain lifted marrel bins and hook bins; site bins for hire; and crane-able skip bins for building sites. The company also provides commercial waste bins, such as front lift bins, rear lift bins, bulk bins, compactors, and balers for bulk waste removal, event waste management, liquid and plastic waste removal, secure product and document destruction, co-mingled recycling, general waste collection, paper and cardboard waste collection, and timber waste removal applications. In addition, it offers commercial bulk waste collection and disposal, recycling, waste baler, and waste compactor services. Further, the company operates recycling centres in Sydney, Australia. Bingo Holdings Pty Ltd. was incorporated in 2013 and is based in Auburn, Australia. Bingo Holdings Pty Ltd. operates as a subsidiary of Bingo Industries Limited.</p>
Cleanaway	Waste processing	<p>Cleanaway is Australia's biggest waste management group and operates a range of municipal and commercial Material Recovery Facilities (MRFs) that have a focus on recovery of packaging materials for recycling. Our recycling program for commercial and industrial businesses is supported by the Australian Packaging Covenant and has been recognised in Packaging Industry Awards.</p>
Closed Loop Environmental Solutions Pty Ltd	Waste management, collection and processing; packaging manufacturing	<p>Closed Loop is an Australian company with more than 13 years’ experience providing comprehensive environmental solutions across industries including aviation, hospitality and health.</p> <p>Based in Australia, New Zealand and the United Kingdom, Closed Loop builds strong partnerships with our clients to design, deliver, communicate and measure bespoke waste management solutions.</p> <p>All of Closed Loop’s packaging solutions are made of 100 per cent recyclable material.</p>

COMPANY NAME	TYPE	DESCRIPTION
Ecopolymers	Plastic waste processing; plastic manufacturing	Eco Polymers Recycling is a plastic reprocessing company, producing recycled resins and powders from recycled plastic
Elite Waste and Recycling	Waste management, collection and processing	Elite provide waste management and recycling services to businesses. Items that fall under the Recycling Services category include items that can be recycled and reused.
Eurokey Recycling	Plastic waste collection and processing	<p>Eurokey delivers cohesive recycling and waste management facilities, providing effortless recycling collections through to full recycling and waste management solutions.</p> <p>Plastic waste must be segregated, clean and in mill size bales. The following types are handled: LDPE, HDPE, PVC, POLYPROPYLENE, ACRYLIC, POLYESTER, HIPS, APET, PET, POLYETHYLENE, POLYCARBON, PMMA, NYLON, ACETYLE, GPPS, ASA, and many more types.</p> <p>Eurokey Recycling was incorporated in 2007 with headquarters in United Kingdom and Australian head office in Brisbane Australia.</p>
Global Renewables Australia Pty Ltd	Waste processing	<p>Global Renewables is a privately-owned and operated Australian company which provides sustainable, high technology solutions for household waste management and avoids the significant environmental problems that are caused by the landfilling of waste.</p> <p>Global Renewables has developed over many years a unique Australian expertise in creating and recovering valuable products from municipal solid waste for the local communities' beneficial use. Global Renewables' Eastern Creek UR-3R Facility currently processes around 15% of Sydney's household waste.</p>
Plastic Recyclers Australia PTY Ltd	Plastic waste processing; Plastic product manufacturing	Undertakes sorting, blending and processing of many different plastics to create a wide variety of practical, long-lasting and environmentally friendly, quality products that are manufactured here in Australia.
Red Cycle	Plastic waste collection and processing	<p>Soft plastics are dropped by consumers into the nearest REDcycle collection bin and RED Group will do the rest. There are more than 630 participating supermarkets around Australia.</p> <p>The collected plastic is returned to RED Group's facility for initial processing, then delivered to Victorian manufacturer Replas.</p>
Replas	Recycled plastic manufacturer	<p>Replas is Australia's leading recycled plastic manufacturer and aims to provide a solution for plastic waste by delivering quality cost effective sustainable products.</p> <p>The company produces a range of over 200 recycled plastic products in Australia using state-of-the-art machinery and robotics together with a high degree of energy efficiency. The range includes bollards, signage, outdoor furniture, fitness equipment and enduroplank/decking as well as products suitable for traffic control, parks and gardens and the utilities industry</p>
SUEZ Australia	Plastic waste management, collection and processing	<p>SUEZ is continually seeking new ways to recover the many different types of plastic products that are still being sent to landfill that could easily be recycled for reuse. In 2015 SUEZ has recycled 3,513t of plastic. SUEZ can tailor a plastics collection and recycling service to meet the individual needs of customers. They provide a variety of containers, balers and cages suitable to site requirements.</p> <p>SUEZ assists in the identification and assessment of all plastic types and provides advice on recycling and resource recovery options for plastic waste generated by businesses.</p> <p>Plastic that is collected by SUEZ or dropped off at one of our resource recovery centres is screened, decontaminated and sorted into specific types e.g. HDPE</p> <p>Soft plastics and most bottles are baled, however, hard plastics are processed and pelletised into granules for transport to manufacturing industries.</p>
SULO	Plastic waste processing; Plastic product manufacturing	SULO 'closes the loop' by buying back old bins and recycling the material for use in the manufacture of new high quality bins

COMPANY NAME	TYPE	DESCRIPTION
Tox Free Solutions Limited	Waste management and processing	<p>Tox Free Solutions Ltd (Toxfree) is one of Australia's leading environment, waste management and industrial service providers. Servicing over 20,000 customers nationally, Toxfree provides solutions for some of Australia's leading businesses and government organisations throughout Australia.</p> <p>With over 70 facilities nationally and employing a team of over 1600 people, Toxfree has a portfolio of treatment technologies and technical expertise to enable the cost effective remediation and treatment of a broad range of solid, liquid, industrial and hazardous waste. Toxfree's national network of waste management facilities and treatment technologies ensures Toxfree can provide innovative and sustainable waste management solutions for all types of waste including commercial, household, industrial, construction and hazardous waste.</p> <p>Tox Free Solutions Limited was founded in 2000 and is headquartered in Osborne Park, Australia.</p>
Transpacific Baxter Pty Ltd (Bought by Cleanaway)	Waste management and processing	<p>Transpacific Baxter Pty Ltd. provides integrated waste management services. It owns and operates sites to manage solid inert waste, including demolished building material, scrap metals, paper, cardboard, glass, and timber, as well as putrescible waste. The company also engages in recycling and recovery operations; the management of council contracts; and the provision of bin hire services in the Latrobe Valley and Murray Valley. Transpacific Baxter Pty Ltd. was formerly known as Baxter Group Ltd. and changed its name to Transpacific Baxter Pty Ltd. in October 2007. The company was incorporated in 2002 and is based in Clarinda, Australia.</p>
Visy Industries Holdings Pty Ltd	Waste management and processing; product manufacturing	<p>Visy sorts and processes recyclable materials and enables the creation of new products from what is discarded by households, schools and businesses.</p> <p>Visy Industries Holdings Pty Ltd provides recycling, packaging, and paper solutions. It recycles papers, cardboards, liquid paper boards, and cartons, as well as plastic, glass, aluminium, and steel food and beverage containers for transport and storage, manufacturing, retailing, wholesaling, construction, services, government, health and community services, and recreation and sports businesses; and magazines, papers, letters, bottles, jars, tins, cardboards, plastics, glasses, and steel and aluminium products for households.</p> <p>It offers recycling services to schools; education tools, including Environmental Detective, a curriculum based program to help teachers and students understand how each product is recycled; and fibre board boxes, food and beverage cans, PET plastic bottles, beverage cartons, food plastics packaging, and printed and plain packaging solutions and services. It produces virgin kraft and recycled corrugated papers for packaging and building industries; paper coating products for light weight laminating applications, paperback book covers, plasterboard liners, corrugated and folding cardboard boxes, and waxable boxes; paper laminates for heavy weight boards; and case erectors, compactors, ladders, tray formers, and packing systems.</p> <p>Visy Industries Holdings Pty Ltd was founded in 1948 and is based in Southbank, Australia with locations in Australia, New Zealand, North America, and Europe. Visy Industries Holdings Pty Ltd operates as a subsidiary of Pratt Holdings Proprietary Limited.</p>
Welvic	Leading PVC recycler	<p>Welvic is the Australian brand associated with quality vinyl compound, delivering market leading products and technology for the past 40 years.</p> <p>Waste PVC from domestic and industrial sources, including surgical saline bags and tubing from Richmond's Epworth Hospital are used to make pellets which can be turned into new products such as hoses for industrial and irrigation uses and new flooring/matting products.</p> <p>Deer Park company, Welvic Australia, is one of a growing number of Victorian businesses which recycle common plastics.</p>

Table 4. Major overseas plastic recycling and waste recovery companies⁷

COMPANY NAME	TYPE	DESCRIPTION
Advanced Environmental Recycling Technologies, Inc.	Manufacturer	Advanced Environmental Recycling Technologies, Inc. develops and commercialises technologies to recycle waste polyethylene plastics; and develops, manufactures, and markets value-added green building products primarily in the United States. Its principal products include composite building materials that are used for exterior applications in building and remodelling homes, and for other industrial or commercial building purposes. The company also offers commercial and residential decking planks and accessories, such as balusters and handrails under the MoistureShield, MoistureShield Pro, and ChoiceDek brands; exterior door components; and green recycled plastic resin compounds. Its products are primarily used in renovation and remodelling by consumers, homebuilders, and contractors as an exterior building alternative for decking, railing, and trim products. The company offers its decking products to the do-it-yourself market, as well as to distributors, who re-sell it to lumber dealers, and contractor yards; and door component products to door manufacturers. Advanced Environmental Recycling Technologies, Inc. was founded in 1988 and is based in Springdale, Arkansas.
Avangard Innovative	Waste management, collection and processing	Avangard Innovative was founded in 1984 and is headquartered in Houston, Texas, US. The company is a sustainable solutions provider that specialises in designing custom recycling optimisation programs. It also owns and operates many support facilities that provide on-site processing and recycling services. The company processes a wide variety of materials, ranging from virgin pellets to post-consumer scrap. Avangard Innovative offers waste management, recycling equipment solutions, and facility evaluations and waste auditing services. It also offers PetStar, an FDA certified post-consumer recycled PET, economic and environmental impact studies, and environmental recycling services. Further, it is engaged in the aggregation and processing of recyclables, freight forwarding and logistics, material recovery, and materials trading and resin distribution.
B. Schoenberg & Co	Waste processing	B. Schoenberg was founded in 1994 and is headquartered in Yorktown, New York, US. The company trades acrylics, acetals, acetated, acrylonitrile butadiene styrene, colour concentrates, ethylene, fluoropolymers, ionomer, K-resin, nylon, PET, PET-G, polycarbonate, PP, polystyrene, PVC-flex, PVC-rigid, Ryton, ULTEM, and urethane products. The company consumes nearly 200 truckloads of flexible PVC scrap, regrind, parts, or purge each month for use in its manufacturing facility. It operates 10 branch offices, two manufacturing plants, and strategically located warehouse facilities in the US.
CarbonLITE Industries	Plastic waste processing	CarbonLITE was founded in 2011 and is headquartered in Los Angeles, California, US. The company is one of the leaders in PET recycling. Its PET recycling plant processes over two billion plastic bottles into resin flakes and pellets each year.
Custom Polymers, Inc.	Plastic waste processing	Custom Polymers, Inc., a plastic recycling company, engages in buying, processing, and selling post-industrial and post-consumer plastics. It offers customised recycling solutions through grinding, washing, pelletising, compounding, densifying, metal separation, sorting, repackaging, and distribution services in the United States and internationally. The company was founded in 1996 and is based in Charlotte, North Carolina with a network of locations worldwide. It has sales offices in Chicago, Illinois; Durham, North Carolina; and Toronto, Canada. The company also has divisional headquarters in Houston, Texas; and Kowloon, Hong Kong.
Delta Plastics of the South	Plastic waste collection and processing; plastic product manufacturer	Delta Plastics of the South was founded in 1996 and is headquartered in Little Rock, Arkansas, US. The company is one of the leading producers of irrigation polytube for the agriculture industry. Its products are used to irrigate corn, rice, beans, cotton, sugar cane, and other crops. It operates two manufacturing plants at Little Rock and Stuttgart in Arkansas, US. The company through its irrigation resource division offers technical information and extensive, informed analysis to improve the effective use of a farm's irrigation water. Delta Plastics recovers, cleans, and processes more than 150-million pounds of plastic waste each year. It also sells its PCRpro technology to the plastics industry for use in other products and offers a variety of accessories to improve the performance and efficiency of poly irrigation tubing. Some of the accessories offered by the company include plugs, gates and gate cutters, hole cutters, bands, PVC fittings, repair tape, polytube rollers, and poly patch.
Marmax Products	Plastic product manufacturer	Marmax Products was founded in 1891 and is headquartered at Durham, UK. The company manufactures outdoor furniture and seating products from recycled plastic. Its offerings include outdoor furniture, produce boxes, pallets, and boardwalks.
Orbis	Plastic product manufacturer	ORBIS was founded in 1849 and is headquartered in Oconomowoc, Wisconsin, US. The company offers reusable plastic containers, pallets, dunnage, and bulk systems. It serves the beverage, food, industrial, and consumer goods markets. It operates as a subsidiary of Menasha.
PolyPrime	Manufacturer	PolyPrime is headquartered at Crawfordsville, Indiana, US. The company manufactures extruded PE and PP sheets and converted poly products. It operates as a division of Crawford Industries.

COMPANY NAME	TYPE	DESCRIPTION
PVC recycling	Recovinyl network	A comprehensive list of European recyclers can be found here https://www.recovinyl.com/all-recyclers
UltePET LLC	Plastic waste processing	UltePET was founded in 1999 and is headquartered at Albany, New York, US. The company recycles PET and other plastic resins. UltePET is an FDA approved PET resin supplier to the bottle and sheet markets in North America. It also serves the high-end fine denier fibre, non-FDA bottle and sheet, and engineered resin markets. The company purchases used PET beverage bottles in bales, shredded, or in ground forms and then processes and sells PET as FDA approved or non-FDA approved clean flake, resin, and solid state resin. The company's resins find applications in different markets.
Waste Connections Inc	Waste collection and processing	Waste Connections, Inc., a solid waste services company, provides waste collection, transfer, disposal, and recycling services in the United States and Canada. The company operates through six segments: Southern, Western, Eastern, Canada, Central, and Exploration and Production (E&P). It offers collection services to residential, commercial, municipal, industrial, and E&P customers; landfill disposal services; and recycling services for various recyclable materials, including compost, cardboard, office paper, plastic containers, glass bottles, and ferrous and aluminium metals. The company also owns and operates transfer stations that receive compact and load waste to be transported to landfills or treatment facilities through truck, rail, or barge; and intermodal services for the rail haul movement of cargo and solid waste containers in the Pacific Northwest through a network of intermodal facilities. In addition, it provides E&P waste treatment, recovery, and disposal services for waste resulting from oil and natural gas exploration and production activity, such as drilling fluids, drill cuttings, completion fluids, and flowback water; production wastes and produced water during a well's operating life; contaminated soils that require treatment during site reclamation; and substances that require clean-up after a spill, reserve pit clean-up, or pipeline rupture. Further, the company offers container and chassis sales and leasing services to its customers. As of December 31, 2016, it owned or operated a network of 261 solid waste collection operations; 135 transfer stations; 7 intermodal facilities; 71 recycling operations; 93 active MSW, E&P, and/or non-MSW landfills; 22 E&P liquid waste injection wells; and 17 E&P waste treatment and oil recovery facilities. Waste Connections, Inc. was founded in 1997 and is based in Vaughan, Canada.
Worldwide Recycler Services	Plastic waste collection and processing	Worldwide Recycler Services is a US-based company that collects, recycles, and processes all grades of pre- and postconsumer and industrial plastic recycling scraps. It recycles waste in the forms of regrind, virgin, bales, film scrap recycling, process and palletised materials, purge, pellets, parts, and obsolete materials.

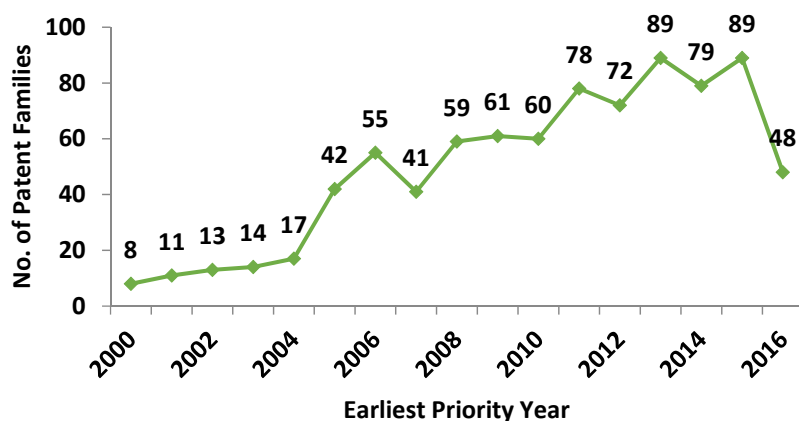
4.2 IP landscape analysis

Patent filing trends

4.2.1 PATENT FILING BY PRIORITY YEAR

Trends indicate a growing intensity in patent filing with approximately 50% of relevant patents (i.e. 407 patent families) having been filed in the 5 years to 2016. This is shown in Figure 6, which depicts the filing distribution for polymer recycling patents⁶. These show the number of patent families according to earliest priority year (year of filing of first patent). Note, the decline shown in 2016 may not reflect complete numbers of patents filed as it takes up to 18 months to publish.

This growth in patent filing in recent times is consistent with overall industry growth, but may also indicate growing R&D competition in this space.

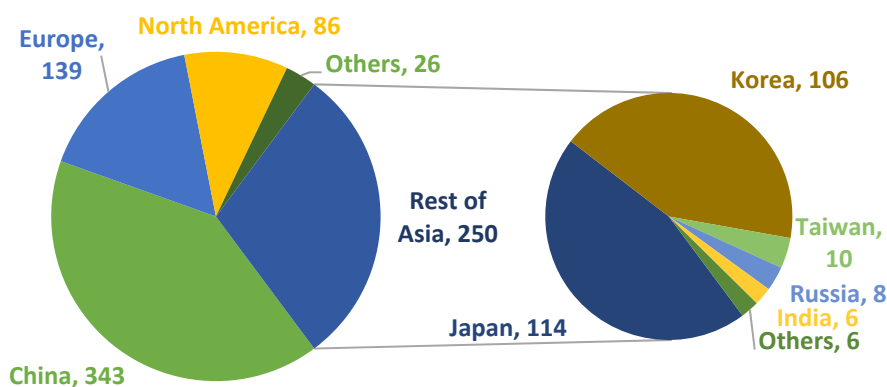


There is a recent intensity in filing with ~50% of patents having been filed in the last 5 years

Figure 6. Patent filing by priority year for polymer recycling patents ⁶

4.2.2 PATENT FILING BY PRIORITY COUNTRY

The number of patents filed according to priority country is presented in Figure 7⁶. This shows a clear domination of the IP landscape by China and the rest of Asia, which make up approximately 70% of the patents filed. This is consistent with Asia being the largest producer of plastic materials¹⁰, and also actively importing plastic waste from USA and Europe to meet needs. These factors hence drive the need for improved recycling technologies.



Asia has dominated the IP landscape, representing ~70% of the patents filed

Figure 7. Patent filing by priority country ⁶

4.2.3 PATENT FILING BY POLYMER TYPE

Except for generic polymer patents, polymer types which dominate patent filings include novel PET, PP, PS and PVC related technologies. This is shown in Figure 8⁶ which depicts the patents filed 2006-2016 stratified according to polymer type. Of the three top patent families, PET accounts for the largest proportion of patents at 188, which is not unexpected given it likely holds the largest market share at 60% in Figure 8. PP and PS, seem to be overrepresented in patent filing when compared with their significantly smaller market shares. This may indicate a future shift towards increased investment for these resin types. HDPE, on the other hand, has a low number of patent filings compared to its market size and growth potential, and the cost efficiencies saved in recycling HDPE compared to using HDPE from virgin plastic.

The field is dominated by novel PET, PP and PS related technologies

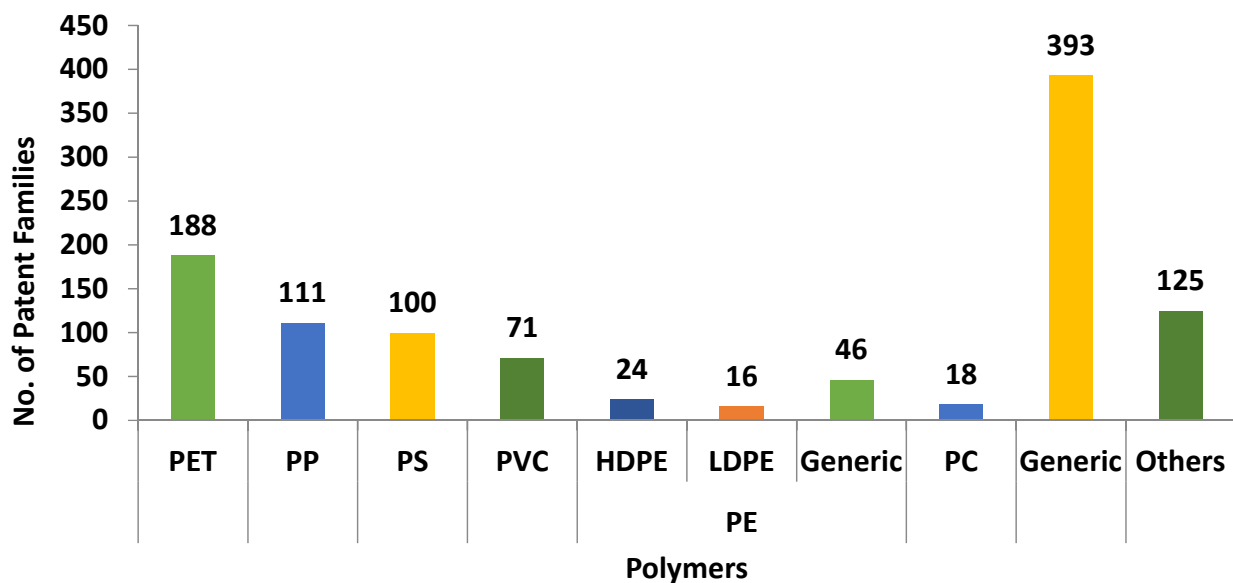


Figure 8. Patent filing by polymer type⁶

4.2.4 PATENT FILING BY PROCESS STEP

Mechanical, chemical, thermal and extrusion processes are the largest polymer processing groups represented in patent filings. The breakdown in the number of patents filed 2006-2016 according to polymer processing type is presented in Figure 9⁶.

Mechanical, chemical and thermal processes are the largest contributors

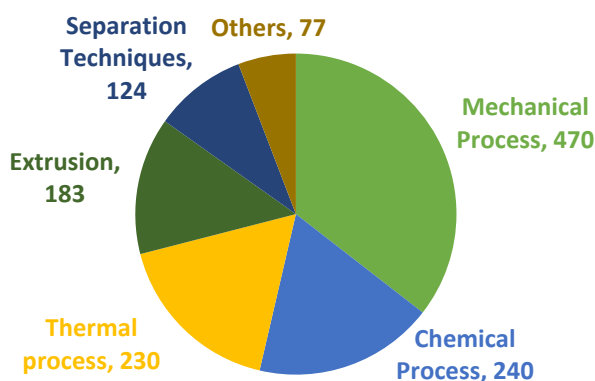
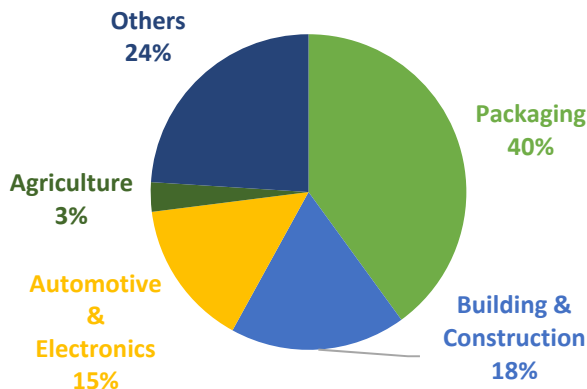


Figure 9. Patent filing by process step⁶

4.2.5 PATENT FILING BY MARKET SECTOR

Patent filings by market sector follow the same trends observed for market value by end user in Figure 4, namely packaging making up the largest portion, followed by construction and automotive. Figure 10⁶ depicts the percentage of filed patents 2006-2016 according to market sector type.

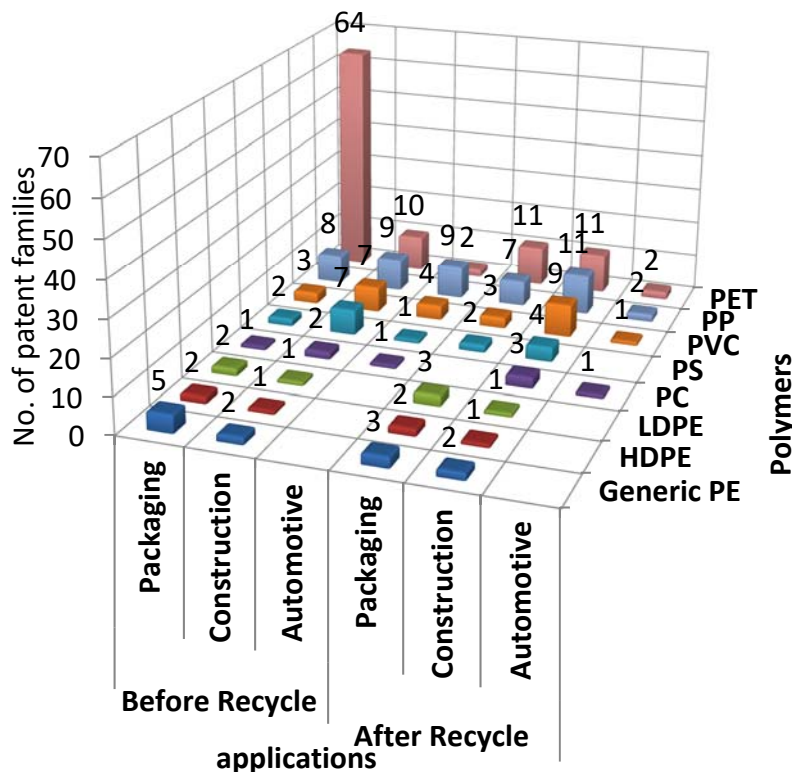


Packaging makes up the largest portion of filed patents

Figure 10. Patent filing breakdown according to market sector ⁶

4.2.6 PATENT FILING BY APPLICATION AND POLYMER TYPE

The recycling of PET in packaging applications is the dominant category in patent filing, with 64 patent families in between 2006 and 2016. This is shown in the results from a deeper level stratification presented in Figure 11⁶. Interestingly, of these 64, 51 disclose the use of bottles, which is consistent with the observation that this is one of the most commonly recycled products.



PET in packaging applications is the dominant category

Figure 11. Patent filing stratified by application, polymer type and before recycle (polymers being recycled) versus after recycle (application area for recycled polymers) ⁶

4.2.7 TOP RANKED PATENT FILING COMPANIES

Commonly represented companies in polymer patent filings are mostly large multinationals in the chemical, automotive, packaging and technology sectors. Table 5 identifies the top 10 patent filing companies as identified by a Quid patent scoping study along with the top cited patent for the company⁵. Resinate Materials Group appears to be the only pure play recycling company represented. The diversity in these companies, and their large industry dominance, indicates there could be strong competition in the R&D space.

The majority of these patents relate to polyethylene and polyol processes

The majority of the top cited patents by these companies appear to relate to polyethylene and polyol processes.

Table 5. Top 10 patent filing companies ⁵

COMPANY	NO. OF PATENTS	TOP CITED PATENT
Dow Global Technologies	27	Producing polyethylene composition comprises e.g. contacting ethylene with free radical initiator, separating unreacted species from high pressure low density polyethylene, and purging dissipative components from recycle stream
SABIC Global Technologies	24	Preparing modified polyalkylene terephthalate, by depolymerising recycled polyethylene terephthalate by mixing it with dihydric alcohol in presence of catalyst, transesterifying depolymerised terephthalate and polymerising molten mixture
Resinate Materials Group	19	New polyester polyol made by heating aromatic polyacid source with glycol, and reacting obtained digested intermediate with digestible polymer containing functional group e.g. ester and amide, used to make e.g. polyurethane and coating
Empire Technology Development	18	Method for collecting recyclables e.g. electronic waste, involves determining whether agent for collector is within threshold distance of address, and fulfilling collection request in response to agent for collector being within distance
Hyundai Motor Co	15	Recycling polyethylene terephthalate composite for component of automobile, comprises recycling polyethylene terephthalate, glass fiber, coupling agent, chain extender, nucleating agent and reinforcing agent
Arkema	12	Melt processible polymer composition useful for forming an article in a melt-process operation, comprises a compatible melt blend formed from one or more recycled multi-layer articles
BASF	12	New polymer obtainable by reaction of one component e.g. polyolefin with component containing at least two epoxy groups, useful for reducing a melt flow rate in polymers e.g. recycled polyolefins
Honeywell	12	Generating polyol from feedstock, comprises contacting hydrogen, water and feedstock with catalyst, separating hydrogen from effluent stream, separating water from effluent stream and recycling portion of separated water and recovering
Mitsubishi	11	Recycled plastic component for indoor unit and outdoor unit of air-conditioner, is obtained by mixing recycled plastic raw material containing recycled plastic, and virgin plastic raw material
Krones AG	8	Method for recycling labeled plastic containers, involves detaching labels from plastic articles, and sorting treated plastic articles, where labels are mechanically and manually detached from plastic articles

Network analysis

4.2.8 IP LANDSCAPE NETWORK ANALYSIS

Themes in the IP landscape are shown in Figure 12⁵ which provides the results from a complex semantic cluster analysis of 5 627 patents granted for plastic recycling⁵. Cluster groups have been coloured and labelled and sized by degree. Analysis shows that plastic waste management appears most central to the overall landscape, which is consistent with the drivers identified for plastic recycling. Storage and waste management systems (8.2%), containers and packaging solutions (7.7%), films, coatings, and packaging (6.0%) and Bottle recycling (5.3%) are common themes associated with sources and applications of recycled plastics identified, especially in packaging. Construction Materials (4.5%) has also been identified as a common theme which is also a growing area identified.

Clusters which could indicate emerging areas, or research themes, which have not been identified include Water cleaning systems (8.5%), Solutions and Solvents (7.5%), Thermoplastics (6.8%), Waste Water systems (5.3%), Manufacturing Waste (5.2%), Gas and steam (5.2%), Fabrics (4.1%), Recycling Catalysts (3.7%), Wood-plastic (3.5%) and Adhesives (3.1%).

Plastic waste management is most central to the overall IP landscape

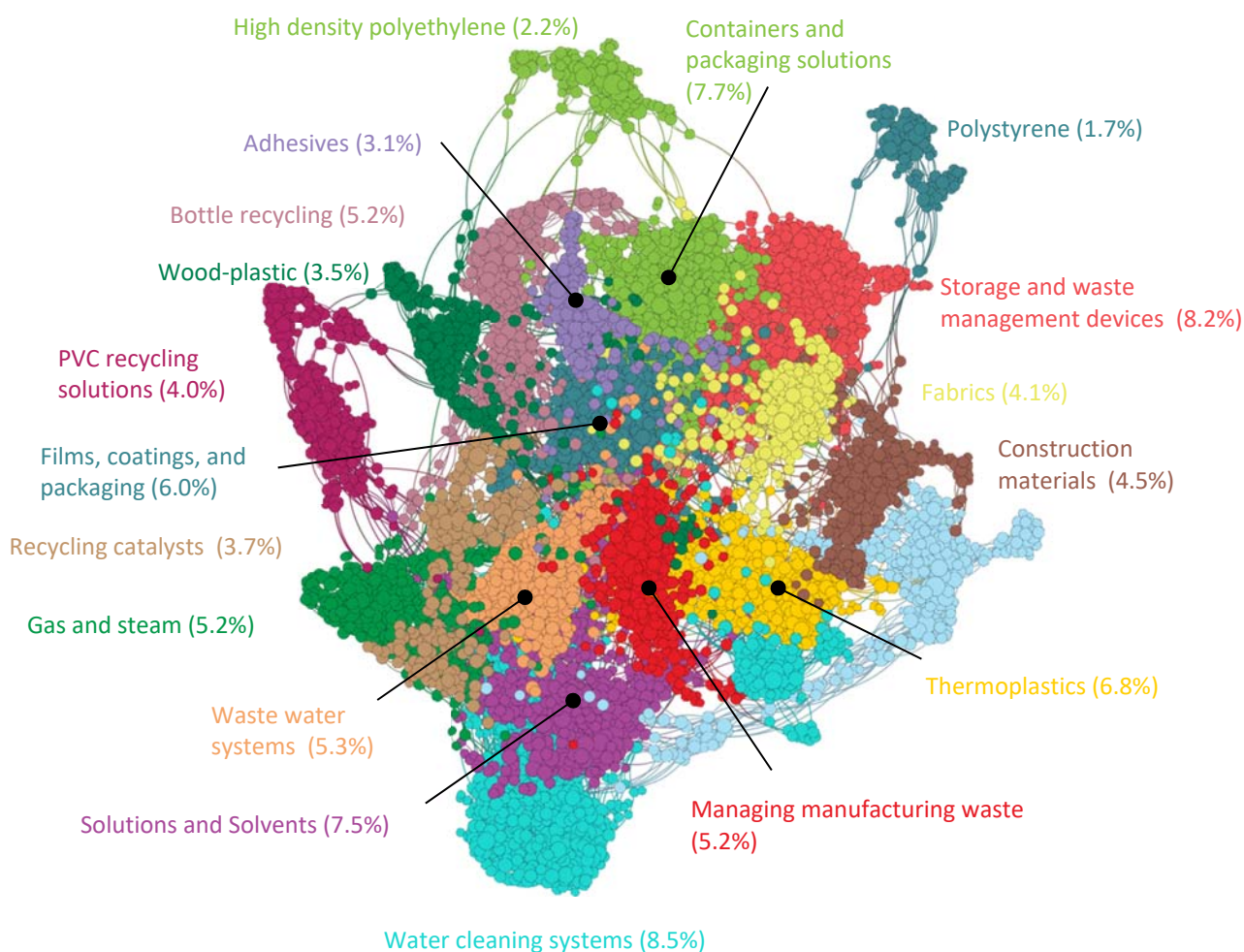


Figure 12. Network analysis diagram of granted plastic recycling patents ⁵

4.2.9 START-UP COMPANY NETWORK ANALYSIS

There appears to be start-ups emerging both in plastic recycling specialty areas and beyond just plastics, developing broader recycling systems and centres. This is shown in Figure 13⁵ which depicts a cluster network analysis performed on a database of 453 plastic recycling start-ups. Clusters, or groups of companies with similar themes, have been coloured and labelled and are sized by degree⁵. Broader focused clusters identified include Recycling Systems (12%), Broad Waste Management Organisation (8.6%), Industrial Waste Management (8.6%), Water treatment (8.4%), Green Waste and Government partners (7.3%), Residential Recycling (7.1%) and Recycling Services (7.1%). Those more singularly focussed on plastics include Recycled Plastic Products (8.8%), PVC and HDPE plastic (6.2%), Bottle Recycling (6.2%), and PET Recycling (5.3%).

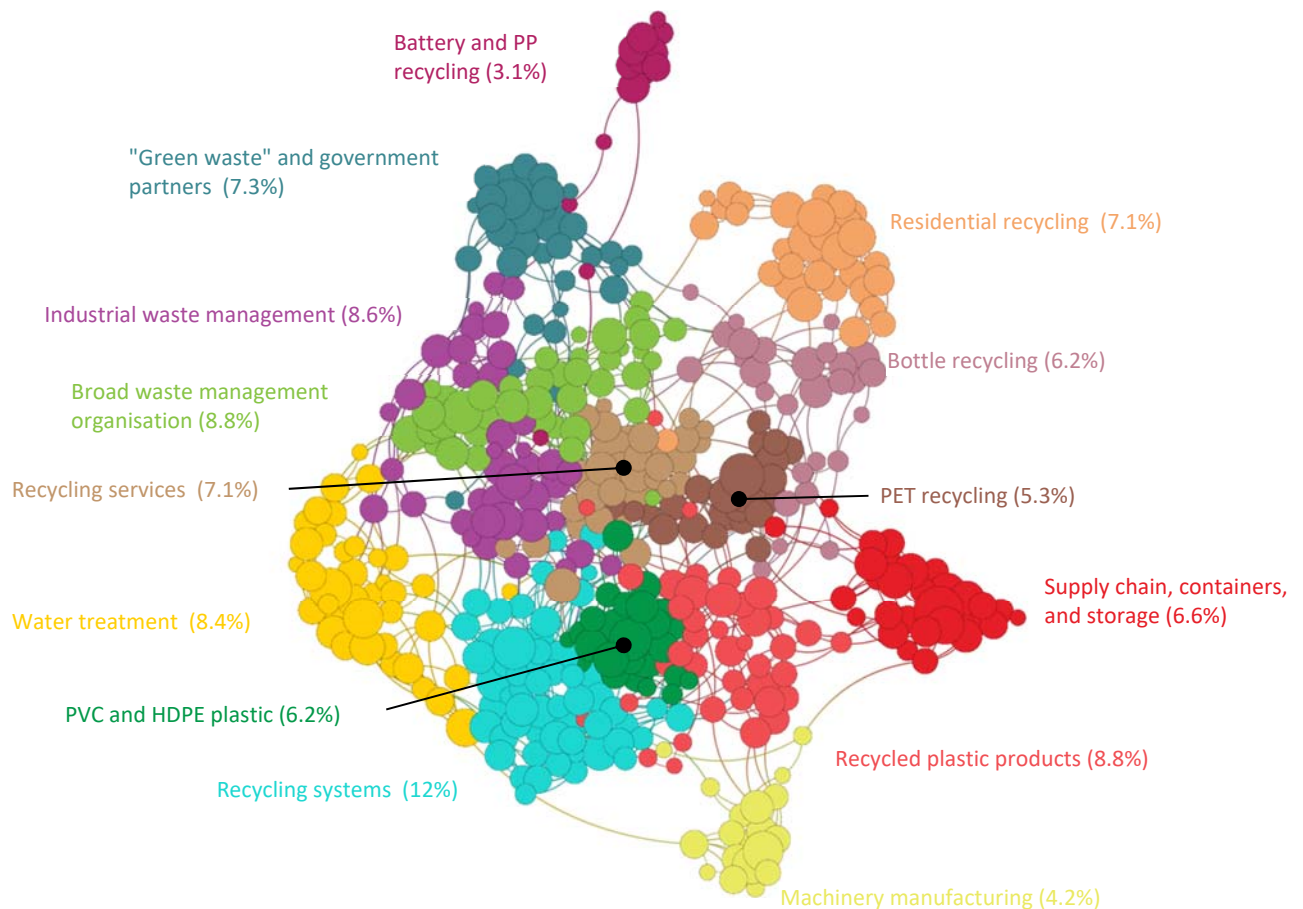


Figure 13. Network analysis diagram of plastic recycling start-up companies ⁵

**Analysis shows a start-up focus beyond just plastics,
developing broader recycling systems and centres**

Patent impact analysis

An assessment of patent impact was performed by stratifying impact area by both size and mean number of citing patents⁵. This revealed a number of impactful areas emerging including wood-plastic, gas and steam, construction materials, modified composite materials, solutions and solvents, water cleaning systems and thermoplastics respectively to be most impactful, having gained the most citations among all IP categories (Figure 14)⁵. The most impactful area, wood-plastic technology, relates to composite materials for construction and building which comprise recycled plastic, plant material and other additives. The second most impactful area, gas and steam, relates to polymerising PP with a catalyst in a gas phase reactor.

Wood-plastic composites and novel gas phase PP polymerisation methods were identified as the highest impact areas

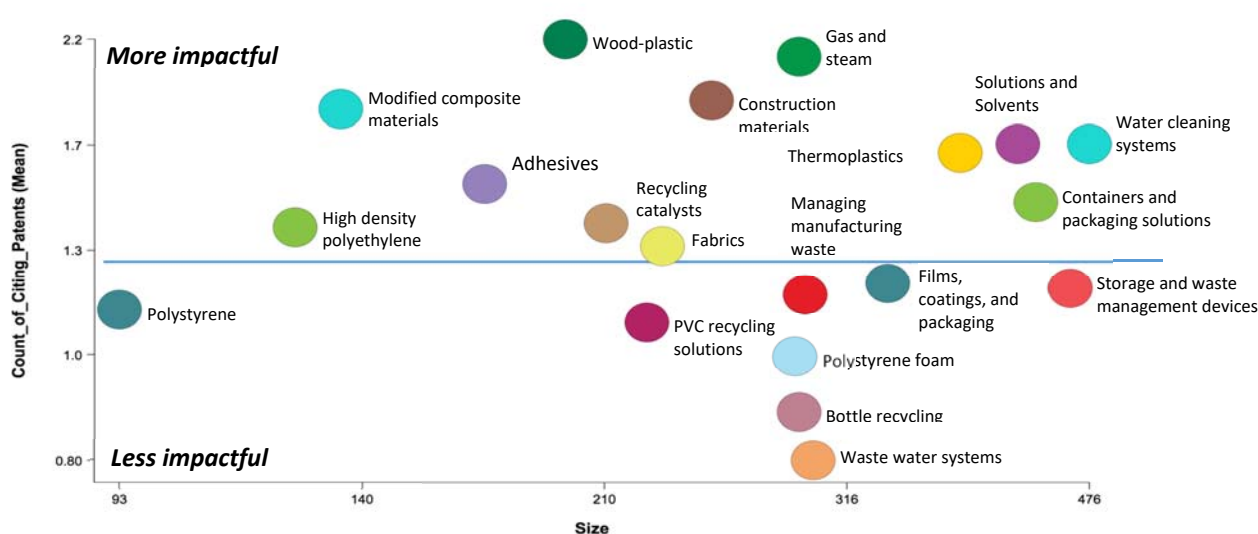


Figure 14. Analysis of patent impact areas⁵

Investment trends

4.2.10 TOP 10 START-UP COMPANIES BY INVESTMENT LEVEL

The top 10 start-up companies according to investment level as identified in a Quid search are listed in Table 6⁵. By far the largest investment has been in Waste Connections, Inc., receiving 1.3 billion in investment which is over 40 times the amount of the next closest company. It is interesting to note that Waste Connections, Inc. appears to be highly vertically integrated in the plastic recycling supply chain, spanning from waste collection through to recycling processes in the USA and Canada. Some of the other companies are similarly vertically integrated including SAS APR2, Plas Recycle Ltd, Horizon Waste Services of Arizona, and Total Recycling Services Limited. This indicates there are, or recently were, opportunities throughout the supply chain to create value in plastic recycling.

Table 6. Top start-up companies by investment level ⁵

COMPANY	BUSINESS DESCRIPTION	FOUNDING YEAR	CLUSTERS	COMPANY TYPE	INVESTMENT RECEIVED (\$M)	INVESTORS
Waste Connections, Inc.	A solid waste services company, provides waste collection, transfer, disposal, and recycling services in the United States and Canada	1997	Residential recycling	Public	1,325	N/A
ECO2 Plastics, Inc.	Engages in recycling PET plastic bottles. It offers a proprietary technology to produce PET plastic flakes without the use of water and are used in industrial applications.	2000	Recycling systems	Private	30.2	Trident Capital, Inc. (4); Roaring Fork Capital SBIC, L.P. (2); Thompson Hutton, LLC; Arbor Malone LLC
SAS APR2 - Atelier Pro Reseaux Recyclage	Engages in the collection and recycling of waste from electrical and electronic equipment. The company specialises in the recovery, processing, and use of industrial plastic wastes that include the shells of screens, printers, computers, etc.	2002	PET recycling	Private	17.8	Xerys Gestion SAS (2)
PlasRecycle Ltd	Engages in recycling post-consumer shopping bags and films collected at the kerbside from households. It recycles high density polyethylene and low density polyethylene bags and films for producing plastic granulates that are used for making bags.	2010	Recycled plastic products	Private	17.1	London Waste and Recycling Board; Waste & Resources Action Programme; Foresight Group
Blue Earth Solutions, Inc.	The company involves in developing, implementing, and marketing means of recycling polystyrene foam or expanded polystyrene (EPS).	2008	Recycling systems	Public	14.2	KCP Capital, Investment Arm
Horizon Waste Services of Arizona, Inc.	Provides waste management and abatement services. It also has materials recycling facilities, which receives, processes, and sends to market tons of cardboard, newspaper, office paper, aluminum, plastic, and glass.	1999	Residential recycling	Operating	10.9	Churchill Equity, Inc.
Total Recycling Services Limited	A waste management company, specialising in recycling, hazardous waste recovery, and industrial services for the commercial and industrial sectors. Its services include commercial recycling; chemical drum recycling; recycling of cardboard, paper, and plastics	2009	"Green waste" and government partners	Operating	9.8	Business Growth Fund plc
PetStar Administracion S. de R.L. de C.V.	Constructs and operates a bottle-to-bottle plastic recycling facility. It offers recycling services for polyethylene terephthalate (PET) bottles and containers. The company also produces recycled PET resin used by beverage industry.	2006	PET recycling	Operating	9.4	The Coca-Cola Company
Professional Waste Technology (1999) Public Company Limited	Provides industrial waste treatment services in Thailand. The company engages in electronic waste recycling; converting plastic to fuel; and retailing plastic and fuel scraps.	1999	Industrial waste management	Operating	9.3	Portchester Asset Management Ltd.; Enviro-Hub Holdings Ltd.

4.2.11 INVESTMENT TRENDS

Investment and exit events across the variety of start-up companies are shown in Table 7. This is shown by start-up company cluster categories as identified in Figure 18⁵. While currently recycling systems appear to lead in volume in the sector, other interesting trends have been highlighted in yellow. Firstly, industrial waste management appears to have been the fastest growing segment in recent times with over a 36% growth recorded over the period 2013-2016. Residential recycling has by far attracted the largest investment, over 59% of that in this space. This may have been driven somewhat by increased government legislation that encourages diversion of waste from landfill.

There has been a high number of exit events and acquisitions which is characteristic of a growing market. The plastic recycling supply chain cluster, however, appears to have experienced the highest value exit and acquisition events.

Industrial waste management appears to be the fastest growing segment

Residential recycling has by far attracted the largest investment

The plastic recycling supply chain has experienced the top exits amongst all market sectors

Table 7. Investment and exit event costs according to start-up type ⁵

CLUSTERS	NUM. COMPANIES	FOUNDING YEAR MEDIAN	INV. RCVD. COUNT (SUM)	INV. RCVD. AMT. (SUM)	INV. RCVD. AMT. (MEDIAN)	INV. CAGR (2013 - 2016)	EXIT EVENT COUNT	EXIT EVENT AMT. (SUM)	ACQ. RCVD. COUNT	ACQ. RCVD. AMT. (SUM)
Recycling systems	56	2009	59	\$157.3M	\$3.8M	-29.7%	7	\$36.1M	7	\$36.1M
Recycled plastic products	40	2004	5	\$29.9M	\$5.0M	-100%	10	\$17.2M	10	\$17.2M
Broad waste management organisation	40	2003	13	\$560.5M	\$16.0M	N/A	10	\$89.0M	9	\$51.6M
Industrial waste management	39	2005	23	\$49.5M	\$4.1M	36.7%	9	\$370.8M	7	\$40.5M
Water treatment	38	2004	14	\$51.9M	\$5.2M	-100%	12	\$209.6M	11	\$100.2M
"Green waste" and government partners	33	2003	4	\$29.3M	\$7.9M	N/A	10	\$228.6M	10	\$228.6M
Residential recycling	32	2003	15	\$1.6B	\$273.2M	N/A	17	\$794.0M	15	\$734.1M
Supply chain, containers, and storage	30	2004	1	\$0	N/A	N/A	15	\$2.0B	14	\$1.8B
PVC and HDPE plastic	28	2007	4	\$7.6M	\$808.3K	-100%	10	\$28.4M	10	\$28.4M
Bottle recycling	28	2005	7	\$10.9M	\$5.5M	-12.9%	10	\$190.6M	10	\$190.6M
PET recycling	24	2004	20	\$166.9M	\$13.6M	-100%	10	\$108.9M	10	\$108.9M
Recycling services	24	2007	7	\$32.2M	\$9.1M	-100%	6	\$5.7M	6	\$5.7M

CLUSTERS	NUM. COMPANIES	FOUNDING YEAR MEDIAN	INV. RCVD. COUNT (SUM)	INV. RCVD. AMT. (SUM)	INV. RCVD. AMT. (MEDIAN)	INV. CAGR (2013 - 2016)	EXIT EVENT COUNT	EXIT EVENT AMT. (SUM)	ACQ. RCVD. COUNT	ACQ. RCVD. AMT. (SUM)
Machinery manufacturing	19	2000	6	\$14.9M	\$1.9M	N/A	4	\$20.8M	4	\$20.8M
Battery and PP recycling	14	2002	5	\$3.9M	\$2.0M	N/A	8	\$155.5M	7	\$153.8M
Recycling services	8	2008	2	\$389.3K	\$389.3K	N/A	1	\$0	1	\$0

4.3 Macroeconomic analysis: PESTLE framework

Political influences

4.3.1 AUSTRALIAN CONTEXT

MAJOR GOVERNMENT POLICIES AND PROGRAMS

- Local Government kerbside recycling** – Cost of programs offset by rate payers
 - **Pros:** Widespread availability in metropolitan areas and biggest contributor to the redirection of household waste into recyclable waste streams
 - **Cons:** Limited or no availability of programs in remote regions (particularly Northern Australia). Recycling programs differ in each local government area which creates confusion over what can be recycled and where. Lack of legislation around recycling symbols and how/when they are displayed adds to confusion. Confusion results in high contamination rates and hence a significant loss of resource to landfill. Lack of recycling options here in Australia mean that recyclable waste can often be sent overseas for processing, adding to carbon footprints. Only addresses collection point of supply chain and does not necessarily translate to manufacture of recycled products²⁰.
- Container deposit schemes (CDSs)** – Currently exist in SA and NT, and planned CDSs in NSW (late 2017), WA (2018) and QLD (2018)
 - **Pros:** Encourages collection of single use plastics, reducing landfill and litter
 - **Cons:** Does not address the rest of the plastic recycling supply chain to ensure that waste is recycled. Can create stockpiles or encourage the shipping of waste offshore which further increases carbon footprint.
- Landfill levies** – Economic instrument to increase the cost of disposing waste in landfill. Currently exists in all states except QLD and NT.
 - **Pros:** Makes price of recycling more competitive than waste disposal, and hence has driven up recovery rates of many recyclable waste streams.
 - **Cons:** Increased economic burden for industry that produces waste. Does not address rest of plastic recycling supply chain to ensure that waste is recycled.
- National waste policy** – Created in 2009 and agreed upon by all Australian environment ministers, sets Australia's waste management and resource recovery direction to 2020. Aims to reduce waste, as well as manage waste and waste impact.
- Product stewardship programs** – Governed by the Product Stewardship Act 2011²¹, attempts to extend producer responsibility of product, importer or seller to reduce environmental, health and safety impacts of product. Program can be voluntary, co-regulatory or mandatory. Examples include:

- **Australian Packaging Covenant** – Created in 1999 which aims to change the culture of business to design more sustainable packaging and increase recycling rates. Provides millions of dollars in funding towards projects that drives recycling of packaging waste.
- **National Tyre Product Stewardship Scheme** – Began in 2014, to encourage sustainable use of Australia’s end-of-life tyres.
- **Operation Clean Sweep** – Worldwide program brought to Australia in 2015 to reduce plastic pellet loss.
- **Australian PVC industry’s Product Stewardship Program** – Created in 2002 and co-developed by the Vinyl Council Australia, CSIRO and industry representatives to enable raw material suppliers, product manufacturers and distributors to be joint stewards of the safe and beneficial production, use and disposal of PVC products.
- **Pros:** Often created through wide consultation, hence results in guidelines that balance stakeholder needs (e.g. realistic targets for industry)
- **Cons:** Often voluntary programs so can suffer from limited uptake. Again appear to suffer from an emphasis on point of collection rather than later stages of recycling supply chain.
- **State based litter reduction targets** – e.g. NSW Premier’s priority to reduce volume of litter by 40% by 2020²²
 - **Pros:** Discourages waste plastics from entering environment
 - **Cons:** Not a mechanism for encouraging the recycling of plastic waste. Could still be directed to landfill.
- **Threat Abatement Plan for the Impacts of Marine Debris on Vertebrate Marine Species** – From the Department of Energy and Environment, draft released for comment in early 2017²³. Entails a national strategy to abate the threat posed by marine debris and guide Government investment.
 - **Pros:** Identifies marine debris as a priority threat on the Government agenda. Aims to create a comprehensive plan with input from Government, research organisations and NGOs, including investment strategies to support key work.
- **Major EPA Victoria Reform Project** – Following from the 2015 ‘Independent Inquiry into EPA Victoria’ (2015) and subsequent Victorian Government response (2017)²⁴. Of particular relevance is Recommendation 12.1 which involves introducing a general preventative duty as part of an overhaul of the Environment Protection Act 1970. A key aim of this approach is to deliver ‘increased clarity and guidance for industry about their environment protection responsibilities’.

Political influences in Australia → Key observations:

- **Policies driving collection rather than recycling:** Government has responded strongly to public support of recycling, developing policies that aim to divert plastic waste from landfill. Stakeholders noted that the majority of these policies, however, do not support other levels of the plastic recycling supply chain to ensure waste is redirected into recycled products. Can often result in waste stockpiles or export of waste offshore.
- **Lack of universal waste management legislation** – A number of participants in this study noted significant variance between states around waste management e.g. QLD has relatively low landfill costs while NSW has relatively high costs. It was also noted that this could impact the access of recycling businesses to national volumes of waste or the ability to replicate approaches across state borders.
- **Low uptake rates for product stewardship programs:** Interviews reinforced that while programs provide needed industry flexibility, they often suffer from low uptake due to voluntary nature.
- **Growing Government concern for the threat that plastic poses to marine environment:** Participants cited State and Federal inquiries into the issue, and resultant abatement plans as evidence for this.

4.3.2 INTERNATIONAL CONTEXT

United Nations

- **Honolulu Strategy:** Framework for a comprehensive and global effort to reduce the ecological, human health and economic impacts of marine debris.
- **Global Clean Seas Campaign Launched:** Launched in February 2017, aims to eliminate use of microplastics in cosmetics and single use plastics by 2020. Also see marine plastics as a potential feedstock opportunity for recycling. Resulted in global brands joining campaign e.g. DELL Computers constructing a commercial-scale supply chain to use recovered ocean plastic in product packaging.

REGIONAL SNAPSHOTS

Europe

- **European Commission adoption of Circular Economy Package in December 2015²⁵.** Focus of package is to transition European businesses and consumers to a stronger and more circular economy where resources are used in a more sustainable way. Instigating various initiatives that work towards ‘closing the loop’ of product lifecycles through increased re-use and recycling to deliver benefits to economy and environment.
- **Incentivising recycling:** The European Union (EU) prohibits the disposal of many materials into landfill and has also brought in high landfill costs, forcing alternatives to be sought.
- **High uptake of energy from waste (EFW) technologies:** To utilise materials that are technically difficult to recycle or materials that are too expensive to process and recycle.
- **Packaging sector:** Use of Product Stewardship Programs and Extended Producer Responsibility have driven increases in recycling rates.
 - **EU** – Has increased recovery targets for plastic packaging to 45% by 2020 and 60% by 2025. Also a ban on landfilling of recyclable materials by 2025²⁶.
 - **UK** – Target of 57% recycling of plastic packaging by 2020, confirmed in 2017 budget
 - **France** – France has become the first country in the world to ban plastic plates, cups and utensils, passing a law that will go into effect in 2020. The country has used the same legislation ‘Energy Transition for Green Growth Act’ to ban plastic bags in grocery stores.
- **Construction sector:** Industry associations have initiated and funded recycling programs for the recovery and recycling of plastics at end of life. Key products have been PVC window profiles & related products, nylon and PP carpets, HDPE and PP pipes.
- **Automotive sector:** EU currently has regulations that require 95% of vehicle need to be sourced from recycled materials²⁷. Key issue with sourcing growing volume of plastics required.

North America

- **Largely unregulated market:** Has relatively low cost landfill rates which means that disposal into landfill is often a cost effective method of disposal, resulting in lower recycling rates.
- Similar trends for **packaging** and **construction sectors** as observed for Europe.

Asia and South America

- **Beginning to develop waste management and processing systems but often based on low-tech, labour intensive measures.**
- China and India in particular are working to rapidly overhaul waste management processes, but typically with standards well below Europe and USA.

Political influences internationally → Key observations:

- **Europe is seen as a forerunner in plastic waste management.** Interviews reinforced that this is a result of strong regulation and incentives to drive alternatives with emphasis on circular economies. Also, that there were high recycling rates and use of energy from waste methods to utilise plastic waste that is unsuitable for recycling.
- **China and India are rapidly overhauling waste management processes,** but current emphasis is on low-tech, laborious solutions.
- **UN has identified marine plastics as a key global threat.** Multiple programs in place to reduce entry of plastics into marine environment, and looking at marine plastics as a potential feedstock for recycling.

Economic influences

4.3.3 AUSTRALIAN CONTEXT

- **Competition between the costs of virgin plastic materials versus recycled feedstock is the biggest economic influence.** Price of virgin material is tied to oil and plastic prices globally. Can be offset by either converting into higher value products or focussing on lower value products that have endless feedstock readily available.
- **Container Deposit Schemes (CDSs)** – Currently in SA and NT, with planned roll out in NSW (late 2017), WA (2018) and QLD (2018). This would see PET, the major value component from kerbside recycling be removed. This would challenge the existing business models that govern current collection contracts offered by local government. May need to support diversification into a wider array of plastics for recycling to adapt e.g. increase recycling rates of HDPE and PP as these are used in the same order of magnitude in packaging as PET. Need to also examine further segregation of plastics to allow closed loop creation to give higher value products.
- **Free trade agreements** – Has seen a mass import of plastics from offshore as they have become cheaper and has been a challenge for local manufacturers.
- **Cost of transport** – Significantly increases cost of recycled feedstock if they have to travel large distances from collection to processing. This is of particular concern in more remote regions of Australia where communities are being sold products with plastic packaging that they have no way of recycling as costs of transport are prohibitive. Results in plastics being sent to landfill or burnt for disposal.
- **Low value of mixed loads/costs of sorting** – Mixed loads of plastic waste have a much lower value as they require an additional sorting step. Can be offset with use of automated sorting systems but large initial outlay for equipment and less flexibility to examine lesser used resins types. Priority might be to separate at source.
- **Contamination** – Of feedstocks with other resin types/degradable resins can significantly reduce quality and hence value of materials.
- **Cost of energy** – With the rising cost of energy in Australia, this subsequently increases the cost of processing plastic waste. This is accredited as the reason behind the closure of Plastics Granulating Services in SA²⁸.
- **Costs of labour** – High labour costs in Australia mean that plants need to be highly automated to remain competitive. Requires large outlay so often lacking in many smaller operators. Means that many resins are sent offshore for processing rather than locally.
- **Packaging sector** – There are a number of recycled plastic processors in Australia who are running profitable business by transforming recycled plastic waste into quality, cost effective sustainable

products (e.g. Astron, Replas, Adroit, Plastic Recyclers Australia, Advanced Plastic Recycling and Copolymers). This is largely driven by increasing consumer demand for sustainable products.

- **Automotive sector** – The Australian automotive industry is at an unprecedented crossroads with the closure of Ford’s plant in 2016 and Holden and Toyota to cease manufacturing by the end of 2017. This has been attributed to the high cost of manufacturing and highly competitive market.
 - Multinational car companies are responding to consumer demand for products that incorporate recycled plastics and have more sustainable design and manufacturing processes.
 - To revive the automotive industry in Australia, manufacturers need to adapt, innovate and evolve to increase efficiency and better compete on the domestic market.

Economic influences in Australia → Key observations:

- **Cost of virgin materials versus recycled plastic waste streams** – tied to oil and plastic prices.
 - Can be offset by producing higher value products or lower value with endless feedstock.
- **Container deposit schemes will challenge current PET collection and recycling business models**
 - Will require diversification of focus resins.
- **Higher purity waste streams have higher value** – avoids costs of sorting and issues with contamination.
- **Costs of transport and/or labor** – can either prohibit collection of waste or force a switch to offshore processing.

4.3.4 INTERNATIONAL CONTEXT

- **Similar observations as for Australian perspective**
- **Incentivising recycling** – More highly regulated market in Europe has relatively high costs of plastic waste going to landfill which drives the economic reasons for recycling.
- **Additional cost recovery through energy from waste methods** – Utilise low value or highly contaminated waste streams.
- **Automotive sector** – The Plastic Trade Association published a report in 2016, *Automotive Recycling: Devalued is now Revalued*, which highlights opportunities for recycled automotive plastic parts as a new product in automobiles with underlying economic benefits⁹.

Economic influences internationally → Key observations:

- **Cost of virgin materials versus recycled plastic waste streams** – tied to oil and plastic prices.
 - Can be offset by producing higher value products or lower value with endless feedstock.
- **High purity waste streams have higher value** – avoids costs of sorting and issues with contamination.
- **Incentivising recycling** – high costs of landfill disposal favors recycling of waste at end of life.
- **Energy from waste** – additional cost recovery stream for low value waste streams.

Social influences

4.3.5 AUSTRALIAN CONTEXT

- **Growing public interest in waste minimisation and environmental footprint of single use plastic products** – social pressure likely to support solutions that relieve consumer guilt.
 - **Growing public support around recycling initiatives** and movement towards sustainable business practices. This is driving increased consumer demand for environmentally friendly products and packaging.
 - **Increasing resonance with the public about single use plastic and microplastics** (including microbeads in personal care products) and their effects on the marine environment.
 - **Growing number of campaigns to ban single-use plastic items** e.g. public push for banning of single use plastic bags, increased use of reusable coffee cups.
 - **Array of recycling and waste awareness campaigns across Australia**
 - **Ban the Bag** – Run by Greenpeace Australia Pacific calling for bans on single-use plastic bags in NSW, VIC, QLD and WA.
 - **Clean Up Australia Day** – 1st Sunday of March each year. Encourages people to clean up their local areas.
 - **Green Industries SA** – From SA Government, runs a series of community programs and services to encourage a ‘green economy’
 - **Cleanway School Program** – School incursion program where Cleanway staff travel to schools to teach students about waste management.
 - **Keep Australia Beautiful** – “Do the Right Thing” campaign, Australian Tidy Town awards, Sustainable Cities awards, Clean Beaches awards.
- **Social licence to operate for plastic manufacturers** – In response to increased public interest, environmental footprint can be a significant risk for the Australian industry. Many industry members are developing social licence commitments.
- **Consumer confusion over local council recycling systems:**
 - Varies greatly between local council areas. Leads to significant contamination of waste streams and reduces recycling rates.
 - Some consumers remain sceptical that separated plastic waste is actually diverted from landfill and recycled.
- **Construction sector** – largely unseen by consumers so less social pressure to recycle plastics
- **Automotive sector** – meeting safety standards and matching performance of virgin plastics often overcome desire for environmentally friendly practices.

Social influences In Australia → Key observations:

- **Growing public interest in reducing environmental footprint associated with plastic products**
 - Beginning to see a shift in consumer habits to more environmentally friendly practices
 - High uptake in curbside recycling programs but consumer confusion can result in high contamination rates
- **Industry responding with social license measures** to offset consumer concerns

4.3.6 INTERNATIONAL CONTEXT

- **Similar observations as for Australian context**
- **Consumer demand driving adoption of better practices for multinationals**
 - An increasing number of companies are incorporating use of recycled materials into their Corporate Social Responsibility programme to promote their brand as environmental friendly and attract loyalty of eco-conscious consumers.
 - **Nike** – Adopting a circular economy approach for plastics and a commitment to reduce their impact on the environment²⁹.
 - Developed sustainable packaging from recycled consumer and industrial waste
 - **DELL** – Adopting a circular economy approach³⁰.
 - Materials - Created a closed-loop plastics network and have offered world first computer made with UL Environment-certified closed loop recycled plastics (OptiPlex 3030 All-in-One). Utilising 10 million pounds of post-consumer recycled plastics in products each year.
 - Packaging – Reducing amount of packaging (and increasing sustainable packaging (in 2015 two out of every three products was shipped using sustainable packaging). 2020 goal to deliver waste-free packaging sources from sustainable materials and 100% recyclable or compostable.
 - **Procter and Gamble (P&G)** – Adopting more sustainable practices³¹.
 - In partnership with TerraCycle and Suez have developed world's first recyclable shampoo bottle made with up to 20% recycled marine plastic³².
 - Target to power all plants with 100% renewable energy and use 100% renewable or recycled materials for all products and packaging
 - **Adidas** – History stretching back to 1989 of adopting more sustainable practices. Released an updated sustainability strategy in 2014 with 2020 targets. Among goals, they are working towards phasing out the use of virgin plastic by:
 - Eliminating plastic bags in stores
 - Increasing the use of recycled polyester in products
 - Creating a new supply chain for ocean plastic in partnership with Parley for the Oceans. In 2017 released "Parley" versions of most popular Boost running shoes from up-cycled marine plastic. Each pair of shoes reportedly utilises an average of 11 plastics bottles that incorporates the recycled plastic into laces, heel webbing, heel lining and sock liner covers³³.
 - **Target** – Established a suite of measures in 2010 to work towards more socially responsible practices³⁴.
 - Convert plastic bottle waste into recycled textiles for own branded jeans and backpacks
 - Diverted 69.2% of waste via recycle or reuse streams
 - Reportedly moving to phase out use of polystyrene from brand packaging, replacing it with recyclable materials³⁵.
- **Packaging sector** – Evidence for increasing consumer concern about the impact of plastic packaging materials. Plastic Industry Association Report in 2015 states that 89% of respondents preferred to buy products in recyclable packaging⁸. Concerns were raised by respondents over the non-renewable resource, waste contribution to landfills and disposal into oceans.
- **Automotive sector**
 - EU customers more accepting of use of recycled materials in car manufacture and respond more to the eco-friendly aspects of car design. Annual car tax is related to CO₂ emissions which favours lighter vehicles with higher plastic content. This provides more scope for reuse of recovered plastics in car manufacture.
 - Younger consumers are in particular, interested in the footprint of their vehicle and it influences their choice of manufacturer. Recycled plastics are used to manufacture new auto parts and components like cushioning, sound proofing and undercarriage.

- In the US, out of an estimated 5 million tons of auto shredder residue (ASR) that are sent to landfill, 0.5% is estimated as automotive plastics. In Europe, a significant amount of this ASR is recovered and diverted from landfills. Government regulations and environmentally conscious-consumers have driven big multinational companies like **Ford, Chrysler, GM, Nissan and Toyota** to embrace environmental programs and include recycled plastic in manufacturing as a part of their global sustainability strategy. It's a big draw-card and differentiating advertising and branding in a highly competitive marketplace.

Social influences internationally → Key observations:

- **Growing public interest in reducing environmental footprint associated with plastic products**
 - Beginning to see a shift in consumer habits to more environmentally friendly practices
- **Industry responding with social license measures to offset consumer concerns**
 - **Multinationals setting ambitious sustainability targets and adopting more circular economy approaches** (e.g. Nike, DELL, P&G, Adidas and Target)
 - **Higher rates of recycled plastic use in automotive industry** due to increased consumer acceptance and downstream effects of EU legislature (e.g. Ford, Chrysler, GM, Nissan and Toyota)

Technological influences

4.3.7 SYSTEM GAPS

Stakeholder interviews identified three major areas of system gaps for the recycling industry. These have been outlined in Table 8 along with potential strategies to overcome issues.

Table 8. System gap analysis for the plastic recycling industry

GAP	STRATEGIES TO OVERCOME
Cost effective collection of waste	<ul style="list-style-type: none"> • Processing at source or close to customers – Reduces costs of transport. Particularly relevant to remote regions where ideal would be in field processing for a local market. • Identifying new waste streams <ul style="list-style-type: none"> ○ Marine plastic waste – currently transferred to landfill due to issues with sorting and questions over resin quality/safety. If these could be overcome, represents an endless supply stream. ○ Construction plastic waste – often overlooked in favour of methods to recycle metals and concrete as plastic makes up only a small weight contribution to overall waste. If methods could be instigated to segregate plastic waste on site, could deliver a significant new waste stream of high purity. ○ Agricultural plastic waste – large volumes of filmic plastic and piping that are not commonly utilised due to remote location. Processing in field may overcome associated costs. • Diversity of resins – PET and to a lesser extent, HDPE, are the key focus of domestic recycling efforts. Need to increase volume of waste collected and increase efficiency of processing a wider array of plastic resins.
Maximising the volume, useability and value of waste collected	<ul style="list-style-type: none"> • Automated processing methods – overcomes costs of labour associated with sorting by hand <ul style="list-style-type: none"> ○ E.g. can utilise Raman Spectroscopy to simplify and accelerate sorting and recovery of many complex and expensive plastics (polycarbonate (PC), /acrylonitrile butadiene styrene (ABS), nylon) and PVC amongst the commodity polymers such as PP and ABS. ○ Can suffer from issues relating to contaminants interfering with automated sourcing – e.g. carbon black interferes with near-infrared signature of polymers.

GAP	STRATEGIES TO OVERCOME
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- **Methods to avoid contamination of plastic waste stream**
 - Increased segregation at collection point
 - Access to higher purity waste streams – e.g. industry waste
 - Integration of technologies in product design to assist with ease of recycling (e.g. movement away from multilayer trays)
 - Plastic additives – some additives can effect recyclability of plastic waste. Need to consider during product design or develop additives that are better tolerated by recycling process.
- **Methods for contaminated streams**
 - Methods that overcome contamination e.g. depolymerisation,
 - Methods to remove contaminants e.g. cost effective deinking methods
 - Methods that maintain performance of product using a blended polymer feedstock
 - Movement away from degradable/biodegradable/compostable plastics (or clear segregation from conventional waste streams)

Maximising value of products produced	<ul style="list-style-type: none"> • Legislation to incentivise recycling, not just collection of waste plastics – need to support entire supply chain • Integration of technologies that reduce environmental impact of plastic products to respond to consumer attitudes. • Methods to upcycle – conversion of lower value waste streams into higher value products. This would insulate the market from fluctuating oil and virgin plastic prices and convert from commodity polymers into a more defined marketplace. • Closed loop recycling – conversion of waste plastic into its original state for re-manufacturing. • Energy from waste and pyrolysis to recover hydrocarbons and chemicals. Allows cost recovery from low value plastic waste streams.
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4.3.8 RESIN SPECIFIC GAPS

Stakeholder interviews revealed an array of resin specific technology gaps as outline in Table 10. Many of these provide further detail on system gaps identified in section 4.3.7.

Table 9. Resin specific technological gaps analysis identified in stakeholder interviews.

RESIN TYPE	IDENTIFIED GAPS
PET	<ul style="list-style-type: none"> • Collection volume and quality, when sorted from kerbside recyclables. Increased CDL collection in NSW, QLD will improve both of these aspects. • Contaminated or mixed waste streams <ul style="list-style-type: none"> ○ Contamination with PVC during sorting creates a cost/performance issue as well as potential equipment damage given PVC releases HCl at high temperatures • Packaging that contains two or multilayered packaging (e.g. thermoformed pots, tubs and trays) • Sorting PET and other thermoplastic textiles – colour range is wider than with plastic bottles and the fibres and colour can be intimately integrated with other coloured fibres. • Removal of pigments via a low-energy, non-toxic bleaching process. • CSIRO in-house technologies to overcome high contamination rates involve depolymerisation. <ul style="list-style-type: none"> ○ E.g. X-ray films – depolymerisation reaction of PET with DEG to produce polyester polyols for insulation foam ○ INPET (Innovations in PET) – technology developed by SWIG (Simon West Innovation Group) and licenced to Southcorp/VISY – tolerates PET rich mixed plastics through depolymerisation methods
HDPE	<ul style="list-style-type: none"> • Sorting and separation based on application (food / non-food / household chem / personal care / industrial) and grades that would allow for closed loop recycling for many applications. • Separation of PP is an issue and removal of residual odour of final recycled resins.

RESIN TYPE	IDENTIFIED GAPS
PVC	<ul style="list-style-type: none"> • Sorting and separation of the different types, plasticised, filled, stabilised flame retardants etc. • Sourcing from post industrial uses. • Contamination of other waste streams with PVC can cause a significant problem given it releases HCl at elevated temp • Recycling via chlorine recovery • Separation by application (pPVC vs uPVC) • Legacy additives which affect the use of recyclate by manufacturers in new applications as companies may have internal policies to avoid lead, phthalates etc.
LDPE	<ul style="list-style-type: none"> • Mostly as soft plastics (film) main issue is cost of collection, sorting and processing due to low bulk density (tonnes per hour) and contamination from multilayer materials. Otherwise similar existing commercial processes can be used.
PP	<ul style="list-style-type: none"> • Sorting and separation based on application (food / non-food / household chem / personal care / industrial) and grades that would allow for closed loop recycling for many applications. • Separation of HDPE from PP and residual odour is an issue.
PS	<ul style="list-style-type: none"> • The main issue for extended polystyrene (EPS) is the cost of collection • PS food packaging – food contamination often results in rejection from recycling – low recycling rates
Nylons	<ul style="list-style-type: none"> • Separation from other polymers in multilayer structures for rigid and film packaging plastics. Small quantities used in packaging. Post-industrial, a collection system and sufficient volume of material. • Low recycling rates

Legal influences

Legal influences relate closely to political influences as outlined in sections 4.3.1 and 4.3.2. Additional points raised in stakeholder interviews have been outlined below.

4.3.9 AUSTRALIAN CONTEXT

- **National Industrial Chemicals Notification and Assessment Scheme (NICNAS)** has greater flexibility than European equivalent to recognise differing economy in Australia.
- **Packaging sector**
 - The move towards deposits for packaging is becoming a mechanism to maximise recovery and/or reduce single use plastics.
 - The National Packaging Covenant is Industry's solution to state by state differences in legislation. There is debate whether the current form has been particularly effective. Currently in process of review and may see integration of stronger reforms.
- **Construction sector**
 - Currently no specific plastic targets in this area and hence increased regulation would serve to encourage good practice. There are some instances where Government tenders favour businesses that meet renewable targets, but this does not extend specifically to plastics.
- **Automotive sector**
 - Currently no specific plastic targets in this area and hence increased regulation would serve to encourage good practice.

Legal influences in Australia → Key observations:

- **Closely related to political influences as outlined in section 4.3.1**
- National Industrial Chemicals Notification and Assessment Scheme (NICNAS) has greater flexibility than European equivalent to recognise differing economy in Australia.
- **Taking EU as an example, likely that Australia will need increased regulation to incentivise plastic recycling to see a large scale industry shift**

4.3.10 INTERNATIONAL CONTEXT

European Union

- **General observation**
 - **Environmental concerns in EU** have evolved a fully integrated model of product design, material specification, end of life destination specification and these have encouraged the comprehensive recovery and recycling of all materials including plastics. The role of governments has been instrumental in setting long term targets and encouraging the countries lagging in performance to reach the set targets.
 - **EU Chemicals Policy REACH (registration, evaluation and authorisation of chemicals)** is fairly stringent and has impacts on every member of the supply chain including additive and plastic producers, convertor and retail. Restrictive guidelines can force companies to completely change composition of material to meet specification regarding acceptable monomers, pigments, plasticisers and catalysts.
- **Packaging sector**
 - **EU framework for recycling targets and reuse of plastics leads the world** in terms of regulating plastic recycling although this system can be seen to be slow and overly conservative when compared with USFDA equivalents.
- **Construction sector**
 - EU regulation of this sector mostly via strong landfill restrictions. Any specific guidelines driven by Industry product stewardship programs.
- **Automotive sector**
 - EU requirement for 95% of vehicles to be sources from recycled materials²⁷ along with directive on waste electronic and electronic equipment (WEEE)²⁶ has served to significantly boost recycling rates for the automotive industry.

Legal influences internationally → Key observations:

- **Closely related to political influences as outlined in section 4.3.2**
- **EU represents the gold standard for increased regulation driving industry transition** to increase both recovery and recycling rates for plastics, although some argue that this creates a slow and overly conservative environment.

Environmental influences

MAJOR ENVIRONMENTAL CONCERNS

- **Increasing amounts of plastic in environment** – The world's increasing population has seen an accelerated consumer demand for plastics. With more plastics, we see more waste plastic enter our environment³⁶⁻³⁸.
- **Legacy of plastics in the environment due to their durability** – As conventional plastic resins do not readily degrade, it is likely that plastics in the environment will exist for centuries if not millennia, leaving a growing problem for future generations.
- **Impact of plastics in the environment**
 - **Ecological** – Loss of habitat and loss of wildlife due to ingestion and entanglement
 - **Economic** – Cost to tourism, also damage to vessels and fishing operations
 - **Health** – Impact to human health through food chain or environmental exposure
- **Microplastics (including microfibers)** – Continued negative and growing impact with no effective way to remove them from the environment. Public concern particularly around the ability of microplastics to be ingested by marine life that are subsequently ingested by humans³⁹⁻⁴².
- **Depletion of virgin resources** – Ineffective use of fossil fuels to make single use items, the majority of which are not recycled. This is seen as misuse of a precious, non-renewable resource.
 - Oil used for both monomers synthesis as well as fossil fuel generated energy for processing
- **Impact of additives used in plastic manufacture** – have the potential to leech out of plastic litter and be released into environment
 - **Plasticisers** such as phthalates and other oestrogenic/androgenic compounds
 - **Fire retardants** used in automotive industry
- **Impact of increasing waste disposal requirements** – Particularly a problem for developing nations and remote regions where landfill sites are stretched for capacity. Often results in unsafe landfill disposal or domestic burning of plastic waste.
 - **Impact of burning plastic waste** – Domestic burning of plastic waste does not reach sufficient temperatures to destroy toxic dioxins and furans, resulting in significant human exposure as well as release to the environment. Also, PVC at elevated temperatures released hydrochloric gas, another significant health concern.
 - **Impact of unsafe landfill disposal** – There are numerous examples of landfill collapse in developing regions due to disposal of waste beyond safe capacity. These include death tolls of at least 28 in Colombo, Sri Lanka in April 2017⁴³, 113 in Addis Ababa, Ethiopia in March 2017⁴⁴, and at least 69 in Shenzhen, China in December 2015⁴⁵.
- **Increases in illegal dumping** – Almost all local councils in Australia are dealing with overfilled landfill sites so rising costs of waste disposal are being transferred to local residents, resulting in increased rates of illegal dumping.
- **Impact of degradable plastics** – Degradable plastics were initially developed as a solution for the growing amount of plastic waste but their global footprint has been poorly understood and they appear to pose a significant environmental risk⁴⁶.
 - **Insufficient conditions to drive degradation** – compostable and biodegradable polymers (for definitions see **Table 1**) typically require extended exposure to temperatures in excess of 50°C for period of up to a week or months to suitably degrade¹⁶. Such temperatures are unlikely to be reached in many environments, particularly within a marine setting. This leads to incomplete degradation and persistence within the environment.
 - **Leaching of toxic additives** – Risk of the release of toxic additives and degradation products¹⁶.

- **Contribution to the microplastic problem** – Of particular issue with plastics that degrade through fragmentation or with incomplete polymer degradation. Both conditions result in micro fragments of plastic that persist in the environment, contributing to the microplastic issue.
- **Contamination of recyclable plastic waste streams** – Can be difficult to separate degradable plastics from conventional waste streams. This can cause significant contamination of recycled resins, reducing value and performance.

Environmental influences → Key observations:

- **Increasing volume and long legacy of plastics in the environment**
 - Leads to ecological, economic and health impacts
- **Impact of growing microplastics problem**
 - No way to remove and they have ability to move up through the food chain to cause human exposure
- **Depletion of virgin resources** – for low value, single-use items
- **Impact of toxic additives in plastics** – e.g. plasticisers and flame retardants that are potentially released during degradation
- **Increasing waste disposal requirements** – landfill sites often stretched beyond capacity
 - Resulted in increase in domestic burning of waste and exposure to toxic derivatives
 - Human mortalities from unsafe landfill disposal
- **Impact of degradable plastics** – designed to combat issue of plastic entering environment.
 - Ambient conditions may not be sufficient to completely degrade plastic and hence compound the microplastic problem
 - Contaminate recyclable plastic waste streams, reducing value and performance

4.4 Microeconomic analysis: Thompson and Strickland's Seven Strategic Questions

Question 1: Dominant economic features

Refer to Section 3.2 for a detailed market landscape overview. The key trends identified in Figure 15.



Figure 15. Key economic trends identified for the global plastic recycling market ^{1,4}

Question 2: Competitive forces

The global recycled plastic market is fragmented due to the presence of many small and large vendors. Regional vendors dominate the market in many areas. Regional and local vendors control the market in many emerging and less developed countries by offering cost effective and recycled plastics for niche applications⁷. Figure 16 depicts a five force analysis for the industry^{1,7}.



Figure 16. Five forces analysis for the plastic recycling industry ^{1,7}

Question 3: Forces driving change

A number of global market drivers and challenges for the growth of the plastic recycling industry were identified⁷. These have been discussed below and summarised in Figure 17. Geographical market forces have also been discussed in Section 4.4.3.

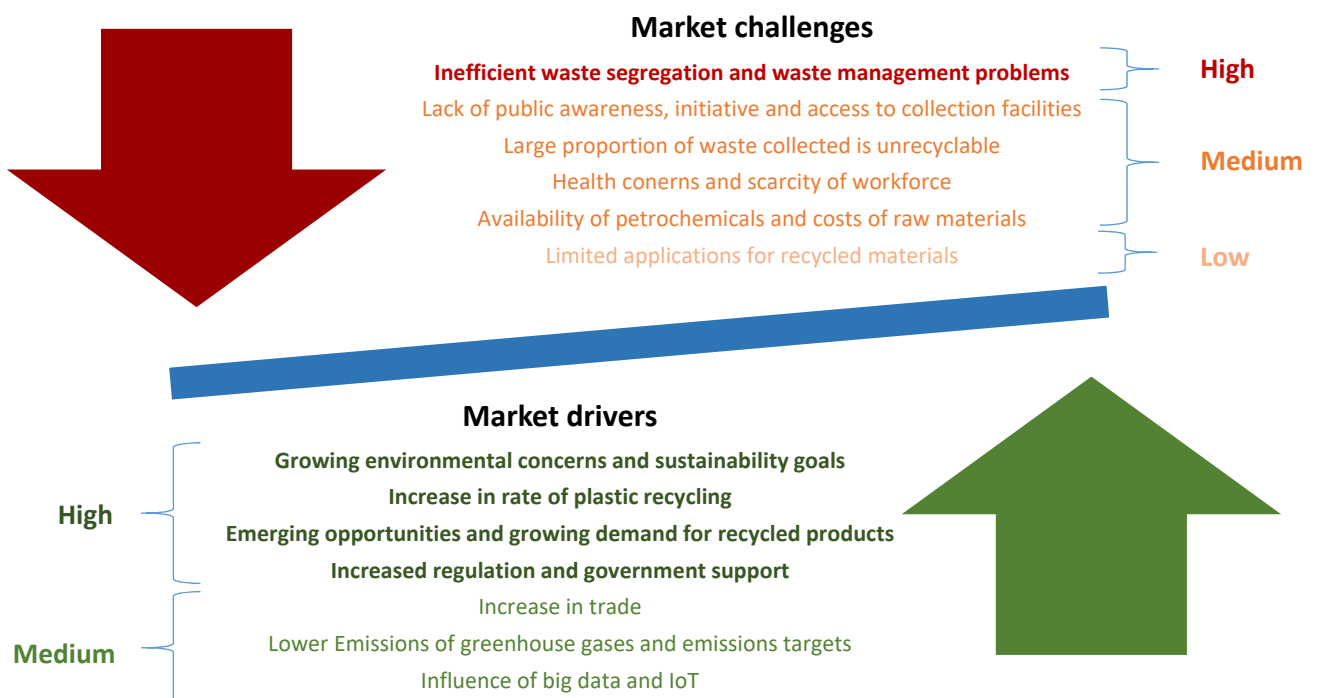


Figure 17. Key market drivers and challenges controlling growth of the plastic recycling industry ⁷

4.4.1 GLOBAL MARKET CHALLENGES

HIGH IMPACT

Inefficient waste segregation and waste management problems

- The growth in the use of plastics as a packing material has created serious problems with solid waste disposal.
- The management of plastic bottles and related products is tedious, and it is not completely possible to recycle all wastes in an eco-friendly manner. Segregating different types of plastics is complex and requires many processes. Further, it is also energy and labour consuming.
- Most waste collection and recycling programs face the problem of material and waste quality when dumping mixed waste at designated sites. Hazardous waste is sometimes dumped in landfills. This contamination is worsened when metals, electronics, and chemicals are included in the recycling system. The removal of metal and electronic wastes is difficult and deters potential buyers from purchasing the recycled material.
- The concerns regarding finding solutions for controlling contamination are increasing.

MEDIUM IMPACT

Lack of public awareness, initiative and access to collection facilities

- The lack of public awareness regarding the value and significance of recycled plastics is a prime challenge in the market which leads to lower penetration rates of recycled plastic products.
- It has been estimated that Americans dispose 33.6 million tons of plastic each year. Less than 6.5% of it is recycled and 7.7 % is combusted in waste-to-energy facilities to create electricity or heat from waste plastics

A large proportion of the plastic that is procured for recycling is not suitable for recycling

- Most plastics used are semi-porous and absorb molecules of the stored material. The removal of these residues is tedious and additional treatments for the same can potentially alter the properties of the recycled plastics.
- In addition, recycling is low because polyethylene (PE) and polypropylene (PP), which account for two-thirds of the plastic used, have different chemical structures that do not permit their joint recycling.

Health concerns and scarcity of workforce

- Noxious chemicals are released during the treatment of plastic bottles. These can pose significant health hazards to the workers. Therefore, it is difficult to procure workforce, which poses a barrier to the market growth.

Availability of petrochemicals and costs of raw materials

- The development of feedstock from newer sources such as coal, shale gas, and biobased materials will indirectly provide polyethylene with price or sustainability advantage over other plastic resins.
- The US is expected to gain the most capacity as shale-based production is likely to on-stream. Vendors based in the Middle East have most price advantage of feedstock. PE producers in North America are directed to find buyers in Asia and Europe to sustain a balance of trade.
- In Asia, manufacturers based in South Korea, Thailand, and Singapore are in fierce competition while there is an oversupply of HDPE globally.

LOW IMPACT

Limited applications for recycled materials

- Most recycled plastics are used to make lower grade products so there are limited applications for their use

4.4.2 GLOBAL MARKET DRIVERS

HIGH IMPACT

Growing environmental concerns and sustainability goals

- Consumer preferences are shifting towards products and manufacturers that can demonstrate environmental benefit particularly in developed countries such as North America.
- There are also growing concerns in the APAC region over uncontrolled waste dumping and proper waste management practices.
- The market for biodegradable plastics and sustainable packaging is predicted to increase during the period to 2020 owing to the growing environmental concerns.
- Companies will establish corporate sustainability responsibility (CSR) targets and strategies to stay competitive in the market. Development of sustainable business plans will also be beneficial for customers. This will boost growth and drive competitiveness considerably in the market.
- The Circular Economy and “Zero Waste” concepts are mega trends that have spread across the globe, and many cities have committed targets and initiatives to achieve their zero waste goals. For instance, the City of Copenhagen has formed a waste management plan for 2018. Considering economic, environmental, and social benefits, the city is moving towards building a sustainable zero-waste city.

Increase in rate of plastic recycling

- Plastic recycling volumes and growing demand for recycled plastic materials have increased significantly. The rate of plastic recycling has been rising due to the increased consumption of plastic packaging materials, in particular plastic bottles. Although the volume of recycled bottles is increasing, the rate of recycling remains steady.
- PET plastics that are used in the manufacture of water bottles, milk bottles, and jars contribute a significant proportion of source material for recycling. HDPE is recycled and is used to produce higher-grade plastic bottles. The growing popularity of plastic lumber and garden plastic products such as chairs, tables, and other furniture are expected to drive the use of recycled HDPE.
- Substantial investments are being made in developing countries, including India for establishing recycling facilities. India has been importing enormous quantities of plastic bottles and related materials such as pellets and plastic furniture waste for recycling primarily from Japan and Hong Kong.
- Technavio analysts estimate that the consumption of plastics in India will increase to 20.08 million tons per year in 2020 from 8.03 million tons per year in 2015. Plastics have been the largest contributor to India’s gross domestic product, growing at a rate of 13%-16% per annum.

Emerging opportunities and growing demand for recycled products

- There is a growing demand for plastics across industries from automotive, construction, healthcare, food and beverage, oil and gas, and household products.

Increased regulation and government support

- Constant support from federal, state, and local governments for recycling efforts will encourage the collection and processing of plastics for recycling. However, the overall rate of plastic recycling will remain moderately low in the US as less than half of the collected plastic is being completely recycled (the rate is higher in Europe).
- These policies are implemented regarding generation, transport, storage, treatment, and disposal of plastics wastes efficiently. Landfill taxes, waste disposal taxes, recycling credit schemes, deposit refund

systems, and waste pricing approaches promote effective waste management. Further, local collection plans, recycling advocacy, and voluntary decisions to contribute to recycling have boosted the market growth.

- The governments of many countries are also supporting the establishment of recycling units and are encouraging small and large recycling industries by providing grants and other support. Further, many national and international regulations are also prescribed for efficient segregation of plastics in households and industries.
- For instance, directives such as the Publicly Available Specification (PAS) 103, developed by the British Plastic Federation, enforce measures for plastics waste classification based on its polymer type, its original use, and contaminants
- The European Commission Regulation No (EC) 282/2008 and amending Regulation (EC) No. 2023/2006 were enforced on April 24, 2008. These regulations establish requirements for recycled plastics to be used in food contact materials. It implements an authorisation procedure of recycling processes used in the manufacture of recycled plastics for food contact use.
- India will see significant growth in the waste recycling market due to new legislation in place. These new rules will tackle both eWaste and municipal solid waste (MSW) as well as improve the recycling rate.

MEDIUM IMPACT

Increase in trade

- The global economic growth has increased consumer spending and manufacturing activity. PE continues to be the most widely used plastic resin due to its low cost, recyclability, versatility, and ease of processing.

Lower emissions of greenhouse gases and emissions targets

- Plastics are cheaper to produce and do not incur significant transportation costs as they are lighter than the existing counterparts such as steel, aluminium, and glass. The recycling of aluminium, steel, and glass containers is energy intensive and emits hazardous gasses including carbon monoxide and carbon dioxide, which contribute extensively to the depletion of the ozone layer

Influence of big data and IoT

- Evolution of Smart Cities is paving the way for Big Data technologies to transform the waste recycling landscape. The Internet of Things is significantly changing the waste management sector by using sensor technologies, smart bins, and smart monitoring systems. Many IoT companies are rising to optimise waste management, thereby reducing costs and delivering better services. Use of RFID chips in waste containers will improve waste collection and waste recycling efficiency.

4.4.3 DRIVERS AND CHALLENGES BY GEOGRAPHY

AMERICAS

50.10% of global market, 5.33% CAGR predicted to 2020

- The US is the second largest consumer of plastics globally and majorly depends on China and the UK for absorbing its waste plastics. It has been estimated that the US exported more than 2.1 metric tons of plastic waste, which was worth \$1.05 billion. Note that this may be significantly disrupted given the recent announcement that China will ban the import of “foreign garbage” by the end of 2017 ⁴⁷.
- USA and Canada are the main contributors.
- Key drivers:
 - Availability of advanced technology
 - Skilled Workforce
 - Large scale residential and industrial facilities

EMEA

34.94% of global market, 3.4% CAGR predicted to 2020

- The market had remarkable growth prospects in France, Germany, Austria, Sweden, and Belgium.
- The recovery rate of all plastics has increased by nearly 60%, and recovery of plastic packaging was 66%.
- Europe is the major exporter of waste plastic for recycling that directly depends on China or Hong Kong.
- Europe will continue to maintain its strong position with improving legislations and circular economy targets. Recycling of different materials is being introduced in Europe. This will drive market growth.

APAC

14.96% of global market, 2.85% CAGR predicted to 2020

- The demand for plastics in China, India, and Malaysia is high due to the rising population
- APAC exceeded North America and Western Europe in 2014 to become the leading market for PET packaging.
- A larger proportion of globally traded used plastics are being recycled in India. This is attributable to the availability of cheap and skilled labor, low installation cost of recycling plants, and cheaper freight and logistics costs
- The per capita consumption of plastics in Asia is comparatively lesser than that of the developed markets. This is forecast to increase significantly.
- There is currently an oversupply of plastic resins in Asia. The consumption share of Asia is almost 37%, and the production capacity of plastics in Asia is growing more rapidly than the consumption rate.
- APAC provides more dynamic prospects because of increasing consumer driven economies and industrialisation. Innovation is one of the few sources of competitive advantage.
- China is the main importing country for waste plastics which holds approximately 55% of the global market. Hong Kong is also a significant import destination.
- Used bottles will likely remain the leading source material for recycling.
- India is expected to have significant growth due to new legislation.

Question 4: Market positions

Four major market position variables were identified based on stakeholder interviews and market analysis⁷ and are summarised in Table 10. R&D opportunities will likely be different for each of these positions occupied. Price Leaders for example are likely to be interested in opportunities with affect product price or volume outcomes.

Table 10. Major market positions identified for the plastic recycling industry

POSITION	DESCRIPTION	POTENTIAL R&D APPROACH
Price leader	<p>Recycled plastics are a widely traded commodity globally; export of these plastics from APAC to the other emerging economies has been growing. India, China, and Hong Kong are considered the cheapest sources. Other regions will have to match the prices especially that of China and India, as these countries export bulk volumes.</p> <p>Cost is an important criteria across all market segments, but particularly so where robustness and quality criteria do not rate as highly such as in Food Contact Packaging</p>	Technologies that increase the value of recycled plastic feedstocks (e.g. improved sorting techniques to reduce contamination, new recycling methods that make use of low value or underutilised feedstocks).
Backward integration	<p>Manufacturers directly supply bulk quantities to end users. The involvement of a trader is limited as the product margins are small.</p> <p>Many large manufacturers are backward integrated to plastic manufacturing units where recycled plastics are available in large quantities, which gives cost advantage over other non-integrated suppliers.</p>	Technologies that transition manufacturers to a more vertically integrated position in the supply chain.

POSITION	DESCRIPTION	POTENTIAL R&D APPROACH
Quality	<p>Virgin resins are the incumbent and compete aggressively on price and quality / consistency advantages. Recycled resins are seen as inferior quality, and they often are, and with inconsistent properties. This results in lower prices compared to virgin materials.</p> <p>Quality is more of a concern where virgin plastics are the alternative in high end products such as Automotive. This is in terms of purity percentage of plastic, durability, and strength compared to virgin plastics.</p> <p>Recycled plastics should regularly meet the set quality standards.</p> <p>In Europe there are recyclers that are focussing on making high quality resins for the manufacture of goods as an alternative to virgin resins. Virgin resin companies have purchased recycling operations with the view to integrate the supply of high quality resin with recycled content as a new product.</p>	Technologies that result in higher quality recycled resins that can compete with virgin resin properties.
Proximity of supplier	Recycled plastics should be readily available to consumers in required quantities.	

Question 5: Likely strategies

Four major likely strategies for company growth were identified based on stakeholder interviews and market analysis⁷ and are summarised in Table 11. A market entrant with strong R&D capability is likely going to benefit most to strategies being pursued in the plastic recycling industry because innovation will be a key enabler for growth. This is especially true for the key strategy of technological innovation and new product development.

Table 11. Likely strategies identified for the plastic recycling industry

STRATEGY	DESCRIPTION
International player growth	International players are expected to grow organically, but also by acquiring regional or local players during the period until 2020.
Small player growth	Small players are best positioned for rivalry by focusing on end-user requirements and modifying their business operations to suit the needs of end-users. This is especially in markets where large multinationals do not compete because there is likely to be less competition on price.
Technological innovations and new product development	The competition in the market is likely to intensify due to technological innovations and new product development. Given some of the low recycling rates, which are partly due to technological issues, there are opportunities for technology innovations to improve the efficiency and effectiveness of plastic recycling.
Integrating down the supply chain	Virgin resin suppliers may choose to integrate down the chain and adapt recycled resins as part of their portfolio, to provide global brand owners with confidence in the quality and consistency of recycled resins. Examples of these can be seen in the IP landscape analysis presented in Section 4.2 with companies such as Dow and BASF showing a clear diversification into plastic recycling technologies.
Integrating up the supply chain	Brand owners / Converters may integrate up the chain to take responsibility for recycled resin quality used in their products. This is already happening in Europe and USA.

Question 6: Key factors for future success

Five key factors for future success in the plastic recycling industry were identified based on stakeholder interviews and market analysis ⁷ and are summarised in Table 12. The key factors under 'Technology and Manufacturing related' is highly favourable to potential future investments in R&D due to issues of inefficiency, health concern, quality and product innovation that need to be addressed. Government regulations will also lend favourably to R&D development as types of plastics which can be used are regulated, and targets for recycling are tightened.

Table 12. Key factors for future competitive success for the plastic recycling industry

CATEGORY	KEY FACTORS FOR FUTURE COMPETITIVE SUCCESS
Technology and manufacturing related	<ul style="list-style-type: none"> • Inefficiency is a problem in sorting, and removing unwanted and contaminated materials. Recycling is low in the US because polyethylene (PE) and polypropylene (PP), which account for two-thirds of the plastic used, have different chemical structures that do not permit their joint recycling. • There is health concerns for people working in this industry which could be partially addressed by technology. Certain types of hazardous waste require expertise and automatic handling to reduce reliance on human intervention. Demand for automatic handling systems like size reduction and manipulator arms is increasing. • Emerging players are using manufacturing and or channel and distribution technologies to enter the market, such as online marketplaces, alternative uses for plastics e.g. in textiles, new sorting, chipping, washing, pelleting or collection technology etc. • 3D-printing has opened up doors to manufacturing. It uses plastic waste for printing, and waste reduction can be achieved by converting plastic waste to a thermoplastic 3D-model. The American market, by far the largest, is driven by availability of advanced technologies and a skilled workforce. • Quality of recycled plastics is rated as the key parameter for procurement so technology which can provide high quality plastic is an advantage. • Upcycling is becoming an interesting trend that prompts manufacturers and industries to anticipate the lifecycle of raw materials and products at the initial stage of production, so as to organise reuse and recycling before the products are disposed.
Distribution-related	<ul style="list-style-type: none"> • Recycled plastics are predominantly supplied directly from the manufacturer to the end-user without any intervention of a trader and distributor, especially for bulk quantities. Because of low margins, the supply of distributor to end-user through trader is insignificant, particularly in regions such as MENA and South East Asia. • Direct relationship with the customers and off-take agreements are therefore critical success factors. • Yearly contracts are preferred. Long-term contracts with discounts against lifting targets are some of the preferred trade conditions. • The end users prefer entering into annual contracts, thereby securing a source that also helps them in maintaining the quality parameters. • To gain a competitive advantage, waste management companies should diversify their services and build an integrated channel to offer a wide range of value-added services to the customers. Flexibility and agility are the two vital factors that can add more value to the services offered.
Marketing-related	<ul style="list-style-type: none"> • Presenting a closed-loop or circular economy type image is a promising strategy for attracting customers and suppliers. • Value-add services will provide numerous opportunities to both the operators and customers. It will be beneficial in terms of revenue increase and customer retention. For example offering on-site assessments and waste management programs to help businesses improve their waste management strategy. Or working closely with customers to help them improve their logistics and efficiency of their supply chain.
Skills and capability-related	<ul style="list-style-type: none"> • The American market, by far the largest, is driven by availability of advanced technologies and a skilled workforce.

CATEGORY	KEY FACTORS FOR FUTURE COMPETITIVE SUCCESS
	<ul style="list-style-type: none"> • Market participants need to conduct research and development in order to come up with innovative business models. This can be done by combining capabilities in different ways that are not considered by the existing models.
Other factors – Government regulation of market	<ul style="list-style-type: none"> • Clear and supportive government targets for the collection and recycling of plastics coupled with strong and uniform environmental standards on waste. This will include positive incentives for businesses in this sector such as tax relief, R&D support, and innovation support. • Creation of nation recycling targets with real penalties for deviation. • Setting national waste diversion targets • Factors will serve to create a more stable market for recycled resins that enables recyclers to invest to improve quality and reduce cost based on automation and volume

Question 7: Outlook for industry

Strong positive growth is expected in Plastic Recycling markets. Increases in demand across the segments will spur growth in packaging, construction and automotive industries. In addition, environmental concerns and regulations are expected to be strong positive drivers for growth in this industry.

Business opportunities for R&D exist because technological barriers are limiting recycling rates, efficiency and safety in the industry.

Business opportunities also exist in redefining business models, to increase penetration, and offer more value added services (especially across the value chain).

5 Conclusion

This report provides strong evidence for steady growth of the plastic recycling industry due to increased demand for plastic products and packaging, as well as rising environment concerns.

IP landscape analysis displays an intensity in patent filing particularly in the last 5 years, consistent with overall industry growth. This may also indicate growing R&D competition in this space. Technologies dealing with PET use in packaging, particularly with the use of bottles, appear to far outweigh the number of patents in other categories.

Investment trends appear to favour companies that are highly vertically integrated within the plastic recycling supply chain, providing significant competitive advantage against other rivals. There have also been a high number of exit events and acquisitions noted in the market, typically characteristic of growth. Within these, recycling systems appear to lead in volume for the sector, but industrial waste management is revealed as having the steepest growth of 36% between 2013 and 2016. Residential recycling has also by far attracted the largest investment, over 59% of that in the space, driven somewhat by government legislation encouraging diversion of waste from landfill.

The macroeconomic analysis of stakeholder reported political influences indicated that government policies here in Australia favour driving the collection of plastic waste, rather than activities further along the supply chain. Without similar incentives available for plastic recycling processors and manufacturers, companies will likely need to seek additional R&D support to increase processing efficiency, reduce costs and diversify product lines to remain competitive. Internationally, stakeholders labelled the European Union as a global forerunner in plastic waste management, citing their strong legislation regarding disposal and subsequent high recycling rates and use of energy from waste methods.

The reported key economic factor that governs the plastic recycling industry concerns the cost and quality competitiveness of recycled resins when compared with virgin materials. While this is often tied to oil and plastic commodity prices, this can be offset by the development of technologies that maximise the volume, usability, purity, quality and value of waste collected, or redirection of material to other streams such as energy from waste.

As seen by the stakeholders, a large driver of growth in the industry stems from growing public interest in reducing the environmental footprint of plastic products. As a result, large multinationals are beginning to set ambitious sustainability targets, and adopting more circular economy approaches. Companies are hence showing an increased interest in new technologies that allow them to use recycled plastics in their consumer products, particularly for more problematic waste materials such as marine plastics.

The largest technological gaps that were identified involve the cost effective collection of waste, appropriate sorting technologies that allow the extraction of high quality waste streams for reprocessing, and processes that maximise the volume, usability and value of waste collected. Of particular interest are waste streams or resin types that current suffer from low recycling rates due to contamination or issues with multilayered packaging.

Reported legal drivers particularly focus on government-based legislation and incentive programs that encourage increased diversion from landfill and recycling rates. Given the strong position on plastic recycling of the EU, interviewed stakeholders noted that Australia will need to see similarly increased regulation to spur a large-scale industry shift.

Our interview results indicate that plastic products are associated with an array of environmental concerns, including the increasing volume and long legacy of plastics, the accumulation of marine and microplastics in the environment, increasing waste disposal requirements, depletion of virgin resources and potential impact of toxic additives in plastics. Stakeholders reported that growth of the plastic recycling industry has hence been driven by the increasing consumer focus on environmental issues and sustainability. This has translated into both a shift in preference towards global brand owners with sustainable processes, as well as political action from government to introduce legislation and policies that support plastic recycling measures.

An analysis of dominant competitive forces and forces driving change revealed strong cases for the development of innovative technologies that either increase efficiency or penetration of waste segregation and management. Strong market positions would also be delivered by R&D directed towards increasing the value of recycled plastics via reduced contamination, new processes for low value/underutilised feedstocks or processes that deliver higher quality recycled resins that are able to compete with virgin materials. Also technologies that help transition manufacturers to a more vertically integrated position.

This report provides strong evidence for numerous R&D opportunities that would assist the plastics recycling industry to overcome identified market challenges and support future growth. It is hence the recommendation of the authors that a further body of work be commissioned that involves in depth industry consultation to facilitate the crafting of an industry aligned R&D roadmap for the CSIRO.

References

- (1) Technavio. *Global Recycled Plastics Market 2016-2020 (IRTNTR8986)*; 2016.
- (2) Technavio. *Global Recycled Plastics Market 2018-2022 (IRTNTR21968)*. *Global Recycled Plastics Market 2018-2022 (IRTNTR21968)* **2018**.
- (3) Transparency Market Research. *Plastic Recycling Market 2018*.
<https://www.transparencymarketresearch.com/pressrelease/plastic-recycling-market.htm>
- (4) Accuray Group LLP. *Global Plastic Recycling Market Analysis & Trends - Industry Forecast to 2025 (AGLP15326208)*; 2017.
- (5) Quid. *CSIRO Plastic Recycling Landscape Report*; 2017.
- (6) Stellarix. *Final Report: Landscape study on recycling of polymers*; 2017.
- (7) Jessica Deane. *CSIRO Market Analysis Report on the Plastic Recycling Industry*; 2017.
- (8) The Plastics Industry Trade Association. *Plastics Market Watch: Plastics Packaging Wraps it Up*; 2015.
- (9) The Plastics Industry Trade Association. *Automotive Recycling: Devalued is now Revalued*; 2016.
- (10) Plastics Europe; European Association of Plastics Recycling and Recovery Organizations. *Plastics - the Facts 2016: An analysis of European plastics production, demand and waste data*; 2016.
- (11) Frost & Sullivan. *Global Waste Recycling Market Outlook, 2017: Sustainability-related targets and smart applications trigger innovative business models for resource recovery (MCCF-15)*; 2017.
- (12) Arthur A. Thompson; A. J. Strickland; John Gamble. *Crafting and executing strategy : the quest for competitive advantage : concepts and cases / Arthur A. Thompson, Jr., A.J. Strickland III, John E. Gamble*. McGraw-Hill/Irwin: Boston, 2008.
- (13) International Organization for Standardization. *Plastics - Guidelines for the recovery and recycling of plastics waste (ISO 15270:2008)*. In Switzerland, 2008.
- (14) J. Hopewell; R. Dvorak; E. Kosior. *Plastics recycling: challenges and opportunities. Plastics recycling: challenges and opportunities* **2009**, 364 (1526), 2115-2126.
- (15) J. H. Song; R. J. Murphy; R. Narayan; G. B. H. Davies. *Biodegradable and compostable alternatives to conventional plastics. Biodegradable and compostable alternatives to conventional plastics* **2009**, 364 (1526), 2127-2139.
- (16) UNEP. *Biodegradable Plastics and Marine Litter. Misconceptions, concerns and impacts on marine environments*; United Nations Environment Programme (UNEP): Nairobi, 2015.
- (17) ASTM International. *ASTM D7611 / D7611M-13e1, Standard Practice for Coding Plastic Manufactured Articles for Resin Identification*. <https://www.astm.org/Standards/D7611.htm>
- (18) American Chemistry Council. *Plastic Packaging Resins*. <https://plastics.americanchemistry.com/Plastic-Resin-Codes-PDF/>
- (19) Rory Masterson. *IBISWorld Industry Report C1951-GL. Global Plastic Product and Packaging Manufacturing*; 2016.
- (20) Sustainable Resource Use Pty Ltd; Helen Millicer; Kyle O'Farrell. *Plastics Recovery Market Development Study for NSW EPA*; Sydney, 2013.
- (21) Australian Government. *Product Stewardship Act 2011 (C2011A00076)*. <https://www.legislation.gov.au/Details/C2011A00076>
- (22) NSW Government. *The NSW Government is offering \$1.3 million in litter reduction grants to help reach its target of reducing litter by 40% by 2020*. <https://www.nsw.gov.au/news-and-events/news/1-3-million-to-reduce-litter/>
- (23) Australian Government Department of the Environment and Energy. *Draft Threat Abatement Plan for the Impacts of Marine Debris on Vertebrate Marine Species (2017)*. <http://www.environment.gov.au/biodiversity/threatened/threat-abatement-plans/draft-marine-debris-2017>
- (24) EPA Victoria. *Government response to the Independent Inquiry into EPA*. <http://www.epa.vic.gov.au/about-us/response-to-epa-inquiry>
- (25) European Commission. *Proposed Circular Economy Package 2015*.
- (26) European Commission. *Directive of the European Parliament and of the Council - amending Directives 2008/98/EC on waste, 94/62/EC on packaging and packaging waste, 1999/31/EC on the landfill of waste, 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment (2014/0201 (COD))*; Brussels, 2014.
- (27) European Commission. *Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles*; Brussels, 2000.
- (28) Isabel Dayman. *SA plastics recycling business closes due to \$100k hike in power bills*. <http://www.abc.net.au/news/2017-06-27/sa-recycling-business-power-bills-rise-causing-closure/8654638> (01/09/2017).
- (29) Nike Inc. *Nike, Inc. Promotes Circular Economy at World Economic Forum*. <http://news.nike.com/news/nike-inc-promotes-circular-economy-at-world-economic-forum> (27/06/2017).
- (30) DELL Corporation. *Dell on the Circular Economy*. <http://i.dell.com/sites/content/corporate/corp-comm/en/Documents/circular-economy-0316.pdf> (27/06/2017).
- (31) P&G. *Helping to Enable Consumers to Make More Sustainable Choices*. <http://us.pg.com/sustainability> (27/06/2017).
- (32) Jessica Lyons Hardcastle. *P&G Circular Economy Partnership Creates World's First Recyclable Shampoo Bottle Made with Beach Plastic*. <https://www.environmentalleader.com/2017/01/pg-circular-economy-partnership-creates-worlds-first-recyclable-shampoo-bottle-made-with-beach-plastic/?amp=1> (27/06/2017).
- (33) Adidas Corporation. *adidas Introduces Parley Editions of Game-Changing Running Footwear*. <http://news.adidas.com/US/Latest-News/ALL/adidas-introduces-parley-editions-of-game-changing-running-footwear/s/c1722809-0c26-40bc-8393-8d664701d326> (27/06/2016).

- (34) Target Corporation. *2015 Target Corporate Social Responsibility Report*; 2015.
- (35) As You Sow. Target Agrees to Engage Corporate Peers on Phase out of Polystyrene Foam Packaging in E-Commerce. http://www.asyousow.org/wp-content/uploads/2017/04/Target_Polystyrene_Release_20170405-2.pdf
- (36) Global Industry Analysts. *Plastics: a Global Industry Outlook*; 2012.
- (37) J. R. Jambeck; R. Geyer; C. Wilcox; T. R. Siegler; M. Perryman; A. Andrady; R. Narayan; K. L. Law. Plastic waste inputs from land into the ocean. *Plastic waste inputs from land into the ocean* **2015**, 347 (6223), 768-771.
- (38) Denise Hardesty; Chris Wilcox. Eight million tonnes of plastic are going into the ocean each year. <http://theconversation.com/eight-million-tonnes-of-plastic-are-going-into-the-ocean-each-year-37521>
- (39) Louise Tosetto; Culum Brown; Jane Williamson. How microplastics make their way up the ocean food chain into fish. <https://theconversation.com/how-microplastics-make-their-way-up-the-ocean-food-chain-into-fish-69148>
- (40) Camilla Alexander-White. The massive problem of microplastics. <https://eic.rsc.org/feature/the-massive-problem-of-microplastics/2000127.article>
- (41) Carl Safina. Pesky plastic: The true harm of microplastics in the oceans. <http://voices.nationalgeographic.com/2016/04/04/pesky-plastic-the-true-harm-of-microplastics-in-the-oceans/>
- (42) John Vidal. Microplastics should be banned in cosmetics to save oceans, MPs say *The Guardian* 24th August 2016, 2016.
- (43) Himal Kotelawala. Sri Lanka Death Toll Rises in Garbage Dump Collapse. *New York Times* April 17, 2017, 2017.
- (44) Zacharias Abubeker. Death toll doubles in Ethiopia garbage dump collapse. *CBS News* 15th March 2017, 2017.
- (45) Hong Yang; Xianjin Huang; Julian R. Thompson; Roger Flower, J. Chinese landfill collapse: urban waste and human health. *Chinese landfill collapse: urban waste and human health* **2016**, 4 (7), e452.
- (46) UNEP. *Marine plastic debris and microplastics – Global lessons and research to inspire action and guide policy change*; United Nations Environment Programme (UNEP): Nairobi, 2016.
- (47) Steve Toloken. China to WTO: Scrap plastic imports banned by year-end. <http://www.plasticsnews.com/article/20170718/NEWS/170719892/china-to-wto-scrap-plastic-imports-banned-by-year-end> (01/09/2017).

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